KVASNÝ PRŮMYSL

Kvasny prumysl (2022) 68: 628–636
https://doi.org/10.18832/kp2022.68.628

Sensory analysis of malt

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Abstract

Various malts are suitable for the production of a certain type of beer, which can also be selected on the basis of their sensory properties. Sensory evaluation of malts is part of the development of sensory tools (maps) used in malting and brewing practice. Malt, as the main raw material, brings a large amount of sensorially active substances into beer, as well as precursors of other aromatic and taste-important substances that are created during beer production technology. The Maillard reaction is the basis for the production of aroma and colour of malts. Reducing sugars together with amino acids create high molecular weight pigments, melanoidins, which are the carriers of the brown colour of malts. At the same time, important desirable sensory active compounds are formed which give the characteristic colour, flavour and aroma to the malt. The enhancement of some special characteristics of malts is achieved by modifying the technology of the malting process, especially by increasing the temperature. The results of the sensory analysis of malt can be applied in the selection of suitable raw materials for beer production or the development of new beer recipes with predictable sensory properties.

Key words: malt, colouring substances, flavour substances, aroma substances, sensory analysis

1 Introduction

Sensory analysis is a scientific discipline used to evoke, measure and analyse the responses to those characteristics of food that are perceived by the senses of sight, smell, taste, touch and hearing. It is the evaluation of food directly by our senses, including the processing of the results by the human central nervous system. Sensory analysis must be carried out under conditions that ensure objective, accurate and reproducible measurements.

A sensory quality of food is the most important psychological factor in human nutrition, which fundamentally influences the type and quantity of food consumed. It is determined by the sensory active substances present – substances that we perceive through our senses. The most important sensory active substances are aroma substances (which influence the smell of food), taste substances (which impart taste to food), colouring substances (which impart colour to food) and texture substances.

Sensory analysis is performed by assessors. An assessor is a person who has been trained and tested on his/her ability to assess. A group of people who have been instructed, trained or have certain knowledge or skills is called a sensory panel. The panel uses human senses that cannot be replaced by an instrument; it is a real measuring instrument (Ježek and Saláková, 2012).

Today, the sensory analysis is an essential part of a quality control program in the food and beverage industry. It is an important and effective tool in the assessment of sensory stability, in the detection of product quality deviations or in the evaluation of the quality and intensity of a certain parameter (flavour, aroma). The advantage of sensory analysis is the possibility of assessing the organoleptic character as a whole, as individual sensory active components interact with each other. Despite the state-of-the-art laboratory instrumentation, there is still no other comprehensive method that can evaluate the overall sen-

Research Institute of Brewing and Malting
Published online: 15 August 2022

sory profile of a food or beverage as quickly and correctly in such a short time as human receptors in conjunction with the central nervous system (Olšovská et al., 2017).

Malt is one of the basic raw materials for beer production. It is a source of extractive substances, which are converted during fermentation into carbon dioxide, ethanol and other fermentation products, and it also provides enzymes that break down high-molecular substances (e.g. starch) into low-molecular substances, which are further utilised in the mashing process. The malts are evaluated by a number of qualitative parameters. The precursors of malt aroma and flavour include carbohydrates, amino acids, proteins and lipids occurring in the barley grain. During the germination of barley and, in particular, during malt kilning, under conditions of non-enzymatic browning reactions, highly complex mixtures of low-molecular-weight substances are formed. These are responsible for the characteristic flavour and aroma of malt.

Substances that contribute to the flavour and aroma of malt include acids, alcohols, aldehydes, ketones, esters and heterocyclic compounds that contain oxygen, nitrogen or sulphur. In addition to the products of the Maillard reaction, products of other reactions also contribute to the aroma of malts. Kilning makes lipids partially oxidise and degrade to form a range of substances, including unsaturated aldehydes, alcohols, lactones and other acids, usually with an undesirable characteristic aroma.

