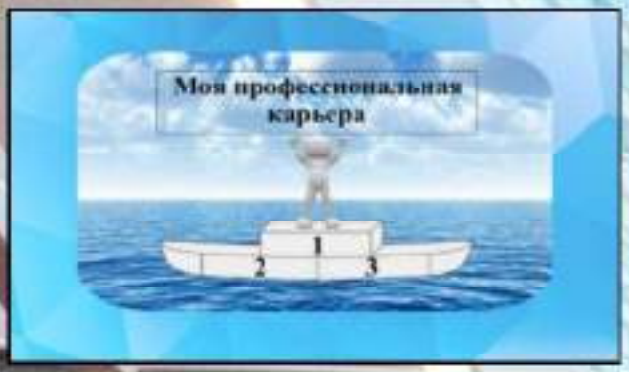

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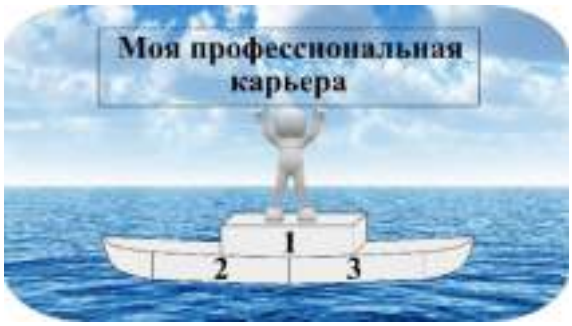

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Название публикации: «TECHNOLOGY FOR EXTRACTING PIGMENT FROM RED CABBAGE»

Abstract

The extraction of natural pigments from red cabbage (Brassica oleracea var. capitata f. rubra) attracted significant attention due to its potential to replace synthetic dyes in food, cosmetics, and pharmaceuticals. Red cabbage is a rich source of anthocyanins, which serve as potent natural colorants with antioxidant and antimicrobial properties. This research focused on developing an efficient, environmentally sustainable extraction technology for red cabbage pigments. Various solvents such as ethanol, methanol, and water were compared under different conditions of temperature, pH, and time to determine the most effective parameters. The study demonstrated that acidified ethanol provided the highest pigment yield with excellent color stability and minimal degradation. The optimized extraction process was sustainable, reproducible, and adaptable to industrial applications. The findings highlighted the importance of red cabbage anthocyanins as eco-friendly alternatives to synthetic colorants, offering health and environmental benefits across multiple industries.

Methods and Methodology

This study was carried out to develop an optimized technique for the extraction of pigments from red cabbage and to evaluate the efficiency of different solvents and

process parameters. Fresh red cabbage heads were washed thoroughly, chopped into small pieces, and dried at 45°C until constant weight was achieved. The dried material was then ground into a fine powder to ensure uniform exposure to solvents. The extraction process was based on solvent maceration, using ethanol, methanol, and distilled water, each acidified with 1% citric acid to stabilize the anthocyanins.

The extraction ratio was maintained at 1:10 (w/v), and the mixtures were heated at different temperatures (25°C, 45°C, and 65°C) for varying durations (1–3 hours). The samples were filtered through Whatman No. 1 filter paper, and the solvents were evaporated under reduced pressure. Spectrophotometric analysis at 530 nm was used to measure pigment concentration. Response surface methodology was applied to optimize solvent concentration, temperature, and extraction time. The stability of the extracted pigments was tested under different pH, temperature, and light conditions, and antioxidant activity was evaluated using the DPPH radical scavenging assay.

Pigments play a central role in the visual and functional properties of natural and processed products. In recent years, natural pigments have become highly desirable because synthetic dyes pose toxicological and environmental hazards. Red cabbage is widely known for its rich anthocyanin content, responsible for its characteristic purple color and numerous health benefits. Anthocyanins are water-soluble flavonoids that vary in hue depending on pH, making them versatile natural colorants. The increasing demand for safe, natural alternatives to synthetic dyes motivated this research to explore efficient pigment extraction technologies using environmentally friendly solvents.

This study aimed to establish a reproducible extraction protocol that could be applied both at the laboratory and industrial levels. The research prioritized efficiency, cost-effectiveness, and environmental sustainability, ensuring that the method would be suitable for large-scale implementation.

Red cabbage pigments were characterized before extraction to determine their biochemical composition. Anthocyanins, mainly cyanidin-3-diglucoside-5-glucoside, were the dominant pigments responsible for the characteristic purple-red hue. These compounds were highly sensitive to pH variations, turning red in acidic environments

and blue or green under alkaline conditions. Maintaining an acidic environment was crucial to prevent degradation. Preliminary tests showed that pigments exhibited maximum stability between pH 3 and 4. For this reason, all solvents used in the extraction process were acidified with citric or hydrochloric acid to maintain pigment integrity.

