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Shinya Kasajima & Hideharu Araki

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Improvement of yield performance by examining the morphological aspects of a leading winter wheat variety, 'Kitahonami', in Hokkaido, the northernmost region of Japan

Shinya Kasajima^a and Hideharu Araki^b

^aFaculty of Bioindustry, Tokyo University of Agriculture, Abashiri, Japan; ^bAgricultural Technologies Dissemination Division, Department of Agriculture, Hokkaido Government, Sapporo, Japan

ABSTRACT

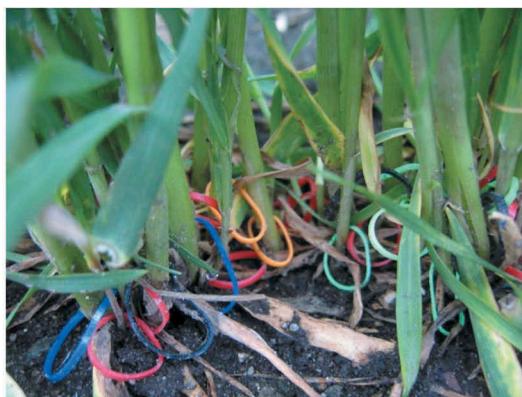
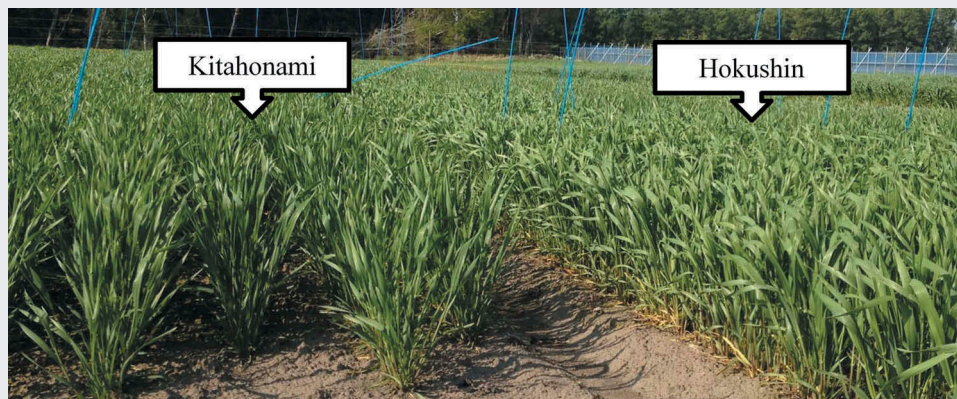
Hokkaido is a major wheat production region in Japan and is located in the northernmost area of the country. The winter wheat variety 'Kitahonami' is the most extensively grown variety in Hokkaido. We established a novel cultivation method to achieve stable high yields of 'Kitahonami' following examination of the morphological aspects of wheat cultivated in Hokkaido, Japan. The leaves of 'Kitahonami' are highly erect and potentially absorb radiation more effectively than those of 'Hokushin', which is the previous variety grown in Hokkaido, leading to a higher net assimilation rate in the later grain-filling phase and higher dry matter production after the milk-ripe stage; thus, we consider 'Kitahonami' as an ideotype. Furthermore, tracking tillering has been attempted using commercially available colored rubber bands. In winter wheat varieties including 'Kitahonami' in Hokkaido, the productive capacity of the tillers with >2 leaves before winter is high, leading to increased grain number and heavy spike weight. A decrease in the sowing rate is critical for stable high yields of 'Kitahonami'. We have developed a novel nitrogen topdressing method that considers the plant type and tillering of 'Kitahonami'. When the nitrogen topdressing is applied at the spike formation stage, maintaining a higher net assimilation rate until later phases of grain filling is possible using improved plant types with erect leaves. This paper summarizes the novel techniques for improving grain yield performance based on findings of the tillering trends and a plant type of 'Kitahonami'.

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Winter wheat; plant type; tillering; Hokkaido; Kitahonami



Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally and can be grown in a wide range of climatic conditions. The levels of wheat production need to be increased to meet the increasing demand of wheat that corresponds with the increasing global human population. Therefore, agronomic studies on the improvement of wheat grain yield per unit land area remain essential for determining future strategies of agricultural production.

In Japan, paddy rice (*Oryza sativa* L.) is mainly cultivated for consumption as a staple food. Conversely, the self-sufficiency rate for wheat in Japan was 14% in 2017 (MAFF, 2019). A major production area of wheat in Japan is Hokkaido, which is located in the northernmost region of the country (Hokkaido Government, 2019). Especially, in eastern Hokkaido, wheat is one of the most important field crops, in addition to potato (*Solanum tuberosum* L.) and sugar beet (*Beta vulgaris* L. var. *rapa* Dumort.). The wheat production in Hokkaido has played a major role in the domestic wheat production in Japan, so that Hokkaido produces >60% of the wheat produced in Japan (Hokkaido Government, 2019), and winter wheat production accounts for approximately 90% of the total wheat production in Hokkaido. The high-yielding ability of winter wheat varieties in Hokkaido has been achieved by expanding resistant varieties to diseases such as snow mold and preharvest sprouting and by improving fertilization to achieve appropriate protein content (Yoshimura, 2013, 2014). Winter wheat varieties cultivated in Hokkaido over the recent years are highly appreciated by food manufacturers based on both yield and quality (Yoshimura, 2013). However, grain yield per unit area varies considerably annually, and stable supply to consumers has not been realized (Araki, 2015a).