The Maillard reaction is hardly manifested externally in the production of pale malts. At most, sensory indifferent intermediates are formed here and they can only be transformed into aromatic substances during the brewing process. Special malts contain a lot of aromatic flavouring substances which, although used in limited quantities in the production of special beers, make a significant contribution to their aroma. The total number of volatile substances found in malts is estimated to be at least 250 (Maarse et al., 1996).

2 Types of malts

Worldwide, malting barley is mainly used to produce pale malts of the Pilsner type and dark malts of the Munich (Bavarian) type. Other types of special malts, such as caramel and coloured malts, are used to enhance certain qualitative and specific characteristics of the beers produced. The specific types of malt are obtained by selecting the appropriate barley varieties and by modifying the technology of steeping, germination and kilning. These modifications ensure the necessary degradation of high-molecular-weight substances, the related degree of proteolytic and cytolytic modification and malt brittleness, optimal activation and synthesis of enzymes and other changes in the raw material used. Different formation of colour and aroma substances depends on the kilning or roasting procedures (especially the temperature and reduction of the water content), resulting in different types of malts (Basařová et al., 2015). The types of malts can be divided as follows:

- Pale Pilsner-type malts – used for the production of draught beers, lagers, consumer beers and special beers with different concentrations of original wort;
- Vienna malt is a transitional type between pale and dark malts, it has a distinctive malty aroma and taste;
- Munich (Bavarian) type dark malts – used for the production of dark beers, with a caramel taste and aroma;
- Special malts – for the production of special and dark burs, they are used in a mixture with pale malts. These include:
    - Caramel malts – have a high content of colouring substances, burs are of a brown colour and with caramel or chocolate tones of taste;
    - Coloured (colouring) malts (Figure 1) – used in the production of strong dark beers. A special product is chocolate malt. The beers produced are characterised by roasted, coffee notes with a dry, astringent and sour taste. Coloured and chocolate malts produced in the Czech Republic enhance the colour and taste of the beer and have a positive effect on the stability of the foam, which remains white;
    - Smoked malts – produced in special malthouses from barley malt dried by direct combustion of oak shavings and peat;
    - Wheat malts – used for the production of mainly top-fermented beers. Wheat proteins cause the typical turbidity of the finished beer, a banana taste and clove aroma are present;
    - Malts from other cereals – triticale malt, sorghum malt, rice malt, corn malt, rye malt, oat malt, millet malt – are mainly used for the production of locally produced beers (Basařová et al., 2015; Olšovská et al., 2017).

3 Substances affecting the colour of malt

Colour is one of the basic quality attributes of food and the raw materials used to produce it. It does not necessarily reflect the nutritional, sensory or functional value, but often determines the acceptability of the product by the consumer. Colour can also give information about the technology of food production. This is also the case of malt, as its colour intensity is an important technological indicator in its production. Based on the colour changes during the roasting process, production technologists can decide how long to run the process to achieve the desired colour and taste of the final product. The colour is characteristic of each type of malt and indicates the content of colouring substances, i.e. melanoidins. Malting is one of the industries where the browning of natural organic substances is deliberately induced and where they are used technologically. The colour of malt is a very important criterion for brewers, as it determines the characteristic colour of the beer.

Figure 1 *Coloured malt*

The colour of pale and special malts is determined visually using a comparator against a set of coloured slides. The result gives an indication of the type of malt analysed. Congress wort is prepared from pale malt and after filtering it is measured directly in the comparator cuvette (EBC 4.7.2, 2009), Figure 2. In the case of special malts (EBC 5.6, 2009), wort is made from a mixture of caramel or coloured and pilsner malts and the colour is measured by comparison with the appropriate colour slide disc. If necessary, the malt is diluted. The resulting colour is given in EBC units (Table 1). The assessor must be able to discriminate colours correctly.

