

Attribute enhancement of cereals by enriching phytochemicals: a review

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Abstracts

Cereals are essential foods worldwide, providing not only macronutrients but also phytochemicals. Phytochemicals are bioactive compounds from plant sources that have been receiving significant interest due to their potential beneficial effects on human health, including anti-oxidant, anti-inflammatory and anticancer properties. This review describes the phytochemical profile of different cereals such as wheat, rice, maize, barley, and oats, including their effects on human health. Cereals are rich in phytochemicals such as tannins, saponins, flavonoids, phenolic acids etc. It is also rich in ferulic acid, a powerful antioxidant, found in large amounts in wheat. Rice, especially pigmented types like black and red rice, is a rich source of anthocyanins and other flavonoids. Maize is rich in carotenoids that are important for eye health. Barley derives its cholesterol-reducing properties from beta-glucans, while oats are loved for their avenanthramides, plant compounds unique to the grain that comes with anti-inflammatory baggage. Beyond their nutritional profile, these phytochemicals have gained attention due to their potential preventive and therapeutic effects towards chronic diseases, including cardiovascular diseases, diabetes, and certain types of cancers. This review article emphasises the use of phytochemically enriched cereals in regular diets and urges further studies on optimal conditions for treating diseases and the mode of ingestion as a regular habit.

Keywords: *Phytochemicals, Cereals, Nutraceuticals, Antioxidants, Bioactive Compounds, Genetic Modification, Fermentation, Extrusion Cooking*

1. Introduction

Cereals are part of the most consumed staple foods globally and provide most of the daily requisite calories, dietary fibre, vitamins, and minerals (McKevith, 2004). Aside from their macronutrient profile, cereals have other constituents called phytochemicals that have been lately regarded as being health-promoting. Flavonoids, phenolic acids, carotenoids and saponins are good antioxidant, anti-inflammatory and disease-combating phytochemicals that benefit human health (Zhang *et al.*, 2015).

Promisingly, the enrichment of anti-human diseases/ailments associated with real attributes is another strategy that can be used to increase the nutritional value/standard of the cereal. Since there is increasing demand for functional foods, scholars and food technologists are seeking s on how to increase phytochemical content in cereals (Xiong *et al.*, 2022). Some of these are genetic engineering, processing methods that enhance bioavailability as well as efficiency in growing methods that enhance the extraction and retention of these beneficial aspects.

This paper elucidates the various phytochemicals present in cereals, the potential health benefits that they accord and how phytate – the main anti-nutrient that binds themselves to minerals can be reduced in grains (Tharifikhan *et al.*, 2021). It also discussed the issue of processing, regulation and acceptance by consumers and highlighted future research implications for enhancing positive aspects of phytochemical-enriched cereals as part of a health-promoting Foodscape of tomorrow.

2. Historical Perspective on Cereal Improvement and Early Studies on Phytochemicals

Cereals are considered one of the typical ancient crops that have been cultivated and consumed by humans for millennia (Beta and Camire, 2018). In the earlier societies, crop yields and

grain storage dominated the societies' priority as opposed to what constituents the crops would be composed of. However, the research on the bioactive compounds in cereals began in the late twentieth century as scientists became interested in the presence of secondary metabolites in plants and their functions in the protection and functioning of organisms. Published research focused on phenolic acids, flavonoids, tannins, and saponins grain-attached phytochemicals in wheat, rice, maize and barley. There was evidence from the research carried out in the early 1970s and early 1980s suggesting that these compounds were antioxidants and could therefore reduce the risk of chronic diseases.

3. Summary of Recent Research Findings on Phytochemical Content in Cereals

Recent investigations in the phytochemicals of cereals have focused on their health qualities and in functional foods. The interline whole-grain bioactive compounds are relatively high, which include ferulic acid in wheat and pigmented rice, anthocyanin, beta-glucans in barley and avenanthramides in oats (Belobrajdic and Bird, 2013). This explains why findings in other related studies indeed establish these phytochemicals as possessing anti-inflammatory, anti-cancer, and cardiovascular-protective properties. High-performance liquid chromatography and mass spectrometry pave the way in the characterization as well as the quantification of these compounds.