The winter wheat variety, 'Kitahonami', is the most extensively cultivated wheat variety in Hokkaido. Considering the wheat production in Hokkaido accounts for over 60% of the entire wheat production in Japan, 'Kitahonami' is the most important variety for wheat production in Japan. The variety was developed by the Hokkaido Research Organization, Kitami Agricultural Experiment Station, in 2006, as a high-yielding and high-quality winter wheat variety (Yanagisawa et al., 2007a). The yield capacity of 'Kitahonami' is high in agro-climatic environments with long sunshine hours and moderate temperature that offer appropriate ripening conditions (Shimoda, Hamasaki, Hirota, Kanno & Nishio, 2016), leading to the production of the highest quality of flour for

Japanese wheat noodles. However, under poor conditions with short sunshine hours and high temperatures (Nishio et al., 2013; Shimoda et al., 2016), the number of grains produced is very high, and immature grains (grains that cannot pass through a 2.2-mm sieve) are produced, which leads to a marked decline in the yield (Kasajima & Araki, 2017). In the present paper, we explore the factors that become immature grains after examining the factors determining the high yield capacity of 'Kitahonami'. We previously developed a novel cultivation method for achieving high quality and high yield by improving the sowing rate and the nitrogen fertilization method. In addition, the method has been adopted in major 'Kitahonami' production areas (Tokachi and Okhotsk area) in Hokkaido. We also review a series of studies that have achieved high-yielding capacities of 'Kitahonami', the leading winter wheat variety in Hokkaido, Japan.

Factors influencing the high-yielding capacity of 'Kitahonami'

One of the characteristics of 'Kitahonami' is its plant type. There are reports that consider 'Kitahonami' as ideotype, since its leaves are highly erect, even though the numbers of tillers and spikes in 'Kitahonami' after the regrowing stage is larger than those in 'Hokushin', the previous leading variety in Hokkaido (Yanagisawa et al., 2007a; Yoshimura, 2010) (Figure 1). In paddy rice cultivation, crops with canopies consisting of plants with erect leaves often have higher yields because they have enhanced light-intercepting ability (Matsushima, Tanaka & Hoshino, 1964; Tanaka, Matsushima, Kojyo & Nitta, 1969). However, in the case of wheat, since flag leaves and spikes on the upper sections of wheat canopies have high photosynthetic capacity (Takahashi, Shimauchi, Nakagawa, Shibata & Iiyama, 2002; Tsunoda, 1984), the potential effects of light accessing the lower sections of canopies have not been explored. Therefore, instead of attempting to improve grain yield by enhancing the light-interception capacity, higher grain yield has been achieved by improving the harvest index by shortening culm length (Goto, 1987). However, the leaf blades of 'Kitahonami' are more erect than those of 'Hokushin'. Therefore, more light can penetrate into the middle sections of the canopy in 'Kitahonami' so that the leaves under the canopy may sustain photosynthetic activity throughout the ripening period. Donald (1968) proposed the concept of wheat ideotypes, which are

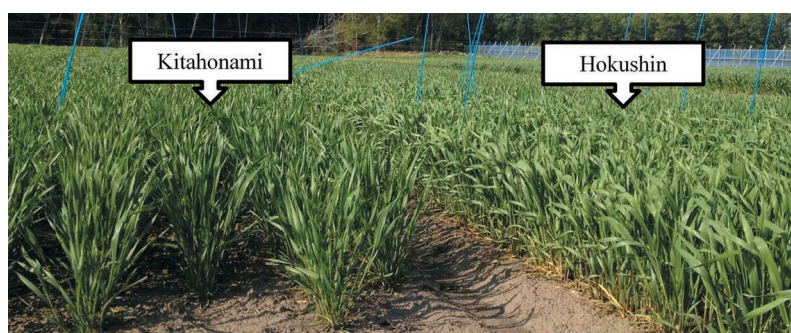


Figure 1. Plant types of winter wheat varieties 'Kitahonami' and 'Hokushin'.

Photograph taken on 22 May 2012.

plants with a unicum habit, a short culm, and erect leaves and spike. Ideotype breeding efforts have been made in gramineous crops (Donald, 1979; Mock & Pearce, 1975; Peng, Khush, Virk, Tang & Zou, 2008). In addition, in wheat, the ideal cultivation technique based on the rice plant type concept suggested by Matsushima (1973) and summarized by Yoshida (1981) is not well understood. Matsushima (1973) proposed the control of plant type to increase rice crop yield.

Kasajima et al. (2016) identified the factors influencing the high-yielding ability of 'Kitahonami' by comparing 'Kitahonami' with 'Hokushin'. The grain yield of 'Kitahonami' was 8% higher than the grain yield of 'Hokushin'. The variation was due to the higher number of grains per spike and higher 1000-grain weight. The high-yielding ability of 'Kitahonami' was attributed to a large sink capacity. At maturity, the total dry weight of 'Kitahonami' was 13% higher than that of 'Hokushin'. The increased total dry weight was due to an increase in crop growth rate between the milk-ripe stage and the maturity stage (Figure 2). A high source activity during the later grain-filling phase also contributed to the high-yielding ability of 'Kitahonami'. The nitrogen contents of the second and third leaves at the milk-ripe and maturity stages were higher in 'Kitahonami' than in 'Hokushin'. The erect green leaves of 'Kitahonami' potentially absorbed light energy more effectively compared with the green leaves in 'Hokushin', leading to a higher net assimilation rate in the later grain-filling phase and a higher dry matter production after the milk-ripe stage. Based on the findings above, since 'Kitahonami' exhibits increased grain numbers, securing the number of spikes required to achieve high yield capacity would increase the number of grains. However, if the levels of dry matter production cannot be maintained at high levels after the milk-ripe stage, the sink capacity would become too high and immature grains might be observed.