Figure 2 *The comparator for determination of malt colour*

4 Substances affecting malt flavour and aroma

A number of sensory active compounds may already be formed during barley germination (Prado et al., 2021), however, the largest proportion of aromatic substances is mainly produced during kilning of green malt. Although some of these substances are present in malts at concentrations below their threshold value, the fact that they occur and act in mixtures makes their actual importance in aroma manifestation sometimes difficult to assess. The concentration of aroma components in malt generally depends on the rates of their formation, transformation and evaporation during fermentation (Woffenden et al., 2001). Some of the aroma compounds later become

Table 1 *The values of colour of different malts*

Type of malt	Colour (EBC units)
Pilsner	< 4.5
Vienna	< 9.0
Munich	< 20
Karapils	< 20
Light caramel	< 120
Dark caramel	< 220
Chocolate	< 1200
Coloured (black)	< 1500

precursors that enter into further reactions during wort boiling and hop brewing or are metabolized by yeast and thus are not present in the beer aroma.

Substances that contribute to the flavour and aroma of malt include acids, alcohols, aldehydes, ketones, esters and heterocyclic compounds that contain oxygen, nitrogen or sulphur. In addition to the products of the Maillard reaction, other reaction products also contribute to the aroma of malts, i.e. the aromatic apocarotenoids with very low stimulus thresholds ((E)-β- 2,4-damascenone) or β-dioxopiperazines with bitter or bitter-metallic flavours (Wimmer et al., 2012) formed from linear dipeptides or amino acids.

As early as in 1964 Damm and Kringstad (Damm and Kringstad, 1964) identified the main aldehydes of caramel malt – 2- and 3-methylbutanal. Since then, a number of studies have been carried out concerning the composition of the volatile fractions of different types of malt. The total number of volatiles found in malts is estimated to be at least 250 (Maarse et al., 1996).

Barley variety and its growing conditions may play a role in the development of malt aroma and flavour (Windes et al., 2021), but the malting process still plays the main role here (Kishnani et al., 2022). From the very beginning of production, some key compounds (e.g. 3-methylbutanal, 2-methylbutanal, (E,Z)-2,6-nonadienal, hexanal, 2-hexenal, and (E)-2-nonenal) are already present during grain germination and are responsible for the green and grainy aromatic notes. S-methylmethionine is formed and converted to dimethyl sulphide during the kilning phase.

The amount of many flavouring substances in malt can be experimentally determined (e.g. Vandecan et al., 2010; Table 3), but the threshold concentrations of the perception of the individual substances are particularly important for the assessment of malt aroma. Using a dilution analysis method (where fraction 1 dilution series: 1 (v/v), n = number of dilutions until no difference was determined in a triangular test, dilution factor FD = 2n), the most intense aroma constituents of the distilled caramel malt extract were percieved 3-methylbutanal, 1-octen-3-one, methional, (E,E)- 2,4-decadienal, vanillin (formed by oxidation of vinylguaiacol, the product of decarboxylation of ferulic acid), 2- and 3-methylbutanoic acid and furaneol (Table 3). Other important highly volatile caramel malt flavourings include dimethyl sulphide (aroma of cooked cabbage or vegetables or maize) and 2-methylpropanal (malty).

Table 2 *Odorant substance content in special malts (mg/kg)*

Odorant	malt		
	coloured	caramel	roasted
Cycloten	1.2	1.9	2.0
Norfuraneol	1.6	2.2	0.5
Furaneol	15.1	14.3	4.0
Maltol	11.8	76.4	28.2
2-Isopropyl-5-methyl-2-hexenal	0.5	0.5	0.1
2-Phenyl-2-butenal	0.3	0.4	0.5
4-Methyl-2-phenyl-2-pentenal	0.1	0.1	0.03
5-Methyl-2-phenyl-2-hexenal	0.5	0.6	Nq.
2,3,5-Trimethylpyrazine	0.5	0.3	0.5
2-Ethyl-3,5-dimethylpyrazine	0.5	0.2	1.5
2,3-Diethyl-5-methylpyrazine	0.1	0.03	0.2
2-Acetylpyrrole	11.6	10.3	1.2
γ-Nonalactone	0.1	0.1	0.05
(E)-β-2,4-Damascenone	1.8	1.4	1.1

Table 3 *The most intense aroma components of the caramel malt (Vandecan et al., 2010; Cejpek, 2014)*

