Soybean Yield and Yield Components Depending on Sowing Rate and Sowing Date

Prinos i komponente prinosa soje u optimalnom i naknadnom roku sjetve

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SOYBEAN YIELD AND YIELD COMPONENTS DEPENDING ON A SOWING RATE AND SOWING DATE

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SUMMARY

A research on the influence of a sowing date on the soybean yield and the yield of its components was carried out at the Experimental Site of the Faculty of Agriculture of the University of Zagreb during 2019 and 2020. The study involved two soybean varieties, the AFZG Ana (maturity group 0) and Gabriela (maturity group 00-0), sown on the two sowing dates (i.e., an optimal and a late one) and three sowing rates: 40, 65, and 90 germinating seeds m^{-2}. The sowing time did not have a significant effect on the soybean seeds' yield and the yield of their components. In both research years, the Gabriela variety achieved a higher seed yield when compared to the AFZG Ana variety, which is a result of a higher number of nodes on the main stem, number of fertile nodes on the main stem, number of pods, number of seeds, and the seed weight per plant. The Gabriela variety achieved a significantly higher harvest index in both years. The seed yield increased with an increasing sowing density up to 65 seeds m^{-2}. However, the differences were statistically significant only in 2019. The values of the yield components decreased with an increasing sowing density.

Keywords: soybean, sowing date, sowing rate, yield, yield components

INTRODUCTION

Soybean is the most important protein and oil crop in the world. Soybean seeds have a high protein content with a very favorable amino-acid composition, which makes them desirable for human and animal nutrition. For the animal feed, the meal that remains subsequent to the oil extraction is mainly used. Due to a high demand for soy protein, Europe imports the large quantities of soybean. To reduce this dependence on imports, the areas sown with soybeans and their production are increasing. Over the last decade, an increase in soybean production in Europe amounts to over 87% (FAOSTAT, 2022). In the same period, soybean production in the European Union increased by 116%. Soybeans are mainly grown in southern and eastern Europe, but the production tends to expand to other areas as well, which indicates its extreme importance (Karges et al., 2022).

Soybeans also play an important role in crop rotation, as it contributes to the preservation of soil fertility while simultaneously reducing the use of mineral fertilizers. Today, a preference is given to the varieties that are not genetically modified but correspond to the agroecological conditions of a particular area and achieve a high production. One of the possibilities to increase the soybean production is sowing subsequent to an optimal period—that is, subsequent to the harvest of winter cereals. For this reason, the varieties with a shorter growing season are gaining an incremental popularity. Simultaneously, along with an increase in production, a greater utilization of agricultural land is also ensured. In order for the post-main crop soybean cultivation to be successful, a variety should be chosen correctly, and it is necessary to properly elect the varieties that are suitable for this type of production in terms of their properties. A production success is also influenced by weather conditions, to which soybean is extremely sensitive during a generative development. A lack of water during the generative stages negatively affects the formation of soybean-yield components and thus the yield and quality of soybean seeds (Purcell and Specht, 2004; Mertz-Henning et al., 2018). A major problem while sowing the soybeans after an optimal time is a lack of precipitation and its influence

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on soybean emergence—namely, on the realization of an optimal plant density. However, the high temperatures also have a negative impact on the soybeans' growth and development. A joint effect of photoperiodism, high temperatures, and precipitation with a delayed sowing contributes to a shorter duration of the vegetative and generative stages, so a photosynthesis degree and plant growth decrease, leading to a reduced yield of soybean seeds (Hu and Wiatrak, 2012). The researchers report that a delayed sowing of soybeans causes a decrease in the seed yield and emphasize the importance of an early sowing of soybeans, when the moisture is not a limiting factor (Bateman et al., 2020).

An optimal sowing density is one of the factors that determine a success of soybean production, and it is directly related to the characteristics of varieties—that is, to their maturity group. The achievement of an optimal plant density is particularly problematic on the delayed sowing dates, when there is an insufficient time to obtain a complete plant density prior to the onset of reproductive evolutional and developmental phases. In such conditions, these disadvantages can be compensated by a higher plant density (Ball et al., 2000a).