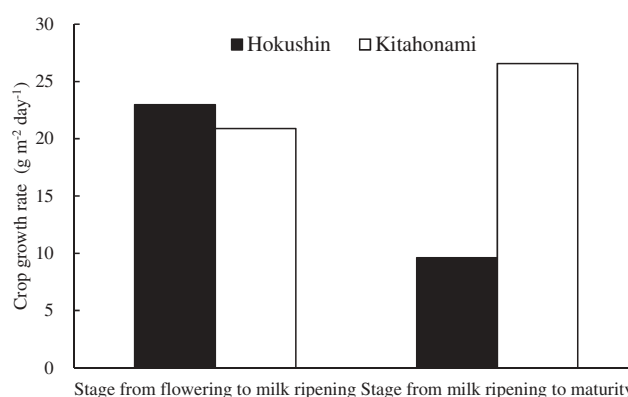


Figure 2. Crop growth rates from flowering to milk-ripe stage and from milk-ripe stage to maturity stage in winter wheat varieties 'Hokushin' and 'Kitahonami' (Kasajima et al., 2016).

The high number of grains per spike is a key characteristic of 'Kitahonami' (Kasajima et al., 2016; Yanagisawa et al., 2007b). It is derived from 'Norman', the English variety, which is the parent plant of 'Kitakei 1660', the farther plant of 'Kitahonami' (Yoshimura, 2014). 'Norman' is a late maturing variety of wheat, which exhibits short and strong culms with large spikes, in addition to being highly tolerant to disease. In England, the selection of short culm varieties increased the harvest index, and the increased lodging and disease resistance resulted in effective nitrogen fertilization, and, in turn, high-yielding ability (Lupton, 1987). One of the reasons for the high yield capacity of 'Kitahonami' is its inherited strong culms, large spikes, and high disease tolerance from 'Norman', and these traits support the numerous heavy grains on the spikes. The heavy grains per spike may be attributed to a heavy grain weight in the third and fourth florets as well as in the first and second florets among each spikelet on the spikes of 'Kitahonami' (Kasajima et al., 2018). Recently, Sakuma et al. (2019) reported that floret fertility of wheat was regulated by *GNI1*, leading to higher grain number per spike. Future studies should explore not only

the phenotypic but also the underlying genetic mechanisms influencing the higher grain number of 'Kitahonami'.

At actual production sites, the high rates of increase of tillers following winter to the spike formation stage lead to over-luxuriant growth and result in lodging challenges (Araki et al., 2011; Yoshimura, 2013). According to Takahashi et al. (2004), removal of the leaves in the bottom sections of wheat individuals resolves the over-luxuriant growth effects while increasing net assimilation rate and grain weight. Considering the findings of the reports above, it might be critical to avoid source-limiting conditions when increasing the sink size of 'Kitahonami' and targeting high crop yields. This should be achieved by managing the tiller numbers appropriately using controlled sowing and fertilization rates.

Determining factors influencing the number of spikes as yield component based on studies on tillering trends

The major cultivation techniques for the winter wheat grown in Hokkaido focus on the sowing density and consider tiller development and tiller number management, in addition to fertilization control. Because the productive tiller number, i.e. the number of tillers that produce spikes and grains, is a key component of wheat grain yield (Naruoka et al., 2011), understanding the tillering trends is the basis for the development of the most appropriate cultivation technique, and it is a key factor influencing stable high yield. The tillering trends of rice and wheat are discussed with a major focus on synchronously emerging leaves and tillering models suggested by Katayama (1951). Rice cultivation techniques that focus on tillering number management based on studies by Matsuba (1987), Yamamoto, Nouno and Nitta (1994), Goto (2003), and Sasaki, Toriyama, Shibata and Sugimoto (2004) are considered to have been established at actual paddy rice production fields. In wheat grown in the warm regions of Japan, differences in productive and non-productive tillers emerge after the internode elongation period (Chujo, Benitani & Momoto, 1989; Hashimoto, Takiguchi & Isoda, 1956; Li & Yamazaki, 1994; Tokunaga, 1956) and there are high production rates of lower-order and lower-position tillers according to the synchronously emerging leaves and tillering (Chujo et al., 1989; Fukushima, Kusuda & Furuhashi, 2001; Li, Harada & Yamazaki, 1993). Attempts to optimize productive tiller number and its physiological basis for the productive capacity of tillers in wheat have been previously described (Cai et al., 2014; Xu, Tie, Wang & He, 2015). However, considering the extended, snowing season in Hokkaido 4–5 months, it is a challenge to track the tillering stages of winter wheat. Therefore, the tillering trends in winter wheat have not been elucidated well in the past.