Odorant	Odour perception	Dilution factor
3-Methylbutanal	malty	2048
Methional	boiled potatoes	1024
2- and 3-Methylbutanoic acid	musty, sweaty	1024
Dimethyltrisulphide	sulphur	512
2-Methyl-3-(methyldithio)furane	after boiled meat	512
4-Hydroxy-2,5-dimethyl-3(2H)-furanone (furaneol)	caramel	1024
3-Hydroxy-2-methyl-4(H)-pyran-4-one (maltol)	caramel	256
3-Hydroxy-4,5-dimethyl-2(5H)-furanone (sotolone)	after flavouring	256
Acetic acid	acid	512
3-Methoxy-4-hydroxybenzaldehyde (vanillin)	vanilla	1024
4-Ethenyl-2-methoxyphenol	root	512
(E,E)-2,4-Decadienal	oily, waxy	1024
1-Octen-3-on	after mushrooms	1024
(E)-β-2,4-Damascenone	sweet; cooked apples	512

The key reactions for caramel malt aroma are Strecker degradation (decarboxylation and deamination) of amino acids and lipid peroxidation. Strecker degradation is usually part of the Maillard reaction complex during thermal food processing. It is an important transamination reaction that is involved, among other things, in the incorporation of nitrogen into melanoidins. The main products of this reaction, Strecker aldehydes, are important odorants of many foods (Buhr et al., 2010). The aldehydes that contribute most significantly to food aroma include methional (after boiled potatoes), phenylacetaldehyde (floral, after honey), 3- and 2-methylbutanal, and 2-methylpropanal (all after malt) (Rychlik et al., 1998; Coghe et al., 2004). 3-methylbutanal exhibits chocolate and almond notes in addition to malty and caramel aromas, while the aroma of 2-methylbutanal is described as malty with notes of cheese and apple esters (Beal et al., 1994). Subsequent reactions of these aldehydes and other Strecker degradation products give rise to other aroma and flavour substances (Cejpek et al, 2004). The amount of the products is often further increased due to redox reactions of the intermediates formed. The methional formed by photooxidative degradation of methionine and its degradation product methanthiol, exhibiting a sulphurous aroma, together with 3-methyl-2-buten-1-thiol, may be one of the causes of the unpleasant lentil skunk flavour of beer (da Costa et al., 2004).

Effective oxidizing agents in Strecker degradation of amino acids are α-dicarbonyl compounds, especially simple compounds formed by degradation of sugars and other food components (glyoxal, methylglyoxal and glycosulose) (Velisek, 2014). These compounds do not exhibit significant organoleptic properties at normal concentrations, but they are precursors of many important aroma and flavour compounds, especially heterocyclic compounds, which are formed in the Maillard reaction and are involved in many redox and addition reactions.

Other important aroma substances of malts are vincine diketones, acetic acid, furan and pyran derivatives, nitrogen heterocycles and dimethyl sulphide. The vicinal diketones (biacetyl and pentane-2,3-dione) are formed during roasting of malts by retroaldolysis or cleavage of intact chains of transformed sugars (Velisek, 2014). Acetic acid is formed from monosaccharides by fragmentation mechanisms.

Vicinal diketones (biacetyl and pentane-2,3-dione) are formed during roasting of malts by retroaldolysis or cleavage of intact chains of transformed sugars (v). Acetic acid is formed from monosaccharides by fragmentation mechanisms.

Furanones are found in significant concentrations only in caramel malts. Basic pale malts contain significant amounts of unspecified precursors – intermediates of the Maillard reaction, from which these furanones are then formed to a greater extent during brewing and fermentation of beer (Mackie and Slaughter, 2000). Furan-2-carbaldehyde, which is formed from pentoses or L-ascorbic acid, and 5-methylfuran-2-carbaldehyde, which is formed from 6-deoxyhexos, both have characteristic pleasant aromas. Pyrans occurring in food are hypothetically derived from α-pyrone or γ-pyrone. Undoubtedly, the most important γ-pyrone is maltol, systematic name 3-hydroxy-2-methyl-4H-pyran-4-one. Maltol, but also δ-lactone 3-hydroxy-2-pyrone, cyclopentenolones and 4-hydroxy-3(2H)-furanones are characterized by a planar arrangement of the molecule and the same configuration of the enol hydroxy group and oxo group. The aroma of all compounds with this structure resembles more or less caramel or malt. Some furanones and pyranones have an aroma comparable to Strecker aldehydes. Norfuraneol, with a caramel aroma and sometimes perceived meat-like notes, is usually found in sub-threshold concentrations in malts. Its homologue 4-hydroxy- 2,5-dimethyl-3(2H)-furanone or furaneol has an aroma reminiscent of strawberries, in higher concentrations sweet caramel. It is found minimally in pale malts and is more abundant in dark malts (Mackie and Slaughter, 2000).