By reducing a plant density, a number of branches increases, which is considered to be the compensatory main mechanism for a smaller number of plants. However, an increased number of pods and seeds per plant as a result of more branches is usually insufficient to compensate for a lower number of plants (Cox and Cherney, 2011). In other studies, with an increase in plant density, the smaller values concerning a number of pods and seeds and the seed weight per plant were obtained (Ferreira et al., 2016). The changes in plant density are related to the amount of light that has a direct effect on the formation of yield components (Mathew et al., 2000; Liu et al., 2006).

The aim of the research was to determine the influence of a sowing date and sowing rates on the soybean yield and yield components of soybean.

MATERIALS AND METHODS

The research was carried out in northwestern Croatia at the Experimental Site of the Faculty of Agriculture of the University of Zagreb during 2019 and 2020. The trial involved two soybean varieties: AFZG Ana (maturity group 0) and Gabriela (maturity group 00-0), sown on the two sowing dates and in three sowing densities: 40, 65, and 90 germinating seeds m^{-2}. Sowing was performed on two occasions: an optimal sowing on 25 April 2019 and 22 April 2020 and a delayed sowing on 1 June 2019 and 28 May 2020. The experiment was set up according to the strip-split plot scheme with four replications. The size of the plot amounted to 16.8 m^2 (4 rows x 0.70 m x 6 m long). The soybeans were harvested in two middle rows, and the size of the harvested plot amounted to 8.4 m^2. Sorghum was a forecrop in 2019, whereas the field peas succeeded it in 2020. The fertilization was performed prior to plowing with 200 kg ha^{-1} NPK 7:20:30.

In 2019, a weed control was carried out with the Agil 100 EC (Propaquizafop) herbicide in a dose of 1.5 l ha^{-1} and the Laguna 75 WG (oxasulfuron) herbicide in a dose of 100 g ha^{-1}, with the addition of the Harmony SX (thifensulfuron-methyl) herbicide in a dose of 8 g ha^{-1}. In 2020, a weed control was carried out with the Agil 100 EC herbicide in a dose of 0.5 l ha^{-1} and the Lentagran 45 WP herbicide in a dose of 2 kg ha^{-1}. During the growing season, two inter-row soybean cultivations were performed.

The soybeans sown in an optimal period were harvested on 16 September 2019 and on 22 September 2020, and those sown during a delayed period were harvested on 8 October 2019 and on 9 October 2020. After harvesting, the yield and seed moisture were determined. The seed yield was calculated at a thirteen-percent moisture. The following analyses were performed on a sample of ten plants per plot, taken before the harvest: a plant weight, a plant height, a number of nodes on the main stem, a number of fertile nodes on the main stem, a total number of nodes per plant, a total number of fertile nodes per plant, a number of pods, a number of seeds per plant, and the seed weight per plant. The harvest index was calculated as a ratio of the seed weight per plant to a weight of the whole plant. The obtained data were processed by an analysis of variance, and the average values were tested by the Duncan test using the Mstat-C (1990) program.

Weather conditions

During the soybean reproductive stages in June and August 2019, precipitation amounted to 22 and 34% less if compared to a long-term average, while the amount of precipitation in July was slightly lower than a long-term average (Table 1). In 2020, the amount of precipitation during the same period was higher if compared to the long-term average. During July, almost 100% more precipitation fell if compared to a long-term average. A daily mean air temperature was more favorable in 2020 than in 2019 (Table 2). All this had a favorable effect on the inflorescence and fertilization of soybeans in 2020 and later on the formation of pods and seeds and the seed filling.

Following a delayed soybean sowing, a sufficient quantity of precipitation fell in both research years, having enabled a good emergence of soybeans. A higher amount of precipitation during the 2020 growing season enabled a good development of soybeans during a delayed sowing. A satisfactory soybean-seed yield was achieved, and a difference was small when compared to an optimal sowing date. In 2019, a lower amount of precipitation during June, July, and August, followed by the higher temperatures when compared to 2020, had a negative impact on the development of reproductive stages of soybeans sown during a delayed term, and a lower yield was achieved when compared to 2020.

