Analytical studies on high-yielding characteristics of US soybean cv. ‘UA4805’ in comparison with Japanese cv. ‘Akimaro’

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Field experiments were conducted in 2020 and 2021 at the Field Science Center of Okayama Univ. (34°41’ N, 133°55’ E). Two Soybean cultivars ‘UA4805’ and ‘Akimaro’ were sown with two planting densities, 12.5 plants m^{-2} (sparse, 80×10 cm) and 25 plants m^{-2} (dense, 80×5 cm)on May 25 (early), June 29 (normal), and Aug. 3 (late) in 2020, and 80 and 30 cm row-width, and 12.5 and 25 plant m^{-2} in 2021 on June 23. Seed yield was higher in ‘UA4805’ than in ‘Akimaro’ in 2020 and 2021. The later the sowing time, the higher the seeds/stem ratio. Both cultivars showed higher dry matter in dense planting. Dry matter was higher in ‘Akimaro’, while seed yield was lower than ‘UA4805’. In contrast, ‘UA4805’ showed lower dry matter with higher seed yield. The numbers of nodes, pods, and seeds were higher in ‘UA4805’ resulting in the higher seed yield. Lodging score is larger in ‘Akimaro’ especially in dense planting. The seeds/stem ratio is much higher in ‘UA4805’ than ‘Akimaro’ across 2 densities, 3 sowing times and 2 row width. Pods setting ratio was nearly two times higher in ‘UA4805’ compared to ‘Akimaro’. The greater seed yield of ‘UA4805’ compared to ‘Akimaro’ was due to the higher pod setting ratio, seeds/stem ratio, and lower lodging score, nevertheless the dry matter was larger in ‘Akimaro’. If late sowing is applied, higher planting density is recommended for better seed yield. Narrow row is an effective way to improve seed yield in soybean.

Key words : Narrow row, Planting density, Podding rate, Seeds/stem ratio, Seed yield, Sowing time, Soybean.

Introduction

In Japan, soybeans have traditionally been used as a food ingredient and seasoning for tofu, natto (fermented soybeans), miso (fermented soybeans), soy sauce, and nimame (cooked soybeans). Even today, soybeans are highly valued by actual consumers for their high quality, including taste and suitability for processing, and almost all of the soybeans produced in Japan are used for food purposes (MAFF[7], 2022). Compared to the world’s harvested area of 129,524,000 ha, production volume of 371,693,000 tons, and yield of 2.87 tons ha^{-1}, Japan’s harvested area is 146,200 ha, 246,500 tons, and 1.69 tons ha^{-1}, with a 41% lower yield than the world (FAOSTAT[2], 2023). In response to the global demand for soybean oil, the introduction of crop rotation with corn and wheat and no-till sowing of herbicide tolerant cultivars in the U.S., Brazil, and other countries has resulted in a high soybean oil yield of 345 kg/10 a in 2021 in both countries, more than double the Japanese yield. In addition to the aforementioned cultivation methods, the high yield is largely due to the effect of improved genetic yield potential of cultivars, especially in North America (Specht et al.[11], 1999).

Kawasaki et al.[4] (2016) conducted cultivation trials at Takatsuki, Japan and Fayetteville, Arkansas, USA, with five Japanese and 10 US cultivars and found that both Japanese and US experimental plots had 18-57% higher seed yields from the US cultivars compared to the Japanese cultivars. Matsuo et al.[8] (2016) also conducted early and normal sowing cultivation trials of five Japanese and seven US cultivars in Chikugo, Japan and found that the seed yield of the US cultivars was 64% higher than the Japanese cultivars in early sowing cultivation, while it was 3% lower in normal sowing cultivation, indicating that the yield potential of the US cultivars was higher when sown early. Among the US cultivars used in both experiments, ‘UA4805’ showed consistently high seed yield and clearly had higher yield potential than the Japanese cultivars. In addition, the soybean cultivar ‘Akimaro’, which is high-yielding with late-sowing (July

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sowing) and suitable for making light-colored miso, is becoming more widespread in the Chugoku region (Takada et al.[12], 2012).

In this study, Japanese cultivar 'Akimaro' and US cultivar 'UA4805' were cultivated in three cropping seasons (early, normal, and late) and two planting densities (sparse and dense) in 2020, and in 2021, in two planting patterns (wide- and narrow-row) and two planting densities. The purpose of this study was to elucidate the factors that cause the higher seed yield of 'UA4805' by investigating the differences in seed yield of the two cultivars.