Araki (2015a) developed a simple method for tracking tillering using commercially available colored rubber bands (Figure 3). The method is highly practical and could be used to track tillering trends in wheat in Hokkaido and it addresses previous practicality and accuracy problems. The method has been used to study the relationships between the starting time of tillering and production rate or yield. The production rates of the tillers (determined by dividing the number of spikes developed from tillers by total tiller number) with more than two leaves before winter were high, 75–100%. In addition, the production rates of tillers developed after winter were low, 0–4% (Figure 4). When we defined strong culm as the tillers with more than two leaves before winter, the number of grains per spike on the before-wintering strong culm was high, and spike weight was heavy. Indeed, 99% of the yield consisted of grains harvested from the tillers developed before winter. Notably, the observation is not only limited to 'Kitahonami' but has also been observed in other winter wheat varieties cultivated in Hokkaido, which exhibit high production rate on the before-wintering strong culm resulting in relatively heavy spikes. Therefore, the number of spikes and subsequent yield is influenced largely by tiller development before wintering (Araki, 2015c, 2016). Xu et al. (2015) reported that the greater productive capacity of tillers was related to stronger leaf photosynthetic capacity, more predominance in terms of grain filling, slower senescence rate, and high yield. From these reports, securing the strong tillers before winter plays an important role in stable high yield, and further studies on the physiological basis of productive tillers are needed.

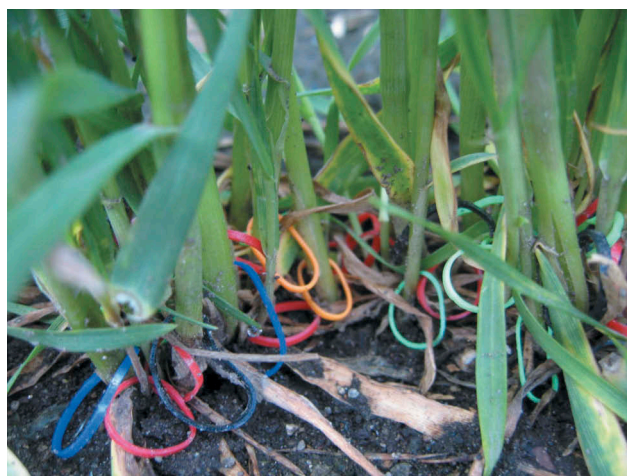


Figure 3. Method of tracking tillering using commercially available colored rubber bands (Araki, 2015a). The different colored rubber bands were used to distinguish between the different starting times of tillering.

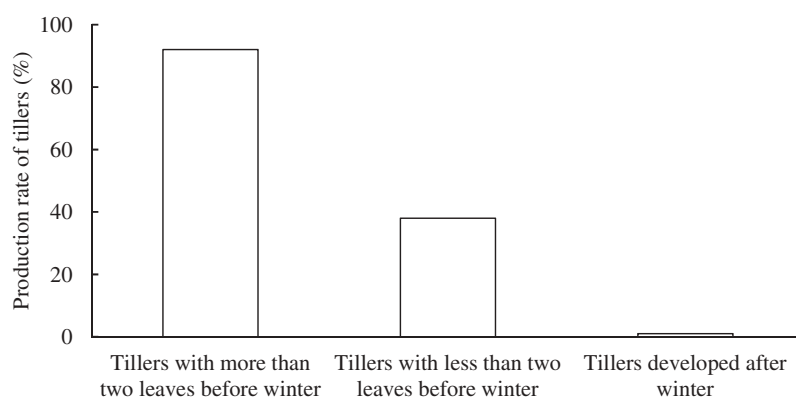


Figure 4. Relationship between the starting time of tillering and production rate in ‘Kitahonami’ (Araki, 2015a). The data is the average of two experimental fields in two growing seasons.

Araki (2016) further investigated if there are any differences in the number of spikes and grain weight per spike based on differences in the number of strong tillers. The author reported that higher proportions of strong tillers formed larger numbers of spikes and heavier grains per spike. In addition, there were relationships between the number of strong tillers and before-wintering leaf ages of the main stem. There were three, four, and five strong tillers at 5.0, 5.5, and 6.0 leaves leaf ages, respectively. In Hokkaido, the optimum sowing date is the day when the cumulative temperature until the number of leaves of the main stem before wintering reaches five leaves is 470° C (Yoshimura, 2010). The present results suggest that the yield decline owing to delayed sowing attributed to lesser number of strong tillers and spikes, resulting in lighter grain weight per spike, in addition to more younger leaf age of the main stem before wintering.

Management of tiller and spike number before winter by controlling sowing rate

Increasing the number of tillers that emerge before winter and develop into strong culms could increase spike number and yield. However, it may have a negative impact on canopy structure and lower the net assimilation rate at the later grain-ripening period. Therefore, it is critical to manage the number of tillers that develop before winter, and, in turn, the number of spikes. Araki (2015b) estimated the appropriate sowing density based on before-winter leaf age of the main stem, the number of strong culms, and the production rate. The estimation was performed by setting the target number of spikes at 700 per square meter as previously reported (Yoshimura, 2010). As a result, the sowing densities were 491, 312, 228, 167, and 132 grains per square meter at 4.0, 4.5, 5.0, 5.5, 6.0 leaves leaf ages, respectively. The result demonstrated

that the plants with older leaves would have heavier grains per spike and high yield levels. However, the sowing rate should be decreased. Generally, machine sowers such as grain drills are used in Hokkaido. The sowing precision of machine sowers is significantly low when the sowing density set to low. Therefore, decreased yield due to missing hill has been indicated (Sawaguchi et al., 2014). The farmers in the field mentioned that the lowest level of precision that could be achieved was 150 grains per square meter. Consequently, the suggested sowing density, 132 grains m^{-2} , for the main stem leaf age, six leaves, is lower than the lowest precision limit, and; therefore it is difficult to achieve precisely. Therefore, to avoid the risk of lowering yield, the target main stem leaf age before winter should be set to approximately 5.5.

