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EFFECT OF DIFFERENT SOWING TIMES, PLANT DENSITIES, AND FERTILISER DOSES ON YIELD AND CROP ELEMENTS OF DRY BEAN VARIETIES (*Phaseolus vulgaris* L.)

Andrea Györgyiné Kovács[1] ✉, Gabriella Tóth[1], Tamás Sipos[1], Judit Csabai[2], Katalin Irinyiné Oláh[2], Edit Kosztyuné Krajnyák[2], Béla Szabó[2], István Henzsel[1]

[1] University of Debrecen, IAREF, Research Institute of Nyíregyháza, H-4400 Nyíregyháza, Westsik Vilmos 4–6, Hungary

[2] University of Nyíregyháza, Institute of Engineering and Agricultural Sciences, Department of Agricultural Sciences and Environmental Management, H-4400 Nyíregyháza, Sóstói 31/b, Hungary

ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is the most widely consumed grain legume in Europe, yet dry bean production in Hungary remains below domestic demand. This study aimed to identify optimal cultivation strategies for improving yield by evaluating the combined effects of sowing time, plant density, and fertiliser dose across three dry bean varieties under field conditions in Nyíregyháza (Hungary) from 2015 to 2017. The results revealed that all three agronomic factors significantly influenced yield and its components, with varietal differences in response patterns. Sowing time and plant density consistently affected pod number, thou-sand-seed weight, and yield per plant. Fertiliser application had a more variable impact, de-pending on the variety and year. The findings underline the importance of variety-specific recommendations to optimise yield under varying environmental and soil conditions.

Keywords: agronomic factors, cultivation strategies, grain legume, yield elements, fertiliser

INTRODUCTION

Beans (*Phaseolus vulgaris* L.) are important for their nutritional value and their ability to enhance soil fertility through nitrogen fixation [McKenzie et al. 2001, Kádár 2005]. In Hungary, domestic production remains insufficient to meet the increasing demand from consumers and the food industry. However, successful dry bean cultivation is highly sensitive to environmen-tal conditions, especially temperature and rainfall, which can negatively influence flowering and pod development [Ovacikli and Tolay 2020].

Although beans can fix atmospheric nitrogen through symbiosis with Rhizobium bacteria [Kádár 2005], this process only becomes effective at later growth stages. Therefore, supplying starter nitrogen is generally recommended to support early development [McKenzie et al. 2001]. Fertilisation with nitrogen, phosphorus, and potassium significantly increases yield and its key components, such as pod number, seeds per pod, thousand-seed weight, and total yield [Begum et al. 2003, Balláné Kovács 2011, Fageria et al. 2013, Faria and Fageria 2014, Mbeke et al. 2014, Turuko and Mohammed 2014, Fageria and Baligar 2016, Seif et al. 2016, Soratto et al. 2017]. Teferi et al. [2022] showed that increasing the N fertiliser dose improved pod number and yield per plant; however, doses exceeding the optimal level had adverse effects. The effects of fertilisation can differ significantly based on the genotype and the

✉ gyorgyine@agr.unideb.hu

current cli-matic conditions [Fageria et al. 2001, Kádár 2013, Karavidas et al. 2022].

Plant density is a key factor influencing bean development. Lower plant densities promote branching and pod formation [Jan et al. 2002, Samago et al. 2018, Bakure et al. 2023]. In contrast, excessively high densities can reduce the yield per plant as competition for light, nutrients, and water increases [Shiv Kumar and Mishra 2002, Tuarira and Moses 2014, Ahmed et al. 2016]. The optimal plant density is not universal and often depends on varietal traits [Shirtliffe and Johnston 2002, Pawar et al. 2007, Mekonnen et al. 2012, Soratto et al. 2017]. Moniruzzaman et al. [2009] and Mehmet [2008] examined the effects of plant density and N fertiliser combination. The highest yield per plant, the most pods per plant, and the most considerable thousandseed weight were observed in the treatment with the lowest plant density and the highest nitrogen application. The highest yield per hectare was achieved at the highest plant density, combined with the most intensive N treatment. The smallest yield per hectare was observed in the treatment with the highest plant density, combined with no N treatment.