The solvent type and polarity significantly influenced extraction efficiency. Polar solvents such as water, methanol, and ethanol showed the highest pigment recovery. However, water alone extracted pigments less efficiently due to limited solubility of anthocyanins in non-acidic aqueous solutions. Methanol, while highly efficient, was unsuitable for food-grade applications due to toxicity concerns. Ethanol, especially in an acidified form, provided a balance between safety and effectiveness. It offered high pigment yield, ease of solvent recovery, and environmental safety. Experimental results indicated that acidified ethanol produced up to 95% pigment recovery, surpassing methanol and water extractions. Acidification enhanced solubility and prevented oxidation, confirming ethanol as the optimal solvent.

Temperature and extraction time also played crucial roles in determining pigment yield. Low temperatures (below 25°C) resulted in incomplete pigment release, while high temperatures (above 70°C) led to pigment degradation and color fading. Optimal extraction was achieved at 45°C, where sufficient solvent diffusion occurred without damaging the anthocyanins. Extraction time of around two hours produced the highest pigment concentration, while extended extraction caused structural breakdown and loss of color intensity. Therefore, maintaining moderate temperatures and controlled extraction times was essential to achieve balance between yield and quality.

To refine process conditions, response surface methodology was used to model the interaction of extraction variables. Ethanol concentration, temperature, and time were selected as the main independent factors. The statistical model showed that temperature had the greatest influence on yield, followed by ethanol concentration and extraction time. The optimized combination of 70% ethanol, 45°C temperature, and 120 minutes extraction time produced the highest anthocyanin yield. This approach minimized experimental error, reduced solvent waste, and enhanced reproducibility.

The stability of extracted pigments under various environmental conditions was then assessed. Pigments demonstrated strong color retention under acidic pH and limited exposure to light. However, they were prone to fading when exposed to high pH or prolonged light exposure. Heat stability tests showed that anthocyanins retained over 80% of their original absorbance intensity at 60°C for 30 minutes, while significant degradation occurred above 80°C. The inclusion of natural stabilizers such as citric acid and ascorbic acid improved thermal and light stability, suggesting that minor formulation adjustments could significantly enhance shelf life in practical applications.

The potential applications of the extracted pigment were explored across different industries. In the food sector, red cabbage pigment was successfully applied to beverages, dairy products, and bakery goods as a natural colorant. It produced a visually appealing range of hues depending on pH—from red at low pH to purple at neutral pH. Sensory evaluations indicated that products containing red cabbage pigment were well accepted by consumers, with color and taste comparable to those containing artificial dyes. The pigment's strong antioxidant properties further added nutritional value, making it an ideal candidate for health-oriented food products.

In cosmetic formulations, the pigment demonstrated stability in emulsions and creams, and it provided a natural purple tint for skincare and makeup products. The antioxidant nature of anthocyanins also contributed to skin protection and anti-aging effects. The DPPH assay showed 72% radical scavenging activity, similar to commercial antioxidants used in cosmetics. Thus, red cabbage pigment could serve as a dual-function additive providing both coloration and bioactive benefits.

The environmental and economic implications of the extraction process were also considered. The use of ethanol as a solvent minimized toxicity risks and supported solvent recycling, reducing environmental pollution. The extraction residues could be repurposed as animal feed, fertilizer, or biomass fuel, further improving the sustainability of the process. Energy consumption was kept low by optimizing temperature and extraction time, and equipment costs were manageable for small to medium enterprises.

Cost analysis revealed that the process could be scaled up for industrial use without substantial financial burden. The production cost per liter of pigment was competitive compared to synthetic dyes, especially when factoring in solvent recovery and waste valorization. Moreover, the increasing consumer preference for natural products made red cabbage pigments economically promising for future markets.

The final phase of the study focused on pigment purification and drying. The extract was concentrated under reduced pressure to remove ethanol and then freeze-dried to obtain pigment powder. The powdered form offered advantages such as longer shelf life, easy transport, and flexibility in formulation. The purified pigment was tested for color consistency, solubility, and stability over time. It retained vibrant color for up to six months under dark, dry storage conditions.

Overall, this research demonstrated that red cabbage anthocyanins could be extracted efficiently using acidified ethanol through a controlled, environmentally sustainable process. The extracted pigment possessed strong color properties, stability under acidic conditions, and valuable antioxidant potential. Its applications extended across food, cosmetic, and pharmaceutical industries, where natural, health-promoting ingredients were increasingly prioritized.

The technological process developed in this study provided a foundation for further innovation in natural pigment extraction. Future research could explore advanced extraction techniques such as ultrasound-assisted or enzyme-assisted methods to further enhance yield and reduce solvent use. Additionally, combining red cabbage pigments with other plant-based colorants might expand their color range and improve overall stability.

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