Improving plant type by altering nitrogen topdressing method

A key challenge for achieving the high-yielding capacity of ‘Kitahonami’ is how to maintain high net assimilation rate until the later phase of grain filling (Kasajima et al., 2016). We developed a novel nitrogen topdressing method based on plant type and tillering characteristics (Figure 5). Compared with previous varieties such as ‘Hokushin’, ‘Kitahonami’ often reveals excessive numbers of tillers at the regrowing stage after snow-melt, when an adequate amount of basal fertilizer is applied. Under such circumstances, the application of nitrogen topdressing at the regrowing stage would lead to over-luxuriant growth indicated by too many tillers and spikes, and the creation of source-limiting conditions due to unstable source–sink relationships. Source limitation and excessive spikes are considered linked to a loss of the erect characteristics of the leaves of ‘Kitahonami’, and the increases in proportions of immature grains and lodging, leading to low yield (Kasajima & Araki, 2017).

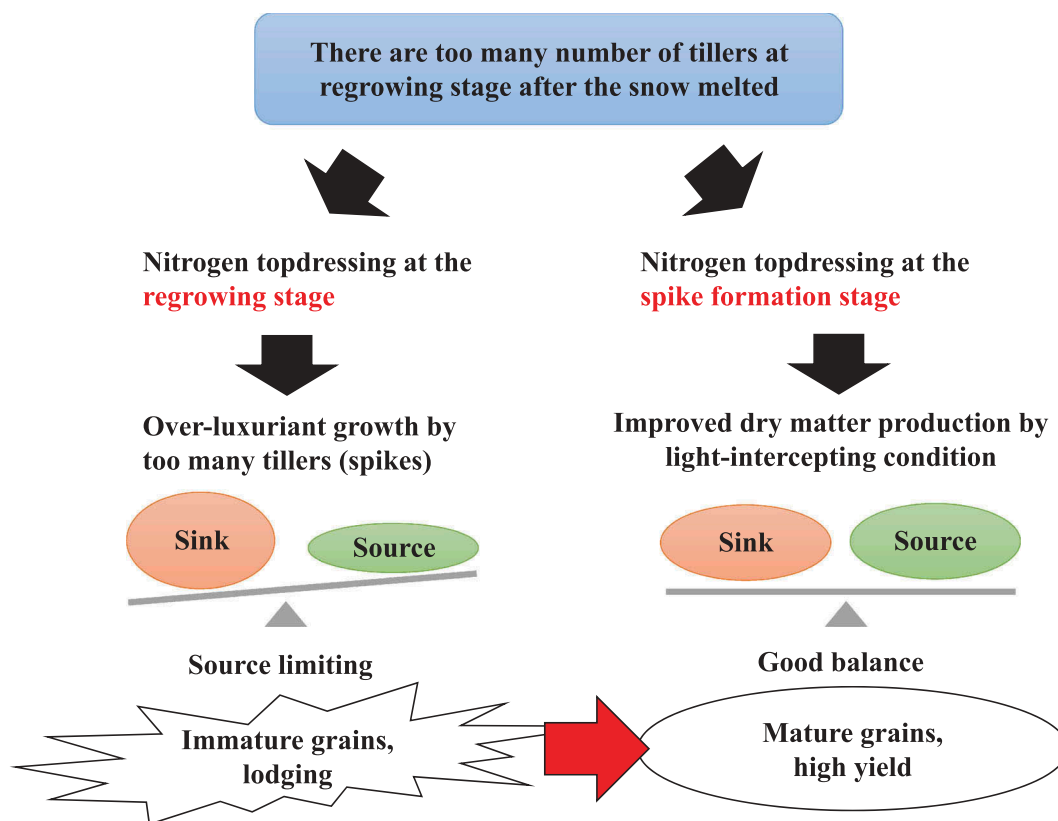


Figure 5. Schematic diagram of improved method for the cultivation of 'Kitahonami' wheat variety with high-yielding ability after winter.

Donald's wheat ideotype concept has been applied by breeders (Donald, 1968; Rasmusson, 1991), but its physiological mechanism in relation to high-yielding ability remains unclear. Therefore, we have previously pointed out that the maintenance of high net assimilation rate until the later phase of grain-filling period is possible in improved plant types that have erect leaves when the nitrogen topdressing is applied at the spike formation stage after the tiller and leaf development is almost completed (Araki, 2017; Kasajima & Araki, 2017).

Conclusion

The factors enhancing the high-yielding capacity in 'Kitahonami' have been explored in the present paper, and dry matter production was maintained at high levels until the later phase of grain filling. Such high-yielding ability is considered due to the canopy consisting of plants with strong erect leaves, i.e. an ideotype. In addition, tillering trends could be tracked using simple methods despite the challenges experienced in Hokkaido, particularly prolonged snow. Based on the findings present here, information regarding the novel cultivation technique based on the sowing rate and nitrogen topdressing is accessible. To date, ideotype and productive capacity of tillers are hardly focused on wheat breeding

programs. The information may facilitate our understanding of the high yield attributes of other wheat varieties. Overall, the insights will facilitate agricultural production by optimizing and enhancing the yield performance of various wheat varieties.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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References

