https://doi.org/10.17221/174/2023-HORTSCI

Analyzing the effects of different GA_3 applications on plant root architecture and above-ground properties in tulip cultivars

Ömer Sari

Black Sea Agricultural Research Institute, Samsun, Türkiye

**Corresponding author: omer.sari@tarimorman.gov.tr*

Citation: Sari Ö. (2024): Analyzing the effects of different GA3 applications on plant root architecture and above-ground properties in tulip cultivars. HortSci. (Prague), 51: 244–254.

Abstract: In the study, the effects of 0, 100, 200 and 400 ppm spray applications of GA_3 on root and above-ground parts of 'Jan Reus', 'Bloody Mary' and 'Yokohama' tulip cultivars were determined. According to the results, on the development of plant upper part properties, 200 ppm in 'Jan Reus' and 'Yokohama' and 100 ppm in 'Bloody Mary' were the most effective applications. Again, the least increases in upper part properties were obtained from the control plants in 'Jan Reus' and 'Bloody Mary', and from the 100 ppm application in 'Yokohama'. While 100 ppm was the most effective application in 'Jan Reus' and 'Yokohama' in terms of root development, the effect of the applications in 'Bloody Mary' was lower than the control. The application that least increased root development was determined as 400 ppm in 'Jan Reus' and 200 ppm in 'Bloody Mary' and 'Yokohama'. Root growth was found to be negatively related to GA_3 content. High GA_3 is thought to negatively affect overall root growth, possibly by suppressing the effect of auxin. It is assumed that GA_3 produced by the plant itself may be sufficient for root development or may be effective at much lower dose applications. On the other hand, it has been determined that the effects of GA_3 application vary depending on the variety. According to these results, it is recommended to apply it at a dose of 200 ppm to ensure flowering by providing cooling in tulip cultivars and cut flower cultivation. High doses of GA_3 are not recommended for root development.

Keywords: tulips; GA_3; root analyzing; growing; flowering; plant height

Tulips are the most important geophytes in the world. Millions of tulip bulbs are sold annually and there are more than 5 000 registered cultivars (Kılıç 2018). The cultivars were mainly obtained from *Tulipa gesneriana* species (Bach, Sochacki 2013). Gibberellic acid (GA_3), one of the important growth regulators, has a significant effect on plant growth. Many plants grew larger shoots, leaves, stems, and roots as a result of the exogenous application of GA, which encouraged cell growth and division (Bose et al. 2013). In addition with three different blueberry varieties, foliar GA_3 spray greatly improved bloom return (Zang et al. 2016). In the absence of gibberellin, the internode length of the plant may not extend as much as in the presence of gibberellin, and therefore plant development may not be at the desired level (Da Silva Vieira et al. 2010). Saniewski et al. (2010) reported that gibberellins, together with auxin, control internode elongation and thus tulip stem growth in tulips. Root growth of pot-grown plants is a central element in overall plant performance. A strong root structure positively affects crop productivity by increasing water and plant nutrient intake and resistance to disease and pest factors (Bucksch et al. 2014). In addition root structure could change depending on the plant type and variety (Praveen et al. 2009; Kul et al. 2020). It is not very easy to examine the root structure. For this

https://doi.org/10.17221/174/2023-HORTSCI

reason, the number of studies based on the phenotypic characteristics of the root is generally quite low. Many advances have been made in root measurements in recent years. Techniques such as plant image analysis software that can be easier, faster, reproducible and more descriptive of root growth have been developed (Judd et al. 2015).

In this study, the effects of GA_3 application on the development of above-ground vegetative properties and root architectural characteristics of three tulips cultivars were investigated. It is known that GA_3 applications applied to different tulip species and cultivars increase some plant above-ground characteristics such as plant height, flower height, flower stem length and number of flowers (Vanbragt, Zijlstra 1971; Suh 1997; Zengin, Kelen 2016). However, studies on the effects of root architectural features on the development of tulip species and cultivars are limited. In this study, the effect of GA_3 application on root architectural features along with the development of the above-ground parts of the plant were both evaluated and revealed what effects GA_3 exongenous application had on root architectural development. The most effective dose of GA_3 was determined to promote both good above-ground vegetative development and root growth.

MATERIAL AND METHODS

The research was carried out at the Black Sea Agricultural Research Institute, Samsun, Türkiye.

Plant material. In the study, tulip bulbs with a circumference of 12 cm and over (12/+) belonging to the red colored 'Jan Reus', 'Bloody Mary' and yellow colored 'Yokohama' Triumph cultivars used as cut flowers from the were used. Tulip bulbs were obtained from a Asian Tulip company. Before planting, the tulip bulbs were sprayed with fungicide (Captan 50 WP) and allowed to dry. Dried bulbs were planted in 2 L pots containing peat + perlite (3 : 1) mixture, one in each pot. Plantings were done in September 2021. The pots were placed in a suitable area in the institute garden. During the experiment period (Eylül-Nisan), the average temperature was measured as 20 ± 3 °C and humidity as 70 ± 5%.

Experimental design

GA_3 applications. Gibberellic acid (GA_3) at 0, 100, 200 and 400 ppm were applied. GA_3 solutions were put into a 2 L hand-held pressure spraying pump and sprayed in such a way that all parts of the plants were wet completely. The application was made when the plants were 15 cm tall. Considering the dryness of the pot soil, 200 mL irrigation was applied to each pot. Fertilization was not done.