Materials and Methods

1. Cultivation method and experimental plots

The US soybean cultivar 'UA4805' and the Japanese cultivar 'Akimaro' were tested in field plots (granitic sandy loam) at the Field Science Center, Faculty of Agriculture, Okayama University, in 2020 and 2021. In 2020, there were three sowing levels : early sowing on May 25, normal sowing on June 29, and late sowing on August 3, and two planting densities : sparse planting (80 cm between rows, 10 cm between plants, 12.5 plants m^{-2}) and dense planting (80 cm between rows, 5 cm between plants, 25 plants m^{-2}). In 2021, two row-widths : a wide-row plot with 80 cm between rows and a narrow-row plot with 30 cm between rows, and two levels of planting density : a sparse planting (80 cm between rows, 10 cm between plants, 30 cm between rows, 26 cm between plants, 12.5 plants m^{-2}) and a dense planting (80 cm between rows, 5 cm between plants, 30 cm between rows, 26 cm between plants, 25 plants m^{-2}). In 2020, each plot was 24 m^2 (6 × 4 m), and in 2021, each plot was 96 m^2 (12 × 8 m) with no replications.

Soybean chemical fertilizer No. 550 ($N : P_2O_5 : K_2O$ = 5 : 15 : 20) was applied as a basal fertilizer at a rate of 60 kg per 10 a. The fertilizer was mixed into all layers of the soil using a tractor rotary. Two seeds were sown per point on the sowing date, and the seedlings were thinned out after the primary leaf fully expanded to make one plant per point. After seeding, soil treatments (Alachlor emulsifiable concentrate and Linuron wettable powder) were applied for weed control. Spray-type plastic tubes were installed between the rows and irrigated as necessary. For insect control, Affirm emulsifiable concentrate was sprayed twice for control of the common cutworm.

2. Growth Characteristics Survey

The number of nodes, main stem length, stem diameter, stem weight, and grain-stem ratio were investigated for each individual used in the yield survey according to the soybean research standards of the Ministry of Agriculture, Forestry and Fisheries (National Institute of Agricultural Science, Ministry of Agriculture, Forestry and Fisheries, Soybean Research Standards Review Committee, 1974). At the harvesting time, the angle of the lodged plants to the vertical plane was measured at four levels (0, 1, 2, and 3) in 30° increments from no lodging (0°) to complete lodging (90°), and the average degree of lodging for all individuals was calculated.

3. Number of flowers and pods setting ratio

To analyze the reason why the number of pods of 'UA4805' was about twice that of 'Akimaro' in 2020, we recorded the number of flowers for each node of main stem and branches every 2 days after the beginning of flowering, and the number of pods at harvest time for three average plants of 'Akimaro' and 'UA4805' grown in 2021 in the wide and sparsely planted plots, respectively. The number of pods on each node at harvest time was also examined. The podding rate was calculated as number of capsules/number of flowers (%).

4. Dry matter production

To investigate the dry matter weight and leaf area of above-ground parts of the plants, five individuals were selected from each of three locations in each plot at approximately three-week intervals from the first leaf unfolding stage to the maturity stage, and three average individuals were selected. The dry matter weights were measured.

Results

1. Meteorological summary

In 2020, the rainy season ended late, with heavy precipitation in July and low temperatures; there was no rainfall in August, and temperatures were about 2℃ higher from mid-August to early September (Fig. 1, Japan Meteorological Agency[3], 2023). There was no rainfall in late September and early October, and temperatures were 2 to 3℃ higher than normal.

2. Growth characteristics

The total number of nodes per m^2 in 2020 was not significantly different among the cultivars, and the number of nodes per m^2 was higher in the order of early > normal > late for both cultivars, and was higher in the dense planting than in the sparse planting, and the extent of the difference was more pronounced in the number of main stem nodes (Table 1). The number of branches per m^2 was slightly lower in 'Akimaro' than in 'UA4805'. Main stem length was 2 to 28 cm shorter in

'UA4805' than in 'Akimaro' and tended to be longer in the order of early> normal > late sowing, and also in dense planting, but the differences were not significant. Similar to stem weight, stem diameter and stem cross-sectional area were slightly thinner in 'UA4805' than in 'Akimaro', in the order of early > normal > late sowing, and slightly thinner in the dense planting. The seeds/stem ratio was 0.3 to 1.5 higher in 'UA4805' than in 'Akimaro' in the order of late > normal > early-sowing, and slightly higher in sparse planting than in dense planting, but this tendency differed depending on the sowing time. Dry matter production of 'Akimaro' was significantly higher than that of 'UA4805' in the order of early > normal > late, and in the sparse planting compared to the dense planting. The highest values were observed in the early and dense plantings of 'Akimaro'.

