DEVELOPMENT OF A FUNCTIONAL BEVERAGE BASED ON FOOD BY-PRODUCTS, ENRICHED WITH BLACKCURRANT POWDER: TECHNOLOGICAL AND EXPERIMENTAL ASPECTS

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Abstract

Functional foods are also referred to as "foods of the future" since they are defined as foods that, while still being categorized as food, have additional advantageous components that can enhance bodily health in addition to their present fundamental nutritional value. Brewery spent malt, rye bread, and blackcurrant pomace powder are three food industry byproducts that were valorized to create the novel functional beverage known as ROOTS. The study's objectives were to use the HACCP system for food safety, optimize the technological manufacturing process, and qualitatively characterize the finished product. The technological process included the stages of infusion, controlled fermentation and pasteurization, identified as critical control points. The results demonstrated that the obtained beverage has an average pH of 3.9, alcohol content <0.5% vol., high antioxidant activity and a balanced sensory profile. The product is part of current trends in circular economy and sustainable consumption, offering a functional, natural and sustainable alternative to conventional beverages.

Keywords: functional beverage; food by-products; controlled processes; food safety.

The European circular economy places a high priority on reducing food loss and recovering resources. Every year, one-third of the food produced worldwide is lost or wasted, with significant negative effects on the environment and economy, according to FAO. In this regard, the beverage sector presents special chances to profit from fermentation processes, food byproducts, and the possibility of technological advancement (Sharma S. *et al.*, 2021). Functional foods are also referred to as ”foods of the future” in a study by Obayomi *et al*. (2024) because they are defined as foods that, in addition to their current essential nutritional value, contain additional beneficial components that can benefit the body's health while still being considered food. According to the same authors, foods in the functional category have the potential to improve health and fulfill an individual's physiological needs, but they cannot treat illnesses.

According to Gupta *et al.* (2023) ”any non-alcoholic beverage that offers additional health benefits through the incorporation of a bioactive component derived from plant, animal, marine, or microorganisms” is the definition of a functional beverage.

MATERIAL AND METHOD

Raw materials used: The primary raw materials used to make ROOTS, a functional beverage, were food industry by-products that were chosen for their nutritional value, availability locally, and potential for reintroduction into the food chain. In keeping with the circular economy's tenets and the demands of food safety management systems, the goal was to incorporate them into a sustainable process (ISO 22000:2018).

Technological process: The ROOTS functional beverage was created using a technological technique that was adapted to the utilization of food byproducts, modern safety and sustainability regulations, and the traditional principles of kvass manufacturing. An optimized flow served as the foundation for the technological stage sequence, which was confirmed by HACCP risk analysis and the identification of important control points.

Physico-chemical analyses: The physico-chemical determinations aimed to characterize the composition of the ROOTS beverage and verify

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compliance with internal product specifications. Some of the analyses were performed in the quality control laboratory of the Faculty of Agriculture at USV Iași, using standardized methods according to AOAC (2019) and ISO 2172/2018, some being performed in specialized accredited laboratories.

Parameters analyzed:

- pH was determined with a digital pH meter (Hanna Instruments, USA) calibrated daily with pH 4.00 and 7.00 buffer solutions.
- Total acidity was expressed in g lactic acid/L, by titration with 0.1 N NaOH solution until the phenolphthalein indicator turns.
- The soluble solids content (°Brix) was measured with the Atago digital refractometer, at 20°C, on a degassed sample.
- Density was determined by the pycnometric method at 20°C.
- The reducing sugar content was determined by the Lane-Eynon method, expressed in g glucose/100 mL.
- Dissolved carbon dioxide (CO_2) was determined by volumetric analysis according to the EBC 9.37 (European Brewery Convention) method.
- The ethanol content was evaluated by gas chromatography (GC Agilent 7890A, DB-WAX capillary column, FID detector), expressed in % vol.
- Total ash was determined by incineration at 550°C (AOAC 940.26 method).
- The dietary fiber and total polyphenol content was analyzed by the gravimetric method (AOAC 985.29) and the Folin–Ciocalteu method, respectively, expressed in mg GAE/100 mL.

Microbiological analyses: The microbiological control was carried out to assess the safety of the final product and the efficiency of the process steps identified as critical points (fermentation and pasteurization). The determinations were carried out according to the standards SR EN ISO 21528-1:2017 and SR EN ISO 21527-1:2018, on samples collected at three times: after primary fermentation, after pasteurization and after 7 days of storage.