- Araki, H. (2015a). Hokkaidou no aki maki komugi ni okeru bun getu sei ni kan suru kenkyuu — dai 1 hou bun getu tuiseki syuhou no kentou to bun getu syutugen ziki ga ho keisei □ syuuryou ni oyo bosu eikyou —. [Studies on the tillering of winter wheat in Hokkaido. 1. Development of tillering tracking method and effect of tillering appearance time on ear formation and yield]. *Japanese Journal of Crop Science*, 84(1), 34–40.
- Araki, H. (2015b). Hokkaidou no aki maki komugi ni okeru bun getu sei ni kan suru kenkyuu □ dai 2 hou ettou mae syu keiyou rei no sai ga syuuryou ni oyo bosu eikyou □. [Studies on the tillering of winter wheat in Hokkaido. 2. Effect of difference in leaf age on the main stem before wintering on yield]. *Japanese Journal of Crop Science*, 84(3), 264–270.
- Araki, H. (2015c). Hokkaidou no aki maki komugi ni okeru bun getu sei ni kan suru kenkyuu — dai 3 hou bun getu syutugen no kisokusei to hinsyu kan sai —. [Studies on the tillering of winter wheat in Hokkaido. 3. Regularity of tiller appearance and varietal difference]. *Japanese Journal of Crop Science*, 84(4), 351–357.
- Araki, H. (2016). Hokkaidou no aki maki komugi ni okeru bun getu sei ni kan suru kenkyuu. □ dai 4 hou bun getu syutugen ziki ga ho keisei to syuuryou ni oyo bosu eikyou no hinsyu kan sai □. [Studies on the tillering of winter wheat in Hokkaido. 4. Varietal difference in the effect of tillering time on ear formation and yield]. *Japanese Journal of Crop Science*, 85(2), 218–222.
- Araki, H. (2017). 1 ton to reru mugu ha koko ga tiga u bun getu kara miete kita tyouta syuu no suzi miti. [Points for 1,000 kg/10a yield of wheat, super high yield from viewpoint of tillering behaviour]. In Y. Takahashi (Ed.), *Komugi 1 ton dori. [1,000 kg/10a yield of wheat]* (pp. 42–66). Tokyo: Nobunkyo.
- Araki, H., Naito, M., Chiba, K., Mori, M., Imura, N., Uebori, T., & Kishima, M. (2011). *Oho-tuku tiiki ni okeru aki maki komugi □ Kitahonami □ no kei suu kanri gizyutu. [Control of expected stem number at various stages of winter wheat “Kitahonami” in the Okhotsk area]*. Hokunokai: Hokuno. Vol. 78. pp. 402–408. Retrieved from. <https://agriknowledge.affrc.go.jp/RN/2030814793>.
- Cai, T., Xu, H., Peng, D., Yin, Y., Yang, W., Ni, Y., ... Wang, Z. (2014). Exogenous hormonal application improves grain yield of wheat by optimizing tiller productivity. *Field Crops Research*, 155, 172–183.
- Chujo, H., Benitani, H., & Momoto, H. (1989). Nisinhon wase komugi hinsyu ni okeru bun getu no syoutyou. [Appearance and heading of tillers in early wheat cultivars of west Japan]. *Japanese Journal of Crop Science*, 58(4), 611–616.
- Donald, C. M. (1968). The breeding of crop ideotypes. *Euphytica*, 17(3), 385–403.
- Donald, C. M. (1979). A barley breeding programme based on an ideotype. *The Journal of Agricultural Science*, 93(2), 261–269.
- Fukushima, A., Kusuda, O., & Furuhashi, M. (2001). Danti ni okeru haya maki sita akimakisei komugi □ lwainodaiti □ no bun getu no hatuiku. [Tiller development of winter type wheat lwainodaichi sown early in the southwestern part of Japan]. *Japanese Journal of Crop Science*, 70(2), 173–178.
- Goto, K. (1987). Syuukaku sisuu no igi to genkai. [Harvest index, its implications and limitation in plant breeding]. *Advances in Breeding*, 28, 21–28.
- Goto, Y. (2003). Suitou no bun getu sei. [Tillering behavior of rice plants]. *Japanese Journal of Crop Science*, 72(1), 1–10.
- Hashimoto, Y., Takiguchi, S., & Isoda, R. (1956). Ine mugu no mukou bun getsu ni kan suru seirigaku teki kenkyuu: I. komugi no tihatu bun getsu ga yuukou bun getsu no touzyuku ni oyo bosu eikyou: II. komugi no eiyou seityouki ni okeru zyakyusyou kei to kyoudai kei to no sougo kankei. [Physiological studies on ineffective tillers in rice, wheat and barley plants: I. Effect of the small tillers on the ripening of fruitful stems in wheat plants.: II. On the relation between weak and strong tillers at the stage of vegetative growth in wheat plants]. *Japanese Journal of Crop Science*, 24(3), 166.
- Hokkaido Government. (2019). Agriculture in Hokkaido. Retrieved from <http://www.pref.hokkaido.lg.jp/ns/nsi/for/english-top.htm>
- Kasajima, S., & Araki, H. (2017). □ kitahonami □ no hinsyu tokusei wo ikasi ta saibaihou. [Cultivation methods based on the varietal characteristics of ‘Kitahonami’]. Sapporo: Hokkaido Rice & Wheat Improve Association. Vol. 5. pp. 1–8. Retrieved from. <http://www.beibaku.net/wheat/2017/pdf/kitahonami.pdf>.
- Kasajima, S., Fujimura, T., Itoh, H., Jinno, H., Ohnishi, S., & Takahashi, T. (2018). Hokkaidou ni okeru akimakisei komugi sin kyuu-hinsyu no syouka betu ryu zyuu. [Grain weight of each floret in old and new winter wheat varieties in Hokkaido]. *Abstracts of Meeting of the CSSJ*, 246, 108.
- Kasajima, S., Takahashi, T., Imai, K., Shimizu, T., Itoh, H., Nakamaru, Y., ... Yoshimura, Y. (2016). Hokkaidou ni okeru akimakisei komugi sin kyuu-hinsyu Kitahonami to hokusin no seiiku □ syuuryou tokusei no sai. [Differences in growth and grain yield performance between old and new winter wheat varieties ‘Hokushin’ and ‘Kitahonami’ in Hokkaido]. *Japanese Journal of Crop Science*, 85(2), 155–161.
- Katayama, T. (1951). *Ine □ mugu no bun getu kenkyuu. [Studies on the tillering of rice and barley]* (pp. 1–117). Yokendo, Tokyo.
- Li, J., Harada, J., & Yamazaki, K. (1993). Komugi ni okeru bun getu no seiiku ni kan suru kenkyuu: Dai 2 hou syutsu you □ syukkou kankei ni tyakumoku si ta bun getu syutugen no saikentou. [Studies on growth and development of tillers in wheat: II. Reexamination of the emergence of tillers from the developmental relationships of leaves and roots]. *Japanese Journal of Crop Science*, 62(4), 534–539.
- Li, J., & Yamazaki, K. (1994). Komugi ni okeru bun getu no seiiku ni kan suru kenkyuu: Dai 3 hou bun getu no seiiku tokusei to sono yuukou ka. [Studies on growth and development of tillers in wheat: III. Developmental properties of tillers and their survival]. *Japanese Journal of Crop Science*, 63, 460–466.
- Lupton, F. G. H. (1987). History of wheat breeding. In F. G. H. Lupton (Ed.), *Wheat breeding, its scientific basis* (pp. 51–70). London: Chapman and Hall.
- MAFF. (2019). Ministry of Agriculture, Forestry and Fisheries. Retrieved from <http://www.maff.go.jp/j/zyukyu/fbs/index.html>
- Matsuba, K. (1987). Ine no keiyou seiiku no kisokusei ni kan suru hatuiku keitaigaku kenkyuu: Dai 1 hou douitu saibai zyoukenka de sou you suu wo i ni si ta syu kan no seiiku gata ni tui te. [Morphological studies on the regularity of shoots development in rice plants: I. Different growth types indicated by total leaf number on the main stems in the same plot]. *Japanese Journal of Crop Science*, 56(3), 313–321.
- Matsushima, S. (1973). *Inasaku no kaizen to gizyutu. [Improvement and technique of rice cultivation]* (pp. 1–393). Yokendo, Tokyo.
- Matsushima, S., Tanaka, T., & Hoshino, T. (1964). Suitou syuuryou no seiritu genri to sono ouyou ni kan suru sakumotou