In 2021, the total number of nodes per m^2 and the number of branching nodes per m^2 were higher in 'UA4805'than in 'Akimaro', and in the order of narrow-row > wide-row, the dense-planting > sparse-planting ; the number of branches per m^2 was slightly lower in 'Akimaro' than in 'UA4805', there were no significant

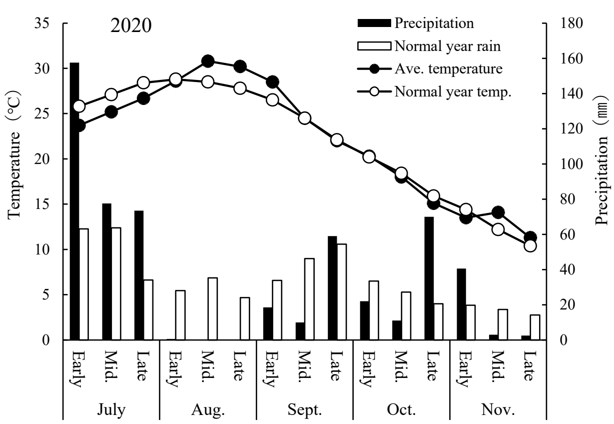

Fig. 1 Seasonal changes in daily mean air temperature and precipitation in 2020.

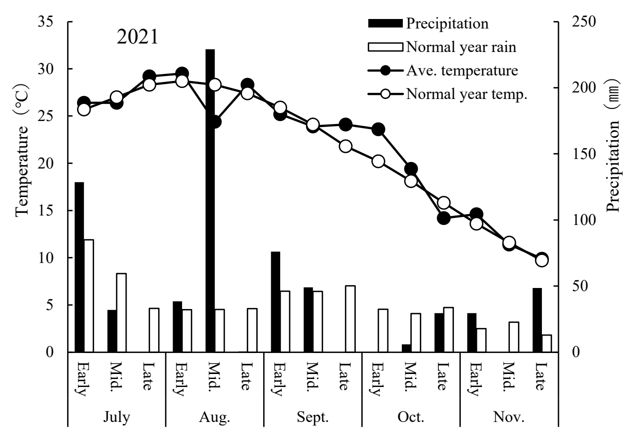

Fig. 2 Seasonal changes in daily mean air temperature and precipitation in 2021.

Table 1 Effect of sowing time and planting density on agronomic characters in 2020

Cultivar	Sowing time	Density	Number of nodes on main stem (plant^{-1})	Number of nodes per (m^{-2}): Main stem	Branch	Raceme with com pound leaves	Total	Number of branches (m^{-2})	Stem length (cm)	Stem weight (g m^{-2})	Stem diameter: Major (mm)	Minor (mm)	Stem section area (mm^2)	Stem diameter ratio	Seed/ stem ratio	Dry weight (g m^{-2})
Akimaro	Early	Sparse	18.9 a	236 c	580 ab	183 a	999 b	76 bc	116 a	470.4 b	10.4 a	8.6 a	70.9 a	1.21 b	0.80 d	1,073 a
		Dense	15.1 b	378 a	639 a	208 a	1,225 a	103 a	103 ab	543.1 a	9.0 b	7.0 c	50.0 b	1.32 a	0.83 d	1,127 a
	Normal	Sparse	15.6 b	195 d	416 c	215 a	826 c	70 c	90 c	253.0 c	8.7 b	7.9 b	54.4 b	1.10 c	1.34 c	752 b
		Dense	14.2 bc	356 a	484 bc	184 a	1,024 b	110 a	95 bc	292.2 c	7.1 d	5.9 d	32.8 c	1.22 b	1.12 c	784 b
	Late	Sparse	13.3 c	167 d	290 d	43 b	500 d	65 c	76 c	141.1 d	7.9 c	6.0 d	37.5 c	1.34 a	2.02 b	558 c
		Dense	12.7 c	317 b	233 d	53 b	603 d	84 b	74 c	153.5 d	6.3 e	4.5 e	22.6 e	1.39 a	2.35 a	680 bc
UA 4805	Early	Sparse	18.3 a	229 c	462 ab	121 c	813 c	69 c	103 a	320.4 ab	10.2 a	8.2 a	66.5 a	1.23 bc	1.21 d	885 b
		Dense	17.0 b	424 a	515 a	238 a	1,177 a	109 a	96 a	464.9 a	8.9 b	7.0 b	49.2 b	1.29 b	1.13 d	992 a
	Normal	Sparse	14.6 c	183 d	450 b	104 c	737 cd	81 bc	62 c	154.6 c	8.5 b	7.0 b	46.3 b	1.22 c	2.88 b	764 c
		Dense	13.8 cd	346 b	518 a	181 b	1,044 b	114 a	71 bc	174.5 bc	6.3 d	5.3 cd	26.5 d	1.19 c	2.07 c	706 cd
	Late	Sparse	13.7 d	172 d	395 b	20 d	587 e	78 c	60 c	108.7 c	7.7 c	5.7 c	34.4 c	1.36 a	3.28 a	603 e
		Dense	13.3 d	332 b	304 c	11 d	647 de	91 b	72 b	143.4 c	6.3 d	4.8 d	23.9 d	1.30 ab	2.82 b	677 de
ANOVA	Cultivar		ns	ns	ns	**	ns	**	**	**	**	**	**	ns	**	**
	Sowing time		**	**	**	**	**	**	**	**	**	**	**	**	**	**
	Density		**	**	ns	**	**	**	ns	**	**	**	**	**	**	**
	Cult × Sow		**	**	**	*	**	ns	**	*	ns	**	*	*	**	**
	Cult × Density		**	ns	**	**	**	**	**	ns	*	**	**	**	**	**
	Sow × Density		**	**	ns	**	ns	ns	ns	ns	ns	**	ns	**	**	ns
	Cult × Sow × Density		*	*	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	**	ns

