Sustainable Alternatives in Beer Production: Replacement of Barley Malt with Malt from Unused Beans

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Beer is considered to be one of the most widely consumed beverages worldwide (Callejo *et al* 2020), with its market experiencing ongoing growth due to the incorporation of alternative raw materials such as sorghum, maize, rice, buckwheat, and quinoa (Cadenas *et al* 2021). In countries renowned for their beer production, such as Germany, the brewing process is rigorously confined to the utilization of just four fundamental ingredients: water, malted barley, hops, and yeast (Salanță *et al* 2020). In numerous other nations, the regulatory environment is comparatively less stringent, allowing brewers the opportunity to explore alternative ingredients. Such substitutions frequently encompass both malted and unmalted sources of carbohydrates (Humia *et al* 2019). In this dynamic market, brewers are consistently seeking novel ingredients for the production of beers with distinctive organoleptic characteristics and align with marketing trends emphasizing sustainability and innovation.

Adjuncts have become a key feature of modern brewing practices, with approximately 85-90% of global beer production incorporating them (Cadenas *et al* 2021; Trummer *et al* 2021). Legume grains represent a cost-effective source of dietary protein, essential minerals such as potassium, iron, and zinc, as well as vitamins and polyphenolic compounds. These include flavonoids, isoflavones, phenolic acids, and tannins, all of which are significantly linked to a variety of health advantages (Ferreira *et al* 2021). Traditionally, peas were favored in brewing due to their beneficial impact on viscosity and flavor of the produced beers (Markham 1986). Recent developments have incorporated adjuncts like fava bean flour and both malted and unmalted lentils, enhancing the protein, mineral, and polyphenol compositions of beer (Black *et al* 2019; Luneia *et al* 2018; Trummer *et al* 2021). The increasing interest in the utilization of legumes and other supplementary ingredients has not yet been matched by a corresponding rise in the number of scientific studies conducted in this area.

The aim of this study is to explore the feasibility of replacing barley malt with bean malt in the brewing process, with the intention of diversifying the raw materials utilized in beer production and advancing the principles of a circular economy. This research specifically examines second-grade beans, which are often considered unsuitable for direct human consumption due to their aesthetic qualities or size, despite being microbiologically safe and free from spoilage. It is estimated that around 10-15% of total bean production is discarded after harvest sorting because of visual flaws. Employing these undervalued beans as substrates for brewing presents a viable approach to minimizing agricultural waste.

A series of experiments was conducted to assess the impact of substituting barley malt with varying proportions of bean malt on key physicochemical and sensory characteristics of beer. Parameters such as sugar and ethanol content, pH, specific gravity, total phenolic content, antioxidant capacity, and sensory attributes were systematically evaluated. A control beer, along with four experimental samples incorporating 10, 20, 30, and 40% bean malt substitutions, were produced and analyzed. The findings revealed that the addition of bean malt significantly altered the physicochemical characteristics of the beers produced.

The conducted measurements indicate that the addition of bean malt had a significant effect on both the kinetics of saccharification and the overall fermentation process. It was observed that as the substitution rate increased, there was a corresponding decline in fermentation efficiency, which can likely be attributed to a higher concentration of non-fermentable solutes and proteins. Nevertheless, the beer with a 20% substitution rate achieved the best results in terms of ethanol concentration. A sensory analysis was carried out to evaluate the organoleptic properties of the produced samples, focusing on parameters such as aroma, color, clarity, taste, and aftertaste. The beer with a 30% substitution rate exhibited enhanced color and clarity; however, it was noted to have an undesirable aftertaste. In contrast, the 20% substitution not only improved the overall quality but also the sensory attributes, making it the most balanced and organoleptically favorable option according to the sensory analysis.

The replacement of cereals with legumes in the production of alcoholic beverages significantly enhances their protein content, thereby providing additional nutritional benefits to consumers. This innovation responds to the growing consumer interest in diverse flavors, aromas, and options for low-alcohol and gluten-reduced beers. Furthermore, legumes possess a distinctive nutrient profile that aligns with contemporary dietary preferences, which increasingly favor plant-based and high-protein foods. Additionally, the incorporation of second-grade beans in the brewing process illustrates the principles of a circular economy by transforming potential waste into valuable resources. This strategy not only alleviates the challenges associated with managing by-products in the

food industry but also contributes to overarching sustainability objectives, including the reduction of waste throughout the supply chain.

In conclusion, this research advances the understanding of alternative raw materials in the brewing sector by suggesting bean malt as a feasible and sustainable substitute for traditional barley malt. This strategy not only minimizes the ecological impact associated with beer manufacturing but also tackles the problem of food waste by incorporating visually imperfect but nutritionally sound legumes into the brewing process. The results highlight the capacity of second-grade beans to improve both the nutritional value and sensory characteristics of beer, while simultaneously promoting wider sustainability objectives within the food and beverage industry.

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