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BREWING WITH CITRUS: REVIEW OF LEMON-INFUSED WHEAT BEER

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Abstract:

In recent years, consumer interest in craft beers produced by craft breweries and microbreweries has been growing. Craft beer beverages provide the opportunity to produce new, unprecedented, and often amazing combinations of plant-based raw materials with beer, which affects the flavor and aroma qualities. Among the various beer styles produced by craft breweries are wheat beers. Wheat beers use wheat malt or unmalted wheat grain to replace part of the barley malt (generally 40 to 60% of the hopping). Wheat beers are characterized by an intense haze, a fine but stable head, a slight bitterness, and a slightly sweet aftertaste due to the fermentation process carried out, during which compounds are produced that give flavor to the finished product (including phenols, aldehydes, esters, and their derivatives). Lemon-flavor-infused wheat beer is a specialty beer that combines the refreshing citrus character of lemon with the smooth, slightly hazy profile of wheat beer. This review explores the chemistry of lemon flavor infusion, brewing techniques, sensory attributes, and microbial interactions associated with lemon-infused wheat beer.

Keywords: beer, wheat malt, lemon-infused wheat beer, Hops, breweries.

Introduction :

Wheat beer has a long history, originating from regions such as Bavaria and Belgium, where brewers developed styles like hefeweizen and witbier, known for their light, refreshing qualities. These beers traditionally feature fruity and spicy esters, often complemented by ingredients such as coriander, orange peel, and other botanicals, since beer is conventionally produced from barley malt, wheat beer is considered a special type of beer **Villasreces *et al.*, (2014).** Wheat beer popularity has varied over the years but in the last few years, the expansion of craft and home brewing has added to the demand for wheat beers. In addition, wheat beers produced by international breweries have gained more attention **Bethany *et al.*, (2012)**. Wheat beers are characterized by an intense haze, a fine but stable head, a slight bitterness, and a slightly sweet aftertaste due to the fermentation process carried out, during which compounds are produced that give flavour to the finished product (including phenols, aldehydes, esters and their derivatives). Lemon infusion in wheat beer is a natural extension of these traditions, leveraging the complementary flavors of citrus and wheat malt to create a beer that is both refreshing and complex **Bethany *et al.*, (2015)**. The tartness of lemon pairs well with the slight acidity of wheat beers, enhancing their drinkability and broadening their appeal to a wider range of consumers. Additionally, citrus-infused beers align with current craft brewing trends that emphasize unique flavors, natural ingredients, and innovative brewing techniques. Beyond sensory appeal, lemon offers functional benefits in brewing. Its citric acid content can aid in pH balance, potentially improving beer stability and microbial control. The selection of high-quality brewing ingredients is of utmost importance, as these are the source of all constituents affecting the flavor, aroma, and color of beer **Anderson *et al.*, (2019).** Furthermore, lemon-derived compounds such as flavonoids and vitamin C may provide antioxidant properties, contributing to both shelf stability and potential health benefits. As consumer preferences shift toward lighter, fruitier beers, lemon-infused wheat beer stands out as a promising innovation in the brewing industry.

Chemistry of Lemon Flavor Infusion:

Lemon contributes a range of volatile and non-volatile compounds that impact aroma, taste, and mouthfeel:

- **Limonene & Citral:** Key aroma compounds responsible for the characteristic lemon scent and fresh citrus notes.
- **Ascorbic Acid & Polyphenols:** Antioxidant compounds that may contribute to beer stability and potential health benefits.
- **Organic Acids (Citric & Malic Acid):** Enhance acidity and brightness, complementing wheat beer's natural tartness.
- **Essential Oils:** Found in the lemon peel, these contribute to aroma complexity but require careful dosing to avoid overpowering bitterness **Bethany *et al.*, (2015).**

Sensory Attributes

Beer is a very complex beverage, and the objective evaluation of beer flavour is a skill that many breweries can ill afford to be without. Beer contains many flavour-active substances derived from the raw materials and from processing.

It is essential, therefore, for each panelist to follow the same tasting procedure so that this complexity of beer flavor can be evaluated in the same way.

• Appearance: assess the beer foam for head depth, bubble size and colour and lacing (foam adhering to the glass during consumption). The colour and clarity of the beer is also considered.