Values are means of 30 plants. Between the same cultivar, means followed by the same letter in each year, are not significantly different at *P < 0.05* by Tukey's test. ** and * indicate significant at *P < 0.01* and *0.05*, respectively. ns : nonsignificant.

Table 2　Effect of row width and planting density on agronomic characters in 2021

Cultivar	Row width	Density	Number of nodes on main stem (plant^{-1})	Number of nodes per (m^{-2}): Main stem	Branch	Raceme with compound leaves	Total	Number of branches (m^{-2})	Stem length (cm)	Stem weight (g m^{-2})	Stem diameter: Major (mm)	Minor (mm)	Stem section area (mm^2)	Stem diameter ratio	Seed/stem ratio	Dry weight (g m^{-2})
Akimaro	Wide	Sparse	17.7 a	221 c	421 b	16 ab	660 c	68 b	117 bc	383 c	9.4 a	6.6 b	49.2 b	1.44 b	0.69 b	796 c
		Dense	16.6 a	416 b	398 b	8 b	825 b	72 b	126 a	439 b	7.7 c	5.0 d	30.5 d	1.56 a	0.62 bc	873 b
	Narrow	Sparse	17.2 a	215 c	449 b	28 a	695 c	74 b	113 c	372 c	9.7 a	7.4 a	56.7 a	1.32 c	0.88 a	879 b
		Dense	17.6 a	440 a	617 a	33 a	1,083 a	100 a	124 ab	590 a	8.8 b	6.0 c	41.3 c	1.48 ab	0.52 c	1,117 a
UA4805	Wide	Sparse	16.5 bc	206 c	473 b	27 b	705 c	97 b	85 b	218 c	9.4 b	7.3 b	54.0 b	1.30 a	1.35 b	645 b
		Dense	16.1 c	403 b	570 ab	32 ab	1,005 ab	165 a	93 a	270 b	7.5 d	5.8 c	35.0 d	1.30 a	1.26 b	756 b
	Narrow	Sparse	17.4 a	218 c	656 a	53 a	927 b	74 b	81 b	274 b	10.5 a	8.8 a	73.3 a	1.20 b	1.64 a	908 a
		Dense	16.9 ab	422 a	599 ab	46 ab	1,067 a	105 ab	93 a	340 a	8.2 c	6.7 b	43.3 c	1.24 b	1.21 b	919 a
ANOVA	Cultivar		**	**	**	**	**	**	**	**	ns	**	**	**	**	**
	Row width		**	**	**	**	**	ns	ns	**	**	**	**	**	ns	**
	Density		*	**	*	ns	**	**	**	**	**	**	**	**	**	**
	Cult × Row		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	Cult × Density		ns	ns	ns	ns	ns	ns	ns	**	**	ns	**	**	ns	**
	Row × Density		ns	**	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	**	ns
	Cult × Row × Density		*	ns	**	ns	**	*	ns	**	*	ns	**	ns	ns	**