Sowing time is equally important. Early sowing can enhance germination and promote stronger initial growth due to increased soil moisture availability [Hadnagy 1981, Sreelatha et al. 1997, Prasad et al. 2002, McCormack 2004]. In contrast, late sowing often exposes plants to drought stress during critical growth phases. The later sowing date decreases the number of pods per plant, seed yield per plant, and yield per hectare [Bayrak et al. 2022]. Several studies have demonstrated the significant impact of sowing time and variety on pod number, seed number, seed yield per plant, seed number per pod, and thousand-seed weight. Postponing the sowing date decreases the crop components' yield and value [Jan et al. 2002, Mirzaienasab and Mojaddam 2014, Uddin et al. 2017].

While the effects of sowing time, plant density, and fertilisation have been studied, there remains limited information on how these factors interact under specific environmental and soil conditions, especially in Hungary.

This study evaluated the effects of sowing time, plant density, and fertiliser dosage on the yield and components in three dry bean varieties cultivated under field conditions in Eastern Hungary.

MATERIAL AND METHODS

The study was based on a 3-year series of experiments that we set up in Nyíregyháza (Hungary, GPS coordinates: 47.974961, 21.691528, located at approximately 100 meters above sea level) in 2015–2017. It involved three sowing dates, plant densities, fertiliser doses, and dry bean varieties, replicated four times in a randomised arrangement without irrigation. Each plot measured 10 m², and the sampling area within the plots was 0.25 m². In 2015, the experiment was conducted on a site with naturally lower humus content (0.84%), whereas in 2016–2017, it was relocated to a different area with more favourable soil conditions and a higher humus content (2.00%). In 2015 and 2016, the experiment was conducted on slightly acidic soils with (pH_{KCl}) values of 6.00 and 5.58, respectively, while in 2017, the trial was set up on neu-tral soil with a (pH_{KCl}) of 7.12. The soil type was classified as sand in 2015 and sandy loam in the following two years. Potassium supply was outstanding in 2015 and 2017 (AL-soluble K_2O: 247 and 328 mg kg^{-1}) and good in 2016 (211 mg kg^{-1}). Phosphorus availability was medium in 2015 (AL-soluble P_2O_5: 96 mg kg^{-1}) and good in 2016 and 2017, reaching 123 and 142 mg kg^{-1}, respectively. Nitrogen supply was rated as medium in 2015 (KCl-soluble NO_3^- + NO_2^-–N: 10 mg kg^{-1}) and good in the subsequent two years, with concentrations of 52 and 36 mg kg^{-1}, respectively. According to the WRB, the soil type is Arenosol and Aric [IUSS 2022].

The preceding crops were triticale (*Triticosecale* Wittm.) in 2014, buckwheat (*Fagopyrum esculentum* L.) in 2015, and oats (*Avena sativa* L.) in 2016. Fertiliser was applied before sowing, and soil was prepared using a combinator.

The sowing times: the most common in Hungary (between May 7–10), an earlier when the soil temperature increased permanently above 12 °C, and a later which was sowed until May 20 in all three years. In our experiment, the sowing dates were as follows: in 2015, April 24, May 8, and May 19; in 2016, April 25, May 9, and May 19; and 2017, May 3, May 11, and May 23. Typically, there was a 14-day interval between the early and standard sowing dates, except in 2017, which had a shorter 8-day difference. The interval between the standard and late sowing dates usually ranged from 10 to 12 days. Sowing was conducted with a row spacing of 0.5 m and a depth of 3 to 5 cm.

The plant densities were set at 200,000, 300,000, and 400,000 per hectare. The fertiliser doses were as follows: control (0%), 100%, and 150%. The 100% dose is based on the recommendations of Antal [1983] and Velich [1994], which are 95 kg of N, 40 kg of P, and 80 kg of K for a yield of 1 ton per hectare.

Our research incorporated three distinct dry bean varieties. The Hópehely variety is characterised by its bushlike growth and large white seeds, making it suitable for salad production in regions with higher humidity and cooler climates. The Diana variety presents pintotype variegated beans and exhibits semideterminate growth. As for the Start variety, it features small white pearl seeds and follows a bushlike growth pattern.

