

Review Paper

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Multiple Utilization Pathways of Buckwheat: Food, Feed, Medicine and Eco-Tourism

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Abstract Buckwheat is increasingly recognized as a highly multifunctional pseudocereal whose value extends far beyond conventional grain production. This review places particular emphasis on the distinctions between common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat (*Fagopyrum tataricum*), especially regarding reproductive biology, rutin accumulation, environmental adaptability, and product quality characteristics. Buckwheat possesses a combination of relatively uncommon traits within a single crop species, including adaptability to low-input cultivation systems, broad ecological plasticity, a well-balanced amino acid composition, high concentrations of flavonoids and phenolic compounds, and deep cultural integration within regional food traditions. These characteristics collectively support the extensive utilization of buckwheat in gluten-free and functional foods, livestock feed ingredients and feed additives, phytochemical-based health applications, and flower landscape-oriented agro-tourism systems, while simultaneously contributing to local cultural identity and rural revitalization. At the same time, the development of the buckwheat industry continues to face several important constraints related to breeding systems, production stability, processing technologies, and evidence-based functional evaluation. The present study argues that buckwheat should not be regarded as an isolated niche crop with limited applications, but rather as a strategically integrative crop whose food, feed, medicinal, ecological, and cultural functions can be developed synergistically. Such an integrated utilization model is particularly significant for mountain agriculture, marginal land use, circular bioeconomy development, and regionally differentiated rural development strategies.

Keywords *Fagopyrum esculentum*; *Fagopyrum tataricum*; Functional food; Rutin; Flavonoids; Feed utilization; Pharmacological activity; Agro-tourism; Rural revitalization

1 Introduction

Buckwheat has increasingly been described as a “smart crop” or a “climate-resilient pseudocereal” because of its value in nutritional security, ecological adaptation, and regional economic development. Compared with conventional cereal crops, common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat (*Fagopyrum tataricum*) belong to the same genus within the Polygonaceae family, but they differ considerably in genetic background, environmental adaptation, and the accumulation of functional compounds (He and Zhou, 2022).

Both common buckwheat and Tartary buckwheat generally show better protein quality and higher mineral contents than many traditional cereal grains. Buckwheat grains are rich in lysine, arginine, and soluble dietary fiber, while common cereals such as wheat and maize are usually deficient in lysine. For this reason, buckwheat has long been considered an important plant resource for improving amino acid balance in human diets (Ahmed et al., 2014). In particular, Tartary buckwheat contains much higher levels of flavonoids, especially rutin, than common buckwheat. Because of this characteristic, Tartary buckwheat has gradually become an important raw material for functional foods and natural antioxidant products.

Compared with major grain crops that often depend heavily on a single commodity market, buckwheat has more diverse utilization pathways. The grains can be consumed directly as food or further processed into functional starch products, flavonoid extracts, and plant-based feed ingredients. Bran and hulls can be used in dietary fiber products, pillow filling materials, and biomass utilization. Buckwheat straw can also serve as roughage for ruminants or as ecological mulching material. Therefore, buckwheat is not only regarded as a crop suitable for

future low-carbon agriculture, but also as an important link connecting nutritional health, ecological farming, and rural revitalization.

The present review includes both common buckwheat and Tartary buckwheat, with particular attention given to their similarities and differences in morphology, physiology, bioactive compounds, and end-use properties. This study also attempts to connect several research areas that are often discussed separately, including plant science, food chemistry, animal nutrition, pharmacology, and rural development studies. Through this integrated perspective, it becomes easier to understand how buckwheat can simultaneously function as a low-input crop, a functional food resource, a feed ingredient, a medicinal raw material, and a landscape-cultural asset. This review aims to provide theoretical support and practical references for promoting the transition of buckwheat from a traditional minor crop into a modern specialty crop with nutritional, ecological, and economic value.

2 Botanical Characteristics and Genetic Resources of Buckwheat

2.1 Taxonomy and classification of buckwheat species

Buckwheat belongs to the genus *Fagopyrum* in the family Polygonaceae. Its taxonomic position is relatively clear in crop science, but it still has important research value in phylogeny, utilization of wild relatives, and the study of breeding relationships. Modern studies generally recognize common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) as the two most important cultivated buckwheat species. Among them, common buckwheat is widely distributed in temperate regions and is the main raw material used in buckwheat food processing worldwide. Tartary buckwheat is mainly cultivated in the mountainous regions of southwestern China, the margins of the Qinghai-Tibet Plateau, the Himalayan region, Japan, Korea, and some parts of Europe. Because of its high rutin content and stronger cold tolerance, Tartary buckwheat has received more attention in functional food and medicinal research.

The differences between common buckwheat and Tartary buckwheat are not limited to morphology. More importantly, they differ in reproductive biology and genetic structure. Common buckwheat usually shows heterostylous flowers and self-incompatibility. Populations contain both pin flowers and thrum flowers, and seed production mainly depends on insect pollination and cross-fertilization. In contrast, Tartary buckwheat is generally self-compatible, making it easier to maintain homozygosity and genetic stability in breeding populations.

2.2 Morphological and physiological characteristics

The basic morphology of buckwheat is easy to recognize, but its agricultural value largely depends on the interaction between morphological and physiological traits. Both common buckwheat and Tartary buckwheat are dicotyledonous herbaceous plants with erect or semi-erect stems, heart-shaped or arrow-shaped leaves, raceme or corymb inflorescences, and typical triangular achenes. Flowers of common buckwheat are usually white or pale pink. The plants produce abundant flowers over a relatively long flowering period and possess well-developed nectaries. Because of this, common buckwheat also has value as a nectar source crop and as a landscape plant in ecological tourism systems. Tartary buckwheat plants are generally shorter and more robust, with smaller seeds, thicker hulls, and a stronger bitter taste. However, Tartary buckwheat usually accumulates much higher levels of flavonoids than common buckwheat.