Microbiological parameters analyzed:

- *Enterobacteriaceae* – by seeding on VRBG agar medium, incubation at 37°C for 24 h.
- Yeasts and molds – on YGC agar medium, incubation at 25°C for 5 days.
- Lactic acid bacteria – on MRS agar, anaerobic incubation at 30°C for 72 h.
- *Salmonella spp*. and *Listeria monocytogenes* – qualitative tests performed according to European legislation (Reg. EC 2073/2005).

Sensory analysis: The sensory evaluation of the ROOTS beverage was carried out to determine the level of consumer acceptability and the correlation of analytical data with subjective perception. The test was carried out in the accredited sensory analysis laboratory of USV Iași, under controlled conditions (temperature 20 ± 2°C, standard lighting). A number of 25 untrained evaluators, selected from the university population (age 20–40), participated in the product testing, completing a questionnaire with a rating on a 9-point scale (from 1 – ”*not at all pleasant*” to 9 – ”*very pleasant*”). The analyzed attributes were:

- appearance (clarity, color, foam);
- smell/aroma (malty, fruity, fermentative notes);
- taste (sweet-sour balance, aftertaste, astringency);
- texture (effervescence level, body, swallowing sensation);
- overall acceptability.

Implementation of HACCP requirements - Given the use of food by-products in the formulation of ROOTS beverage and the fermentative nature of the technological process, the implementation of a HACCP (Hazard Analysis and Critical Control Points) system was essential to guarantee food safety and compliance with the ISO 22000:2018 standard.

RESULTS AND DISCUSSIONS

Raw materials

1. Brewers’ Spent Grain (BSG) - It represents the solid residue resulting from the brewing process, after the extraction of the malt wort. It was collected from the local producer, in a wet state (≈75% humidity). To prevent microbial growth, the spent grain was processed immediately or dried at 60°C to a humidity of 8–10%. BSG is a valuable source of dietary fiber (≈42%), protein (≈19%) and phenolic compounds (Ikram S *et al*, 2017). Through subsequent thermal processing (infusion at 80°C), part of these bioactive components is transferred to the liquid phase of the beverage, contributing to the malt aroma and oxidative stability.
2. Rye Bread Waste (RBW) - The surplus bread was provided by the local partner, under a zero waste agreement. The products were selected based on freshness and the absence of mold, then dried at 100°C for 15–20 minutes to avoid the development of unwanted microflora. Rye bread provides the beverage with fermentable carbohydrates, aromatic Maillard compounds and a characteristic reddish-brown color. The bread also contributes to the fiber load (≈6%) and the content of B vitamins, derived from the wholemeal flour (Kaszuba J *et al*., 2024).
3. Blackcurrant Pomace Powder (BPP) - This raw material was obtained in the microproduction workshops of the “Ion Ionescu de la Brad” University of Life Sciences in Iași, by drying at 40°C the pomace resulting from pressing blackcurrant juice (Ribes nigrum L.), to 5%

humidity. The powder was subsequently finely ground (size <0.5 mm) and stored at 4°C, in airtight packaging. BPP is a concentrated source of anthocyanins (3.1 mg C3G/g), polyphenols (≈9.8 mg GAE/g) and dietary fiber (≈15%), contributing both to the color intensity and to the antioxidant and functional profile of the beverage.

4. White sugar and brewer's yeast (*Saccharomyces cerevisiae*) - Sugar was added at a concentration of 15 g/L in the "priming" stage, acting as a fermentable substrate for obtaining natural carbonation. *Saccharomyces cerevisiae* yeast was used as the inoculum for the controlled fermentation, due to its ability to adapt to complex environments and moderate alcohol production (<0.5% vol.). It was rehydrated before use and inoculated at a temperature of 25°C.

5. Technological water - The water used was of drinking quality, according to Order 161/2006, subjected to filtration and microbiological verification (absence of coliforms and mesophilic bacteria). All raw materials were previously analyzed from a physico-chemical and microbiological point of view, ensuring full traceability through compliance documents and batch codes.

Technological process - The diagram of the technological operations for manufacturing the functional drink is shown in figure 1.

