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.