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Research paper

Effects of planting density on branching habit in common and Tartary buckwheat

Shinya KASAJIMA*, Wakana WATANABE, Maki KITADE, and Hirotake ITOH

Faculty of Bioindustry, Tokyo University of Agriculture, Yasaka 196, Abashiri, Hokkaido 099-2493, Japan
* Corresponding author: Shinya Kasajima (s3kasaji@nodai.ac.jp)

E-mail addresses:
s3kasaji@nodai.ac.jp (SK); 49518102@nodai.ac.jp (WW); 49518032@nodai.ac.jp (MK); h-ito@nodai.ac.jp (HI)

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ABSTRACT

This study investigated the effects of planting density on the branching habit of common and Tartary buckwheat. A field experiment was conducted using a split-plot design with three replicates, comparing sparse (67 plants m^{-2}), moderate (111 plants m^{-2}), and dense (222 plants m^{-2}) planting densities in 'Kitawasesoba' (common) and 'Manten-Kirari' (Tartary) buckwheat varieties. Growth characteristics were examined at the stages of flower bud appearance, full flowering, and maturity. Results revealed that planting density had no significant effect on main stem length but showed significant effects on the number of branches in both species. As planting density increased, the number of branches decreased, with Tartary buckwheat exhibiting more significant changes in response to planting density than common buckwheat. The number of flower clusters on branches also decreased with increasing planting density. These findings suggest a potential role for branching plasticity in adapting to different planting densities while maintaining stable yields and indicate the importance of developing ideotypes with optimal branching habits for both species. This research contributes to a better understanding of buckwheat ideotypes and can contribute to future breeding efforts and crop management practices.

INTRODUCTION

Two species of buckwheat are mainly used for food: common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*F. tataricum* (L.) Gaertn.). Although common buckwheat is grown throughout the world, mainly in Russia and China, Tartary buckwheat production is primarily limited to China, Bhutan, and Nepal. Tartary buckwheat seeds contain rutin, a major polyphenol, at levels approximately 100 times higher than that found in common buckwheat seeds (Kitabayashi et al., 1995a, b). Consequently, both common and Tartary buckwheat have recently gained attention due to their potential health benefits (Kreft et al., 2020; Kasajima, 2021).

Although common buckwheat produces abundant flowers, its seed set is generally low due to self-incompatibility, resulting in poor seed yield (Woo et al., 2016). At present, the seed yield of common buckwheat in Japan is less than 1,000 kg ha^{-1}. In contrast, Tartary buckwheat is an autogamous plant with high fertilization efficiency, leading to higher seed yield than common buckwheat. However, pre-harvest shattering, aborting loss, and threshing caused by combine harvester lower the seed yield of both common and Tartary buckwheat (Funatsuki et al., 2000; Morishita and Suzuki, 2017). Additionally, Tartary buckwheat is more susceptible to excess soil moisture and salinity than common buckwheat (Matsuura et al., 2005a, b).

Buckwheat breeders have been developing varieties by improving plant type, including short plant height and determinate type, to increase yielding ability (Funatsuki et al., 1996; Honda et al., 2009; Morishita et al., 2013). Recently, a useful semi-dwarf common buckwheat line and a Tartary buckwheat cultivar with lodging resistance were developed (Shimizu et al., 2020; Morishita et al., 2015). In terms of cultivation technique, maintaining the ideal plant density through effective crop management is crucial for stabilizing seed yield (Donald, 1963). Planting density is a critical factor that affects the agronomic traits and yield of both common and Tartary buckwheat (Matsui et al., 1974; Xiang et al., 2016; Fang et al., 2018). Previous research on soybeans has shown that yield response at different planting densities is related to branch development, which is closely related to the ideotype of crops (Agudamu et al., 2016; Peng et al., 2008). However, an understanding of the effects of planting density on the branching habit in these species is limited.

The objective of the present study was to investigate the effect of planting density on the branching habit of common and Tartary buckwheat. This information will be useful for developing optimal crop management practices and ideotypes for these important food crops.