4. Critical Analysis of Methodologies and Outcomes from Previous Studies

It can therefore be said that while considerable strides have been made in studying cereal phytochemicals, variations in the approaches used by different researchers have resintvariationsiation in the data obtained. That is why extraction and quantification methods which include solvent extraction, enzymatic hydrolysis, and chromatography vary across the studies and resin the differences in the amount of phytochemical obtained and consequently estimated bioavailability (Stohs *et al.*, 2019). In vivo and in vitro experiments have, therefore, established varying efficacy

levels of factors present in phytochemical-rich cereal products in disease prevention. Although science that makes use of animal and cell culture has offered some encouraging results, there is a deficiency of bright clinical trials on humans. This was contributed to by the lack of well-defined standard value and processing methods, as well the as lack of agreement between organizations on which specific method should be used.

5. Identification of Research Gaps and the Need for Further Investigation

From this review, it is evident that phytochemicals play a crucial role in cereals despite having such gaps. Nevertheless, more research is required about their bioavailability and metabolism in humans pointing toward enhanced consumption through diets. There is also a need to investigate the interactions of the identified plant-borne bioactive compounds and the additive, synergistic, and antagonistic effects in human diets or diets typical of specific regions of the world (Wu *et al.*, 2017). Furthermore, both genetic modification and agronomic approaches have been used to increase the phytochemical content but there is a need for more voluntary effects, safety and acceptability among consumers. Future studies should in this case involve the use of human subjects, new food processing technologies and practices that will increase the phytochemical content in cereals without reducing their organoleptic properties or nutritional value.

6. Types of Phytochemicals in Cereals and Their Bioavailability

Overview of Major Phytochemical Classes

Cereal grains contain many phytochemicals which are beneficial chemicals in the human body due to health-promoting properties. Some of the common classes of these phytochemicals are the phenolic as flavonoids, tannins, saponins and carotenoids. Some of the phenolic compounds that are most abundant in whole grains include the ferulic and cinnamic acids which are antioxidant compounds (Saxena *et al.*, 2013). Flavonoids constitute a vast group of compounds; there are more than 4,000 known anthocyanins, which are

pigments that play in cereals and possess oxidant properties. Tannins as polyphenolics are compounds that are present in cereals whereby they affect their astringency characteristics as well as their heart values. Based on the fact that some grains contain saponins, then this substance has the ability to reduce cholesterol levels and modulate the immune system. Carotenoids are the pigments that are essential agents of an antioxidant in nature that are essential for the health of the eyes.

Specific Examples from Cereals

It is now evident that each cereal grain possesses its specific phytochemicals responsible for the health benefits related to one of the integral elements of the wheat grain ferulic acid, which is a powerful antioxidant that is mainly found in the bran layer to prevent oxidative stress. The pigments of pigmented rice are anthocyanins, which give bevel natural colours to coarse grains and an abundance of antioxidant properties (Saikia *et al.*, 2012). Among all the tested crops, see Figure 2, maize, corn, is a great source of carotenoids, such as lutein and zeaxanthin which are useful in vision and the skin. In 2008, market-size statistics showed that barley had a high beta-glucan content a soluble fibre that has been associated with a better cardiovascular as well as metabolic profile. Avenanthramides, which are non-polyphenolic substances extracted from oats, have several properties among which are anti-inflammatory and antioxidant characteristics availability of Phytochemicals in Cereals.

The effects of these phytochemicals almost entirely depend on bio-availability, which is the degree to which the compounds in the vegetable are absorbed and used by the body. Several characteristics of these compounds were: Their chemical structure, solubility or the food matrix within which they exist Phenolic acids in cereals are mainly bound with cell wall components and this makes it difficult for their absorption. However, certain joints can be processed by methods like fermentation to increase bioavailability. Carotenoids are fat-soluble molecules thus the need to consume foods containing fats so that they can be absorbed efficiently (Ravisankar *et al.*, 2015). The methods of processing and preparation

of cereals affect the chemical structure of cereals and also phytochemicals including cooking, milling, and microbial fermentation. Fermentation on the other hand reduces the phytic acid which inhibits the bioavailability and minerals; it also enhances the degree of extraction by solubilizing the fibre matrix of phytochemicals. Knowledge of these factors is important when aiming at creating positive health impacts from cereal-based based impacts cereal-basement food processes.

