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Chemistry of Organic Compounds in the Beer Production

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Abstract

Beer can be considered as a hydrous solution of ethanol, in which several organic substances are dissolved. These organic substances are subject to a variety of reactions, which occur during fermentation, storage, and eventually these kinds of chemical reactions determine the characteristic aging of the beer, and its quality as well.

Keywords: Chemistry, Organic Compound, Mechanism and Beer.

Introduction

Beer is obtained by fermentation of glucose molecules of plant origin. In other words, beer is an alcoholic beverage obtained by transformation of starchy substances by enzymatic and microbiological means. The aim of this review is to show different organic reactions, which take place during the production of beer with emphasis on the reactivity of organic compounds as well as the reaction mechanisms. It is important to mention that the understanding of a reaction mechanism helps to select starting materials and predict the formation of a desired product or the knowledge of a reaction mechanism permits to set up appropriate conditions in order to generate a targeted product.

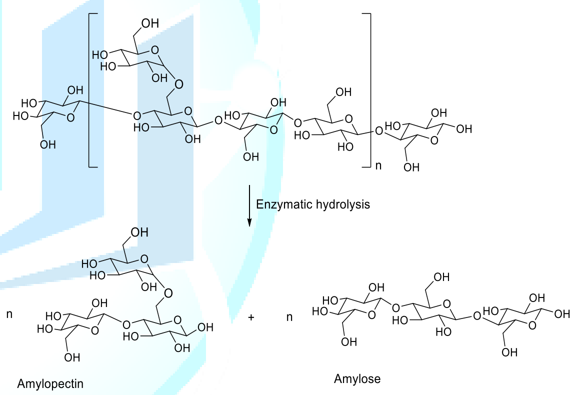
Chemical Ingredients

Water

Water in the beer must be free of organic and inorganic pollutants or any undesirable products such as bacteria, sediments, halogenated aromatic organic compounds. Water contains mineral salts, which must be controlled. Water is necessary for brewing as well as for cleaning and rinsing equipment used in the brewery. Spring or well water is desirable because it contains a small amount of mineral salts, but it has to be checked regularly in order to verify its purity. It is very important to mention that the quality of beer depends on the chemical characteristics of water [1,2,3].

Malt

Malt is made from cereals particularly barley, which is most often utilized in brewery. In this regard, at the malt house, cereals are placed in conditions which allow their germination and then, they are dried. This kind of technology is called malting, a technology that sets free enzymes, which hydrolyse the starch to produce amylopectin (branched polymer of glucose molecules) and amylose (linear chain composed of glucose molecules) into the reaction medium **(Scheme 1)**. The plausible enzymatic mechanism of starch hydrolysis has been recently reported in the literature [4,5].



Scheme 1: Starch enzymatic hydrolysis.

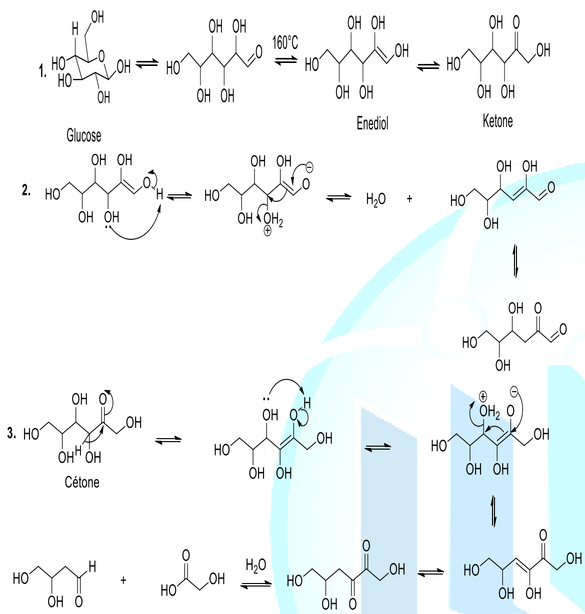
In utilizing diverse temperatures, at least colored, caramelized or roasted malts are obtained and the procedure is called kilning. It is by using these different malts in varying proportions that the brewer will obtain the desired color, and the taste for different beers. The malt is important in beer production because it contains starch, proteins and enzymes. During brewing, enzymes hydrolyse the starch of malt to produce glucose units (Scheme 1). Glucose units will be transformed into alcohol and carbon dioxide under the action of yeast during fermentation [5,6].