MATERIALS AND METHODS

The present study used the leading buckwheat varieties in Hokkaido, Japan, namely 'Kitawasesoba' and 'Manten-Kirari' that were developed by the NARO Hokkaido Agricultural Research Center (Inuyama et al., 1994; Suzuki et al., 2014). The seeds of 'Kitawasesoba' were purchased from a commercial source. The cultivation was carried out in an unused field on a local farm, located in Yobito district, Abashiri, Hokkaido, which is the northernmost region of Japan, from June to September 2021. The field had peat soil with a slightly acidic texture (pH: 6.1). The study employed a split-plot design with three replicates, resulting in 18 subplots, where the main plots were assigned to two buckwheat species, namely, common buckwheat cv. 'Kitawasesoba' and Tartary buckwheat cv. 'Manten-Kirari.' The subplots were assigned to three planting densities, including sparse (67 plants m^{-2}), moderate (111 plants m^{-2}), and dense (222 plants m^{-2}) planting. Each subplot measured 4.8 m^2, consisting of four 4 m-long rows, spaced 1.2 m apart, and with a within-row spacing of 0.3 m. Border rows were excluded from any investigation. The seeds were planted using seeder tapes (Nippon Plant Seeder Co., Ltd.) at intervals of one every 5 cm (sparse planting), 3 cm (moderate planting), and 1.5 cm (dense planting). The seeding was conducted manually in rows on June 10, 2021. The fertilizer was applied only as a basal dressing for all plants, at the rate of 2 g m^{-2} of N, 8 g m^{-2} of P_2O_5, and 4.7 g m^{-2} of K_2O.

The study investigated the main stem length and number of primary branches for 10 individuals of average growth from each plot at the stages of flower bud appearance and full flowering. The stage of flower bud appearance was defined as the day on which flower buds were observed in 40–50% of all plants. The stage of full flowering was defined as the day on which the apical inflorescence of the main stem bloomed in 40–50% of all plants. Owing to the differences in flower bud appearance and full flowering stages between common buckwheat and Tartary buckwheat, the investigation was conducted on an intermediate date, with respective investigations performed on July 12 and 23, 2021. Harvesting was conducted on September 3 and 6, 2021 for common and Tartary buckwheat, respectively. After harvesting, 10 individuals of average growth from each plot were collected, and their main stem length, number of primary branches, number of nodes on main stem, and number of flower clusters on the main stem and branch were measured. All small flower clusters were counted as one cluster. Subsequently, the plant samples were examined for seed yield after oven-drying at 80 °C for 48 h, and threshed. In this study, we only investigated the seed yield of Tartary buckwheat, as feeding damage by birds was observed in common buckwheat during the seed ripening period. Analysis of variance (ANOVA) was used to evaluate the effect of planting density on the growth and yield characteristics in the present study.

RESULTS AND DISCUSSION

Tables 1 and 2 show the main stem length and number of branches in common and Tartary buckwheat grown under different planting densities at the stages of flower bud appearance and full flowering, respectively. In both cases, the main stem length was significantly longer in common buckwheat compared to Tartary buckwheat, with no significant difference between planting densities. Conversely, the number of branches showed significant differences between planting densities and between the two species (only at the stage of flower bud appearance) but no significant interaction between planting density and species was observed. As planting density increased from sparse to dense, the number of branches decreased for both common and Tartary buckwheat. These findings indicate that while planting density did not significantly impact the main stem length, it had a significant effect on the number of branches at the stage of flower bud appearance.

Table 3 shows the results of the main stem length and number of nodes and branches in common and Tartary buckwheat grown under different planting densities at the stage of maturity. The main stem length was significantly shorter in common buckwheat compared to Tartary buckwheat, but there was no significant difference between planting densities. The number of nodes on the main stem showed significant differences between planting densities and between the two species. The number of branches also showed significant differences between planting densities and between the two species. As the planting density increased from sparse to dense, the number of branches decreased from 3.87 to 1.73 for common buckwheat and from 7.00 to 4.27 for Tartary buckwheat. There was no significant interaction between planting density and species for both the length of the main stem and the number of nodes and branches. Results presented in Table 3 show that the main stem length of Tartary buckwheat was shorter than that of common buckwheat until flowering, but it became longer at maturity. This result is consistent