7. Health Benefits of Phytochemicals in Cereals

Antioxidant Properties and Reduction of Oxidative Stress

Phenolic acids and flavonoids that exist in cereals exhibit antioxidant activity. These compounds act for example by counteracting free radicals to diminish their negative impact and thereby diminishing oxidative stress to cells. This antioxidant activity is relevant and important in the reduction of the development of the aforementioned diseases because oxidative stress is an essential factor in the development of diseases and ageing (Cichoż-Lach and Michalak, 2014). The intake of antioxidant-rich cereal foods will be antioxidant-rich to the body and maintain the integrity of the body cells with minimal cases of degenerative illnesses.

Anti-inflammatory and Anticancer Effects

Apart from their antioxidant effects cereal phytochemicals also possess potent anti-inflammatory effects (Jimenez-Pulido *et al.*, 2022). Thus, such compounds can regulate the inflammatory processes in the body, which is one of the causes of chronic diseases including arthritis and metabolic diseases. It has also been found that some phytochemicals possess antitumor activity since they can suppress cancer cell growth and trigger apoptosis. According to scientists, whole grain phenolic compounds red whole grains of colon cancer and other types of cancers as they impacts carcinogenic gene expression signalling pathways.

Mitigation of Chronic Diseases

The observation of the typical cereal diets high in phytochemicals significantly reduces the possibility of

developing certain diseases, including cardiovascular and diabetes (Belobrajdic and Bird, 2013). It should be noted that flavonoids act as antioxidants and hence prevent inflammation of the heart, apart from regulating blood glucose levels. For example, phenolic acids slow the progression of diseased conditions with cardiovascular due to anti-inflammatory, and anti-oxidant properties which help to save antioxidant-active arterial stiffness help their brand oat contain beta-glucans that aid in the regulation of insulin and thus useful for patient with type 2 diabetes.

8. Methods for Enhancing Phytochemicals in Cereals

Genetic Modification and Breeding Strategies

Scientists have been able to increase the phytochemical content of cereals through the use of enhanced genetic technologies in plant breeding. Conventional breeding along with the help of modern molecular techniques can help to improve the desired characteristics, including the higher content of antioxidants and other useful elements. Marker-assisted selection (MAS) and genomic selection (GS) are among the techniques that have favoured the identification and usage of genes that cause variation in the phytochemical levels (Boopathi, 2013). Furthermore, transgenic breeding involves the insemination of specific genes that help increase the levels of micronutrients and phytochemicals that are useful in eliminating malnutrition, which is sustainable.

Innovative Processing Techniques

Maize processing methods that were identified include washing, soaking, cooking simmering/boiling, sun-drying, oven-baking, roasting, frying and high pressure processing. The fermentation process has been also found to increase the phenolic value and its digestibility in cereals such as rice, wheat, oats, maize, and sorghum (Fărcaș *et al.*, 2021). This is an action of microorganisms that helps to degrade the complex matrix and release phytochemicals. Other techniques for processing cereals include extrusion cooking, which exports the cereals to high-temperature pressure and shear forces (De Pilli & Alessandrino, 2020). This also contributes to the enhancement of the nutritional quality of

cereal-based products since it helps in the digestion of cereal-based proteins and recalls the bioactive compounds within those products.

Agronomic Practices and Post-Harvest Interventions

Different agricultural practices provide a great impact towards the nutrition level of the cereal crops. This shows nutrition factors like the type and condition of the soil, irrigation and even the use of fertilizers affect the synthesis and deposited bioactive compounds in the plant. The practitioners of crop rotation, organic farming, and proper use of manure can help in increasing nutrient depth in the soil and hence improve the phytochemical in cereals (Aulakh *et al.*, 2022) any of these compounds are sensitive and, when harvested, require other post harvest treatments and minimal processing to maintain post-harvesting. For instance, the retention of cereals' phytochemicals starts at the farm and continues to the table – it suggests that avoiding exposure of cereals to light, heat, and oxygen during storage and processing helps in the retention of cereals' phytochemicals.

9. Optimum Utilization of Phytochemicals

Strategies for Maximizing Retention During Processing and Storage

HHP has a better shelf-life of phytochemicals compared to high-heat treatments since they do not require heat and, therefore, do not cause the degradation of nutrients (Khouryieh, 2025). This technique uses high pressure to avoid thermal stress on the compound and thereby there is less destruction on the compounds. Another factor that influences the stability is the duration and the conditions under which the foods are stored; optimal conditions that minimize exposure to light, oxygen and moisture will enhance the stability of these bioactive compounds.