Values are means of 30 plants. Between the same cultivar, means followed by the same letter in each year, are not significantly different at $P < 0.05$ by Tukey's test. ** and * indicate significant at $P < 0.01$ and 0.05, respectively. ns : nonsignificant.

differences between the narrow-row and wide-row, and the dense-planting was higher than the sparse-planting (Table 2). Stem weight per m^2 was 98 to 250 g lighter in 'UA4805' than in 'Akimaro' and was greater in narrow-row and dense planting. Stem diameter and stem cross-sectional area differed from those in 2020, 'UA4805' being slightly thicker than 'Akimaro', and slightly thicker in the narrow-row and sparse planting. The seeds/stem ratio was higher in 'UA4805' than in 'Akimaro' as in 2020, and there was no significant difference between the narrow-row and wide-row, and the sparse planting was higher than the dense planting. Dry matter production was higher in 'Akimaro' than in UA4805, in the order of narrow-row to wide-row, and in the order of dense planting to sparse planting.

3. Seed yield and yield components

Seed yield per m^2 in 2020 was higher in 'UA4805' than in 'Akimaro', in the order of early > normal > late sowing for 'Akimaro', and in the order of normal > early > late sowing for 'UA4805', and tended to be higher in dense planting than in sparse planting, but there was no significant difference (Table 3, Fig. 3). The number of pods per m^2 was about 1.5 times higher in 'UA4805' than in 'Akimaro', and the number of pods per m^2 for both cultivars was higher in the order of normal > early > late sowing, and significantly higher in the dense planting than in the sparse planting. The number of seeds per pod was higher in the 'UA4805' average (2.13) than in the 'Akimaro' average (1.89), but there was no significant difference in sowing time or planting density. 100-seeds weight was about twice as large, 31.5 g in the 'Akimaro' average and 15.9 g in the UA4805 average, and tended to be larger in the order of early > normal > late-sowing, with no significant differences due to planting density. Seed setting ratio was not significantly different between cultivars, but tended to be lower in the normal sowing for 'Akimaro' and in the early sowing for 'UA4805' but not significantly different by planting density. The lodging scores of 'Akimaro' were 1.3 to 2.3 in the early and normal sowing and almost no lodging in the late sowing; in 'UA4805', some lodging occurred in the early sowing, around 0.1 to 0.2, but no lodging was observed in the normal and late sowings, indicating that 'UA4805' was highly resistant to lodging.

In 2021, as in 2020, the seed yield was higher in 'UA4805' than in 'Akimaro', and also in narrow-row compared to wide-row, but there was no significant difference between sparse planting and dense planting (Table 4, Fig. 4). The number of pods per m^2 was also more than twice as high in 'UA4805' as in 'Akimaro' and was higher in the narrow-row than in the wide-row, dense planting > sparse planting, in that order. In 2020, the number of seeds per pod differed between cultivars, but in 2021, no significant difference was observed, and all the cultivars showed a value of around 1.8. 100-seeds weight was smaller in 'UA4805' as in 2020, but there were no significant differences among the row widths or planting densities. In 2021, there was a lot of rainfall in mid-Au-

Table 3 Efect of sowing time and planting density on yield and yield components in 2020

Cultivar	Sowing time	Density	Seed yield (g.m^{-2})	Pod number (m^{-2})	Seed number per pod	100 Seeds weight (g)	Seed setting ratio (%)	Lodging score
Akimaro	Early	Sparse	431 a	955 b	1.95 a	30.7 b	90.4 a	1.6
		Dense	458 a	971 a	1.92 a	31.3 ab	90.1 a	2.3
	Normal	Sparse	350 b	1,026 a	1.89 a	29.1 b	81.4 b	1.3
		Dense	329 b	1,108 a	1.82 a	30.4 b	76.7 b	2.3
	Late	Sparse	304 b	592 c	1.86 a	33.9 a	93.8 a	0.0
		Dense	379 ab	792 b	1.86 a	33.7 a	89.5 a	0.1
UA 4805	Early	Sparse	404 b	1,724 b	2.02 c	16.0 bc	83.7 b	0.1
		Dense	438 ab	2,142 a	2.04 c	14.1 c	86.6 b	0.2
	Normal	Sparse	475 a	1,650 b	2.23 a	14.8 c	91.0 a	0.0
		Dense	377 b	1,608 bc	2.20 ab	15.7 c	91.0 a	0.0
	Late	Sparse	381 b	1,163 d	2.22 a	17.8 a	90.5 a	0.0
		Dense	423 b	1,255 cd	2.10 bc	17.4 ab	89.2 ab	0.0
ANOVA	Cultivar		**	**	**	**	ns	
	Sowing time		**	**	ns	**	**	
	Density		ns	**	ns	ns	ns	
	Cult × Sow		**	**	**	ns	**	
	Cult × Density		**	*	ns	ns	ns	
	Sow × Density		ns	ns	ns	ns	*	
	Cult × Sow × Density		ns	**	ns	ns	ns	