- gakuteki kenkyuu: Dai 68 hou ine no sisei to douka nouritu (1). [Analysis of yield-determining process and its application to yield-prediction and culture improvement of lowland rice: LXVIII. On the relation between morphological characteristics and photosynthetic efficiency (1)]. *Japanese Journal of Crop Science*, 33(1), 44–48.
- Mock, J. J., & Pearce, R. B. (1975). An ideotype of maize. *Euphytica*, 24, 613.
- Naruoka, Y., Talbert, L. E., Lanning, S. P., Blake, N. K., Martin, J. M., & Sherman, J. D. (2011). Identification of quantitative trait loci for productive tiller number and its relationship to agronomic traits in spring wheat. *Theoretical and Applied Genetics*, 123, 1043–1053.
- Nishio, Z., Ito, M., Tabiki, T., Nagasawa, K., Yamauchi, H., & Hirota, T. (2013). Influence of higher growing-season temperatures on yield components of winter wheat (*Triticum aestivum* L.). *Crop Science*, 53, 621–628.
- Peng, S., Khush, G. S., Virk, P., Tang, Q., & Zou, Y. (2008). Progress in ideotype breeding to increase rice yield potential. *Field Crops Research*, 108, 32–38.
- Rasmusson, D. C. (1991). A plant breeder's experience with ideotype breeding. *Field Crops Research*, 26, 191–200.
- Sakuma, S., Golan, G., Guo, Z., Ogawa, T., Tagiri, A., Sugimoto, K., ... Ohnishi, S. (2019). Unleashing floret fertility in wheat through the mutation of a homeobox gene. *Proceedings of the National Academy of Sciences*, 116(11), 5182–5187.
- Sasaki, R., Toriyama, K., Shibata, Y., & Sugimoto, M. (2004). Suitou no sanpa zikamaki saibai ni okeru nae dati mitudo to 1 zi saisyuu bun getu no syutugen setui to no kankei ni oyo bosu syoki seikou no eikyuu. [Effect of the suppression of tiller emergence on the relationship between seedling density and nodal position of the last visible primary tiller in direct seeding cultivation of rice]. *Japanese Journal of Crop Science*, 73(3), 309–314.
- Sawaguchi, A., Tomita, K., Furukawa, K., Takeuchi, T., Araki, K., & Nakamichi, K. (2014). *Doutou tiiki ni okeru aki maki komugi □ Kitahonami □ no teki hasyu ryou to ki sei ki sehi hou no zissyuu*. [Actual proof tests of the cultivation methods for winter wheat "Kitahonami" in the East Hokkaido area]. Hokunokai: Hokuno. Vol. 81. pp. 227–230. Retrieved from: <https://agriknowledge.affrc.go.jp/RN/2010873196>.
- Shimoda, S., Hamasaki, T., Hirota, T., Kanno, H., & Nishio, Z. (2016). *Komugi syuuryo wo hendou sa seru kisyou youso ha Tokachi to Ohotoku de koto naru*[Regional difference in climatological characteristics affects to wheat yield in Tokachi and Okhotsk regions]. Hokunokai: Hokuno. Vol. 83. pp. 158–162. Retrieved from: <https://agriknowledge.affrc.go.jp/RN/2010902660>.
- Takahashi, T., Shimauchi, K., Nakagawa, Y., Shibata, K., & Iiyama, T. (2002). Nisinhon danti de saibai si ta hokkaidou ikusei komugi hinsyu haru yutaka no bussitu seisan to gunraku kouzou to no kankei. [Relationship between dry matter production and canopy structure in wheat cultivar "Haruyutaka" bred in Hokkaido when grown in warm area of western Japan]. *Japanese Journal of Crop Science*, 71(4), 481–487.
- Takahashi, T., Shimauchi, K., Nakagawa, Y., Shibata, K., Iiyama, T., Fujimoto, K., ... Zhang, L. (2004). Nisinhon danti de saibai si ta hokkaidou ikusei komugi hinsyu haru yutaka no kai you zyokyo syori to bun getu zyokyo syori ga ryu zyuu ni oyo bosu eikyuu. [Influence of removal of lower leaves and detaching of tillers on kernel weight of Hokkaido-bred wheat cultivar "Haruyutaka" grown in a warm area of western Japan]. *Japanese Journal of Crop Science*, 73(3), 276–281.