Improving Bioavailability and Bioactive Interactions

Bioavailability of phytochemicals means how much such compounds can be taken in the body and used efficiently (Holst and Williamson, 2008). Bioavailability of compounds involves increasing the extent to which phytochemicals can

be absorbed and used by the body. Some procedures such as fermentation would enhance the levels of phenolic content since these complexes are broken down to permit absorption. Also, one compound may influence the absorption and efficacy of another compound by either increasing or decreasing the absorption of nutrients or bioactive compounds. Bioavailability and efficacy can easily be enhanced when plant-based nutraceuticals are administered in combination.

Incorporating Enriched Cereals into Regular Diets

In order to maximize nutrition from phytochemicals, one needs to include phytochemical-containing cereals in the daily basis diet. Phytochemical-containing cereals, it is recommended that one choose that has been processed to the least degree to ensure that the grain contains high levels of these compounds. Oats, barley and pigmented rice containing different types of cereals can help in achieving the consumption of a variety of phytochemicals (Raj *et al.*, 2023).

Besides, the integration of cereals with other nutrient-dense foods helps to increase nutrient interaction, nutrient density and other nutritional advantages, which in turn increases the overall health advantages obtainable from consumption.

10. Challenges and Future Directions

Technical and Processing Challenges

Several technical and processing issues arise in the effort to increase the phytochemical content in cereals (Saleh *et al.*, 2019). Narrators realise that certain food processing steps like milling and cooking can lead to very low concentrations of provitamin A, other vitamins and phytochemicals. For instance, multivitamin strips of grain products of nutrient-rich bran make layers, thus eradicating most of the vitamins and bioactive compounds. Besides, steaming can lead to significant losses of vitamin content and boiling can lead to smaller losses of vitamins. Therefore, the beneficial phytochemicals lost during processing and palatability or safety construe to high processing must be optimally managed (Ravi and Rana, 2024).

Regulatory, Safety, and Consumer Acceptance Issues

The current change to genetically modified (GM) cereals for purposes of improving phytochemical features is reliable with regulatory and safety issues. The following guidelines also pay special emphasis to make certain that these biofortified crops are safe makeup. However, customer willingness to consume GM foods differs across countries depending on cultural, ethical, and info across countries. Such modifications should be explained clearly to the people and the possible safety of them should be explained to the people so that they can accept them.

Emerging Trends and Future Research Directions

The next steps will shift toward the improvement in the content of phytochemicals from cereals, meeting consumers' expectations. Furthermore, investigations on conventional techniques like fermentation that has been discussed in this paper have demonstrated the capacity have enhance the bioavailability have phenolic compounds in cereals. Current and future investigations are carried out to improve these techniques in the production of functional foods with improved health qualities.

It is apparent that there are some possible ways that the above-discussed obstacles can be overcome in order to increase the level of phytochemicals contained in cereals These include improved techniques in genetics process techniques and consumers' awareness.

11. Conclusion

The phytochemicals that are present in cereals have benefits such as acting as antioxidants anti-inflammatory, and preventive to diseases. That is why this kind of review has outlined the various forms of phytochemicals found in cereal, their role in the well-being of human beings and the various methods of increasing them. Breeding techniques, genetic engineering, the use of superior processing techniques and effective utilization of agro-techniques have been used as potential ways of enhancing phytochemical concentrations in cereal grains. The impact of phytochemical enrichment

in cereals especially common cereals can be seriously felt in food sciences and food nutritional values. These bioactive compounds can play a role in chronic disease prevention especially those of cardiovascular diseases, diabetes, and cancers. Furthermore, regulating the consumption of meals with phytochemical-containing cereals can help in boosting immune-modulatory and antioxidant levels.

That said, a few issues still arise, including processing losses, the level of acceptance with consumers and the regulatory environment. These issues have to be further studied and receive a focus on the development of new, efficient methods in the food processing area, enhancement of phytochemical bio availabilities and clinical trials in humans in order to corroborate the long-term effects of phytochemical-enriched cereals. There is, therefore, a need to have the food scientists, nutritionists and policymakers work together in an effort to come up with strategies for implementing the enhanced cereals within the food chain. Therefore, it is worth seeking improvements in the phytochemical content of cereal grains as a way to improve nutritional value for use by the public. More research should be conducted to identify ways through which retention and bioavailability of these grains are improved as they should be incorporated as staple food in various countries.

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