Table 1. A total monthly precipitation (mm) during the 2019 and 2020 growing seasons and a long-term (1991–2020) average in Zagreb-Maksimir

Tablica 1. Ukupna količina oborina (mm) tijekom vegetacijskih sezona 2019. i 2020. godine i višegodišnji prosjek (1991. – 2020.) za Zagreb-Maksimir

Month / *Mjesec*	Growing season / *Vegetacijska sezona*		Long-term average / *Višegodišnji prosjek*
	2019	2020	1991-2020
April / *travanj*	81.1	23.4	60.6
May / *svibanj*	147.7	96.7	76.5
June / *lipanj*	70.8	104.4	90.8
July / *srpanj*	76.8	159.6	80.4
August / *kolovoz*	56.7	98.8	85.6
September / *rujan*	150.1	100.7	103.8
October / *listopad*	42.3	159.3	88.5
Total / *ukupno*	625.5	742.9	586.2

Table 2. The mean monthly air temperature (°C) during the 2019 and 2020 growing seasons and a long-term (1991–2020) average in Zagreb-Maksimir

Tablica 2. Srednje mjesečne temperature zraka (°C) tijekom vegetacijskih sezona 2019. i 2020. godine i višegodišnji prosjek (1991. – 2020.) za Zagreb-Maksimir

Month / *Mjesec*	Growing season / *Vegetacijska sezona*		Long-term average / *Višegodišnji prosjek*
	2019	2020	1991-2020
April / *travanj*	12.4	13.2	12.2
May / *svibanj*	13.7	15.7	16.7
June / *lipanj*	23.8	20.3	20.6
July / *srpanj*	22.9	21.8	22.2
August / *kolovoz*	23.5	22.9	21.8
September / *rujan*	17.2	18.1	16.7
October / *listopad*	13.2	12.6	11.7

Soil characteristics

The experiment was set up on an anthropogenic eutric cambisol (Vidaček et al., 1994). In the upper layer, the soil was acidic (pH in 1 M KCl = 5.42), poorly supplied with humus (2.06%) and well-supplied with nitrogen (0.13%). The soil was moderately supplied with the plant-available phosphorus (AL - P_2O_5 = 14.3 mg 100 g^{-1} soil) and potassium (AL - K_2O = 15.8 mg 100 g^{-1} soil).

RESULTS AND DISCUSSION

A sowing date did not have a significant effect on the soybean-seed yield in any of the research years. In 2019, the seed yield amounted to 2.4 t ha^{-1} on an optimal sowing date and 2.5 t ha^{-1} on a delayed one (Table 3). In 2020, the seed yield amounted to 3.4 t ha^{-1} and 3.2 t ha^{-1}, respectively (Table 4), due to the more favorable weather conditions. In 2020, subsequent to a soybean sowing, more precipitation fell following a delayed sowing date, with the averagely lower daily air temperatures when compared to 2019, which had a favorable effect on germination and later on the development of soybeans' vegetative stages. The amount of precipitation after a soybean sowing beyond the optimal terms is cited as the main problem in the realization of an optimal plant density. To ensure a success of soybean production on a delayed date, it is important to ensure a sufficient amount of water during the summer months, if possible, through irrigation. A lack of water as well as the high air temperatures during the generative stages of growth and development, have a negative impact on the formation of yield components and seed yield (Popović et al., 2012; Onat et al., 2017; Mertz-Henning et al., 2018).

In 2019, on an optimal sowing date, a significantly higher plant height and a number of nodes on the main stem were achieved (Table 3). The sowing date had no influence on a number of fertile nodes on the main stem, a total number of nodes on the plant, and a total number of fertile nodes on the plant (Table 3).

In 2020, a significantly higher plant height (by 48%) was achieved on a delayed sowing date when compared to the optimal one. However, a higher plant height did not result in a greater number of nodes on the main stem. On the contrary, on an optimal sowing date, a significantly higher number of fertile nodes was achieved on the main stem (Table 4).