Values are means of 30 plants. Between the same cultivar, means followed by the same letter in each year, are not significantly different at $P < 0.05$ by Tukey's test.
** and * indicate significance at $P < 0.01$, and $P < 0.05$, respectively. ns : nonsignificant.
Lodging score was measured from 0 (stand upright) to 4 (fully lodged).

gust and mid-September, which caused significant lodging, especially in 'Akimaro'. The lodging score was 3.0 in the wide-row and 2.2 in the narrow-row for 'Akimaro', but 2.25 in the wide-row and no lodging in the narrow-row for 'UA4805'.

Discussion

This study investigated the variation in seed yield by using the Japanese cultivar 'Akimaro' and the US cultivar 'UA4805' and cultivating them in three cropping seasons and two planting densities in 2020, and in two planting patterns, one with a wide row and the other with a narrow row, and two planting densities in 2021.

'UA4805' produced higher yields than 'Akimaro' in all experimental plots in the two years, except for the early sowing plot, where the highest seed yield of 'UA4805' was 475 g m^{-2} in the normal sowing and sparse planting plot, and 'Akimaro' also produced high seed yields, 456 g m^{-2} in the early sowing and dense planting plot (Table 3, Fig. 3). Yields of both cultivars in the late sowing and dense planting were comparable to those in the normal sowing, indicating that both cultivars are highly tolerant to late sowing. In 2021, the yields were lower than in

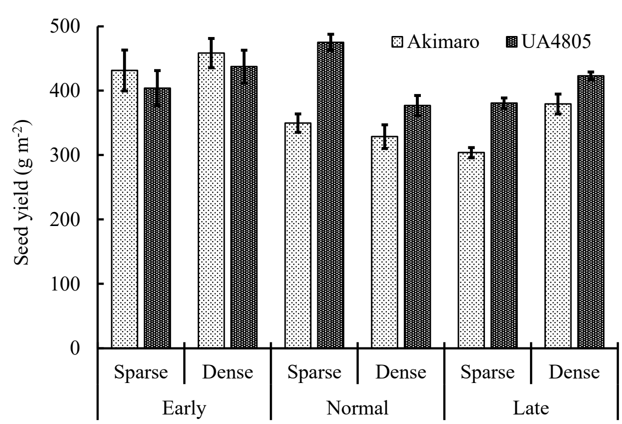

Fig. 3 Comparison of seed yield with different sowing time and planting density in 2020.

2020, but the yields of both cultivars were significantly higher in the narrow-row than in the wide-row, especially in the dense planting (Table 4, Fig. 4). In other words, both cultivars showed higher yields in the early sowing and narrow-row, but the occurrence of lodging was observed (Table 4), suggesting that to avoid the risk of lodging, late sowing and narrow-row, dense planting would provide relatively stable yields with no

Table 4 Effect of sowing time and planting density on yield and yield components in 2020

Cultivar	Row width	Density	Seed yield (g.m^{-2})	Pod number (m^{-2})	Seed number per pod	100 Seeds weight (g)	Seed setting ratio (%)	Lodging score
Akimaro	Wide	Sparse	262 b	724 c	1.81 ab	33.6 a	88.8 a	3.0
		Dense	272 b	832 bc	1.80 b	31.6 bc	85.0 b	3.0
	Narrow	Sparse	339 a	941 ab	1.76 b	32.3 ab	81.6 b	2.2
		Dense	307 ab	1,056 a	1.87 a	29.9 c	85.3 ab	2.3
UA4805	Wide	Sparse	296 c	1,483 c	1.83 a	16.6 a	78.6 b	0.2
		Dense	334 bc	1,673 bc	1.81 a	17.3 a	69.0 c	0.3
	Narrow	Sparse	386 ab	1,963 ab	1.79 a	13.9 b	84.5 a	0.0
		Dense	415 a	2,001 a	1.75 a	17.1 a	87.9 a	0.0
ANOVA	Cultivar		**	**	ns	**	**	
	Row width		**	**	ns	*	**	
	Density		ns	*	ns	**	ns	
	Cult × Row		**	*	ns	**	**	
	Cult × Density		ns	ns	*	**	ns	
	Row × Density		**	ns	ns	ns	**	
	Cult × Row × Density		ns	ns	ns	**	ns	