The weather was hot and dry in 2015, especially during flowering. In the 2015 growing season, 120 mm of rain fell. The average maximum temperatures at flowering for all three varieties averaged 31°C in the third sowing season, compared to 26.5 °C in the first two seasons. It was unfavourable for fertilisation and the development of pods and seeds. In 2016–2017, the temperature and rainfall were more favourable for beans' development and crop for-mation. In 2016, 254 mm of precipitation fell during the growing season; in 2017, the amount was 239 mm. The average temperature at flowering in 2016 was 28 °C, whereas in 2017, the average maximum temperature was lower at 26 °C. During the first two sowing seasons, the average maximum temperature at flowering was 29.7 °C in 2016 and 27.6 °C in 2017, which was offset by the increased rainfall.

We applied a preemergence herbicide mixture of S-metolachlor and linuron, followed by hoeing to maintain weedfree plots. Plant protection was carried out using the following treatments: first, copper hydroxide, then mancozeb and lambda-cyhalothrin, and finally, copper oxychloride and acetamiprid.

Each year, the crop from the first sowing date was harvested in early August, the second in mid-August, and the third in late August. Samples were collected from the two central rows. Over three years, six plants were sampled per plot at 200,000 plants/hectare, eight plants at 300,000 plants/hectare, and 10 plants at 400,000 plants/hectare. We recorded the pod number per plant and developed seeds per pod by test plot (0.25 m^2). We weighed the developed seeds and calculated the thousand seed weight and yield per plant. The yield per hectare was calculated based on the sum of yields from individual plants within the sample plots. The analysis of variance was conducted using the SPSS software package. We opted for a straightforward statistical method, using one-way ANOVA for each variety to emphasise significant differences in the yield parameters we studied. During the variance analysis, the results shown in the tables were evaluated as averages of the other two agronomic factors. The Tukey-b method was used for the homogeneous data set, and the Games-Howell method was applied to the non-homogeneous data set at a 5% significance level. The crop element values follow a pattern similar to an exponential distribution, resulting in an increased standard deviation. The variance is explained by anomalies in crop production resulting from extreme weather conditions and variations in treatments.

Unfortunately, in the case of the Hópehely variety, the crop was lost due to waterlogging during the second sowing time in 2016, so we cannot provide data on that variety for that year.

RESULTS

Yield per hectare

The plant densities did not significantly affect yield per hectare for no variety. The significant effect of the fertiliser doses was verified only in the case of the Hópehely variety in 2016 when the treatment without fertiliser yielded more than 56% than fertilised treatments (Table 1). The effect of sowing times varied by variety. Diana and Hópehely varieties consistently had higher yields in the first sowing times. In 2015, the third sowing date yielded the lowest production levels across all three varieties analysed. In 2015, Diana's yield from the first sowing date was twelve times higher than that from the third sowing date. In 2016, it was three times higher; in 2017, it was 85% higher. In the case of Hópehely, the first sowing in 2015 produced 3.7 times more than the third sowing, and in 2017, this difference increased to five times. In 2015, the yield for the Start variety from the second sowing

Table 1. Effect of the sowing time, plant density and fertiliser dose on the yield (mean ±standard deviation, kg ha^{-1})

Value	Diana			Start			Hópehely		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Sowing times									
1	351 ±179a	1638 ±701a	2373 ±912a	343 ±195b	1187 ±538c	2724 ±851a	374 ±246a	1419 ±800a	3592 ±788a
2	144 ±197b	567 ±465b	1938 ±705a	1005 ±463a	1630 ±615b	2607 ±814a	151 ±104b	–	2884 ±858b
3	30 ±32c	556 ±403b	1282 ±499b	38 ±56c	2025 ±540a	1911 ±422b	101 ±99b	1188 ±520a	713 ±372c
Plant densities (thousand plants per hectare)									
200	196 ±225a	915 ±659a	2104 ±1034a	567 ±568a	1524 ±675a	2453 ±789a	223 ±241a	1152 ±724a	2728 ±1443a
300	180 ±224a	1051 ±875a	1827 ±781a	564 ±492a	1765 ±654a	2496 ±851a	169 ±133a	1400 ±686a	2577 ±1413a
400	146 ±153a	799 ±665a	1685 ±664a	382 ±423a	1579 ±635a	2337 ±790a	247 ±248a	1337 ±631a	2326 ±1285a
Fertiliser doses (%)									
0	231 ±208a	1072 ±674a	1816 ±918a	487 ±580a	1700 ±497a	2354 ±756a	248 ±160a	1717 ±711a	2365 ±1334a
100	127 ±167a	836 ±816a	1837 ±804a	513 ±479a	1463 ±606a	2446 ±741a	189 ±193a	1100 ±645b	2893 ±1241a
150	169 ±224a	853 ±716a	1956 ±837a	439 ±436a	1707 ±809a	2479 ±920a	202 ±255a	1079 ±465b	2422 ±1521a