• Aroma: swirl the beer in the glass with the lid on to release volatile components into the headspace. Remove the lid and assess the initial aroma, ensuring that a mental note is taken as some volatiles will flash off very quickly (e.g. sulphur compounds). Then take a few small sniffs to evaluate the intensities of the other volatile compounds.

• Taste: take a sample into the mouth and swirl to cover the inside of the mouth and tongue. Although there are taste buds all over the tongue, the bitterness of beer is detected more toward the back of the tongue and after swallowing. Assess the intensities of the different malt, hop and yeast-derived flavors. Also, the mouth-feel characteristics should be considered.

• After-taste: once swallowed, the after-taste of the beer is assessed, including the lasting flavours and length of linger **Parker (2012).**

Microbial and Biochemical Interactions

- **Yeast Metabolism:** Interacts with lemon-derived compounds, potentially modifying ester production.
- **pH Stability:** The acidity from lemon can slightly lower beer pH, influencing microbial stability and enhancing tartness.
- **Oxidation Concerns:** Citrus-derived antioxidants (ascorbic acid) may improve shelf life but excessive oxygen exposure can lead to off-flavors.
- Whatever the type of alcoholic product and elaboration procedure they are made, they are all obtained through a microbiological process, in which yeast and bacteria are responsible for the aromatic profile and quality achieved during fermentation.The main interactions in alcoholic beverages are between S. cerevisiae and non-Saccharomyces and between yeasts and lactic acid bacteria. These interactions can be related to metabolites produced by fermentation such as ethanol, or to secondary metabolites such as proteinaceous toxins, or are feed-related, either by competition for nutrients or by beneft from released compounds during yeast autolysis **Torres-Guardado *et al.*, (2022).**

Potential Health Benefits

Lemon-infused wheat beer may offer certain health-related advantages:

- **Rich in Antioxidants:** Lemon-derived flavonoids and vitamin C provide oxidative stress protection.
- **Improved Digestibility:** Moderate acidity may aid digestion and enhance palatability.
- **Lower Alcohol Perception:** The refreshing citrus character can mask alcohol harshness, encouraging moderate consumption.
- Nutritional features of special and regular beers in general and on their proven or potential beneficial actions on one's health status and in preventing certain diseases. The main bioactive compounds of such products will be reviewed, and the impact of alcohol consumption will be discussed, showing the potentials of improving the nutritional profile of special beers and their prospective therapeutic properties **Salanță *et al.*, (2020).**

Manufacturing Process:

The production of lemon-infused wheat beer follows a systematic brewing process incorporating traditional wheat beer techniques with specialized citrus infusion methods:

Beer is traditionally produced using four main ingredients: water, malted cereal, hops and yeast **Carvalho *et al.*, (2023).**

A. Ingredient Selection:

- **Malt:** A high proportion of wheat malt (50-70%) is combined with pale barley malt to ensure a smooth and slightly hazy body.
- The term "malt" defines the material that results from germination, under controlled conditions, of any cereal (e.g., barley, rice, corn, wheat etc.). Among many other compounds, malt contains three highly valuable constituents from a brewer's perspective: starch, proteins and hydrolytic enzymes **Carvalho *et al.*, (2023).**
- **Hops:** Low to moderate bitterness hops such as Hallertau or Saaz to avoid overpowering the lemon flavor.
- Hops are plants classified as Humulus lupulus which are typical from cold regions and thus require strict cultivation conditions. This plant possesses glands where lupulin granules are produced, which contain brewing's substances of interest such as α-acids and essential oils that are responsible for the typical beer's bitterness and aroma.
- **Yeast:** Belgian wheat beer yeast strains known for fruity ester and phenolic production.
- Yeast is a eukaryotic, single-celled organism that belongs to the fungi kingdom [25]. Currently, beer is classified in one of the following categories: ale, lager and lambic. The main criterion that divides these categories is the yeast species used in the production of the beer: Saccharomyces cerevisiae strains (i.e., top-fermenting yeasts) are responsible for ale beers, Saccharomyces pastorianus (i.e., bottom-fermenting yeasts) generate lager beers and indigenous yeasts strains (i.e., wild yeasts) present both in the atmosphere of the brewery and in beer's raw materials generate lambic beers **Iorizzo *et al.*, (2021).**
- **Lemon:** Fresh zest, juice, or dried lemon peel to be added at controlled stages for optimal citrus infusion.

