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Review

The chemistry of beer aging – a critical review

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Abstract

Currently, the main quality problem of beer is the change of its chemical composition during storage, which alters the sensory properties. A variety of flavours may arise, depending on the beer type and the storage conditions. In contrast to some wines, beer aging is usually considered negative for flavour quality. The main focus of research on beer aging has been the study of the cardboard-flavoured component (*E*)-2-nonenal and its formation by lipid oxidation. Other stale flavours are less described, but may be at least as important for the overall sensory impression of aged beer. Their origin has been increasingly investigated in recent years. This review summarizes current knowledge about the chemical origin of various aging flavours and the reaction mechanisms responsible for their formation. Furthermore, the relationship between the production process and beer flavour stability is discussed.

Keywords: Beer; Staling; Aging; Flavours; Brewing

1. Introduction

As for other food products, also for beer, several quality aspects may be subject to changes during storage. Beer shelf-life is mostly determined by its microbiological, colloidal, foam, colour and flavour stabilities. In the past, the appearance of hazes and the growth of beer spoilage micro-organisms were considered as the main trouble-causing phenomena. However, with progress in the field of brewing chemistry and technology, these problems are now largely under good control. Most of the interest has shifted to factors affecting the changes in beer aroma and taste, as beer flavour is regarded as the most important quality parameter of the product. However, bearing in mind that *de gustibus et colouribus non est disputandum*, consumers do not necessarily dislike the flavour of an aged beer. Indeed, a study (Stephenson & Bamforth, 2002) with consumer trials pointed out that aging flavours are not always regarded as off-flavours. More important for appreciation of a beer were the expectations consumers have in recognizing the flavour of just the particular brand of beer that they generally drink. To meet the consumers expectations, the flavour of a certain beer brand must be constant. However, as the expected flavour is normally the flavour of the particular fresh beer, as a result of beer aging, such flavour may change, and the expected flavour is lost. This should mainly be considered as the most important reason that beer staling is undesirable.

Starting from the 1960s, several studies have focussed on the chemical aspects of beer staling. Notwithstanding 30–40 years of research, beer aging remains difficult to control. With the increasing export of beer, due to market globalisation, shelf-life problems may become extremely important issues for some breweries. Beer aging is a very complex phenomenon. This overview on the chemistry of beer aging intends to illustrate the complexity of the aging reactions.

2. Sensory changes in beer during storage

The literature on beer staling reveals only few reports dealing with the actual sensory changes during beer

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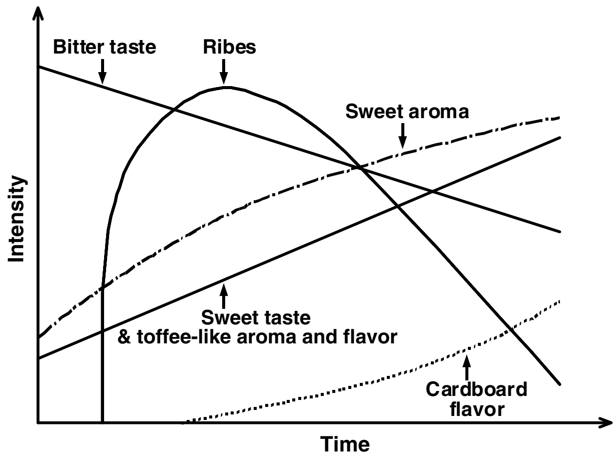

Fig. 1. Sensory changes during beer aging according to Dalgliesh (1977).

storage. Dalgliesh (1977) described the changes in the most detail. However, the Dalgliesh plot (Fig. 1) is a generalization of the sensory evolution during beer storage and is by no means applicable to every beer. A constant decrease in bitterness is observed during aging. This is partly due to sensory masking by an increasing sweet taste. In contrast to an initial acceleration of sweet aroma development, the formation of caramel, burnt-sugar and toffee-like aromas (also called leathery) coincides with the sweet taste increase. Furthermore, a very rapid formation of what is described as *ribes* flavour is observed. The term *ribes* refers to the characteristic odour of blackcurrant leaves (*Ribes nigrum*). Afterwards, the intensity of the *ribes* flavour decreases. According to Dalgliesh (1977), cardboard flavour develops after the *ribes* aroma. On the other hand, according to Meilgaard (1972), cardboard flavour constantly increases to reach a maximum, followed by a decrease. Besides these general findings, other reported changes in flavour are harsh after-bitter and astringent notes in taste (Lewis, Pangborn, & Tanno, 1974) and wine- and whiskey-like notes in strongly aged beer (Drost, Van Eerde, Hoekstra, & Strating, 1971). Positive flavour attributes of beer, such as fruity/estery and floral aroma tend to decrease in intensity. For the overall impression, the decrease of positive flavours may be just as important as development of stale flavours (Bamforth, 1999b; Whitear, Carr, Crabb, & Jacques, 1979).

Often beer staling is presented as just being related to cardboard flavour development. While, in some cases, and especially in lager beers, cardboard flavour is the major manifestation of beer staling, this can not be generalized. Aging flavours vary between beer types and certainly, for speciality beers, other stale flavours are often more prominent. Whitear (1981) reported aging notes of a strong ale as burnt, alcoholic, caramel, liquorice and astringent flavours, whereas cardboard and metallic flavours were not found. Moreover, strong initial burnt flavours in dark beers may mask the development of aging flavours and result in a better flavour stability of this beer type. However, as will be explained further on, other factors probably also account for this observation.

Contact of beer with oxygen causes a rapid deterioration of the flavour and the type of flavour changes depends on the oxygen content of bottled beer. For instance, there is a close correlation between the *ribes* odour and headspace air, and this flavour can be avoided in the absence of excessive contact with air (Clapperton, 1976). Furthermore, it is found that beer staling still occurs at oxygen levels as low as possible (Bamforth, 1999b), which suggests that beer staling is partly a non-oxidative process.

Apart from oxygen concentration, storage temperature affects the aging characteristics of beer, by affecting the many chemical reactions involved. The reaction rate increase for a certain temperature increase depends on the reaction activation energy. This activation energy differs with the reaction type, which means that the rates of different reactions do not equally increase with increasing temperature. Consequently, beer storage at different temperatures does not generate the same relative level increase of staling compounds. Some sensory studies confirm this prediction. According to Furusho et al. (1999), cardboard flavour shows different time courses during lager beer storage at 20 and 30 °C. In the early phase of beer aging, this results in a sensory pattern with relatively more cardboard character when beer is stored at 30 °C compared to 20 °C. This agrees with the findings of Kaneda, Kobayashi, Furusho, Sahara, and Koshino (1995b) that lager beer aged at 25 °C tends to develop a predominantly caramel character whereas, at 30 or 37 °C, more cardboard notes are dominant.

From these examples, it follows that the Dalgliesh plot (Fig. 1) is a simplification of the sensory changes during storage. The nature of flavour changes is complex and mainly depends on the beer type, the oxygen concentration and the storage temperature.

3. Chemical changes in beer during storage

3.1. General

Flavour deterioration is the result of both formation and degradation reactions. Formation of molecules, at concentrations above their respective flavour threshold leads, to new noticeable effects, while degradation of molecules to concentrations below the flavour threshold may cause loss of initial fresh beer flavours. Furthermore, interactions between different aroma volatiles may enhance or suppress the flavour impact of the molecules (Meilgaard, 1975a).