1. *Raw material reception* - All ingredients were received according to internal quality specifications. At this level, organoleptic controls, moisture determinations and verification of compliance documents were carried out. A traceability register was drawn up for each batch, which includes the origin, date of reception and internal identification code. Non-compliant raw materials (presence of mold, foreign bodies, atypical odors) were rejected.

2. *Raw material storage* - BSG was stored for a maximum of 24 h at 4°C or dried for later use. The RBW and BPP were stored at room temperature (18–20°C), in clean, ventilated spaces, away from moisture and light. Sensitive materials (yeast, sugar) were stored in sealed containers, under strict hygienic conditions.

3. *Infusion and maceration* - This is the essential stage for the extraction of soluble compounds and the inactivation of contaminating microflora. The solid ingredients (spent malt, dried bread and currant powder) were introduced into water at 80°C, maintained for 60–90 minutes, under gentle agitation. The following effects were achieved through this heat treatment: solubilization of sugars, diffusion of anthocyanin pigments, release of aromatic compounds and reduction of microbial load. The resulting must had an average density of 1,040 g/cm³ and an intense reddish-brown color.

4. *Cooling and inoculation* - After maceration, the liquid was rapidly cooled to 20–25°C using a double heat exchanger, thus preventing the development of unwanted microorganisms. Inoculation was performed with Saccharomyces cerevisiae yeast at a rate of 0.05% (m/m), rehydrated according to the manufacturer's instructions. In some experimental variants, mixed fermentation (yeast + lactic acid bacteria) was also tested to obtain a complex aromatic profile and a balanced acidity.

5. *Primary fermentation* - The fermentation process took place in stainless steel tanks, at 22–25°C, for a period of 18–24 hours. The monitored parameters were: temperature, pH (<4.2) and °Bx. The decrease in sugar content and natural acidification indicated the completion of fermentation. Once the preset limits were reached, the process was stopped by cooling the mixture to 4°C, preventing excessive alcohol accumulation. The result was a raw, non-carbonated drink, with an opalescent appearance and a characteristic aroma of fermented malt.

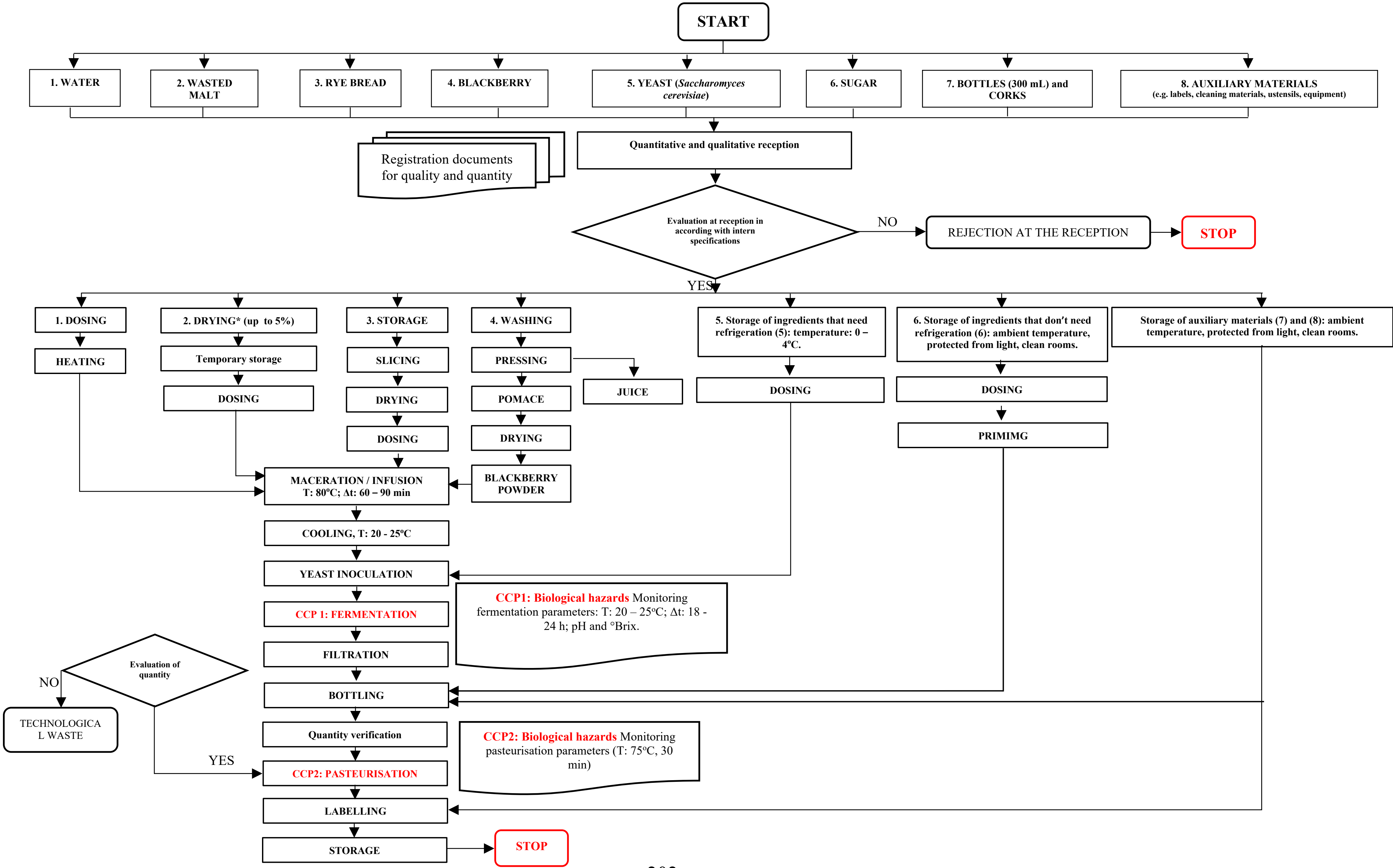
6. *Filtration and homogenization* - The fermented liquid was coarsely filtered through sterile textile sieves to remove large cereal particles and pulp residues. Fine filtration (5 µm plates) was applied only in samples intended for microbiological evaluation.