Different letters indicate statistical difference ($p < 0.05$)

Table 2. Effect of the sowing time, plant density and fertiliser dose on the pod number per plant (mean ±standard deviation)

Value	Diana			Start			Hópehely		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Sowing times									
1	3.4 ±2.0a	5.5 ±3.5a	9.5 ±6.5a	7.6 ±6.2b	22.2 ±15.7a	22.8 ±11.9a	4.1 ±2.4b	9.8 ±5.7a	9.7 ±4.9a
2	3.8 ±2.6a	4.6 ±3.2b	9.4 ±6.0a	16.6 ±13.6a	15.3 ±9.8b	17.6 ±8.6b	6.4 ±3.8a	–	10.6 ±6.6a
3	1.7 ±1.0b	4.5 ±3.6b	6.7 ±4.3b	3.0 ±3.3c	18.7 ±10.7a	12.7 ±6.0c	3.4 ±2.3c	10.2 ±6.3a	6.7 ±3.3b
Plant densities (thousand plants per hectare)									
200	3.7 ±2.4a	6.4 ±4.1a	12.0 ±6.7a	12.9 ±13.4a	23.0 ±13.5a	20.6 ±11.1a	5.2 ±3.4a	12.2 ±7.8a	12.2 ±5.8a
300	3.7 ±2.4a	5.0 ±3.2b	8.5 ±5.7b	10.8 ±10.0b	17.3 ±9.9b	18.5 ±9.1a	4.4 ±3.2b	10.0 ±5.7b	9.3 ±5.6b
400	2.6 ±1.5b	4.1 ±2.7c	6.6 ±4.3c	8.8 ±8.9b	15.4 ±10.8b	14.1 ±8.1b	3.8 ±2.1c	8.9 ±4.9b	7.2 ±3.9c
Fertiliser doses (%)									
0	3.7 ±2.5a	5.0 ±3.2a	8.3 ±6.2a	9.8 ±10.4a	14.6 ±9.6b	16.9 ±10.1a	4.4 ±3.0a	8.8 ±5.1b	8.2 ±4.6b
100	3.1 ±1.9b	4.9 ±3.5a	8.2 ±5.6a	11.3 ±12.1a	18.8 ±11.9a	16.6 ±9.1a	4.6 ±3.2a	10.4 ±6.3a	10.4 ±6.2a
150	3.0 ±1.8b	5.2 ±3.7a	9.3 ±5.7a	11.0 ±9.9a	21.2 ±12.5a	18.3 ±10.0a	4.2 ±2.6a	11.8 ±6.8a	9.4 ±5.3a

Different letters indicate statistical difference ($p < 0.05$)

date was 26 times greater than from the third. In 2016, the first sowing date had the lowest yield, while the third date saw a 70% increase. In 2017, the second sowing date outperformed the third by 36%.

Pod number per plant

There were significant effects of the sowing times, plant densities, and fertiliser doses in cases of three varieties (Table 2). The effects of the fertiliser doses depended on the varieties.

In 2015, the Diana variety had 23% more pods per plant without fertiliser than with the highest dose. In 2016, the Start variety produced 45% more pods under the highest fertiliser dose, while Hópehely had a 34% increase compared to the unfertilised control. In 2017, Hópehely showed 27% more pods with 100% fertiliser than in the untreated control.