Table 1. *Main stem length and number of branches in common and Tartary buckwheat grown under different planting densities at time of flower bud appearance.*

Species	Planting density	Main stem length (cm)	Number of branches (/plant)
Common buckwheat	Sparse planting	50.7	3.17
	Moderate planting	51.5	2.07
	Dense planting	48.8	0.87
Tartary buckwheat	Sparse planting	25.7	1.90
	Moderate planting	31.1	1.17
	Dense planting	32.0	0.13
ANOVA	Planting density	ns	**
	species	**	**
	Interaction	ns	ns

** and ** represent significance at 5 and 1%, respectively. ns indicates not significant.*

Table 2. *Main stem length and number of branches in common and Tartary buckwheat grown under different planting densities at time of full flowering.*

Species	Planting density	Main stem length (cm)	Number of branches (/plant)
Common buckwheat	Sparse planting	114.9	4.13
	Moderate planting	102.6	3.43
	Dense planting	104.2	1.93
Tartary buckwheat	Sparse planting	87.7	5.00
	Moderate planting	96.0	3.70
	Dense planting	92.3	2.30
ANOVA	Planting density	ns	**
	species	**	ns
	Interaction	ns	ns

** and ** represent significance at 5 and 1%, respectively. ns indicates not significant*

Table 3. *Main stem length and number of nodes and branches in common and Tartary buckwheat grown under different planting densities at the stage of maturity.*

Species	Planting density	Main stem length (cm)	Number of nodes on main stem (/plant)	Number of branches (/plant)
Common buckwheat	Sparse planting	132.0	13.1	3.87
	Moderate planting	122.7	11.8	2.87
	Dense planting	120.6	11.9	1.73
Tartary buckwheat	Sparse planting	162.4	20.9	7.00
	Moderate planting	162.6	20.1	4.43
	Dense planting	152.7	18.8	4.27
ANOVA	Planting density	ns	*	**
	species	**	**	**
	Interaction	ns	ns	ns

** and ** represent significance at 5 and 1%, respectively. ns indicates not significant.*

with the reports by Kasajima et al. (2012) and Kasajima (2021). Furthermore, the extremely high number of branches (seven) in the sparsely planted Tartary buckwheat, compared to other planting densities, revealed that the effect of planting density was more significant in Tartary buckwheat than in common buckwheat.

Fig. 1 shows the numbers of flower clusters on the main stem and branches of each planting density in common and Tartary buckwheat. The number of flower clusters on both the main stem and branches tended to be lower in common buckwheat compared to Tartary buckwheat. Tartary buckwheat is an autogamous plant and has been noted to have a higher yield potential than common buckwheat because of the ease of its seed set (Kasajima et al., 2021). The large number of branches and flower clusters also suggests that these factors contribute to its high yield. Further research is needed to examine the high-yielding traits of Tartary buckwheat from a

Table 4. *Seed yield in Tartary buckwheat grown under different planting densities.*

Species	Planting density	Seed yield per plant (g/plant)	Seed yield per square meter (g/m^2)
Tartary buckwheat	Sparse planting	1.79	120
	Moderate planting	0.93	104
	Dense planting	0.82	183
ANOVA		ns	ns

ns indicates that the differences among the planting densities are not significant (one-way ANOVA). The seed yield values per square meter were calculated based on the row and hill spacing for each planting density.

