Review paper

Recent advances in the nutritional, functional, and agronomic traits of Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.)

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ABSTRACT

Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) is considered a functional food because its seeds contain higher amounts of polyphenols (e.g., rutin) compared to common buckwheat. However, because of its highly bitter taste and difficulties in cultivation, the agricultural production and usage of Tartary buckwheat in food products remain limited. The nutritional and functional ingredients of Tartary buckwheat include quercetin, which causes its bitterness and is generated by rutinosidase (rutin-degrading enzyme). A nonbitter Tartary buckwheat variety with trace levels of rutinosidase has recently been developed. Despite such research, there is still a lack of agronomic information on Tartary buckwheat. Lodging can be a significant problem during its cultivation, and a lodging-resistant, semidwarf variety has been developed. This paper summarizes recent advances in our knowledge regarding the nutritional and agronomic traits of Tartary buckwheat. The information extends our understanding of the health benefits of Tartary buckwheat and the solutions to challenges in its agricultural production.

INTRODUCTION

Common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) comprise the two species of buckwheat. Common buckwheat is cultivated throughout the world, mostly in Russia and China, whereas Tartary buckwheat production is limited mostly to China, Bhutan, and Nepal. Although limited in its production, Tartary buckwheat has several advantages compared to common buckwheat. Being an autogamous plant, Tartary buckwheat produces high and stable yields due to its high seed set. Its seeds contain rutin, a major polyphenol, at levels approximately 100 times more than that found in common buckwheat seeds (Kitabayashi et al. 1995a, b). It can be grown in cold and harsh climatic conditions, and it is recognized as a functional food. Thus, like common buckwheat, Tartary buckwheat has recently been attracting interest in several countries and regions, including Japan and Europe, because of its health benefits (Ikeda et al. 2012).

Despite its positive attributes, Tartary buckwheat cultivation and utilization in food products remain limited because of two main reasons. Firstly, the flour of Tartary buckwheat is highly bitter because of the presence of high concentrations of flavonoids (Fabjan et al. 2003). This is the main reason that Tartary buckwheat has never become a major food crop in many countries. Secondly, its cultivation is difficult because of its tendency to lodge due to its height (Hagiwara et al. 1999). To enable the mechanized and efficient cultivation of this plant, it is necessary to first address these key challenges. Recent research on Tartary buckwheat in Japan has focused on the development of novel varieties. For example, bitterness and lodging have been addressed by the development of nonbitter (Suzuki et al. 2014b) and semidwarf varieties (Shimizu et al. 2020). Both of these varieties have been evaluated in detail.

The nutritional and functional aspects of Tartary buckwheat have been reviewed previously (Ruan et al. 2020; Zhu, 2016; Kreft et al. 2020), but there is still a lack of information on its agronomic characteristics. This review focuses on presenting some new findings on the nutritional qualities, functionality, and agronomic traits of Tartary buckwheat.

Nutritional ingredients in Tartary buckwheat

Table 1 shows the general compositions of Tartary buckwheat, common buckwheat, and wheat flour. The data on Tartary buckwheat are from 'Manten-Kirari,' a leading variety in Japan. The main nutritional components of Tartary buckwheat do not differ significantly from those of common buckwheat, although their levels vary greatly by region, variety, cultivation, and milling methods. On the basis of data presented in Table 1, the

Table 1. *General ingredients in Tartary buckwheat, common buckwheat, and common wheat flours. Values are expressed in units per 100 g of flour.*

	Tartary buckwheat (Manten-kirari) (Buckwheat flour)	Common buckwheat (Buckwheat flour)	Common wheat (medium-strength flour, first grade)
Energy (kcal)	347	361	367
Water (g)	14.8	13.5	14.0
Proteins (g)	9.1	12.0	9.0
Lipids (g)	2.3	3.1	1.6
Carbohydrates (g)	72.5	69.6	75.1
Ash (g)	1.3	1.8	0.4
Sodium (mg)	-	2	1
Potassium (mg)	441	410	100
Calcium (mg)	17.1	17	17
Magnesium (mg)	204	190	18
Phosphorus (mg)	419	400	64
Iron (mg)	3.42	2.8	0.5
Zinc (mg)	3.22	2.4	0.5

The data for 'Manten-Kirari' were provided by the Japan Food Research Laboratories. The rest of the data were obtained from the Japan 2015 (7th edition) Standard Tables of Food Composition. '–' indicates 'no data.'