7. *Bottling and sugar addition* (*priming*) - The beverage was bottled in brown glass bottles (330 mL) fitted with metal caps. Before closing, sugar was added at a dose of 15 g/L to allow a slight secondary fermentation in the bottle, which generates natural carbonation. The bottles were kept at room temperature for 12 hours, then refrigerated at 4°C.

8. *Pasteurization* - For microbiological stabilization, the sealed bottles were pasteurized in a water bath at 75°C for 25 minutes, ensuring the destruction of residual yeasts and potentially pathogenic microorganisms. This step was automatically monitored by temperature sensors with continuous data recording.

9. *Labeling and final storage* - After cooling, the bottles were labeled with the ingredients, nutritional content, gluten warnings and shelf life (180 days). The finished products were stored at 18–20°C, protected from light, in recycled cardboard boxes.

Implementation of HACCP - Given the use of by-products in the formulation of beverage and the fermentative nature of the technological process, the implementation of a HACCP system was essential to guarantee food safety and compliance with the ISO 22000:2018 standard.


START
1. WATER
2. WASTED MALT
3. RYE BREAD
4. BLACKBERRY
5. YEAST (Saccharomyces cerevisiae)
6. SUGAR
7. BOTTLES (300 mL) and CORKS
8. AUXILIARY MATERIALS
(e.g. labels, cleaning materials, ustensils, equipment)
Registration documents for quality and quantity
Quantitative and qualitative reception
Evaluation at reception in according with intern specifications
NO
REJECTION AT THE RECEPTION
STOP
YES
1. DOSING
HEATING
2. DRYING* (up to 5%)
Temporary storage
DOSING
3. STORAGE
SLICING
DRYING
DOSING
4. WASHING
PRESSING
JUICE
POMACE
DRYING
BLACKBERRY POWDER
5. Storage of ingredients that need refrigeration (5): temperature: 0 – 4°C.
DOSING
6. Storage of ingredients that don't need refrigeration (6): ambient temperature, protected from light, clean rooms.
DOSING
PRIMIMG
Storage of auxiliary materials (7) and (8): ambient temperature, protected from light, clean rooms.
MACERATION / INFUSION T: 80°C; Δt: 60 – 90 min
COOLING, T: 20 - 25°C
YEAST INOCULATION
CCP1: Biological hazards Monitoring fermentation parameters: T: 20 – 25°C; Δt: 18 - 24 h; pH and °Brix.
CCP 1: FERMENTATION
FILTRATION
Evaluation of quantity
NO
TECHNOLOGICAL WASTE
BOTTLING
Quantity verification
YES
CCP2: Biological hazards Monitoring pasteurisation parameters (T: 75°C, 30 min)
CCP2: PASTEURISATION
LABELLING
STORAGE
STOP

The technological flow was graphically represented and validated on-site by the HACCP team, according to the principles of the Codex Alimentarius (Rev. 2020). The diagram included the stages of reception, storage, maceration, fermentation, filtration, bottling, pasteurization and labeling, each of which is correlated with hygiene and control procedures.