A sowing date had no influence on a number of pods and on a number of seeds per plant, as well as on the weight of seeds and a number of branches per plant (Tables 5 and 6). In 2019, a significantly higher harvest index was achieved on a delayed sowing date. Kawasaki et al. (2018) also obtained an increase in the harvest index with a subsequent sowing, and a sowing density had no effect on the harvest index. The authors reported that the harvest index was correlated to the stem's dry-matter mass and not to a soybean-seed yield.

In both research years, the Gabriela variety had a significantly higher seed yield than the AFZG Ana variety (Tables 3 and 4). In 2019, the yield amounted to 2.7 t ha^{-1} and 3.7 t ha^{-1} in 2020. A higher seed yield in 2020 was a result of the more favorable weather conditions during the inflorescence, seed formation, and filling. Soybean is highly sensitive to drought during the inflorescence period (Zhou et al., 2022), and a period during the seed formation and filling is critical for the yield formation (Vega et al., 2001; Borrás et al., 2004).

In both research years, the Gabriela variety achieved a higher plant height, a number of nodes on the main stem, and a number of fertile nodes on the main stem (Tables 3 and 4). In 2020, this variety achieved a significantly higher total number of fertile nodes on a plant.

In 2020, the Gabriela variety achieved a higher number of pods and seeds and the per-plant seed weight when compared to the AFZG Ana variety. The higher yield-component values in the Gabriela variety had a positive effect on this variety's seed yield in both research years. These results were consistent with a research by De Bruin and Pedersen (2009) and Liu et al. (2006), in which it was determined that a soybean-seed yield was strongly related to a number of seeds per m^2—that is, to an increased number of pods.

In both years, the Gabriela variety had a significantly higher harvest index when compared to the AFZG Ana variety (Tables 3 and 4). Kumudini et al. (2001) stated that an increase in the yield of varieties with a shorter growing season was associated with a higher harvest index and a higher dry-matter accumulation.

In 2019, a sowing density had an impact on a soybean-seed yield and on a sowing density of 40 seeds m^{-2}, so a significantly lower yield was achieved if compared to the higher sowing densities (Table 3). Thus, increasing a plant density to achieve an optimum yield is particularly important in the areas with a short growing season (Ball et al., 2000a).

Sowing density had a significant impact on a total number of nodes on a plant, and a greater number of fertile nodes was achieved at the lower sowing densities (Tables 3 and 4).

With an increasing sowing density, a number of pods and seeds and a per-plant seed weight decreased in both research years, but the differences in a number of pods and seeds per plant were statistically significant only in 2020. However, a higher number of pods and seeds per plant at the lowest sowing density did not have a positive effect on the yield, which agrees with research conducted by Cox and Cherney (2011). In a research by Ball et al. (2000b), a decrease in a per-plant seed weight, combined with an increase in the plant density and joined with a simultaneous increase in the yield per unit area, was also detected. Sobko et al. (2019) stated that the number of pods and branches per plant increased with a decrease in the plant density. The higher yield-component values at the lower sowing densities can be associated with a better plant illumination (Liu et al., 2010). The retention of individual seed weight is an important strategy for the achievement of high yields at high plant densities. If the distribution of light within the crop is optimal, plant density can be increased to achieve a higher soybean yield (Liu et al., 2007).

In both research years, the lowest sowing density indicated the highest branching, and a difference compared to the other two densities was statistically significant only in 2020. Cox and Cherney (2011) stated that the number of branches at a lower sowing density was approximately 20% higher. An increase in the number of branches per plant is the main vegetative mechanism to compensate for a lower seeding density (Board, 2000; Cox and Cherney, 2011). At a higher sowing density, the number of branches decreases due to a lower amount of light inside the crop (Wang et al., 2013; Hu et al., 2021). In this research, the sowing density had no significant effect on the harvest index. Ball et al. (2000b) also reported the constancy of harvest index at different plant densities.