The heterostylous flower structure of common buckwheat is one of its most representative morphological and reproductive characteristics. Pin flowers and thrum flowers differ in style length, stamen height, and pollen morphology. Effective fertilization usually occurs only between different flower morphs. Fawcett et al. (2023) used high-quality genome analysis to reveal the genetic basis of heterostyly and domestication history in common buckwheat. Their study showed that the S-locus region has a complex structure closely associated with self-incompatibility, floral differentiation, and population reproductive behavior.

Buckwheat is characterized by a short growth period, rapid seedling emergence, fast early growth, and relatively good adaptation to low-input environments. Many cultivars require only about 70~90 days from sowing to maturity, making buckwheat suitable for high-altitude regions, multiple-cropping systems, post-disaster replanting, and short-season agriculture. However, buckwheat should not be considered a completely stress-resistant crop.

Seedling growth and flowering stages are sensitive to low temperature, frost, heat stress, drought, and strong wind. In particular, common buckwheat often shows increased empty grain rates and yield reduction when high temperatures, continuous rainfall, or insufficient pollinator activity occur during flowering (Penin et al., 2021). The physiological advantages of Tartary buckwheat are mainly reflected in its adaptation to high-altitude, cool, and nutrient-poor environments. Its relatively stable grain production under these conditions is associated with its shorter growth cycle, stronger root nutrient uptake ability, and higher secondary metabolic activity.

2.3 Genetic diversity and germplasm resources

Because common buckwheat is cross-pollinated and self-incompatible, natural populations usually maintain high heterozygosity and abundant genetic variation. Although Tartary buckwheat is mainly self-pollinating, long-term cultivation in mountainous regions, ethnic communities, and different altitudinal environments has also resulted in substantial ecological differentiation and the formation of diverse local landraces.

The wild ancestral form *F. esculentum* ssp. *ancestrale* is closely related to cultivated common buckwheat and provides valuable material for studying domestication traits such as larger seed size, reduced seed shattering, altered flowering behavior, and adaptation expansion. Similarly, the wild ancestral type *F. tataricum* ssp. *potanini* is important for understanding high rutin accumulation, bitter taste formation, and mountain adaptation in Tartary buckwheat. Compared with cultivated forms, wild buckwheat relatives usually show stronger seed shattering and seed dormancy. Although these traits are unfavorable for direct cultivation, they may contain genes related to stress tolerance and ecological adaptation.

2.4 Adaptation to marginal environments and climate resilience

Buckwheat is often considered suitable for marginal land cultivation, but this conclusion depends on environmental conditions and species differences. Both common buckwheat and Tartary buckwheat have relatively short growth periods and low nutrient requirements. They can therefore play important roles in areas with poor soil fertility, short frost-free seasons, or high risks for major cereal production. In mountain agricultural systems, buckwheat can function as a supplementary grain crop, a rotation crop, a nectar source plant, and an ecological landscape crop. Compared with high-input crops such as maize, wheat, and rice, buckwheat depends less on chemical fertilizers and irrigation, making it suitable for resource-limited agricultural regions.

However, the climate resilience of buckwheat should not be oversimplified. Although it shows relatively strong tolerance to poor soils and cool climates, it is still sensitive to salt stress, heat stress, drought, and frost. For example, Zhang et al. (2023) investigated the effects of salt stress on root morphology, carbon and nitrogen metabolism, and yield formation in Tartary buckwheat. Their study showed that increasing salt concentration inhibited root growth, disrupted carbon-nitrogen metabolic balance, and ultimately reduced grain yield.

Tartary buckwheat is generally better adapted to high-altitude and cool environments than common buckwheat, which corresponds closely with its long-term geographical distribution. Tartary buckwheat is widely cultivated in Liangshan Yi Autonomous Prefecture, the Yunnan Plateau, mountainous regions of Guizhou, and parts of the Himalayan region. It can complete reproductive development within a short growing season while accumulating high levels of flavonoids in the grain. This may be related to adaptation to strong ultraviolet radiation, large day-night temperature differences, and environmental stress conditions. In comparison, common buckwheat is more suitable for temperate and cool regions, but its flowering and seed setting are strongly influenced by weather conditions and pollinator activity. Under the increasing frequency of extreme climate events, breeding programs for common buckwheat need to pay greater attention to seed-setting stability, heat tolerance, and flowering regulation.

3 Nutritional Composition

3.1 Carbohydrates, proteins, lipids, and dietary fiber

Buckwheat grains are mainly composed of carbohydrates, but their nutritional profile differs from many traditional cereals because the starch matrix is accompanied by relatively high-quality proteins and dietary fiber components. Studies comparing common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat

(*Fagopyrum tataricum*) have shown that different milling fractions, including flour, semolina, bran, and husk layers, vary considerably in nutrient composition. Protein, lipid, mineral, and antioxidant-related compounds are unevenly distributed among these fractions, with bran and coarse fractions generally containing higher concentrations of nutritionally valuable compounds (Sinkovič et al., 2022) (Figure 1).

Buckwheat protein is especially important because it is naturally gluten-free and contains a relatively balanced essential amino acid profile compared with many cereal grains. However, its digestibility and functional properties may change depending on processing conditions and the surrounding food matrix. Dietary fiber further strengthens the value of buckwheat as a functional food ingredient. In both common buckwheat and Tartary buckwheat, fiber-rich fractions such as bran often contain higher levels of bioactive compounds than refined flour fractions. As a result, less refined buckwheat products are usually considered nutritionally superior to highly processed forms.