The pod number per plant decreased as plant densities increased at the three varieties. In the case of the Start variety, the number of pods per plant decreased by 67–68% when plant density increased from 200,000 to 400,000 plants per hectare. For the Hópehely variety, the reduction reached 73%, while in 2017, it was 59%. Diana's decline in pod number ranged between 55% and 70%, depending on the year.

The third sowing time has had the lowest number of pods per plant of the three varieties. For the Diana variety, in 2016, the first sowing date produced 22% more pods; in 2017, the first two sowing dates produced 42% more pods than the third sowing time. For the Start variety, the sowing date, which results in the highest number of pods per plant, varied yearly. Compared to the sowing date with the lowest number of pods, the increase was 1.5 to 5.5 times. At the Hópehely variety, the pod number was the highest in the second sowing time. It was approximately twice as high as the third sowing time, with increases of 60% in 2017 and 88% in 2015.

Thousand-seed weight

The sowing time significantly affected the thousand-seed weight of the three varieties (Table 3). The effect of plant density was not significant on the thousand-seed weight of the Diana variety. The effect of fertiliser doses was not significant on the thousand-seed weight of the Start variety. The most considerable thousand-seed weight was at different yearly sowing times at the Diana variety.

The small-seeded Start variety showed a higher thousand-seed weight in the third sowing time, increasing by 25% in 2016 and 4% in 2017. The large-seeded Hópehely variety had its highest thousand-seed weight at the first sowing, with 70% and 31% increases over two years. Thousand-seed weight consistently rose with earlier sowing dates.

In 2017, higher plant density led to a decrease in weight per thousand seeds for the Start variety. The highest weight was at 200,000 plant density, 3% higher than 400,000. Conversely, at the Hópehely variety, we observed different results in two years. In 2015, the thousand-seed weight at the 400,000-plant density was 7% higher than at the 200,000-plant density. However, in 2016, the 200,000-plant density had a significantly higher – by 5% thousand-seed weight than the value of the 400,000-plant density.

The effect of fertiliser doses depended on the varieties. Significant differences were observed in one year for both the Start and Hópehely varieties, while in the case of the Diana variety, significant differences were confirmed in two years. In 2016, for the Hópehely variety, the thousand-seed weights in the fertilised treatments were 5% and 6% higher than in the unfertilised control. Still, the value of the treatment without fertiliser did not differ significantly from the value of the 150% fertiliser doses. In the case of the Start variety, the thousand-seed weight in the fertilised treatments was significantly higher, by 5%, than that of the untreated control in 2016. For the Diana variety, fertilised treatments consistently produced higher values – by 6% and 4% in 2016 and 2017, respectively, with the 150% dose producing a signifi-cantly greater thousand-seed weight than the control under all conditions.

Well-developed seed number per pod

In 2016, the well-developed seed number per pod of the first sowing time was the largest of the three varieties (Table 4). For Diana, the increase was 28%; for Start, 42%; and for Hópehely, 45%. 2015 was a varied year; for Diana and Hópehely, the highest values were recorded at the third sowing time, 36% and 30% higher, respectively, compared to the lowest at the second sowing date. The Start variety had the most significant well-developed seed number at the second sowing time, 58% greater than the first.

Table 3. Effect of the sowing time, plant density and fertiliser dose on the thousand-seed weight (mean ±standard deviation, g)

Value	Diana			Start			Hópehely		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Sowing times									
1	274 ±39b	264 ±41b	265 ±41a	187 ±35a	163 ±23c	161 ±14b	363 ±94a	306 ±46b	374 ±31a
2	288 ±43a	266 ±51b	255 ±40b	161 ±29b	180 ±21b	162 ±15b	254 ±38b	–	364 ±36b
3	260 ±50b	296 ±56a	250 ±33b	180 ±44a	203 ±24a	168 ±14a	214 ±46c	392 ±52a	285 ±34c
Plant densities (thousand plants per hectare)									
200	275 ±43a	278 ±48a	261 ±39a	173 ±34a	186 ±27a	167 ±14a	293 ±97b	362 ±71a	349 ±50a
300	280 ±41a	269 ±51a	256 ±37a	179 ±38a	187 ±28a	164 ±15ab	296 ±96ab	346 ±64ab	349 ±51a
400	274 ±42a	272 ±49a	254 ±39a	175 ±36a	187 ±24a	162 ±15b	314 ±104a	344 ±62b	346 ±50a
Fertiliser doses (%)									
0	276 ±41a	265 ±49b	253 ±39b	175 ±35a	182 ±26b	166 ±16a	277 ±89a	338 ±65b	343 ±50a
100	278 ±43a	275 ±49a	255 ±35ab	175 ±36a	191 ±28a	163 ±14a	304 ±98a	360 ±69a	350 ±46a
150	275 ±43a	280 ±51a	262 ±40a	178 ±38a	191 ±25a	163 ±14a	335 ±104a	354 ±60ab	351 ±54a