The amino acid proline is of particular importance as a precursor of nitrogenous malt odorants because its Strecker degradation leads to specific volatile products with low thresholds in which the pyrrolidine ring is retained (e.g. 2-acetyl-1-pyrroline) or extended (e.g. 2-acetyl tetrahydropyridine – the latter is a mixture of 2-acetyl-3,4,5,6-tetrahydropyridine and 2-acetyl-1,4,5,6-tetrahydropyridine). 2-acetyl-1-pyrroline is an important odorant with a roasty and sweet aroma and a very low threshold (Rychlik, 1998). 6-acetyl tetrahydropyridine also has a roasty aroma but a somewhat higher threshold. The presence of 2-acetyl-1-pyrroline and 2-acetyl tetrahydropyridine has a major influence on the aroma of baked or roasted cereal products, and therefore special malts. In addition to proline, ornithine, arginine and lysine are also important precursors of these substances. The immediate precursor of 2-acetyl-1-pyrroline from ornithine is 4-aminobutanal, which is formed by Strecker degradation. This aldehyde condenses further with hydroxyacetone and cyclization and dehydration of the product yields 2-acetyl tetrahydropyridine (Velisek, 2014). Pyrazine derivatives (alkyl-, acyl-, alkoxypyrazines, etc.) are found in virtually all heat-processed foods. (Velisek, 2014). Pyrazine derivatives (alkyl, acyl, alkoxypyrazines, etc.) are found in all thermally processed foods. They carry a characteristic roasted, nutty aroma. They are formed by the Maillard reaction or by pyrolysis of certain amino acids. The product of the reaction of amino acids with glyoxal is pyrazine. The reaction of amino acids with a mixture of glyoxal and methylglyoxal produces methylpyrazine. The reaction with methylglyoxal alone produces 2,5-dimethylpyrazine, etc. From simple alkylpyrazines, their methyl- and ethyl-substituted derivatives are also formed by reaction with formaldehyde and acetaldehyde. Simple alkylpyrazines may also be formed by pyrolysis of non-volatile polyhydroxyalkyl-substituted pyrazines, which are the products of reactions of reducing sugars with amino acids. The most prominent odorants include 2-ethyl-3,5-dimethyl- and 2,3-diethyl-5-methylpyrazines (Rychlik, 1998).

In the production of certain types of lager, the precursors present in the malts produce appreciable quantities of volatile dimethyl sulphide with a characteristic aroma. Dimethyl sulphide in higher concentrations causes an unpleasant smell of cooked vegetables in beer. It is formed during kilning by the decomposition of the thermolabile acid S-methyl-L-methionine. This is a natural constituent of plants, in which it serves as a source of methyl groups. Malt with a high content of S-methyl-L-methionine is produced from barley varieties rich in nitrogen which modify very well during germination. In order to avoid the decomposition of S-methyl-L-methionine, kilning should be carried out for the shortest possible time and at the lowest possible temperature. Another precursor of dimethyl sulphide is dimethyl sulfoxide (DMSO), which is probably formed by oxidation of diemthyl sulphide or S-methyl-L-methionine. DMSO is non-volatile and can be reduced by yeast during fermentation. Dimethyl sulphide may also be formed by spontaneous oxidation of methanethiol, which is formed by Strecker degradation of methionine.