Table 3. The effect of a sowing density and of a sowing date on the soybean yield and yield components in 2019

Tablica 3. Utjecaj roka i gustoće sjetve na prinos i komponente prinosa istraživanih sorata soje 2019. godine

Treatment / *Tretman*	**Seed yield** / *Prinos sjemena* (t ha^{-1})	**Plant height** / *Visina biljke* (cm)	**Number of nodes on the main stem** / *Broj etaža na glavnoj stabljici*	**Number of fertile nodes on the main stem** / *Broj plodnih etaža na glavnoj stabljici*	**Total number of nodes on the plant** / *Ukupan broj etaža na biljci*	**Total number of fertile nodes on the plant** / *Ukupan broj plodnih etaža na biljci*
Sowing date / *Rok sjetve*						
Optimal / *Optimalni*	2.4	92.4 a	15.9 a	14.2	21.5	19.5
Delayed / *Naknadni*	2.5	76.2 b	14.0 b	13.0	24.3	22.8
Variety / *Sorta*						
AFZG Ana	2.2 b	76.5 b	13.6 b	12.4 b	23.5	21.7
Gabriela	2.7 a	92.0 a	16.3 a	14.9 a	22.3	20.5
Sowing density seeds m^{-2} / *Gustoća sjetve sjemenaka* m^{-2}						
40	2.2 b	80.5	15.1	13.8	25.3 a	23.5 a
65	2.5 a	86.9	15.1	13.8	22.3 ab	20.5 b
90	2.7 a	85.4	14.7	13.3	21.1 b	19.4 b

The values followed by the same letter are not significantly different at a 5% probability level.

Table 4. The effect of a sowing density and of a sowing date on the soybean yield and yield components in 2020

Tablica 4. Utjecaj roka i gustoće sjetve na prinos i komponente prinosa istraživanih sorata soje 2020. godine

Treatment / *Tretman*	**Seed yield** / *Prinos sjemena* ($t\ ha^{-1}$)	**Plant height** / *Visina biljke* (cm)	**Number of nodes on the main stem** / *Broj etaža na glavnoj stabljici*	**Number of fertile nodes on the main stem** / *Broj plodnih etaža na glavnoj stabljici*	**Total number of nodes on the plant** / *Ukupan broj etaža na biljci*	**Total number of fertile nodes on the plant** / *Ukupan broj plodnih etaža na biljci*
Sowing date / *Rok sjetve*						
Optimal / *Optimalni*	3.4	86.2 b	16.2	15.0 a	22.8	21.1
Delayed / *Naknadni*	3.2	127.8 a	15.1	13.3 b	20.5	18.3
Variety / *Sorta*						
AFZG Ana	2.9 b	93.9 b	14.2 b	12.9 b	20.2 b	18.4 b
Gabriela	3.7 a	120.2 a	17.1 a	15.4 a	23.0 a	21.0 a
Sowing density seeds m^{-2} / *Gustoća sjetve sjemenaka* m^{-2}						
40	3.2	107.5	16.2 a	14.9 a	23.9 a	22.0 a
65	3.4	108.0	15.5 b	13.9 b	20.6 b	18.5 b
90	3.3	105.5	15.2 b	13.7 b	20.4 b	18.5 b

The values followed by the same letter are not significantly different at a 5% probability level.

Table 5. The effect of a sowing density and of a sowing date on the soybean yield components in 2019

Tablica 5. Utjecaj roka i gustoće sjetve na komponente prinosa istraživanih sorata soje 2019. godine

Treatment / *Tretman*	**Pod number plant^{-1}** / *Broj mahuna po biljci*	**Seed number plant^{-1}** / *Broj sjemenaka po biljci*	**Seed weight g plant^{-1}** / *Masa sjemena po biljci (g)*	**Branches number plant^{-1}** / *Broj grana po biljci*	**Harvest index** / *Žetveni indeks*
Sowing date / *Rok sjetve*					
Optimal / *Optimalni*	51.0	88.2	17.0	1.7	0.38 b
Delayed / *Naknadni*	53.3	106.1	19.4	1.9	0.51 a
Variety / *Sorta*					
AFZG Ana	46.3	90.4	16.5	2.1	0.40 b
Gabriela	58.1	103.9	19.8	1.5	0.49 a
Sowing density seeds m^{-2} / *Gustoća sjetve sjemenaka* m^{-2}					
40	55.8	110.0	20.0	2.1	0.45
65	51.2	93.7	17.8	1.8	0.44
90	49.6	87.6	16.7	1.6	0.45

The values followed by the same letter are not significantly different at a 5% probability level.