Figure 1 Representative samples of common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) whole grain and seven grain fractions obtained by traditional stone-milling (Adapted from Sinkovič et al., 2022)

3.2 Vitamins, minerals, and essential amino acids

Buckwheat is considered a good source of minerals such as magnesium, phosphorus, iron, zinc, and potassium. It also contains vitamins and has a more balanced amino acid composition than many refined cereal products. These nutritional advantages are especially important in gluten-free food systems, where products based mainly on rice flour or purified starches often show nutritional limitations.

Research on bread fortification demonstrated that the addition of buckwheat flour increased protein content, improved amino acid scores relative to wheat bread, and enhanced antioxidant properties as well as inositol phosphate levels (Kowalski et al., 2022). Both common buckwheat and Tartary buckwheat contribute nutritional benefits, although Tartary buckwheat is generally associated with higher levels of bioactive compounds. The amino acid quality of buckwheat proteins makes them valuable in the development of nutritionally improved gluten-free foods, where protein quality is often a major concern.

3.3 Bioactive compounds: rutin, quercetin, flavonoids, and polyphenols

The biological value of buckwheat is closely related to its flavonoid composition. Rutin is the best-known compound, but the phytochemical profile of buckwheat is much more complex. In addition to rutin, buckwheat contains quercetin, orientin, isoorientin, vitexin, isovitexin, phenolic acids, fagopyritols, D-chiro-inositol derivatives, bioactive peptides, and other specialized metabolites. Tartary buckwheat usually contains much higher rutin concentrations than common buckwheat, which is one reason why Tartary buckwheat is more frequently studied for medicinal and functional food applications. However, processing conditions and the activity of endogenous rutinase can strongly influence rutin retention in final products (Wang et al., 2024).

The distribution of these compounds is highly tissue-specific. Flowers, leaves, bran, and some coarse milling fractions generally contain higher concentrations of flavonoids and polyphenols than refined flour. This uneven distribution means that nutritional quality is closely connected with processing methods and fraction selection. In recent years, rutin content has become not only a nutritional trait but also an important target in breeding and metabolic regulation research, especially in Tartary buckwheat improvement programs focused on functional food development.

4 Processing Technologies and Food Applications

4.1 Traditional buckwheat foods in different cultures

Traditional buckwheat foods are not simply “coarse grain foods.” They developed through the interaction of climate, religion, ethnic dietary habits, and local processing techniques in different regions. In Japan, the most representative buckwheat food is soba noodles, which are mainly made from common buckwheat (*Fagopyrum esculentum*). Traditional soba usually contains a certain proportion of wheat flour because pure buckwheat dough lacks gluten and breaks easily during processing. According to the Japanese Ministry of Agriculture, Forestry and Fisheries, soba is regarded as a traditional regional food closely linked with local identity. In Nagano, Yamagata, and Hokkaido, soba is not only consumed as a daily staple food, but is also connected with tourism, hand-made noodle experiences, and seasonal festivals.

In Europe, especially in the Brittany region of France, buckwheat has long been known as “blé noir” or “sarrasin.” Common buckwheat flour is traditionally used to prepare savory galettes. Today, galettes are still promoted by regional tourism authorities as a typical local specialty food. In Eastern Europe and Slavic regions, roasted buckwheat groats are commonly processed into kasha, a porridge-like or rice-like dish made from whole buckwheat kernels. Compared with Japanese soba, these foods are relatively simple in processing, but they are highly filling and suitable for long-term storage, which matched the dietary needs of traditional agricultural societies in cold regions.

In South Asia, buckwheat has a different cultural role. During religious fasting festivals such as Navaratri and Shivratri, people in northern India commonly consume buckwheat flour known as kuttu ka atta. Since buckwheat is not classified as a conventional cereal grain in Hindu dietary practice, it can be consumed during fasting periods when grains are prohibited. Therefore, the cultural importance of buckwheat in this context comes not only from nutrition, but also from its acceptance within religious dietary systems. In Nepal, Bhutan, and Himalayan mountain regions, both common buckwheat and Tartary buckwheat (*Fagopyrum tataricum*) are used to prepare flatbreads, noodle soups, and local traditional foods. These products are closely associated with high-altitude agriculture, short growing seasons, and local mountain lifestyles.

4.2 Buckwheat flour and noodle processing technologies

The main challenge in buckwheat flour processing is that buckwheat proteins cannot form the three-dimensional elastic gluten network found in wheat dough. In wheat flour, glutenins and gliadins interact after water addition and kneading, producing a viscoelastic structure that gives dough strength and extensibility. Buckwheat proteins have relatively high nutritional quality, but they cannot provide the same structural support. As the proportion of buckwheat flour increases in noodles, pasta, and bread products, problems such as strand breakage, higher cooking loss, rough texture, and reduced elasticity become more common.

De Arcangelis et al. (2020) studied gluten-free buckwheat pasta and found that proper control of starch pre-gelatinization improved product structure and cooking quality. In the absence of a gluten network, buckwheat products rely more heavily on starch gelatinization, protein gel formation, or external structuring agents to maintain processing stability.

The particle size, dehulling degree, and milling method of buckwheat flour also strongly influence final product quality. Whole buckwheat flour retains more dietary fiber, minerals, and phenolic compounds, but it usually produces darker color and rougher texture, and may weaken dough-forming properties. Refined flour has better sensory acceptance, but some nutritional compounds are lost during processing. Sinkovič et al. (2021) analyzed

different stone-milled fractions from common buckwheat and Tartary buckwheat and showed clear differences in mineral composition, nutritional value, and bioactive compound distribution among milling fractions. Their study demonstrated that flour fractionation can significantly affect the nutritional and functional quality of buckwheat foods.