- Tanaka, T., Matsushima, S., Kojyo, S., & Nitta, H. (1969). Suitou syuuryo no seiritu genri to sono ouyou ni kan suru sakumotu gakuteki kenkyuu: Dai 90 hou ine gunraku no sisei to hikari - douka kyokusen to no kankei. [Analysis of yield-determining process and its application to yield-prediction and culture improvement of lowland rice: XC. On the relation between the plant type of rice plant community and the light-curve of carbon assimilation]. *Japanese Journal of Crop Science*, 38(2), 287–293.
- Tokunaga, H. (1956). *Komugi ni okeru yuukou kei to tika bu no hatuiku ni kan suru kenkyuu* [Studies on development of productive tiller and underground part in wheat]. Kyushu Sakumotsu Danwakaiho. Vol. 10. pp. 40–45. Retrieved from: <http://dl.ndl.go.jp/info:ndljp/pid/11086132>.
- Tsunoda, S. (1984). Ine no seibutugaku. [Biology of rice]. *Kagaku to Seibutsu*, 22(10), 688–694.
- Xu, H. C., Tie, C. A. I., Wang, Z. L., & He, M. R. (2015). Physiological basis for the differences of productive capacity among tillers in winter wheat. *Journal of Integrative Agriculture*, 14, 1958–1970.
- Yamamoto, Y., Nouno, J., & Nitta, Y. (1994). Suitou no syu kan ni okeru setui betu bun getu no sizitu seisanryoku: Dai 2 hou kotai ata ri no bun getu suu oyobi bun getu no zii betu kousei wo ittei to si ta baai. [Difference in grain productivity of tillers among main stem nodes in rice plant: II. Comparison under the conditions of the same panicle number and constituent of each order tiller per plant]. *Japanese Journal of Crop Science*, 63(4), 601–609.
- Yanagisawa, A., Yoshimura, Y., Amano, Y., Kobayashi, S., Nishimura, T., Nakamichi, K., & Sato, N. (2007a). *Aki maki komugi sinhinsyu □ Kitahonami □ no ikusei*. [A new winter wheat variety "Kitahonami"]. *Bulletin of Hokkaido prefectural agricultural experiment stations*. Vol. 91. 1–13. Kyushu: Crop Science Society of Japan. Retrieved from: <https://agriknowledge.affrc.go.jp/RN/2010752276>.
- Yanagisawa, A., Yoshimura, Y., Kobayashi, S., Nishimura, T., Maeno, S., & Watanabe, Y. (2007b). *Aki maki komugi no ta syu sei ikusyu ni kan suru itikousatu: □ Kitahonami □ wo rei tosite*. [A study on high-yielding winter wheat breeding: A case study on Kitahonami]. *Report of the Hokkaido Branch, the Japanese Society of Breeding and Hokkaido Branch, the Crop Science Society of Japan*, 48, 73–74.
- Yoshida, S. (1981). *Fundamentals of rice crop science* (pp. 1–269). Phillipin: International Rice Resource Institutionais.
- Yoshimura, Y. (2010). *Aki maki komugi sinhinsyu □ Kitahonami □ no saibai no pointo □ hinsyu ni atta hasyu ziki to hasyu ryou wo mamori tekisetu na tisso sehi kanri de ta syu □ kouhinsitu wo □* [Points for cultivation of a new winter wheat variety "Kitahonami" -proper sowing time and rate, and method of nitrogen fertilization-] (Vol. 54, pp. 9–13). Hokkaido Rice & Wheat Improve Association: Hokkaido Beibaku Kairyo. http://www.beibaku.net/report/2010/07_04.pdf
- Yoshimura, Y. (2013). Hokkaidou no komugi hinsyu kaihatu to seisan □ kakou riyoo no henshen [Wheat breeding and improved quality of Japanese noodles in Hokkaido]. *Nippon Shokuhin Kagaku Kogaku Kaishi*, 60(11), 668–672. Retrieved from: https://www.jstage.jst.go.jp/article/nskkk/60/11/60_668/_article-char/en.
- Yoshimura, Y. (2014). Hokkaidou no komugi hinsyu □ saibai no henshen to ta syu gizyutu. [Wheat variety, management and yield improvement in Hokkaido]. *Abstracts of Meeting of the CSSJ*, 237, 458–459.