Yeasts

Yeasts are microscopic unicellular fungi that live and proliferate by consuming sugars. In anaerobic conditions, yeasts convert sugars into ethanol and carbon dioxide. This kind of conversion is called fermentation. This chemical process is the basis for the production of any alcoholic beverage. During fermentation, the yeasts also produce a variety of aromatic substances, which give the beer its own characteristic [5,6].

Caramelization

Caramelization is a non-enzymatic oxidation reaction extensively utilised in cooking to obtain the natty flavor and brown colour. During caramelization, volatile organic substances are released, and that allows a characteristic flavor of the caramel. Indeed the reaction involves the loss of water in the form of vapor, and the cleavage of glucose **(Scheme 2, reaction 1)**. The thermal degradation of sugar, during the caramelization process, involves diverse reactions such as the intra molecular rearrangement or Lobry-de Bruyn-van Ekenstein Rearrangement. This step is followed by beta elimination of a molecule of water (dehydration reaction) and dicarbonyl group cleavage as well **(Scheme 2, reaction 2,3)** [7-10].



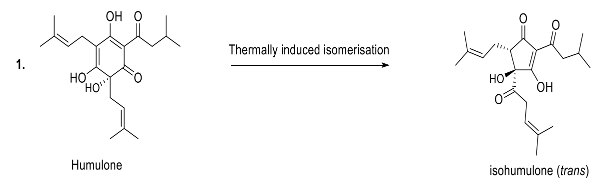
Scheme 2: Thermal decomposition of glucose mechanism.

Most importantly, the enolization of glucose is a pivot reaction because it initiates the degradation process. Indeed, the organic compounds generated during the thermal decomposition of glucose can subsequently react to produce carboxylic compounds, and oxygenated heterocyclic substances via aldol condensation. From all the sugar degradation reactions, the strategic intermediate compounds from thermal caramelization are dicarbonyl compounds. These kind of compounds lead not only to the formation of caramel coloration, but also they generate volatile products, which are typical of the caramel flavor [7-10].

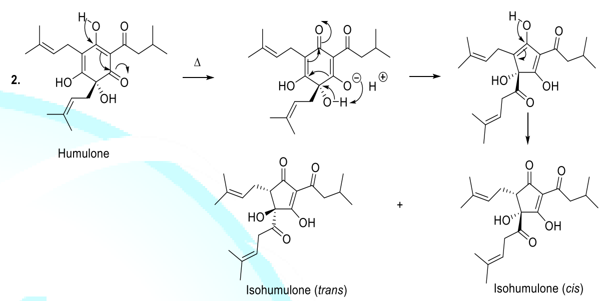
Humulus lupulus

Hop or Humulus lupulus L. is a climbing plant is the Cannabaceae family. The female plants produce flowers in the form of small cones made up of leaflets. Underneath these small leaves are tiny yellow glands with lupulin, which contains better resins and aromatic essential oils. Therefore, the hop gives the beer a bitter taste and a characteristic aroma according to the used technology. It contributes to the retention of foam, and to the shelf life of the beer. It can be utilized as a cone, its coolest form or as a compressed granule, which is practical and durable. In addition, the tannic substances contained in the leaflets allow the hop to play the role of preservative and natural clarifier of the beer [11-13]. During the beer production, lupulin is transformed to produce bioactive humulone and lupulone **(Scheme 3)**.

The antioxidant and antibacterial Lupulone as well as humulone both participate to the preservation of beer. Under thermal conditions, Humulone is, at its turn, converted to isohumulone, an antibacterial with a bitter flavor (Scheme 3) [14-22].

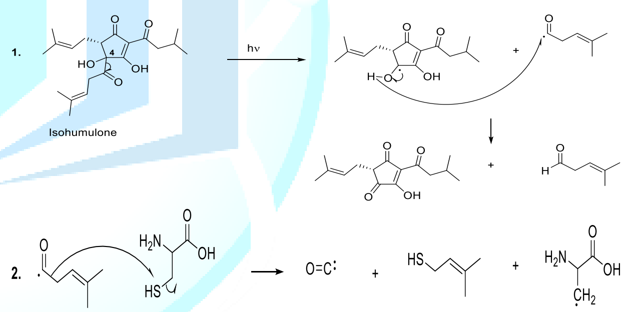


Scheme 3a: Thermally induced isomerisation.