flours of common and Tartary buckwheat contain about 12% and 9% protein, respectively. Other reports suggest that the protein contents of the flour from both species do not differ significantly (Bonafaccia et al. 2003b; Qin et al. 2010). However, among the flours of 21 Chinese Tartary buckwheat genotypes, protein contents ranged from 6.82% to 15.02% (Qin et al. 2010), suggesting large genetic variations. Analyses of seeds from Tartary and common buckwheat show that the protein contents of the bran are twice those of the flour in both species (Bonafaccia et al. 2003b). Furthermore, the proteins of Tartary and common buckwheat share the same amino acid composition (Bonafaccia et al. 2003b; Qin et al. 2010). Lysine, an essential amino acid, occurs at high levels in albumins and globulins (Javornik and Kreft, 1984). Thus, the protein content in both the species of buckwheat is well balanced in terms of essential amino acid composition (Kreft et al., 2020). Moreover, Tartary buckwheat contains higher levels of the proteins soluble in dilute acids or bases, and those soluble in ethanol-water mixtures compared to those in common buckwheat (Ikeda et al. 2003).

The mineral composition of Tartary buckwheat has been studied by Bonafaccia et al. (2003a), Huang et al. (2014), and Ikeda et al. (2004). Both common and Tartary buckwheat have much higher potassium and magnesium levels than wheat (Table 1). Moreover, Tartary buckwheat has higher levels of iron; zinc; vitamins B1, B2, and B6; and total B vitamins than common buckwheat (Bonafaccia et al. 2003b). However, both species of buckwheat share similar compositions of dietary fiber (Bonafaccia et al. 2003b).

The functionality of Tartary buckwheat

Tartary buckwheat seeds contain higher levels of the functional nutrient rutin than common buckwheat. Rutin is a kind of polyphenol that exists widely in the plant kingdom, although among cereal crops, it is found only in buckwheat. It has antioxidant (Morishita et al. 2007) and antihypertensive (Matsubara et al. 1985) activities. Tartary buckwheat seeds contain about 100 times more rutin than common buckwheat. Specifically, 100 g of common and Tartary buckwheat seeds contains about 10–30 and 1100–2000 mg rutin, respectively, with large differences among varieties (Kitabayashi et al. 1995a, b; Morishita et al. 2006, 2007; Suzuki et al. 2020). Noda et al. (2020) reported that the rutin content of Tartary buckwheat bran is fivefold that of its flour, and the authors provide the proper roasting time and temperature for retaining these high levels of rutin in bran. Thus, our current knowledge on rutin in Tartary buckwheat seeds indicates that future studies should explore the possibilities of effective utilization of rutin in both flour and bran. The function of rutin in Tartary buckwheat is to protect the plant body from the environmental stresses of alpine regions, such as ultraviolet (UV-B) rays, low temperatures, and dryness (Kreft et al. 2003; Suzuki et al. 2005).

Tartary buckwheat also degrades and eliminates rutin in the flour, which happens when water is added, such as during noodle making. Rutin is a flavonoid glycoside that is degraded to quercetin and rutinose by the rutin-degrading enzyme rutinosidase, which is abundant in Tartary buckwheat flour and activated by water (Suzuki et al. 2002; Yasuda and Nakagawa, 1994). Quercetin is one of the causes for the strong bitterness of Tartary buckwheat. However, rutinosidase in flour can be deactivated by heat treatment at >70°C (Kawakami et al. 1995; Yasuda et al. 1992).

Meanwhile, the Hokkaido Agricultural Research Center of the National Agriculture and Food Research Organization of Japan has developed a Tartary buckwheat variety that contains high levels of rutin while keeping its bitterness low (Suzuki et al. 2014a, b). This was accomplished by first developing a method to detect rutinosidase on gels that involved staining of a copper–rutin complex. This led to the discovery of 'f3g162,' a Tartary buckwheat line selected from about 500 genetic resources and mutant lines for its low rutinosidase activity. The authors crossed 'f3g162' with 'Hokkai T8,' a Hokkaido standard variety, and selected 'Mekei T27' for its excellent agronomic characteristics and low rutinosidase activity, which is controlled by a recessive single gene (rutA) (Suzuki et al. 2014a). After further improvements in the variety's agronomic characteristics, such as plant height, yield, and maturity, it was registered and named 'Manten-Kirari' in 2014 (Suzuki et al. 2014b). The rutinosidase activity of 'Manten-Kirari' is extremely weak, which is a few hundredths that of the conventional variety 'Hokkai T8,' and the rutin content remains mostly stable even after processing the flour into noodles. Moreover, the antioxidant capacities of the noodles and cookies made from the flour of 'Manten-Kirari' are high (Ishiguro et al. 2016), and these foods are effective in reducing body fat percentage, body weight, and BMI (Nishimura et al. 2016). In recognition of their 'epoch-making variety,' the breeders of 'Manten-Kirari' were awarded the 2019 Japanese Society of Breeding Award.