For each stage of the process, possible biological (bacteria, molds, contaminating yeasts), chemical (detergent residues, pesticides) and physical (metal fragments, solid impurities) hazards were analyzed, according to the ISO 22000:2018 methodology. The risks were assessed based on the probability of occurrence and the severity of the consequence, resulting in a risk classification matrix (low, medium, high).

Based on the decision tree, two critical control points were identified:

- CCP1 – Primary fermentation: monitoring of temperature (22–25°C), pH (<4.2) and duration (18–24 h) to prevent the development of unwanted microflora.
- CCP2 – Pasteurization: maintaining a temperature of 75°C for a minimum of 25 minutes to inactivate pathogenic microorganisms and stabilize the product.

The maceration, cooling, inoculation, maturation and labeling steps were classified as OPRPs (Operational Prerequisite Programs), controlled by continuous monitoring of temperature and equipment hygiene.

For each CCP, measurable critical limits, monitoring procedures (pH meter, digital thermometers, automatic recordings) and corrective actions, such as isolating non-compliant batches or resuming heat treatment, were defined. All data were recorded in specific monitoring sheets.

From a food safety perspective, the implemented HACCP system identified and controlled major biological risks by strictly monitoring fermentation and pasteurization temperatures. Thus, the process ensures microbiological stability without the use of chemical preservatives.

Physico-chemical characterization - The physico-chemical analyses performed on ROOTS beverage confirmed that the technological and qualitative parameters targeted during the product development phase were achieved. The average values obtained were: pH 3.9±0.1, total acidity 5.5 ±0.2 g/L, alcohol content 0.3% vol, reducing sugars 2.4 g/100 mL, CO_2 2.5 g/L and density 1.010 g/cm³.

These results indicate a weakly acidic, microbiologically stable drink with a moderate carbonation level specific to natural fermentation. The mild acidity and pH below 4.0 contribute to protection against pathogenic microorganisms and enhance the sensation of freshness. The low ethanol values (<0.5% vol) confirm the classification of the product in the category of fermented non-alcoholic beverages.

The high content of total polyphenols (33 ± 2 mg GAE/100 mL) and vitamin C (≈4 mg/100 mL) demonstrates the significant contribution of blackcurrant powder and antioxidant compounds from malt and bread. Compared to similar commercial beverages (kombucha, traditional kvass), ROOTS presents a superior antioxidant value, due to the synergy between the anthocyanins from blackcurrant marc and the phenolic compounds from cereals.

In addition, the presence of dietary fiber (≈0.8 g/100 mL) gives the product a functional character, contributing to digestion and the regulation of carbohydrate metabolism. These results confirm that the reuse of food by-products does not compromise nutritional quality, but on the contrary, it amplifies it by transferring residual bioactive compounds.

Microbiological evaluation and stability over time - The results of the microbiological analyses revealed full compliance with the limits allowed by the ISO 21528-1:2017 and ISO 21527-1:2018 standards. 24 h after primary fermentation, the predominance of the *Saccharomyces cerevisiae* population was observed, accompanied by a limited presence of beneficial lactic acid bacteria (*Lactobacillus spp*.), responsible for the rapid acidification of the medium (pH <4.2).

After pasteurization, all samples showed absence of *Enterobacteriaceae*, yeasts and molds <1 cfu/g and absence of *Salmonella spp*. and *Listeria monocytogenes*. Following stability tests carried out after 7 days of storage at 18–20°C, the microbiological parameters were maintained within safe limits, without the development of spoilage microflora.

These results confirm the effectiveness of the pasteurization process (75°C/25 min) as a critical control point (CCP2) and the importance of combining the heat treatment with the natural acidity of the beverage in ensuring microbiological stability.

Controlled fermentation (CCP1) allowed for a balanced fermentation, without excessive alcohol formation, avoiding defects such as the "mousy" taste or ethanol odors, sometimes encountered in spontaneous fermentations.