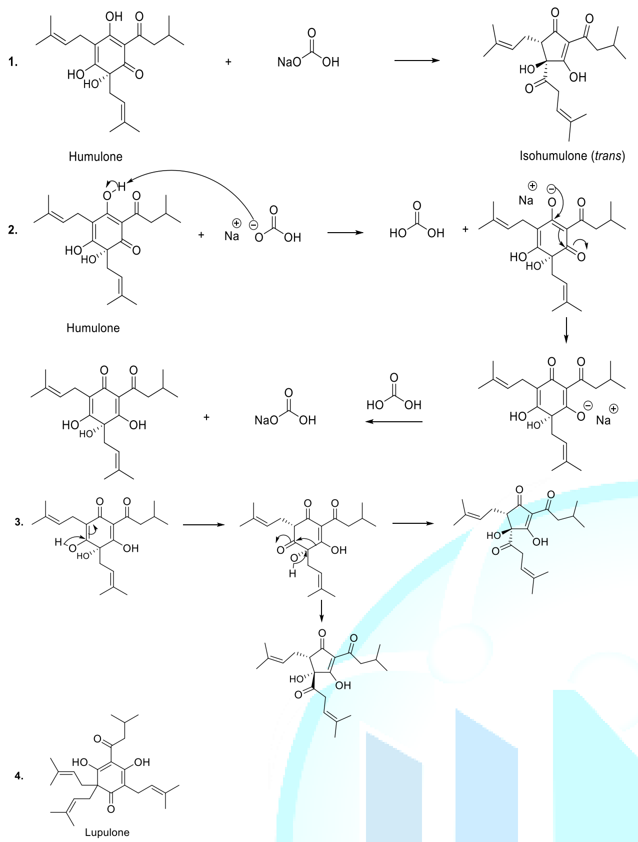
Scheme 3b: Thermally induced isomerisation mechanism.

The humulone derivative, isohumulone is sensitive to light, and in such photolysis conditions it can be easily transformed to the corresponding products **(Scheme 4, reaction 1)** [14-22].



Scheme 4: Isohumulone degradation mechanism.

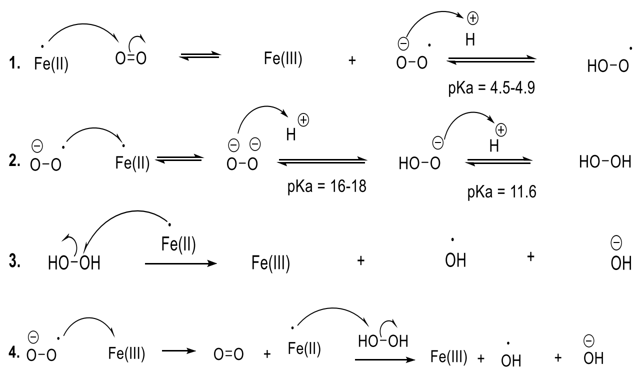
The isomerization of humulone can also be carried out in mild alkaline conditions, and in this case, the plausible mechanism involves the formation of a single anion **(Scheme 5)**. This sequence is followed by the formation of a ketone group in stereospecific manner, and the cyclic contraction to furnish trans and cis isohumulone in ratio of 32/68 [14-22]. It has been reported that in harsh alkaline conditions, two anions are formed, and this results in the production of two trans and cis isohumulone in ratio of 50/50 [14-22].



Scheme 5: Isomerization of humulone mechanism.

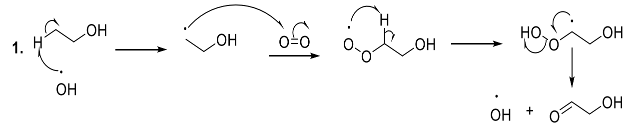
Oxygen

Oxygen alters rapidly the flavorof the beer. This means that oxygen is the initiator of chemical reactions that produce oxygenated reactive entities. Indeed, Oxygen in the ground state is normally stable and it cannot easily react with organic compounds. Nevertheless, in the presence of Fe(II) or Cu(I) in beer, the oxygen can capture an electron to form a radical anion, which can remove a proton to generate a more reactive hydroxyl radical. This later can also react with iron (II) or copper (I) to produce a peroxide anion. In beer, the peroxide anion is transformed into hydrogen peroxide. The hydroxyl radical can be produced from the hydrogen peroxide (Fenton reaction) or from oxygen (radical anion) by metallic induction **(Scheme 6, reaction 1-4)** (Haber-Weiss reaction) [23-26].