Different letters indicate statistical difference ($p < 0.05$); sowing times: 1 – early, 2 – standard, 3 – late

Table 4. Effect of the sowing time, plant density and fertiliser dose on the well-developed seed number per pod **(**mean ±standard deviation)

Value	Diana			Start			Hópehely		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Sowing times									
1	1.8 ±0.9a	2.3 ±1.1a	3.1 ±1.0a	1.2 ±0.5c	2.7 ±0.7a	3.3 ±0.6a	1.1 ±0.6b	1.6 ±0.7a	2.7 ±0.7a
2	1.4 ±0.8b	1.8 ±1.0b	2.7 ±1.0b	1.9 ±0.7a	2.1 ±0.6b	3.1 ±0.7b	1.0 ±0.6c	–	2.3 ±0.7b
3	1.9 ±1.0a	1.8 ±1.0b	2.5 ±1.0c	1.4 ±0.8b	1.9 ±0.5c	2.8 ±0.5c	1.3 ±0.8a	1.1 ±0.6b	1.9 ±0.6c
Plant densities (thousand plants per hectare)									
200	1.7 ±0.8a	2.0 ±1.0a	2.9 ±1.0a	1.5 ±0.7a	2.2 ±0.6a	3.1 ±0.6a	1.1 ±0.7b	1.4 ±0.7a	2.3 ±0.9a
300	1.7 ±0.9a	2.1 ±1.0a	2.8 ±1.0ab	1.5 ±0.8a	2.2 ±0.7a	31 ±0.6a	1.1 ±0.6b	1.3 ±0.8a	2.2 ±0.9a
400	1.8 ±0.9a	2.1 ±1.1a	2.7 ±1.0b	1.5 ±0.7a	2.0 ±0.6b	2.9 ±0.7b	1.2 ±0.7a	1.3 ±0.7a	2.1 ±0.9a
Fertiliser doses (%)									
0	1.6 ±0.8b	2.2 ±1.1a	2.9 ±1.1a	1.5 ±0.8a	2.1 ±0.7a	3.0 ±0.6a	1.2 ±0.7a	1.5 ±0.8a	2.2 ±0.9ab
100	1.7 ±0.9ab	2.1 ±1.1ab	2.7 ±1.1a	1.5 ±0.7a	2.2 ±0.6a	3.1 ±0.7a	1.2 ±0.7a	1.3 ±0.7b	2.3 ±0.8a
150	1.9 ±1.0a	1.9 ±1.0b	2.8 ±0.9a	1.5 ±0.7a	2.2 ±0.7a	3.0 ±0,7a	1.1 ±0.6a	1.1 ±0.6b	2.1 ±0.9b

Different letters indicate statistical difference ($p < 0.05$)

Plant densities had differing effects on Diana, Hópehely, and Start varieties. For Diana, in 2017, the number of well-developed seeds per pod was 7% higher at the 200,000 plant densi-ty than at the 400,000 plant density. In the case of Hópehely, under the highest density (400,000 plants per hectare), 9% more well-developed seeds were formed in 2015 compared to the lower densities. The Start variety had the lowest well-developed seed number at 400 thousand plant density during 2016–2017.

The fertiliser doses had varied effects on analysed plant varieties. The Start variety showed no significant effect. In the case of Diana, the 150% dose in 2015 resulted in an 18% increase in the number of well-developed seeds compared to the unfertilised control, while in 2016, the no-fertiliser treatment produced 16% more well-developed seeds than the 150% dose. For the Hópehely variety, the highest value in 2016 was recorded in the unfertilised treatment, which yielded 36% more well-developed seeds than the 150% dose. In contrast, in 2017, the 100% dose outperformed the 150% treatment by 10%, showing a significantly higher result.