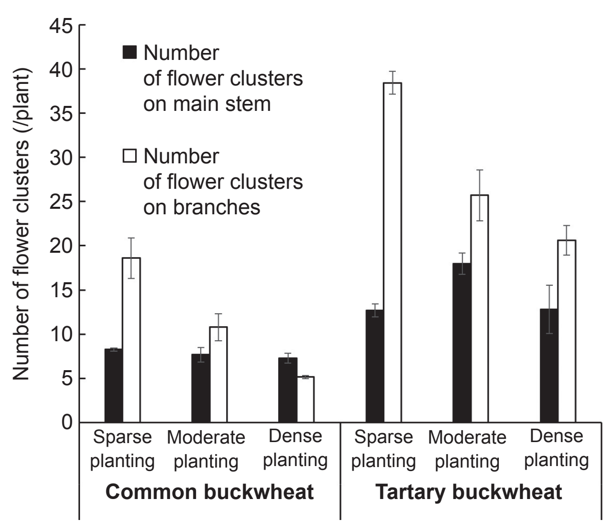
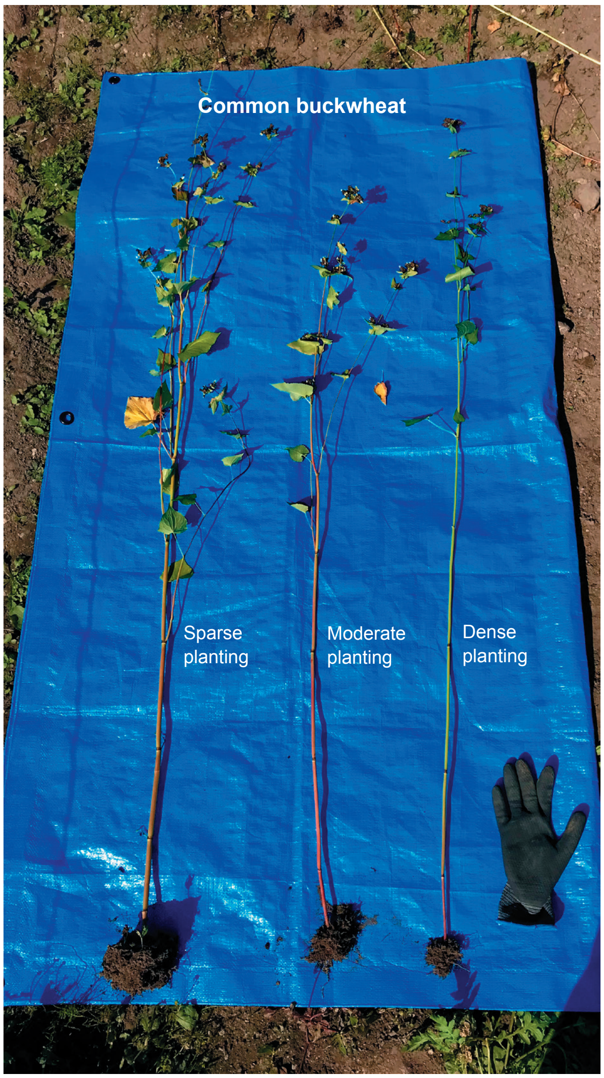


Fig. 1. *Numbers of flower clusters on main stem and branches of each planting density in common and Tartary buckwheat. Vertical bars represent standard errors based on three replicates.*

plant type perspective. There were no considerable differences in the number of flower clusters on the main stem among planting densities in both common and Tartary buckwheat. However, the number of flower clusters on the branches decreased from 18.6 to 5.17 for common buckwheat and from 38.4 to 20.6 for Tartary buckwheat as the planting density increased from sparse to dense. Agudamu et al. (2016) defined branching plasticity in soybean as the ability to adapt to varying planting densities while maintaining a stable yield. This is achieved by controlling branch growth under dense planting conditions and promoting more branches under sparse planting conditions to compensate for the reduced main stem yield. In Tartary buckwheat, the seed yield per plant in sparse planting was higher than that of moderate and dense planting, although the seed yield per square meter was the highest in dense planting (Table 4). Branching plasticity may also play a role in the adaptation to different planting densities while maintaining stable yields in buckwheat as well. Further research is needed to explore the relationship between branching plasticity and yield stability in buckwheat cultivars.