4.3 Fermented buckwheat products and beverages

Buckwheat naturally has a strong cereal-like, nutty, and sometimes slightly bitter flavor. Some consumers consider the taste too heavy or coarse. Fermentation with lactic acid bacteria, yeasts, or mixed microbial cultures can modify sugars, proteins, and phenolic compounds in buckwheat substrates, improving acidity, aroma, and texture. Fermentation can also reduce the effects of certain antinutritional factors and promote the release of proteins and phenolic substances.

Matejčková et al. (2017) developed a fermented probiotic product using buckwheat substrate and *Lactobacillus rhamnosus*. Their results showed that buckwheat could support probiotic growth and maintain product stability during fermentation. Compared with traditional dairy-based probiotic foods, fermented buckwheat products have advantages such as being gluten-free, plant-based, and nutritionally complex. These characteristics make them suitable for lactose-intolerant individuals, vegetarian consumers, and people interested in gut health. Therefore, the significance of fermented buckwheat foods is not limited to flavor improvement or shelf-life extension; fermentation also increases the value of buckwheat as a functional food carrier.

Xiao et al. (2024) investigated the addition of Tartary buckwheat to kombucha fermentation systems. The study showed that Tartary buckwheat significantly increased total phenolics, total flavonoids, and rutin content in the beverage, while also improving DPPH and ABTS radical scavenging activity. This suggests that Tartary buckwheat not only contributes more phytochemicals to the fermentation system, but may also promote the release of bound phenolic compounds during microbial fermentation. After proper formulation adjustment, the addition of Tartary buckwheat did not significantly reduce sensory acceptance. Instead, its cereal and mild nutty aroma complemented the sweet-sour flavor of fruit kombucha, and some treatment groups achieved higher sensory scores than traditional kombucha products.

4.4 Gluten-free and functional food development

The value of buckwheat in gluten-free food development is not only related to the absence of gluten. Buckwheat also has higher nutritional density than many gluten-free products based mainly on corn starch, potato starch, or refined rice flour. Many commercial gluten-free foods meet the basic dietary needs of people with celiac disease or gluten sensitivity, but they are often low in protein, dietary fiber, and minerals, while producing relatively high glycemic responses.

The incorporation of buckwheat flour can significantly improve total phenolic content and antioxidant activity in gluten-free bread, while also enhancing protein, dietary fiber, and functional phytochemical composition compared with conventional starch-based gluten-free formulations (Brites et al., 2022). Both common buckwheat and Tartary buckwheat contain rutin, phenolic compounds, and antioxidant substances that help compensate for the “high starch and low nutritional density” problem common in many commercial gluten-free products. However, increasing the proportion of buckwheat flour also affects bread volume, crumb structure, and texture stability. Since buckwheat lacks a gluten network, dough gas retention becomes weaker. Industrial application therefore requires the use of hydrocolloids, composite starch systems, and optimized processing conditions to balance nutritional quality and processing performance.

Buckwheat has even greater potential in biscuits, cookies, and snack products. Compared with bread, these products depend less on gluten structure and can tolerate higher levels of buckwheat flour. Buckwheat flour can be blended with almond flour, oat flour, quinoa flour, or rice flour to improve flavor, texture, and nutritional composition. In many cases, the darker color and nutty flavor of buckwheat become sensory advantages rather than limitations, especially in low-sugar, high-fiber, plant-based, or functional snack products.

5 Nutritional Value and Feed Utilization

5.1 Nutritional composition of buckwheat straw, grain, and by-products

Buckwheat grains contain starch, protein, lipids, minerals, and moderate amounts of dietary fiber, making them suitable as both energy and protein feed resources. Common buckwheat (*Fagopyrum esculentum*) is more frequently used in grain-based feed formulations because of its relatively mild flavor and broader cultivation scale, whereas Tartary buckwheat (*Fagopyrum tataricum*) has attracted more attention for functional feed applications due to its high flavonoid content, especially rutin. In contrast, buckwheat bran, hulls, and processing by-products contain higher levels of cellulose, hemicellulose, lignin, and phenolic compounds. Although their digestibility is lower than that of grains, these by-products still have value in ruminant roughage systems and in the development of functional feed additives. Tartary buckwheat by-products are particularly rich in rutin, quercetin, and other polyphenols, which may help regulate oxidative stress, intestinal microbiota, and inflammatory responses in animals.

The use of buckwheat straw as roughage is mainly limited by its relatively high degree of lignification and fiber accumulation. Untreated straw is hard in texture, has poor palatability, and is not easily degraded by rumen microorganisms. This is one reason why buckwheat straw has not been widely utilized in animal production systems for a long time. Cao et al. (2023) investigated the effects of extrusion processing on the physical structure, chemical composition, and in vitro ruminal digestibility of buckwheat straw (Figure 2). Their results showed that extrusion treatment changed the structural characteristics of the straw, reduced hardness and chewiness, and improved water-holding capacity and ruminal degradation performance. The treatment also increased the accessibility of structural carbohydrates to rumen microorganisms, suggesting that suitable physical processing can improve the feeding value of buckwheat straw.

Different buckwheat components therefore have different feeding roles. Grains are more suitable as energy and protein sources in compound feed and may partially replace conventional cereal ingredients. Bran and hulls are more appropriate as sources of dietary fiber, antioxidant compounds, and phytochemicals. Straw should preferably enter roughage systems after extrusion, fermentation, alkalization, or microbial treatment. Compared with major feed crops such as maize, wheat, and soybean, buckwheat does not have a clear advantage for large-scale substitution. However, it has more specific value in specialty feeds, functional feed additives, and regional circular agriculture systems, especially in mountainous areas where cultivated buckwheat species are already part of traditional farming systems.