Yield per plant

The significant effects of sowing times and plant densities were verified yearly (Table 5). In 2016, the Diana variety yielded 60% more per plant at the first sowing date, and the Start variety 72% more per plant than at the second sowing date, with the lowest yield. In 2017, the Diana variety yielded 89% more per plant at the first sowing date, and the Start variety twice as much as the third sowing date, with the lowest yield. The Hópehely variety yielded 89% more at the first sowing date in 2015 and four times more at the third sowing date in 2017. Regarding the three varieties, the yield per plant was the significant least in the third sowing time in 2015 and 2017.

The values decreased with an increase in plant densities. The lowest values were in 400,000 plant densities. The 200,000-plant density resulted in significantly higher yield per plant: 38–200% more for Diana, 53–65% more for Start, and 52–81% more for Hópehely. In 2016, there were no significant differences in values between 300,000 and 400,000 plant densities for the Hópehely and Start varieties, similar to the situation with the Start variety in 2015.

The fertiliser doses did not significantly affect the Diana variety. For other varieties, there was only a significant effect in one year. The Start variety had a significantly higher yield per plant with fertiliser treatments – by 38% and 63% – in 2016. In 2017, the 100% fertiliser dose treatment had the highest value, producing 33% more than the unfertilised control for the Hópehely variety, while the values without fertiliser and with a 150% dose did not differ significantly.

DISCUSSION

Our research aimed to identify the best technology for growing three common dry bean varieties. The common bean is sensitive to weather conditions, especially temperature and rainfall, which significantly impact the reproductive development stages. Similar observations were made in 2015, as reported by Ovacikli and Tolay [2020] and Kádár [2013]. During the flowering and fruiting period of the third sowing season, prolonged heat and a lack of rainfall occurred, leading to an atmospheric drought that caused a significant yield reduction.

Among the parameters studied, sowing time had the most significant impact on variations, followed by plant density. Fertilisation only led to a significant difference in one instance: the Hópehely variety of white salad beans yielded more without fertiliser than with it. This aligns with Kádár's [2013] finding that fertilisation can adversely affect unfavourable weather conditions. This variety prefers a cooler climate and yielded more during the initial sowing period, which corresponds to the findings of Jan et al. [2002], Mirzaienasab and Mojaddam [2014], and Uddin et al. [2017]. Late sowing often exposes plants to drought stress during critical growth phases [Bayrak et al. 2022]. Diana pinto beans yield more with early sowing, as their mottled seed coat offers better resistance to infections even in cooler soils after sowing [McCormack 2004]. The Start variety does better with later sowings due to its short growing period and small white seeds [McCormack 2004]. According to Hadnagy [1981], short-growing varieties in Hungary can reach maturity even if sown as late as May 20.

In the case of the Start and Hópehely varieties, fertilisation resulted in more pods per plant, consistent with the literature [Begum et al. 2003, Shubhashree

Table 5. Effect of the sowing time, plant density and fertiliser dose on the yield per plant (mean ±standard deviation, g)