Values are means of 30 plants. Between the same cultivar, means followed by the same letter in each year, are not significantly different at $P < 0.05$ by Tukey's test.
** and * indicate significance at $P < 0.01$, and $P < 0.05$, respectively. ns : nonsignificant.
Lodging score was measured from 0 (stand upright) to 4 (fully lodged).

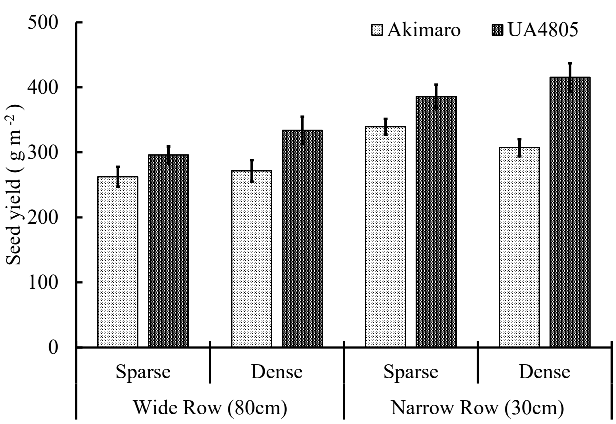

Fig. 4 Comparison of seed yield with different row width and planting density in 2021.

occurrence of lodging.

Kawasaki et al.[5] (2018a) conducted a late-sowing and dense planting of 'Akimaro' in Fukuyama, Japan and achieved a high seed yield of 678 g m^{-2} by using bird netting to prevent lodging, and found that 'Akimaro' has superior late-sowing suitability, higher harvest index and higher seeds production efficiency compared to the normal-sowing. In this study, it was also observed that the seed/stem ratio was higher in the order of late-sowing > normal-sowing > early-sowing (Table 1), indicating higher seeds production efficiency. High yields were also observed in the early dense planting, however, lodging was observed, and it may be important to consider lodging when selecting sowing dates future.

'UA4805' had about twice as many pods compared to 'Akimaro' and the number of seeds per pod was 0.1 to 0.25 higher in 2020, and the 100-seeds weight was about one half of that of 'Akimaro', but the significantly larger number of seeds per m^2 was a factor in its higher yield. The factors contributing to the significantly higher number of pods in 'UA4805' were analyzed from the number of floral buds and the pods setting ratio. Compared to 'Akimaro', 'UA4805' had a higher number of floral buds and a higher pods setting ratio of 54%, which resulted in a higher number of pods (Table 5). The authors conducted a three-year cultivation at three planting densities and found a positive correlation between the number of pods and the number of floral buds, and no significant relationship between the number of pods and the pods setting ratio (Saitoh et al.[10] 1998). A negative correlation, although not significant, was also observed between the number of flower buds and the pods setting ratio, suggesting that an increase in the number of flower buds decreases the pods setting ratio (Saitoh et al.[10] 1998). The characteristics of 'UA4805', which has a high pods setting ratio and a large number of pods in spite of a high number of floral buds, were considered to contribute significantly to the increase in seed yield.

Usually, to achieve high yields, it is necessary to increase

Table 5 Comparison of floral buds number, pods number and pods setting ratio of 'Akimaro' and 'UA4805' in 2021

Cultivar	Number of floral buds (plant^{-1})			Number of pods (plant^{-1})			Pods setting ratio (%)		
	Main stem	Branches	Whole plant	Main stem	Branches	Whole plant	Main stem	Branches	Whole plant
Akimaro	135 a	279 a	414 a	44 a	96 b	140 b	32.8 b	34.4 b	33.9 b
UA 4805	135 a	326 a	461 a	77 a	172 a	249 a	57.1 a	52.7 a	54.0 a

In a column, means followed by the same letter are not significantly different at $P < 0.05$ by Tukey's test.