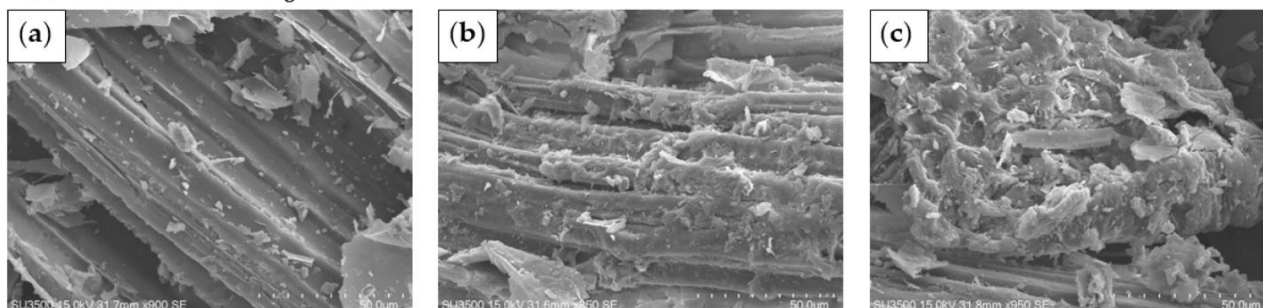
5.2 Digestibility and feed efficiency in livestock

Buckwheat grains contain relatively high-quality proteins and minerals, but the higher levels of fiber and phenolic compounds in hulls, bran, and some by-products may influence nutrient digestion and absorption. In studies involving weaned piglets, Cui et al. (2019) evaluated the combined effects of Tartary buckwheat flavonoids and *Lactobacillus plantarum*. The combination improved growth performance, nutrient digestibility, antioxidant status, and fecal microbial composition in weaned piglets. Their findings suggested that Tartary buckwheat flavonoids do not function simply as nutrient sources. Instead, they may support animal performance through antioxidant activity and regulation of intestinal microecology. This is especially important in weaned piglets because intestinal barrier function is still unstable during the post-weaning stage, and oxidative stress together with microbial imbalance can negatively affect growth and health.

Buckwheat has also been studied in poultry nutrition. Chowdhury and Koh (2018) examined the effects of buckwheat-based diets on phytase activity and nutrient digestibility in broiler chickens. Birds fed buckwheat-containing diets showed significantly higher natural phytase activity in the digestive tract, particularly in the crop and gizzard. The increased phytase activity promoted phytate degradation and released bound phosphorus, calcium, and other minerals, thereby improving phosphorus bioavailability and ileal nutrient digestibility. Compared with conventional corn-soybean meal diets, the buckwheat diets increased phosphorus digestibility and also improved the apparent digestibility of crude protein and several amino acids. The study indicated that buckwheat can function as a natural phytase source under low-phosphorus feeding conditions and

may partly reduce the need for supplemental inorganic phosphorus and exogenous phytase enzymes. This is important because excessive phosphorus supplementation in livestock production contributes to environmental pollution through phosphorus excretion.

Before in vitro rumen digestion:



After in vitro rumen digestion:

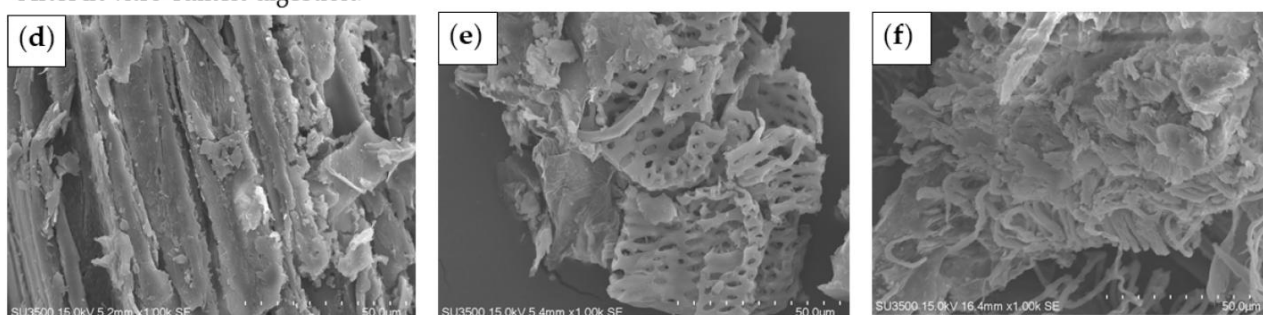


Figure 2 Scanning electron microscopy (SEM) of buckwheat straw before and after in vitro rumen digestion. (a-c) Untreated, once-expanded, and secondary-expanded buckwheat straw before digestion; (d-f) Untreated, once-expanded, and secondary-expanded buckwheat straw after digestion (Adopted from Cao et al., 2023)

6 Medicinal Components and Pharmacological Activities of Tartary Buckwheat

6.1 Bioactive phytochemicals in Tartary buckwheat

Tartary buckwheat (*Fagopyrum tataricum*) contains many functional compounds, including flavonoids, phenolic acids, polysaccharides, proteins and bioactive peptides, as well as D-chiro-inositol-related compounds. Among these substances, rutin is the most representative flavonoid glycoside, while quercetin is commonly regarded as the major active form produced after rutin hydrolysis. Buckwheat protein hydrolysates and peptides have shown potential antioxidant, antidiabetic, antihypertensive, antimicrobial, and anticancer activities. Their structural diversity also provides a basis for the development of functional foods and food-medicine homologous products (Zhu, 2021). Although buckwheat proteins are naturally gluten-free, they may still cause allergic reactions in some individuals. Therefore, medicinal utilization of buckwheat should not focus only on efficacy, but also include safety evaluation.