Value	Diana			Start			Hópehely		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Sowing times									
1	1.8 ±1.4a	3.5 ±3.1a	8.5 ±7.7a	1.8 ±1.9b	10.5 ±8.9a	12.5 ±7.6a	1.7 ±1.4a	5.0 ±3.8a	10.0 ±5.8a
2	1.6 ±1.6a	2.2 ±2.1b	7.1 ±6.4b	6.0 ±6.4a	6.1 ±4.8c	9.1 ±5.5b	1.5 ±1.4a	–	9.4 ±7.0a
3	0.8 ±0.8b	2.5 ±2.6b	4.5 ±3.9c	0.7 ±0.7c	7.4 ±5.1b	6.0 ±3.3c	0.9 ±0.8b	4.5 ±4.2a	2.4 ±2.0b
Plant densities (thousand plants per hectare)									
200	1.8 ±1.6a	3.6 ±3.2a	9.9 ±8.1a	4.3 ±6.3a	9.5 ±7.1a	11.2 ±7.3a	1.5 ±1.4a	6.1 ±4.9a	10.7 ±7.6a
300	1.8 ±1.6a	2.9 ±2.9b	6.7 ±6.2b	3.4 ±4.5ab	7.3 ±5.4b	9.6 ±5.7b	1.3 ±1.1a	4.7 ±4.0b	8.0 ±6.6b
400	1.3 ±1.0b	2.4 ±2.2c	4.9 ±4.4c	2.6 ±3.5b	6.2 ±5.3b	6.9 ±4.7c	1.5 ±1.4a	4.0 ±3.2b	5.9 ±4.6c
Fertiliser doses (%)									
0	1.7 ±1.6a	2.9 ±2.5a	6.6 ±7.1a	3.3 ±4.9a	5.7 ±4.7b	8.7 ±6.2a	1.4 ±1.3a	4.5 ±3.8a	6.9 ±6.0b
100	1.5 ±1.4a	2.9 ±3.0a	6.3 ±6.1a	3.5 ±5.3a	7.9 ±6.3a	8.7 ±6.0a	1.5 ±1.4a	4.8 ±4.1a	9.2 ±7.1a
150	1.7 ±1.3a	3.0 ±3.1a	7.3 ±5.9a	3.4 ±4.1a	9.3 ±6.6a	9.3 ±6.1a	1.5 ±1.4a	5.0 ±4.3a	7.7 ±6.1b

Different letters indicate statistical difference ($p < 0.05$)

et al. 2011, Faria and Fageria 2014]. For the Diana variety, more pods were observed in the unfertilised treatment, which was confirmed in one year of the study. Our findings on plant densities and sowing time align with the literature [Moniruzzaman et al. 2009, Mekonnen et al. 2012, Tuarira and Moses 2014, Seif et al. 2016, Soratto et al. 2017]. The value increases at lower plant densities and decreases with increasing density. Similarly, the value was smallest when sowing was done at the latest time.

The timing of sowing significantly affected the thousand-seed weight for all three varieties. Early sowing resulted in the highest weight for the Hópehely variety, while the Start variety had lower weights during early sowing. The Diana variety showed varied effects of sowing time on thousand-seed weight each year. Our observations align with Mekonnen et al. [2012], Ahmed et al. [2016], and Seif et al. [2016], indicating that thousand-seed weight decreases with higher plant density. The effect of fertiliser doses on thousand-seed weight depended on the variety.

The value of the number of well-developed seeds per pod was significantly highest in the first sowing time regarding all three varieties in 2016–2017, as also reported by Mirzaienasab and Mojaddam [2014] and Uddin et al. [2017]. As the literature [Jan et al. 2002, Bakure et al. 2023] appropriately suggests, the number of well-developed seeds decreased with increased stocking density in the Start and Diana varieties. The Start variety showed no significant effect from fertiliser doses, while the effect varied among the other varieties.

The study confirmed the significant impact of sowing time and plant density on yield per plant over three years. The yield per plant decreased as plant densities increased, as also observed in the study by Shiv Kumar and Mishra [2002]. The fertilisation had minimal effect, possibly due to lack of irrigation. To maximise yield, it is crucial to determine the best sowing time, plant density, and fertiliser dose for the specific crop variety, which are influenced by factors like growth type and seed colour.

SUMMARY

Our three-year field study evaluated the effects of sowing time, plant density, and fertiliser dose on the yield and yield components of three dry bean varieties under Eastern Hungarian conditions. The results showed that the response of each variety differed depending on the examined agronomic factors.

The Diana variety showed the best performance when sown early, resulting in high pod numbers, well-developed seeds per pod, and overall yield. Increasing plant density negatively affected yield components for all varieties. The impact of fertiliser application varied by year; in the case of Diana, it did not consistently lead to increased yield. However, for the Start and Hópehely varieties, specific fertiliser treatments did result in improved performance.

The Start variety showed flexibility in sowing time, with satisfactory yields on standard and late sowing dates. The large-seeded Hópehely variety responded best to early sowing and moderate plant density.

These results demonstrate the necessity for tailored farming strategies for different dry bean varieties. Future research must focus on understanding how these varieties respond to environmental conditions and determining the optimal input levels for sustainable growth.

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