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REVIEW

Beer Volatile Compounds and Their Application to Low-Malt Beer Fermentation

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Low-malt beers, in which the amount of wort is adjusted to less than two-thirds of that in regular beer, are popular in the Japanese market because the flavor of low-malt beer is similar to that of regular beer but the price lesser than that of regular beer. There are few published articles about low-malt beer. However, in the production process, there are many similarities between low-malt and regular beer, *e.g.*, the yeast used in low-malt beer fermentation is the same as that used for regular beer. Furthermore, many investigations into regular beer are applicable to low-malt beer production. In this review, we focus on production of volatile compounds, and various studies that are applicable to regular and low-malt beer. In particular, information about metabolism of volatile compounds in yeast cells during fermentation, volatile compound measurement and estimation methods, and control of volatile compound production are discussed in this review, which concentrates on studies published in the last 5–6 years.

[**Key words:** beer fermentation, esters, higher alcohols, yeast metabolism]

Low-malt beers, in which the amount of wort is adjusted to less than two-thirds of that in regular beer and the malt carbon source is compensated by adding sugar syrup, are popular in the Japanese market. Moreover, new alcoholic beverages that taste like beer, in which a nitrogen source extracted from materials other than wort and sugar syrup is used, are acceptable. The liquor tax on Japanese alcohol beverages depends on the percentage of malt. Therefore, beverages with low concentration of malt are taxed at lower rates than beer made from all malt wort.

In low-malt beer, volatile compounds produced by yeast metabolism are important for approximating the flavor of regular beer. During low-malt and regular beer fermentations, as by-products of yeast metabolism, sugars in wort are converted to ethanol and volatile compounds, such as higher alcohols and esters. The volatile compounds are different from aromatic compounds in malt and hops, and many of them cause undesirable flavors when their concentration exceeds certain thresholds. Some volatile compounds are reduced in concentration during maturation, which follows fermentation. However, a fraction of higher alcohols, esters, and other carbonyl compounds remain, thereby affecting the flavor of the final product. Therefore, it may be necessary to keep the concentrations of volatile compounds in the final product below their taste thresholds so that they do not produce salty, sweet, bitter, or acid flavors.

A major difference between low-malt and regular beer fermentations is that the free amino acid nitrogen (FAN) concentration in low-malt beer wort is low at the beginning of the low-malt beer fermentation process. After nitrogen source depletion, proliferation of yeast cells ceases. Thus, the amount of FAN in the wort affects the number of yeast cells proliferated. To make fewer yeast cells consume the same amount of carbon sources than those in regular beer fermentation, yeast cell activity has to be maintained by increasing the temperature. However, high temperature fermentation can result in higher concentrations of volatile compounds. Therefore, it is important to know the production characteristics of volatile compound biosynthesis.

There are few published articles about low-malt beers; however, volatile compound production has been investigated in regular beer brewing from the viewpoint of gene functions in yeast metabolic pathways, measurement and estimation methods, and control procedures. In the production process, there are many similarities between low-malt and regular beer. For example, the yeast used and the basic fermentation procedure in low-malt beer fermentation are the same as in regular beer production. Therefore, the results from investigations in regular beer production are applicable to low-malt beer production. To creatively improve the fermentation process in low-malt beer and develop dif-

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TABLE 1. List of beer flavors associated with various compounds (1, 2, 4)

	Flavor in beer	Organoleptic threshold (ppm)	Concentration in Japanese beer (ppm)
Higher alcohols			
Propan-1-ol (*n*-propanol)	Alcohol	800	8–15
2-Methyl propanol (isobutyl alcohol)	Alcohol	200	7–14
2-Methyl butanol (active amyl alcohol)	Alcohol, banana, medicinal, solvent	65	46–71
3-Methyl butanol (isoamyl alcohol)	Alcohol, banana, sweetish, aromatic	70	
2-Phenyl ethanol	Roses, sweetish, perfumed	125	20–27
Esters			
Ethyl acetate	Solvent, fruity, sweetish	30	10–20
Isoamyl acetate	Banana, apple, solvent, estery	1.2	1.3–2.5
2-Phenylethyl acetate	Roses, honey, apple, sweetish	3.8	0.4–1.3
Ethyl caproate	Sour apple	0.21	
Ethyl caprylate	Sour apple	0.9	
Carbonyl compounds			
Acetaldehyde	Green leaves, fruity	25	2.9–3.4
2,3-Butanedione (diacetyl)	Butter-scotch	0.15	<0.01–0.06

ferent alcohol beverages with original flavors, the results from regular beer brewing investigations are useful. Thus, several studies, which are applicable to both regular and low-malt beer, relevant to the metabolism of volatile compounds in yeast cells during fermentation, related to measurement and estimation methods, and pertinent to the control of volatile compound production are compiled in this review, which focuses on research studies published in the last 5–6 years.