Agronomic traits of Tartary buckwheat

In Japan, Suzuki et al. (2014b) reported grain yields of 'Manten-Kirari' ranging from 2.16 to 2.48 t ha^{-1} (Suzuki et al. 2014). In China and Italy, grain yields of 1.2–1.5 t ha^{-1} (Zhang et al. 2008; Xiang et al. 2016) and 2.29 t ha^{-1} (Brunori et al. 2006), respectively, have been reported. Thus, the potential yield of Tartary buckwheat appears to be around 2 t ha^{-1}. At actual production sites, however, the yields of Tartary and common buckwheat are often lower because of preharvest shattering and losses due to threshing and aborting by combined harvesters (Funatsuki et al. 2000; Morishita and Suzuki, 2017). Furthermore, Matsuura et al. (2005a, b) reported that Tartary buckwheat is more susceptible to excess soil moisture and salinity than common buckwheat. However, only a few studies have examined the effects of environmental stress on the growth and yield of Tartary buckwheat.

Kasajima et al. (2012a) compared the changes in main stem length, number of leaves on the main stem, number of primary branches, and SPAD values of common and Tartary buckwheat grown in Hokkaido, the northernmost region of Japan (Fig. 1). During the early

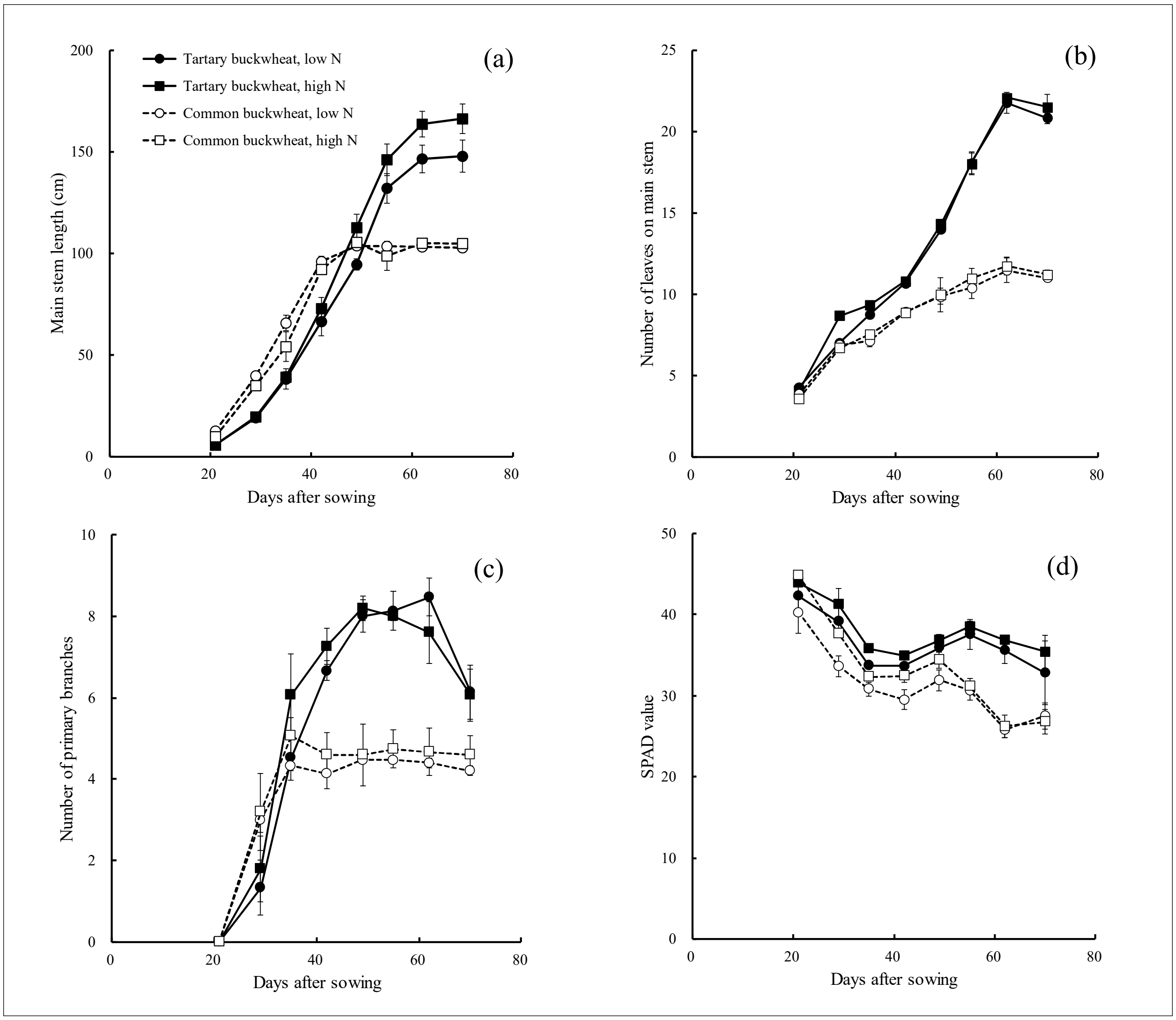

Fig. 1. *Changes in (a) main stem length, (b) number of leaves on the main stem, (c) number of primary branches, and (d) SPAD values in common buckwheat cv. 'Kitawasesoba' and Tartary buckwheat cv. 'Hokkai T8' under different nitrogen levels (Kasajima et al. 2012a). The plants were grown in an experimental field at Abashiri, Hokkaido, northernmost region of Japan. Low and high nitrogen levels correspond to 2 and 5 g m^{-2} of nitrogen as a basal fertilizer, respectively. Vertical bars represent standard errors.*

stage of growth, the main stem of common buckwheat is slightly longer than that of Tartary buckwheat, but the rate of stem elongation of common buckwheat plateaus at around 50 days after sowing, and the stem of Tartary buckwheat continues to grow rapidly. The main stem of Tartary buckwheat is about 50 cm longer than that of common buckwheat at maturity (Fig. 1a). Similarly, Tartary buckwheat has more leaves on its main stem and more primary branches than common buckwheat, and the differences in these parameters tend to be large (Fig. 1b, c). The SPAD value of Tartary buckwheat generally exceeds that of common buckwheat (Fig. 1d). At harvest, the Tartary buckwheat plant is taller and has more branches and leaves than the common buckwheat plant (Campbell, 2003; Morishita et al. 2006; Kasajima et al. 2012a).