The concentration of bioactive compounds differs greatly among different parts of the plant. Tartary buckwheat sprouts, flowers, leaves, seed coats, and bran usually contain much higher levels of flavonoids and polyphenols than refined grain flour (Figure 3). Experiments using methanol extracts of Tartary buckwheat sprouts showed that the total flavonoid content reached 98.6 mg/g. Among the six major flavonoids detected, rutin and quercetin were the dominant compounds. Rutin content reached 89.81 mg/g in the crude extract and 31.50 mg/g in sprouts, while quercetin contents were 23.34 mg/g and 8.17 mg/g, respectively (Zhong et al., 2022).

It is important to note that the medicinal composition of buckwheat is highly dynamic rather than chemically fixed. Variety, cultivation environment, germination treatment, thermal processing, fermentation, milling methods, and storage conditions can all influence its chemical profile. In Tartary buckwheat, rutin can be hydrolyzed into quercetin by endogenous rutinoidase during processing. Although quercetin has strong biological activity, its

bitterness and lower stability may reduce consumer acceptance. In other words, the medicinal value of buckwheat is not automatically guaranteed by the plant itself. It depends heavily on compound standardization, processing control, and bioavailability studies.

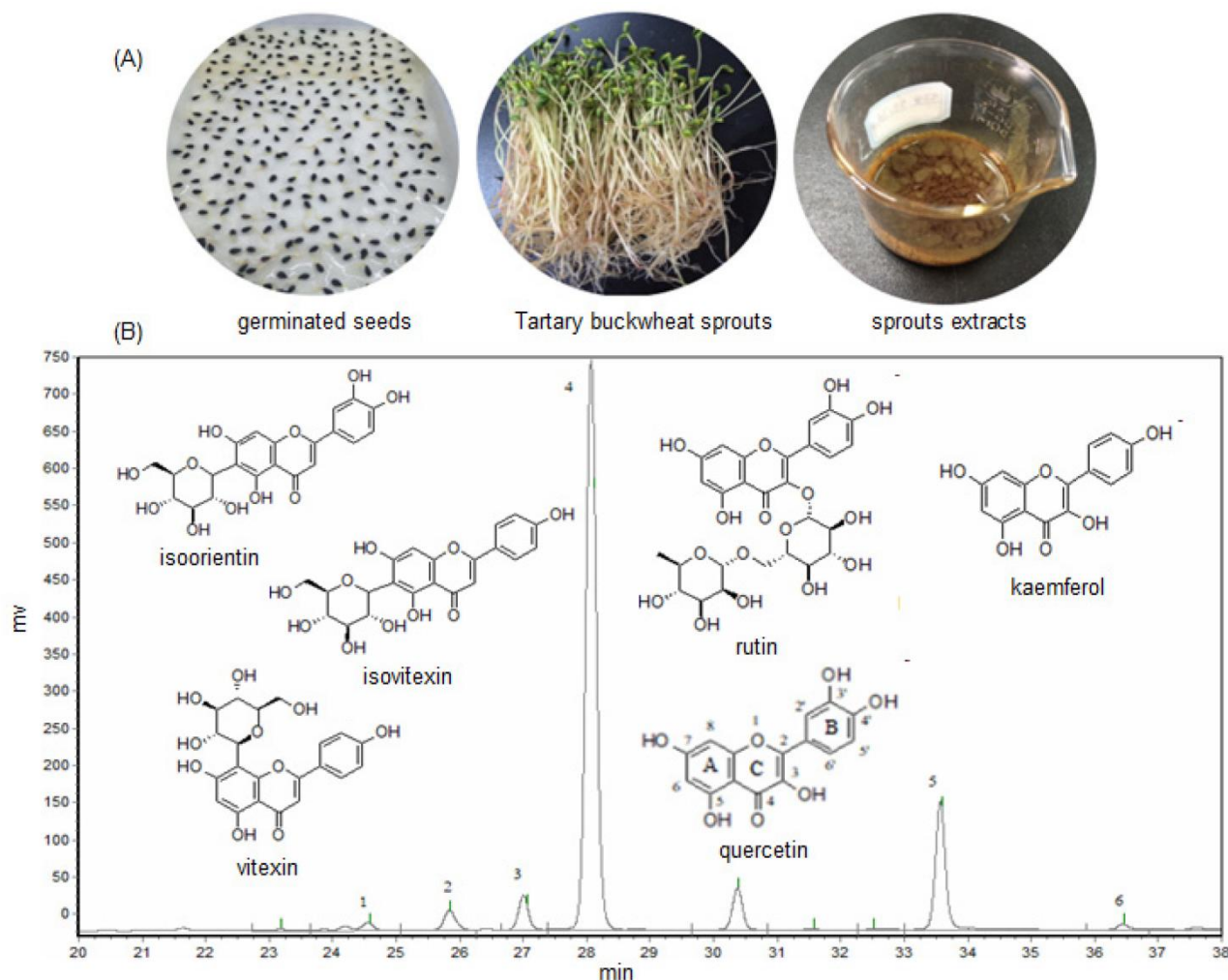


Figure 3 The germinated seeds, sprouts, and methanol extract (A), and the typical HPLC chromatogram of methanol extract (B) of Tartary buckwheat sprout cultures. Here, 1—isorientin, 2—vitexin, 3—isoovitexin, 4—rutin, 5—quercetin, 6—kaemferol (Adopted from Zhong et al., 2022)

6.2 Antidiabetic and cardiovascular protective effects

The health effects of Tartary buckwheat as a functional food are mainly related to the combined actions of dietary fiber, resistant starch, D-chiro-inositol, rutin, quercetin, and other polyphenols. Buckwheat may regulate metabolism by slowing carbohydrate digestion and absorption, improving insulin sensitivity, and reducing oxidative stress caused by hyperglycemia. Buckwheat flavonoids, especially rutin and quercetin, may also contribute to cardiovascular protection through antioxidant activity, inhibition of lipid peroxidation, improvement of lipid metabolism, and maintenance of vascular endothelial function (Giménez-Bastida and Zielinski, 2015).