Some of the products of the Maillard reaction are formed during the kilning and roasting of malts are more involved in the perception of flavon than aroma. These include in particular some products of the reaction of proline with sugars. In the reaction mixtures of hexos and proline, in addition to the prominent spirodiolone derivative, the bispyrrolidinohexos reductone and cyclopen-

Table 4 Selected volatile aromatic substances of pale malt (Voight, 2018)

Substance	Odour perception	Origin
Ethanone, 1,2(1H-pyrrol-2yl)-	nutty, coffee	Maillard reaction (Strecker's degradation)
Pyrazine, 2,6-dimethyl	roasted nuts, fried	Maillard reaction
Pyrazine, methyl	nutty, cacao, roasted, chocolate	Maillard reaction
Pentanal	grass, vegetables, fruity, banana	fat oxidation
Pyridine	roasted, bitter	Maillard reaction
Maltol	caramel	Maillard reaction (Amadori's relocation)
Ethanone, 1-(2-furanyl)-	cacao, chocolate, almond, burnt	Maillard reaction
Pyrazine, 2,5-dimethyl	nutty, roasted, potato chips	Maillard reaction
Pyrazine, ethyl	peanut, butter, woody, nutty	Maillard reaction
Pyrazine, 2-ethyl-6-methyl	roasted, sweet	Maillard reaction
Pyrazine, 2-ethyl-3,5-dimethyl	peanut, coffee, caramel, earthy	Maillard reaction
Hexanoic acid	goat, sweaty, cheesy	oxidation of hexanal
Pyrazine, 2-ethyl-3-methyl	roasted, earthy, potato	Maillard reaction
4H-Pyran-4-one-2,3-dihydro-3,5-dihydroxy-6-methyl	peanut, almond, caramel	Maillard reaction
Pyrazine	roasted, bitter, cacao	Maillard reaction
2,3-Butanedione	butter, caramel	Maillard reaction
Butanoic acid, 3-methyl	cheesy, sweaty, sweet, old hops	Maillard reaction
2,3-Butanediol	sweet, plastic	microbiological degradation
2,3-Pentanedione	butter, fruity	Maillard reaction
2-Furancarboxalhedyhe	almond, burnt, floral	Maillard reaction
Acetic acid	sour, vinegar	Maillard reaction
Hexanal	grass, vegetables, bitter	fat oxidation
5-Hydroxymethylfurfural	stale, vegetable oil, pungent, soapy	Maillard reaction
2-Furanmenthol	sweet, woody	Maillard reaction
Furfural	almond, bitter, cereals, cardboard	Maillard reaction

ta[b]azepin-8(1H)-one also carry a bitter taste. However, in the presence of cysteine, the precursor of these bitter substances, diacetylformoin, preferentially reacts with it, and thus cysteine blocks the proline-induced formation of these bitter substances (Frank et al, 2001). Other proline products such as 2,5-dimethyl-4-(1-pyrrolidinyl)-3(2H)-furanone or 5-methyl-2-(1-pyrrolidinyl)-2-cyclopenten-1-one cause a persistent sensation of a cool and fresh taste in the oral cavity. These substances have also been found in roasted malts (Ottinger et al., 2001).

5 Basic laboratory methods of sensory analysis

Laboratory methods include those tests that are carried out in specially equipped sensory laboratories under standard conditions and using trained assessors or expert sensory evaluators. Most laboratory methods of sensory analysis are standardised on an international or national scale (Czech Accreditation Institute, 2018).

Most of the commonly used methods are divided into three groups:

1. **Difference tests used to determine the likelihood of differences or similarities between products**
   (a) pairwise comparative test
   (b) duo-trio test
   (c) triangular test
   (d) two-out-of-five test
   (e) 'A-not A' test
   There is a different way of analysing the results for all these tests.

2. **Tests using scales and categories to determine the order or magnitude of differences or the category or class to which the sample belongs**

3. **Descriptive tests used to identify specific sensory characteristics present in the sample**

   These tests may be applied to one or more samples to characterise both qualitative and quantitative one or more properties. They may be classified as:
   (a) simple descriptive tests
   (b) sensory profile and descriptive analytical methods
   (c) free-choice profiling

The specific method is chosen according to the task to be solved, the number and quality of evaluators, the amount of samples and other factors (Ježek and Saláková, 2012).