Semidwarf Tartary buckwheat

The growth characteristics of Tartary buckwheat make it susceptible to lodging, i.e., the tendency of the stem to bend until the plant is lying horizontal, and it is a significant problem in the cultivation of Tartary buckwheat (Hagiwara et al. 1999). The lodging resistance of Tartary buckwheat may be enhanced by controlling the planting density or altering certain stem characteristics such as the lignin content and the activities of lignin-related enzymes (Xiang et al. 2016, 2019). Another approach is to shorten the plant, i.e., developing a lodging-resistant semidwarf cultivar. Dwarf and semidwarf genes have been reported in common buckwheat (Ohnishi and Nagakubo, 1982; Minami et al. 1999; Morishita et al, 2015), but little information regarding these genes is available in Tartary buckwheat genetic resources. Thus, seven semidwarf Tartary buckwheat mutants were developed by mutation breeding, resulting in the identification of two semidwarf genes, namely, *sdA* and *sdB* (Morishita et al. 2010). Subsequently, gamma-ray irradiation was used to develop the semidwarf variety, 'Darumadattan,' which was registered in 2013 (Shimizu et al. 2020). The height of 'Darumadattan' is almost half that of a standard Tartary buckwheat variety (Shimizu et al. 2020; Kasajima et al. 2012b). As shown in Fig. 2, the decreased height of 'Darumadattan' (previously known as 'IRBFT-20') is due to the shortening of each internode in its main stem, rather than a decrease in the number of nodes (Morishita et al. 2010; Kasajima et al. 2012b, 2013). In addition to decreased height, 'Darumadattan' expands its leaf area in the latter half of its growth stage, resulting in dry matter production and yields that do not differ significantly from those of standard Tartary buckwheat variety (Kasajima et al. 2012b, 2014). Furthermore, the rooting ability of 'Darumadattan' is superior to that of the standard-height variety (Kasajima et al. 2015). These reports indicate that the lodging resistance of 'Darumadattan' is extremely high and its cultivation is practical. For example, 'Darumadattan' did not lodge