Sensory profile and consumer acceptability - The sensory analysis, conducted on a sample of 25 evaluators, demonstrated a high degree of overall acceptability. The average score of 8.1 ± 0.4 (on a 9-point scale) highlighted the positive perception of the product in terms of taste, color and aroma.

The main attributes appreciated were:

- aroma – specific of malt and black fruits, with balanced sweet-sour notes;
- color – intense reddish-brown, due to the anthocyanin pigments in the currants;
- taste – pleasant, slightly sour, with a fruity aftertaste and a sensation of freshness;
- natural effervescence – giving a fine and creamy texture;
- aftertaste – persistent, with slightly astringent notes typical of blackcurrants.

Statistical analysis (ANOVA, $p<0.05$) revealed significant correlations between color perception, aroma intensity and overall acceptability. Also, 87% of respondents stated that they would purchase the product if it were commercially available, indicating a high market potential for the LOHAS (Lifestyles of Health and Sustainability) segment.

CONCLUSIONS

The results obtained demonstrate the technological feasibility and economic viability of the ROOTS beverage as an innovative, safe and sustainable product. The synergy between controlled biological processes (lactic and alcoholic fermentation), the use of recycled ingredients and the strict control of critical parameters led to the production of a beverage with:

- excellent microbiological stability without preservatives;
- high antioxidant and nutritional properties;
- distinct and attractive sensory profile for modern consumers;
- low environmental impact and added value for the circular economy.

Thus, ROOTS demonstrates that food innovation based on the recovery of by-products can generate competitive products, with scientific, economic and social relevance, constituting a model of best practices for the sustainable development of the functional beverage industry. By turning by-products into useful resources, the functional beverage ROOTS serves as a practical illustration of how circular economy concepts are incorporated into the food business. The outcomes attest to the product's safety, stability, and sensory appeal, as well as its potential for industrial growth and commercial use. BPP enrichment greatly enhances the drink's nutritional and antioxidant profile, providing it distinctive qualities among handmade fermented goods. Overall, the experiment shows how clever component recovery can help create sustainable beverages with extra ecological and nutritional value.

REFERENCES

Gupta A., Sanwal N., Bareen M.A., Barua S., Sharma N., Olatunji O.J., Nirmal N.P., Sahu J.K., 2023 - *Trends in functional beverages: Functional ingredients, processing technologies, stability, health benefits, and consumer perspective*. Food Res. Int., vol. 170, 113046.

Ikram S., Huang L., Zhang H., Wang J., Yin, M., 2017 - *Composition and Nutrient Value Proposition of Brewers Spent Grain*. Journal of Food Science, vol. 82, no. 10, pp. 2232-2242. https://doi.org/10.1111/1750-3841.13794

Kaszuba J., Jańczak-Pieniążek M., Migut D., Kapusta I., Buczek J., 2024 - *Comparison of the Antioxidant and Sensorial Properties of Kvass Produced from Mountain Rye Bread with the Addition of Selected Plant Raw Materials*. Foods, vol. 13, pp. 357. https://doi.org/10.3390/foods13030357

Obayomi O.V., Olaniran A.F., Owa S.O., 2024 - *Unveiling the role of functional foods with emphasis on prebiotics and probiotics in human health: A review*. J. Funct. Foods, vol. 119, 106337

Sharma S., Singh A., Sharma S., Kant A., Sevda S., Taherzadeh M.J., Garlapati V.K., 2021 - *Functional foods as a formulation ingredients in beverages: Technological advancements and constraints*. Bioengineered, vol. 12, pp. 11055–11075.

***Food and Agriculture Organization of the United Nations (FAO), 2023. Global food losses and food waste – Extent, causes and prevention. Rome

***Codex Alimentarius – HACCP principles

*****ISO 22000:2018** - Food safety management systems - Requirements for any organization in the food chain

***AOAC (2019) - Official Methods of Analysis of the Association of Official Analytical Chemists: Official Methods of Analysis of AOAC International. 21st Edition, AOAC, Washington DC.

*****ISO 2172:2018** - Fruit juice. Determination of soluble solids content — Pycnometric method

*****SR EN ISO 21528-1:2017** - Detection of Enterobacteriaceae

*****SR EN ISO 21527-1:2018** - Microbiology of food and animal feeding stuffs - Horizontal method for the enumeration of yeasts and moulds - Part 1: Colony count technique in products with water activity greater than 0,95.