Fig. 2 displays the harvested plants obtained from different planting densities of both common and Tartary buckwheat. Sparse planting conditions exhibited more branches and flower clusters compared to those grown under moderate and dense planting conditions, indicating a close relationship with the buckwheat ideotype. The numbers of flower clusters and bloomed florets are considered important factors that govern seed yield (Ujihara and Matano, 1975). Thus, the ideotype of buckwheat is considered a plant type with numerous branches and flower clusters; however, there has been limited research on this topic. In the past, plant types with many branches and flower clusters in buckwheat carried the risk of lodging. Nevertheless, with the introduction of semi-dwarf



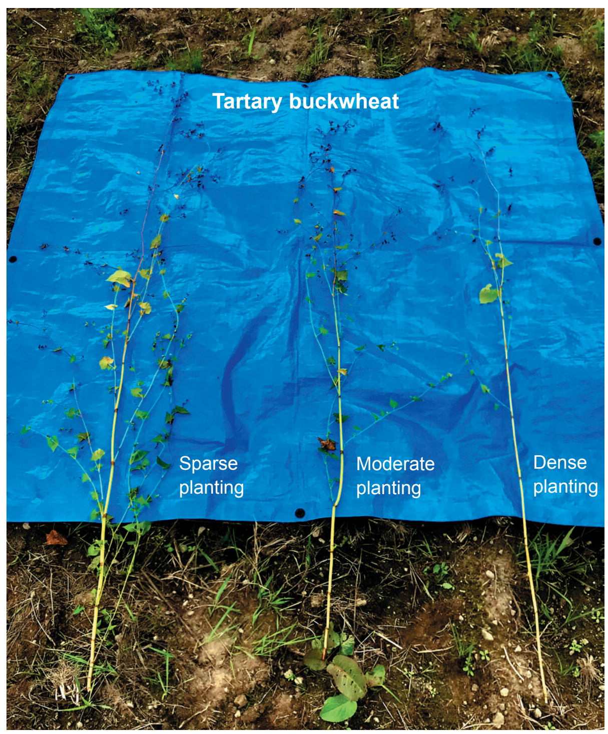


Fig. 2. *Photograph of harvested plant of each planting density in common and Tartary buckwheat. Photograph of common buckwheat (left) on September 3, 2021. Photograph for Tartary buckwheat (right) on September 6, 2021.*

cultivars (Shimizu et al., 2020; Morishita et al., 2015), the risk of lodging is expected to decrease, and the need for research on plant types is likely to increase.

In conclusion, our study demonstrated the impact of planting density on the growth characteristics of common and Tartary buckwheat. The findings contribute to a better understanding of the ideal buckwheat plant type and the role of branching plasticity in adapting to various planting densities. This research has the potential to inform and support future breeding efforts and guide more efficient and sustainable buckwheat cultivation practices.

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IZVLEČEK

Vpliv gostote setve na razvejanje pri navadni in tatarski ajdi

V raziskavi so proučevali učinke gostote setve na razvejanost navadne in tatarske ajde. Poljski poskus je bil izveden z uporabo razdeljene ploskve s tremi ponovitvami, pri čemer so primerjali redko (67 rastlin na m^2), zmerno (111 rastlin na m^2) in gosto (222 rastlin na m^2) gostoto setve pri ‚Kitawasesoba‘ (navadna) in ‚Manten-Kirari‘ (tatarska) ajda. Rastne značilnosti so preverjali v fazah pojava cvetnih popkov, polnega cvetenja in zrelosti. Rezultati so pokazali, da gostota setve ni pomembno vplivala na dolžino glavnega stebla, vendar je pokazala pomembne učinke na število stranskih vej pri obeh vrstah. Z večanjem gostote setve se je število vej zmanjšalo, pri čemer je tatarska ajda pokazala pomembnejše spremembe glede na gostoto setve kot navadna ajda. Z večanjem gostote setve se je manjšalo tudi število socvetij na vejah. Te ugotovitve kažejo na potencialno vlogo plastičnosti razvejanja pri prilagajanju različnim gostotam setve ob ohranjanju stabilnih pridelkov in kažejo na pomen razvoja ideotipov z optimalnimi lastnostmi razvejanja za obe vrsti. Raziskava prispeva k boljšemu razumevanju ideotipov ajde in lahko prispeva k prihodnjim prizadevanjem za žlahtnjenje in način pridelovanja.