Zou et al. (2023) reviewed the bioactive compounds, health effects, and industrial applications of Tartary buckwheat and concluded that its antidiabetic and cardiovascular protective functions are associated with the combined effects of flavonoids, polyphenols, dietary fiber, proteins, polysaccharides, and D-chiro-inositol. Tartary buckwheat flavonoids and phenolic compounds may delay carbohydrate digestion by inhibiting α -amylase and α -glucosidase activities. They may also participate in blood glucose regulation through improved insulin sensitivity, modulation of gut microbiota, and reduction of oxidative stress.

Compared with common buckwheat (*Fagopyrum esculentum*), Tartary buckwheat generally contains much higher levels of rutin and other flavonoids. Because of this difference, Tartary buckwheat has attracted greater attention in studies related to metabolic syndrome, diabetes, and cardiovascular diseases. However, most current evidence still comes from cell experiments, animal studies, and functional food evaluations. More long-term human intervention studies are still needed before these effects can be translated into clinical nutritional recommendations.

6.3 Anticancer and antimicrobial properties

As an underutilized crop, Tartary buckwheat has attracted increasing attention because of its potential anticancer properties. Its anticancer effects are believed to result from a complex phytochemical system rather than from one single therapeutic compound (Hassan and Ganai, 2025). Rutin, quercetin, phenolic acids, polysaccharides, and buckwheat-derived bioactive peptides may contribute to anticancer activity through antioxidant effects, anti-inflammatory responses, induction of tumor cell apoptosis, and inhibition of abnormal cell proliferation.

Tartary buckwheat is usually considered more valuable than common buckwheat in anticancer-related research because its flavonoid content is generally much higher. This makes it an important candidate for the screening of functional anticancer compounds and the development of health-oriented foods. Nevertheless, current evidence remains largely limited to in vitro experiments and animal models. At present, Tartary buckwheat should be regarded mainly as a source of preventive functional foods and natural bioactive compounds rather than as a direct substitute for clinical anticancer drugs.

In addition to anticancer activity, Tartary buckwheat also shows certain antimicrobial potential. Some studies have reported that buckwheat phenolics and peptides can inhibit the growth of several bacterial strains and may interfere with microbial metabolism or membrane integrity. However, antimicrobial activity is strongly influenced by extraction methods, processing conditions, and compound concentration. Therefore, more standardized studies are needed before buckwheat-derived antimicrobial compounds can be widely applied in medicine or food preservation systems.

6.4 Anti-obesity and metabolic regulation functions

Obesity is usually associated with lipid metabolism disorders, chronic low-grade inflammation, insulin resistance, and gut microbiota imbalance. Because these metabolic disturbances involve multiple physiological pathways, single compounds often have limited effects. The advantage of buckwheat lies in its multi-target component system. Dietary fiber can influence satiety and intestinal fermentation, proteins and peptides may regulate lipid metabolism, flavonoids and polyphenols can reduce oxidative stress and inflammation, and some compounds may further affect bile acid metabolism through interactions with gut microbiota.

Bae and Kim (2022) did not only measure flavonoids or antioxidant compounds in germinated buckwheat materials. Instead, they used an in vitro gastrointestinal digestion model to investigate the antioxidant and anti-obesity activities of digested products obtained after simulated digestion. This approach better reflects the physiological state after human consumption. The digested products of germinated buckwheat still maintained strong free radical scavenging activity and reducing power. In lipid metabolism-related experiments, they also showed the potential to inhibit lipid accumulation and alleviate obesity-related oxidative stress.

The germination process may activate endogenous enzyme systems in buckwheat grains and promote the release of bound phenolics and flavonoids, thereby improving the bioaccessibility of small active molecules. Therefore, the anti-obesity effects of buckwheat are not simply determined by its original nutritional composition. They are closely associated with the continuous process of germination, gastrointestinal digestion, release of active compounds, and regulation of lipid metabolism.

7 Buckwheat Landscape Utilization and Eco-Tourism

7.1 Flowering buckwheat landscapes and rural aesthetics

During the flowering period, large areas of buckwheat fields form white, pink, or light purple landscapes with strong visual appeal and obvious seasonal characteristics. The attraction of buckwheat landscapes is not only

related to their visual beauty. More importantly, buckwheat flowers can combine agricultural seasons, local food culture, and ethnic or regional identity into a short but emotionally recognizable rural experience.

In recent years, the Hahaheba tobacco-growing area in Mianning County, Liangshan Yi Autonomous Prefecture, Sichuan Province, has developed a representative “buckwheat flower sea + agro-cultural tourism” model. After tobacco harvesting, local farmers use winter fallow land to rotate with buckwheat, creating large white flowering fields in autumn. During the flowering season, the buckwheat flowers appear “like snow covering the fields,” forming impressive rural scenery together with mountains, villages, and tobacco fields. The local government even organized the first “Buckwheat Flower Festival,” which attracted more than 30,000 visitors for sightseeing, photography, and rural tourism experiences. Unlike traditional agricultural tourism focused only on crop viewing, Mianning integrated buckwheat flower landscapes with grain–tobacco rotation systems, Yi ethnic culture, local food experiences, and rural leisure activities. Visitors can not only enjoy the flower fields, but also participate in buckwheat food preparation, farming activities, stargazing camping, and local barbecue consumption. Local households have also benefited from flower tourism through farmhouse businesses, sales of local agricultural products, and livestream e-commerce activities.