6 Methods of sensory evaluation of malt

For the evaluation of the substances responsible for the aroma of malts, the results of traditional methods for the determination of aroma compounds alone are of low predictive value. More appropriate is the use of olfactometric methods based on aroma dilution analysis using extraction methods that avoid the formation of artefacts (substances that are formed from precursors in contact with water during the application of laboratory procedures for the isolation of odoriferous substances and cause false positive results) and thus do not distort the true profile and importance of the aromatic substances in malt (Cejpek, 2014).

In 2017, the American Society of Brewing Chemists (ASBC) published a new standardized method for sensory and flavour evaluation of malts suitable for brewing. It consists of preparing a hot infusion of finely crushed malt and then filtering it through filter paper (or a coffee filter) to obtain a "hot" (65 ºC) malt liquor. For the evaluation of special and colour malts, a precise ratio with pale malt is used. A sensory evaluation of the wort is carried out within 4 hours from preparation (Smith, 2017).

Based on a combination of aroma and flavour determination, olfactometric methods, sensory evaluation and statistical analysis, sensory tools (maps) have been developed for use in malting and brewing practice.

DraughtMap has created the Base Malt Flavour Map (DraughtLab, 2017a) and the Specialty Malt Flavour Map (DraughtLab, 2017b) as a sensory tool to assist maltsters, brewers, distillers and other users within the craft malt supply chain and associated industries in describing the flavours of basic and specialty malts. Both maps are used as a training tool for evaluators, to help them improve their malt sensory vocabulary and become familiar with the wide range of malt flavours available for basic and specialty malts.

Su et al. (2022) developed a sensory lexicon and a sensory wheel for the evaluation of the brewing malt. Within a sensory evaluation of 22 malt samples, the panel identified 53 attributes that form the brewing malt lexicon, including appearance, taste, aroma, and mouthfeel. In consultation with the brewing industry experts, 46 attributes were selected from the lexicon list to construct the sensory wheel (Figure 3). Based on the lexicon, the rate-all-that-apply analysis was used to discriminate between six samples of different malt types. The results of the principal component analysis (PCA analysis) showed that malt types significantly correlated with sensory traits. To understand the chemical origin of sensory attributes further, a partial least squares regression analysis was used to determine the association between aroma compounds and sensory attributes. According to the colour scale and malt types, 18 samples were used for sensory descriptive analysis and identification of volatile compounds. From the brewing malt sensory wheel, seven main flavours were selected. 34 aromatic compounds were identified by headspace solid-phase microextraction gas chromatography, mass spectrometry and olfactometry. According to the results of the partial least squares regression, the aromatic compound content highly correlated with the sensory attributes of the brewing malt. This approach may have practical applications in the sensory studies of other products.

Figure 3 *Sensory wheel of brewing malts. 46 specific attributes of brewing malt were illustrated in a three-circle sensory wheel, including 15 appearance attributes, 26 flavour attributes and 5 taste and mouthfeel attributes. Adapted from Su et al. (2022)*

7 Conclusion

Not only hops but also malt contribute to the taste of the beer. The Maillard reaction together with other non-enzymatic browning reactions and the oxidation of the lipophilic components of the malted grain are involved in the formation of the substances that are prominent in the aroma of malts. The oxidation of lipids occurs relatively easily, as the water activity of the grain is significantly reduced during malting. However, many of the aromatic products of lipophilic oxidation leak out or degrade during brewing. Pale malts contain few flavour and aroma substances, whereas dark and some special malts contain a rich mixture. This results in a certain amount of sensory inactive precursors which then provide flavour and aroma compounds relatively easily when the beer is brewed. The sensory analysis of malt can thus become a tool for controlling the production technology of malts with suitable sensory properties for the production of the intended type of beer.

8 Acknowledgement

The article was supported by the Ministry of Agriculture of the Czech Republic within Institutional Support MZE-RO1918.

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