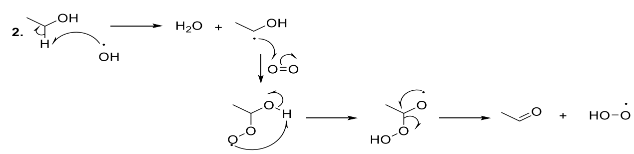


Scheme 6: Generation of oxygenated reactive entities.

Oxygenated entities degrade organic constituents of beer, and correspondingly, they promote the aging or deterioration of the beer quality **(Scheme 7)** [23-26].



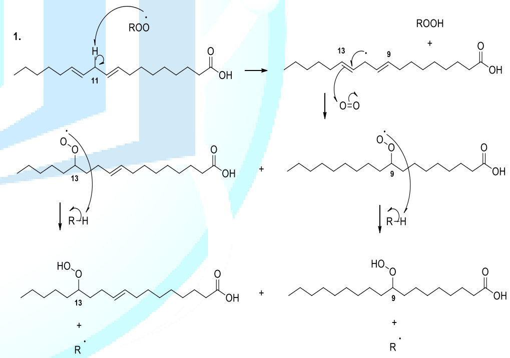
Scheme 7a: Degradation of organic constituents of beer mechanism.



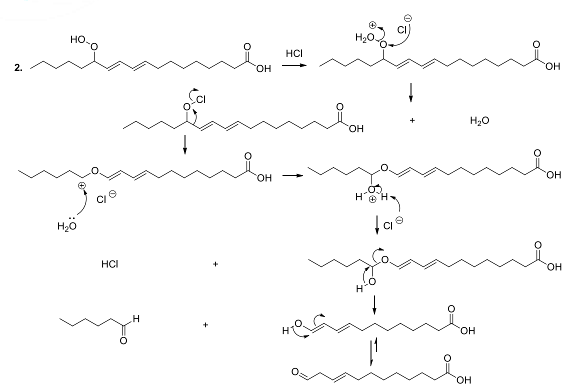
Scheme 7b: Degradation of organic constituents of beer mechanism.

Fatty acids

Reactive oxygenated species also react with lipids or fatty acids. Indeed, the oxidation of lipids starts with the removal of a hydrogen atom by free radicals specially hydroxyl radicals or peroxides. In the case of linoleic acid, the hydrogen situated upon carbon 11 is a hydrogen atom that is easy to be removed because it is activated by the two neighboring double bonds. It has been reported that hydroperoxide acids can be decomposed, in acidic conditions, to produce diverse volatile compounds, and in this perspective, several reaction mechanisms have been proposed whose the ionic mechanism **(Scheme 8, reactions 1,2)** [23-26].



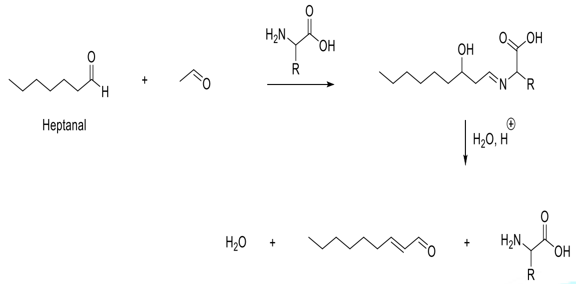
Scheme 8a: Fatty acid oxidation mechanism.



Scheme 8b: Fatty acid oxidation mechanism.

Carbonyl compounds

Experimental observations stated that aldol condensation of carbonyl compounds is plausible under mild conditions in beer during storage, and in this regard, amino acids behave as bases, nucleophiles, organic catalysts, and they contribute to the formation of imine intermediate products. This kind of process can lead to the production of carbonyl compounds after the hydrolysis of the corresponding imines **(Scheme 9)** [23-26].



Scheme 9: Catalysis of aldol condensation.

Conclusion

This review has shown enzymatic and non-enzymatic organic reactions occurring in beer production in order to better understand, for example, why oxygen has to be prevented to get in contact with beer. This is very important so that the quality of beer remains optimal. The knowledge of organic reactions also helps to understand the importance of preventing oxygen during fermentation because it will destroy the enzymatic transformation of sugars due to the presence of yeasts in the production of alcoholic beverage. Organic reactions play a notable role because the aging of beer can be preserved in using additives such as ascorbic acid. In fact, beyond the technology of measurements on devices to reduce the influence of atmospheric oxygen during bottling, ascorbic acid has proven to be a suitable oxygen reducer or a reliable antioxidant during beer brewing.

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