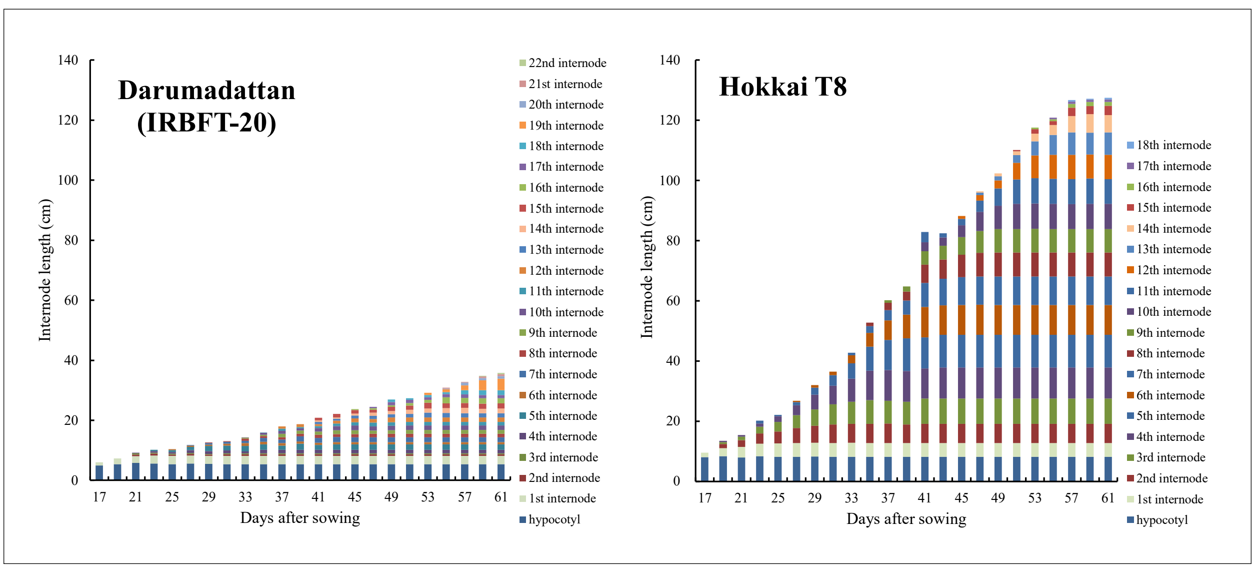

Fig. 2. *Changes in the internode lengths of the semidwarf Tartary buckwheat cv. 'Darumadattan' ('IRBFT-20') and its original cv. 'Hokkai T8' (Kasajima et al. 2013). The plants were grown in pots. 'Darumadattan' was known as 'IRBFT-20' during the breeding process.*

even after strong winds of a typhoon in Japan (Shimizu et al. 2020). In addition, the semidwarf trait in 'Darumadattan' is unique, and it can be used for future Tartary buckwheat breeding efforts. This trait will play an important role in the development of efficient cultivation techniques.

CONCLUSION

The present paper described some recent advances in knowledge regarding the nutritional, functional, and agronomic traits of Tartary buckwheat. In particular, the nonbitter and rutinosidase-deficient variety 'Manten-Kirari' and the semidwarf, lodging-resistant variety 'Darumadattan' are seen as innovative varieties that will have positive impacts on Tartary buckwheat-based industries. Although much is known regarding the nutritional function of Tartary buckwheat, knowledge on its yield performance and cultivation techniques is still limited. Further agronomic studies on Tartary buckwheat are necessary to increase its economic utilization. Knowledge generated from such studies will facilitate the creation of abundant and stable supplies of Tartary buckwheat products that will benefit the health of its consumers.

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IZVLEČEK

Novi dosežki v zvezi s prehranskimi, funkcijskimi in pridelovalnimi lastnostmi tatarske ajde (*Fagopyrum tataricum* (L.) Gaertn.)

Tatarska ajda (*Fagopyrum tataricum* (L.) Gaertn.) je pomemben vir za funkcijsko hrano, saj imajo zrna več polifenolov (na primer rutina) v primerjavi z navadno ajdo. Toda zaradi izrazite grenkosti in težav pri pridelovanju ima pridelovanje in predelava za prehranske izdelke le omejene možnosti. Prehransko in funkcijsko pomemembna snov tatarske ajde

je kvercetin, ki povzroča grenkost izdelkov. Kvercetin nastane kot posledica delovanja encima rutinozidaze (encim, ki razgrajuje rutin). V novejšem času smo razvili sorte tatarske ajde, ki so osnova za izdelke, ki niso grenki, saj imajo rutinozidazo le v sledovih. Kljub temu razvoju je še premalo informacij o možnostih pridelovanja tatarske ajde za izdelke brez grenkobe. Pri pridelovanju tatarske ajde je lahko pomemben problem poleganje rastlin, zato je bil razvit na poleganje odporen kultivar tatarske ajde s krajšimi internodiji in nižjo rastjo. V tej razpravi so povzeti novejši dosežki v zvezi s pridelovanjem in prehranskimi lastnostmi tatarske ajde.