B. Mashing:

The mashing process involves mixing milled wheat and barley malt with hot water to activate enzymes responsible for starch conversion. The mash is subjected to temperature rests at **45–55°C** for protein breakdown, which enhances mouthfeel and foam stability, and at **62–72°C** for starch conversion into fermentable sugars, ensuring proper attenuation. During this process, dried lemon peel or zest may be added to subtly infuse citrus notes. The mash is then held at these temperatures for optimal enzymatic activity before lautering, which separates the liquid wort from spent grains.

Mashing comprises the mixture of milled malt along with water at a controlled temperature according to a previously established program. This operation aims to solubilize malt substances that are directly soluble in water and to promote the enzymatic hydrolysis of starch and proteins into fermentable sugars and amino acids **Schepper *et al*., (2021).**

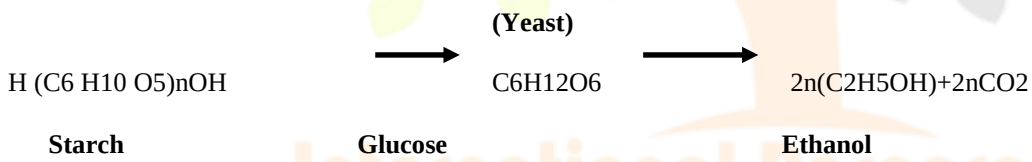
C. Boiling:

The wort is then transferred to the boiling stage, which lasts between 60 to 90 minutes. During this phase, hop additions are made to balance bitterness, and lemon zest or dried peel is introduced in the final 5-10 minutes to retain volatile citrus compounds while avoiding excessive bitterness. Boiling also sterilizes the wort and extracts essential hop compounds.

The boiling stage includes several purposes, such as biochemical stabilization of the wort composition; clarification through the coagulation and precipitation of tannins and proteins; sterilization to eliminate bacteria; extraction of bitter precursor compounds (αacids) from hops; isomerization of α-acids into the bitter molecules that provide bitterness to beer (iso-α-acids); extraction of aromatic hops compounds that contribute to the taste and aroma of beer; and evaporation of undesirable volatile compounds **Kalb *et al*., (2021).**

D. Fermentation:

The fermentation stage dictates the addition of yeasts, which begin to uptake fermentable sugars, amino acids, minerals and other nutrients **Liu *et al*., (2022).** Once boiling is complete, the wort is cooled and transferred to fermentation vessels, where it is inoculated with Belgian abbey yeast strain. Fermentation occurs at temperatures between **18–22°C**, allowing yeast to metabolize sugars and produce alcohol and aromatic compounds. Lemon juice or puree may be introduced at this stage to integrate deeper citrus flavors. The fermentation period typically lasts **7–14 days**, depending on yeast activity and temperature control.



E. Conditioning & Maturation:

Following primary fermentation, the beer undergoes conditioning at **0–4°C** for **2–4 weeks**. This process allows for the development of a smooth, well-balanced flavor profile while also improving clarity. Additional lemon zest may be introduced at this stage to enhance aroma retention. Cold crashing is often performed to help settle yeast and other particulates before final filtration.

F. Filtration & Packaging:

After conditioning, the beer may be lightly filtered or left unfiltered to maintain its hazy appearance. Carbonation is adjusted using either bottle conditioning (by adding priming sugar for natural carbonation) or forced carbonation with CO_2 injection for precise control. The final product is then packaged into bottles, cans, or kegs for distribution.

Conclusion:

The present study reviewed the potential of employing innovative processing technologies Lemon-infused wheat beer presents a unique fusion of traditional brewing with citrus enhancement, offering a balanced, refreshing beverage with distinct sensory and potential health benefits. By carefully selecting ingredients and employing optimized brewing techniques, brewers can achieve a product that is both innovative and commercially viable. The infusion of lemon provides not only a unique flavor profile but also functional advantages such as pH stabilization and potential antioxidant properties. As the craft beer industry continues to evolve, incorporating natural fruit flavors like lemon may drive consumer interest and expand the market for wheat beer. Further research into the biochemical interactions of lemon compounds in brewing could lead to even more refined approaches for maximizing flavor integration and stability.

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