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Opinion Article

Converting Food-Chain Residues into Functional and Nutritional Ingredients

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DESCRIPTION

Upcycled food ingredients are increasingly being investigated as a circular bio economy strategy for converting food-processing side streams into valuable ingredients rather than allowing them to enter conventional waste streams. The approach is particularly relevant because many food by-products retain substantial amounts of carbohydrates, proteins, dietary fiber, minerals, pigments and phytochemicals after the primary food product has been obtained.

A useful distinction is that upcycling is not simply recycling food waste. Recycling generally refers to recovering materials for another use, whereas food upcycling aims to create products with equal or greater value and functionality than the original discarded material. For example, fruit pomace can be processed into a fiber-rich ingredient, while oilseed residues may be developed into protein concentrates. This distinction is important when evaluating the economic and nutritional significance of an upcycling process.

Different food industries generate different types of potentially valuable side streams. Fruit-processing industries produce peels, seeds and pomace, cereal milling generates bran and germ fractions, breweries produce spent grain, vegetable processing generates skins, stems and trimming residues, and oil extraction generates protein-rich press cakes.

These materials should be characterized before processing because their chemical composition can vary according to crop variety, maturity, cultivation conditions, processing method and storage history. Proximate analysis, chromatography, spectroscopy and microbiological testing can help determine whether a particular side stream is suitable for food applications.

Dietary fiber is one of the most promising components of upcycled ingredients. Cereal bran, fruit skins, vegetable residues and seed fractions can provide soluble and insoluble fiber. These materials may be incorporated into bread, biscuits, pasta, breakfast cereals, beverages and snack products.

Protein recovery commonly involves aqueous extraction, pH adjustment, centrifugation, membrane separation and drying. The resulting proteins need to be evaluated for solubility, emulsification, foaming, gel formation, water-holding capacity and digestibility. These properties determine whether the recovered protein is appropriate for beverages, meat alternatives, bakery products or other formulations. Upcycled materials can also provide compounds with technological or biological interest. Polyphenols, carotenoids, flavonoids, anthocyanins and other phytochemicals may be recovered from fruit and vegetable residues.

Modern extraction approaches include ultrasound-assisted extraction, microwave-assisted extraction, enzyme-assisted extraction and pressurized-liquid extraction. These methods can potentially improve recovery while reducing solvent use and processing time. Nevertheless, antioxidant activity measured in a laboratory does not necessarily demonstrate a health effect in humans. Further studies concerning bioavailability, metabolism, effective dosage and clinical outcomes are required before health-related claims can be justified.

Fermentation offers an additional route for improving the value of side streams. Selected microorganisms can transform complex substrates into metabolites and may improve digestibility, flavor, texture or bioactive availability. Lactic acid bacteria, yeasts and filamentous fungi can be investigated depending on the substrate and intended application. Fermentation may also reduce certain undesirable compounds and improve the functional properties of plant-derived ingredients.

Safety is one of the most important aspects of food upcycling. A by-product may contain pesticide residues, heavy metals, mycotoxins, pathogenic microorganisms or allergens. Therefore, the fact that a material originated from food production does not automatically mean that it is suitable for direct human consumption. Storage conditions are especially important. Wet residues can deteriorate rapidly because of microbial growth and enzymatic activity. Rapid stabilization through drying, refrigeration, freezing or other appropriate methods may therefore be required.

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CONCLUSION

Future research should increasingly focus on integrated biorefineries, where one food side stream is separated into several valuable fractions. For example, a fruit-processing residue could potentially yield dietary fiber, phenolic extracts, pigments and fermentable carbohydrates rather than producing only one ingredient. Overall, upcycled food ingredients have the potential to transform food manufacturing from a predominantly linear system into a more resource-efficient circular system. Their long-term success will depend on combining nutritional science, food chemistry, biotechnology, process engineering, safety assessment, sustainability analysis and consumer research.