Table 6 Correlation coefficients between seed yield and yield components

Cultivar	Pod number (m^{-2})	Seed number per pod	100 Seeds weight (g)	Seed setting ratio (%)	Lodging score
Akimaro	0.346	0.728*	−0.236	0.224	−0.266
UA4805	−0.031	0.792**	−0.402	0.705*	−0.444

** and * indicate significance at $P < 0.01$ and $P < 0.05$, respectively.

dry matter production and translocate more of the accumulated dry matter to the sink organ to increase the harvest index (Donald and Hamblin[1] 1976). When final dry matter weights were compared, 'UA4805' was consistently lower than 'Akimaro' (Tables 1 and 2). We conclude that the high yield of 'UA4805' is not due to higher dry matter production but to a higher seeds/stem ratio, meaning that 'UA4805' had shorter stem length, lower stem weight, and accumulated assimilates in a larger sink capacity (number of seeds). Kawasaki et al.[4,6] (2016, 2018b) conducted a cultivation trial with five to eight Japanese and US cultivars, and found that the US cultivars had approximately 18% higher seed yield, 9% greater dry matter weight at harvest, and 9% higher harvest index compared to the Japanese cultivars. In both trials, 'UA4805' was included as a test cultivar, and its seed yield was 18% higher, dry matter weight at harvest was 22% higher, and harvest index was almost the same as that of the Japanese cultivar. Therefore, the dry matter production capacity of 'UA4805' is estimated to be higher than that of the Japanese cultivar. Kawasaki et al.[5] (2018a) found that 'Akimaro' had higher seed yield and dry matter production capacity in late sowing and dense planting, but larger stem dry matter weight and lower harvest index. In this study, the dry matter production capacity of 'Akimaro' was higher than that of 'UA4805', which may explain the relatively lower final dry matter weight of 'UA4805'.

Next, we will discuss the high-yielding characteristics of 'UA4805'. The correlation between seed yield and yield components showed a significant positive correlation coefficient with the number of seeds per pod for 'Akimaro', and with the number of seeds per pod and seed setting ratio for 'UA4805' (Table 6), suggesting that variation in the number of seeds per pod affected the number of seeds per m^2. Kawasaki et al. (2018) also found a negative correlation between the number of pods per m^2 and the number of seeds per pod, which suggested that late sowing increased seeds setting ratio and increased the number of seeds per pod, resulting in higher seed yield than with normal sowing.

The results of this study showed that the seed yield of 'UA4805' was higher than that of 'Akimaro', which was due to higher pods setting ratio, seeds/stem ratio, and lower degree of lodging, but the dry matter production of 'Akimaro' was higher. In late sowing, a higher planting density is recommended to improve seed yield. Narrow rows were found to be effective in improving soybean seed yield.

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アメリカ産ダイズ品種‘UA4805’の多収性に関する解析的研究 −日本品種‘あきまろ’との比較−

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2020年と2021年に岡山大学農学部附属山陽圏フィールド科学センター(34°41'N, 133°55'E)でダイズの栽培試験を行った．アメリカ品種‘UA4805’と日本品種‘あきまろ’の２品種を供試し，栽植密度を12.5株 m^{-2}（疎植，80 × 10 cm）と25株 m^{-2}（密植，80 × 5 cm）の２段階として，2020年５月25日（早期），６月29日（普通期），８月３日(晩期）に播種した．2021年は畦幅80 cm（広畦）と30 cm（狭畦），栽植密度12.5株 m^{-2}と25株 m^{-2}の２段階で栽培した．子実収量は，2020年と2021年ともに‘あきまろ’よりも‘UA4805’の方が高かった．播種時期が遅いほど，粒/茎比が高くなった．両品種ともに疎植区に比べ密植区で乾物重が大きくなった．‘あきまろ’は‘UA4805’よりも乾物重は大きかったが，子実収量は低かった．一方，‘UA4805’は乾物重が小さかったが，節数，莢数，子実数が多く，子実収量が高かった．‘あきまろ’は特に密植区において，倒伏程度が大きかった．粒/茎比は，いずれの試験区においても‘あきまろ’に比べ‘UA4805’が著しく高かった．結莢率は‘UA4805’が‘あきまろ’より２倍近く高かった．‘UA4805’の子実収量が‘あきまろ’に比べて高かったのは，結莢率，粒/茎比が高く，倒伏程度が小さかったことによるが，乾物生産は‘あきまろ’の方が大きかった．晩期栽培の場合，子実収量を向上させるためには栽植密度を高くすることが推奨された．ダイズの子実収量を向上させるには，狭畦栽培が効果的であった．

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