Table 6. The effect of a sowing density and of a sowing date on the soybean yield components in 2020

Tablica 6. Utjecaj roka i gustoće sjetve na komponente prinosa istraživanih sorata soje 2020. godine

Treatment / *Tretman*	**Pod number plant^{-1}** / *Broj mahuna po biljci*	**Seed number plant^{-1}** / *Broj sjemenaka po biljci*	**Seed weight g plant^{-1}** / *Masa sjemena po biljci (g)*	**Branches number plant^{-1}** / *Broj grana po biljci*	**Harvest index** / *Žetveni indeks*
Sowing date / *Rok sjetve*					
Optimal / *Optimalni*	45.9	109.2	19.6	1.5 b	0.55
Delayed / *Naknadni*	46.8	108.3	18.2	1.8 a	0.54
Variety / *Sorta*					
AFZG Ana	42.1 b	100.9 b	16.5 b	1.8	0.53 b
Gabriela	50.6 a	116.5 a	21.3 a	1.6	0.57 a
Sowing density seeds m^{-2} / *Gustoća sjetve sjemenaka* m^{-2}					
40	51.4 a	121.9 a	20.8	2.1 a	0.55
65	44.7 b	105.2 b	18.5	1.5 b	0.55
90	42.9 b	99.1 b	17.4	1.4 b	0.54

The values followed by the same letter are not significantly different at a 5% probability level.

CONCLUSION

Sowing soybeans beyond an optimal period is one of the possibilities to increase production and reduce dependence on soybean imports. However, a success of this type of soybean production depends on several factors. Based on the two years of research on the influence of soybean variety, sowing date, and density on the yield and yield components in northwest Croatia, the following conclusions can be drawn: a sowing period did not have a significant effect on the soybean-seed yield and the yield of their components. In both research years, the Gabriela variety achieved a higher seed yield when compared to the AFZG Ana variety, which is a result of a higher number of nodes on the main stem, number of fertile nodes on the main stem, number of pods, number of seeds, and of a per-plant seed weight. The Gabriela variety achieved a significantly higher harvest index in both years. The yield increased with an increasing sowing density to 65 seeds m^{-2}. However, the differences were statistically significant only in 2019. The yield-component values decreased with an increasing plant density.

According to the results obtained, growing soybeans on the delayed sowing dates may achieve the good results. However, research should be continued with a larger number of varieties from different maturity groups over a longer period to cover a wider range of weather conditions.

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PRINOS I KOMPONENTE PRINOSA SOJE U OPTIMALNOME I NAKNADNOM ROKU SJETVE

SAŽETAK

Istraživanja utjecaja roka sjetve na prinos i komponente prinosa soje provedena su na pokušalištu Agronomskoga fakulteta Sveučilišta u Zagrebu tijekom 2019. i 2020. godine. U istraživanju su bile dvije sorte soje, AFZG Ana (vegetacijska skupina 0) i Gabriela (vegetacijska skupina 00-0), sijane u dvama rokovima sjetve (optimalnome i naknadnome) i trima gustoćama sjetve: 40, 65 i 90 klijavih sjemenaka m^{-2}. Rok sjetve nije imao značajan utjecaj na prinos i komponente prinosa sjemena soje. U obje godine istraživanja sorta Gabriela ostvarila je veći prinos sjemena u odnosu na sortu AFZG Ana, što je rezultat većega broja etaža na glavnoj stabljici, broja plodnih etaža na glavnoj stabljici, broja mahuna, broja sjemenaka i mase sjemena po biljci. Sorta Gabriela u obje je godine ostvarila i značajno veći žetveni indeks. Prinos sjemena povećavao se s povećanjem gustoće sjetve do 65 sjemenki m^{-2}. Međutim, razlike su bile statistički značajne jedino u 2019. godini. Vrijednosti komponenata prinosa smanjivale su se s povećanjem gustoće sklopa.

Ključne riječi: soja, rok sjetve, gustoća sjetve, prinos, komponente prinosa

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