7.2 Integration with rural revitalization strategies

Weining Yi, Hui and Miao Autonomous County in Guizhou Province is one of the three major Tartary buckwheat production regions in China and has long been known as the “Buckwheat Plateau.” In recent years, the county has gradually formed an integrated development model combining Tartary buckwheat cultivation, deep processing industries, and ecological tourism. Supported by its cold high-altitude environment above 2,300 m, Weining maintains about 150,000 mu of stable buckwheat cultivation each year, with annual production exceeding 260,000 tons. Several regional brands, including “Mingqiaoxiang,” “Mabaidashan,” and “Qianhe,” have also been developed.

Through policy support for leading enterprises such as Guizhou Weining Qiaoyuan Agricultural Co., Ltd., the county has promoted the development of a complete Tartary buckwheat industrial chain. More than twenty processed products have been developed, including buckwheat rice, buckwheat tea, buckwheat noodles, buckwheat crisps, and flower cakes. These products are sold to many provinces, including Hunan, Guangdong, and Jiangsu. The annual industrial output value exceeds 30 million yuan and has increased the income of thousands of farming households. At the same time, several thousand mu of flowering buckwheat fields have been combined with rural tourism development. In areas such as Bandi Township, Yi ethnic cultural patterns are incorporated into artistic buckwheat field designs. During the flowering season, the plateau buckwheat landscapes appear “snow-like and cloud-like,” attracting large numbers of tourists for photography, sightseeing, and ethnic cultural activities.

8 Current Challenges and Future Development Directions

8.1 Limitations in breeding and production systems

Although common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat (*Fagopyrum tataricum*) are both important cultivated buckwheat species, the major breeding problems are different between them. The biggest limitation in common buckwheat is its heterostylous flower structure and self-incompatibility system. This biological characteristic naturally promotes cross-pollination, making it difficult to achieve stable homozygous lines and consistent genetic improvement. Therefore, breeding of common buckwheat cannot rely only on traditional population selection. Factors such as S-locus regulation, flower-type ratio, pollination efficiency, and population genetic structure need to be considered together as an integrated breeding problem.

In the future, breeding of common buckwheat should focus more on the utilization of self-compatible materials, pollination control, resistance to seed shattering, and uniform maturity. In contrast, breeding of Tartary buckwheat should pay more attention to stable yield, reduced bitterness, stress resistance, and adaptability to mechanized cultivation. Only by combining genomic breeding, physiological regulation, mechanized farming systems, and region-specific production models can the buckwheat industry move from small-scale specialty cultivation toward stable, standardized, and sustainable production.

8.2 Processing technology bottlenecks

Both common buckwheat and Tartary buckwheat are gluten-free crops. Because they lack gluten proteins, their dough-forming ability is relatively weak. As a result, buckwheat-based noodles, bread, biscuits, and extruded foods often show poor elasticity, high breakage rates, rough texture, and unstable storage quality. Tartary buckwheat faces an additional challenge. Although its high rutin content is considered one of its most valuable functional traits, it is also associated with strong rutinase activity and the formation of bitterness.

Suzuki et al. (2021) reported that the *in vitro* rutinase activity of the Tartary buckwheat variety “Manten-Kirari” was two orders of magnitude lower than that of the conventional rutinase variety “Hokkai T8.” In dough prepared from “Hokkai T8,” rutin was almost completely hydrolyzed within 10 minutes after water addition, whereas only partial hydrolysis occurred in “Manten-Kirari” dough even after 6 hours. Among 29 evaluators, 27 identified clear bitterness in flour made from “Hokkai T8,” while no bitterness was reported for “Manten-Kirari” flour. More importantly, noodles produced with “Manten-Kirari” retained about 90% of their rutin content and showed only slight or no bitterness. However, high-moisture systems such as some pancake-type products still cannot completely prevent rutin hydrolysis. In addition, contamination of the processing chain with seeds or flour from normal rutinase varieties may reduce rutin retention. Future processing of Tartary buckwheat therefore requires a complete quality-control system covering seed purity, flour grading, moisture control, low-temperature storage, pH regulation, and final product formulation, rather than relying only on low-rutinase cultivars as a single technological solution.

8.3 Future trends in sustainable buckwheat utilization

The future development of buckwheat should not focus on only one specialized function. Instead, a comprehensive system based on the differentiated utilization of common buckwheat and Tartary buckwheat should be established. Future breeding programs should move beyond simple yield-oriented goals and focus on multiple traits at the same time, including self-compatibility, resistance to seed shattering, uniform maturity, suitability for mechanized harvesting, low bitterness, rutin retention, and food-processing quality. The future market potential of buckwheat lies more in high-value-added products than in low-value raw grain sales.

Sustainable utilization of buckwheat will increasingly depend on low-input agriculture, mountain agriculture, and circular bioeconomy systems. The future value of buckwheat is also reflected in the integration of agricultural landscapes, local culture, and regional branding. One promising pathway is to establish closed-loop systems in mountainous and cool-climate regions that combine buckwheat cultivation, food processing experiences, local cuisine, cultural tourism, and by-product utilization. In this way, buckwheat can simultaneously provide food, ecological, cultural, and economic functions. Under such a model, buckwheat will no longer remain only a “potential crop” frequently mentioned in review papers, but may become a practical and sustainable specialty crop supporting low-input agriculture and rural revitalization.

Author Contributions

The author conducted this study, including literature review, data analysis, and the drafting and revision of the manuscript. The author has read and approved the final version of the manuscript.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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