CHARACTERISTICS OF VOLATILE COMPOUNDS

Recently, many different volatile compounds responsible for beer flavor have been identified. They may be classified into five main groups: flavor compounds derived (i) from ingredients such as barley and hops, (ii) from roasting malt and boiling wort, (iii) as by-products of yeast metabolism, (iv) from contaminant microorganisms, (v) from the effects of oxygen and sunlight during product storage. In this article, we focus on the third group, particularly on the higher alcohols, esters, and other carbonyl compounds, which were selected as representative compounds responsible for the low-malt beer flavor. The volatile compounds discussed in this review are listed in Table 1 with their characteristic flavor, taste threshold in beer and average concentrations in several brands of Japanese beer (1, 2). Studies focusing on volatile compounds during beer maturation have been reviewed previously (3).

Volatile compounds are structurally divided into higher alcohols, esters, carbonyl compounds such as aldehydes and ketones, and sulfur-containing compounds. In the higher-alcohol groups, amyl alcohol is reported to be the most quantitatively significant flavor compound (1). Active amyl and isoamyl alcohols are sometimes considered as one and represented simply as amyl alcohol. Active amyl alcohol is usually one-fifth to one-quarter of the total amyl alcohol, and it affects drinkability because beer flavor is considered heavier as amyl alcohol concentration increases (1). Isobutyl alcohol has an undesirable effect on beer quality when its concentration exceeds 20% of the total concentration of three alcohols: *n*-propanol, isobutyl, and amyl. Beer flavor becomes fruity and undesirable when the concentrations of esters are high. Representative esters in beer are ethyl acetate, isoamyl acetate, ethyl caproate, ethyl caprylate, and phenyl ethyl acetate (4). Of these esters, ethyl acetate is typically present in the highest concentration and has a fruity and solvent-like flavor. There are experimental data that indicate correlations between ethyl acetate and isoamyl acetate productions and ethanol and isoamyl alcohol productions, respectively (5); however, the correlations were affected by several environmental factors, including oxygen, unsaturated fatty acids, fermentable sugars, and nitrogen. More detailed information is presented in a published review (4).

Concentrations of carbonyl compounds in beer are comparatively low. Even acetaldehyde, the predominant carbonyl compound in beer, is present at no more than 10 ppm. Diacetyl is produced during primary fermentation and its concentration is often used as an index of the completion of beer fermentation or maturation (6). Another volatile compound, 3-methylbut-2-ene-1-thiol (MBT), which is a sulfur-containing compound, has recently been the focus of studies for elucidation of its synthesis pathway (7, 8). MBT is produced not by yeast metabolism, but by the effects of light, and gives off a reported skunk-like odor at concentrations of a few tens of ng l^{-1}.

METABOLISM OF VOLATILE COMPOUNDS DURING FERMENTATION

Generally, bottom-fermenting yeast, *Saccharomyces carlsbergensis*, which is used in regular beer fermentation, is also used in low-malt beer fermentation. *S. carlsbergensis* has been reclassified as *S. pastorianus*, as a natural hybrid between *S. cerevisiae* and *S. bayanus*. Thus, bottom-fermenting beer yeast possesses portions of two genomes: *S. cerevisiae* (Sc)-type and Lager (Lg)-type (9, 10). To investigate gene functions related to biosynthesis of volatile compounds, *S. cerevisiae* is often used because it possesses a wide experimental background and is easy to manipulate in gene-recombination technology. In this review, most of the results discussed are from *S. cerevisiae*.

Gene functions related to biosynthesis of higher alcohols

There are two metabolic pathways for higher alcohol production in *S. cerevisiae* (Fig. 1). One is from amino acids