Measurements of above-ground vegetative characteristics. The experiment was set up with three repetitions of each application and 7 plants in each repetition. A total of 21 plants were measured for each application. Measurements were made in the second week of April, when tulips were in full bloom. In measurements: plant height (cm) (measured from the soil surface to the tip of the plant with a ruler), plant width (cm) (measured from the widest part of the plant with a ruler), flower stem length (cm) (the part from the soil level to the flower base was measured with a ruler), flower diameter (mm) (flower diameter was measured with a digital caliper), perianth length (mm) (the distance between the lowest part of the flower and the tip of the flower was measured with a digital caliper), leaf length (cm) (flower leaf length was measured with a ruler), leaf number (the number of leaves in a plant was determined) and number of blooming flowers (the number of blooming flowers in each application was determined) was measured.

Measurements of root architecture. WinRhizo root analysis program (Instuments, 2013) was used to examine the root architectures. Plant roots removed from the pots were carefully washed and dried with paper towels. After drying, the roots were placed on the scanner (Epson Expression 10000XL, Epson America Inc., Long Beach, CA, USA) and images were transferred to the computer in three dimensions (Figure 1).

The following parameters of root structure and rooting levels were examined with the WinRhizo program. WinRhizo software allowed us to determine total root length (cm), root surface area (cm^2), root volume (cm^3), average root diameter (mm), number of tips, number of forks, and number of crossings.

Data evaluation. The research was established according to a completely randomized design. Three different GA_3 treatments, and a control group were used for applications. Each replication had a single bulb and 21 plants for each treatment were evaluated. Variance analysis was performed using SPSS statistical software version 20.0 and differences between threatments compared with Duncan multiple comparison test (within 5% error limits). Also, the relationships between treatments and plant cha-

https://doi.org/10.17221/174/2023-HORTSCI

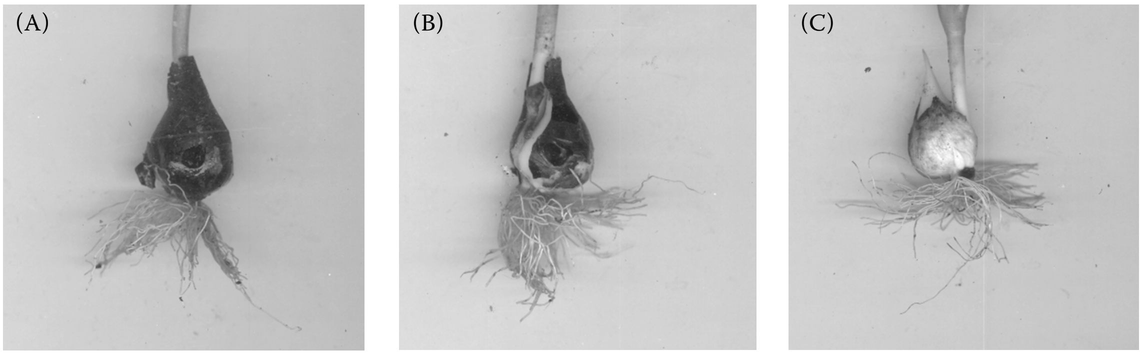


Figure 1. Measurement of tulips roots with 3D scanning WhinRhizo program
(A) 'Jan Reus' roots; (B)'Bloody Mary' roots; (C) 'Yokohama' roots

racteristics were determined in Pearson's correlations (within 5% and 1% error limits).

RESULTS

It was determined that 200 ppm application was the best treatment that increased plant height by 7.7% and 1.1% in 'Jan Reus' and 'Yokohama', respectively, compared to the control. The least increase in plant height was found to be 7.4% and 7.3% in 400 ppm treatment in 'Jan Reus' and 'Yokohama', respectively. Different results were obtained in 'Bloody Mary' compared to the other two cultivars. Accordingly, an increase of 30.7% was found in 'Bloody Mary' at 400 ppm application compared to the control, while the lowest increase was 22.6% at 100 ppm (Table 1).

In 'Jan Reus' and 'Yokohama', 400 ppm application increased the plant width by 29% and 35%, respectively, while the lowest plant width increase was found in control plants. In 'Bloody Mary', while 200 ppm increased plant width by 15% compared to the control, a 9.5% lower plant width increase was found in 400 ppm application compared to the control (Table 1).

In 'Jan Reus' and 'Yokohama', 200 ppm application increased flower stem lengt by 12.5% at the same rate compared to the control. In 'Jan Reus', 400 ppm was 6.7% lower than the control, while in 'Yokohama', the lowest increase was detected in control plants. In 'Bloody Mary', 400 ppm increased flower stem lengt by 32% compared to the control, while the lowest increase was obtained from control plants (Table 1).

Table 1. Effects of different GA_3 applications on vegetative properties

Cultivar	Aplication	Plant height	Plant width	Flower stem length	Flower diameter	Length of perianth	Leaf length (cm)	Number of leaves	Number of flowers	Average
		(cm)			(mm)					
Jan Reus	Control	36.5^{ab}	21.3^{c}	31.8^{b}	56.8^{b}	58.3^{a}	17.2^{a}	3.0	4^{b}	28.6^{b}
	100	38.0^{a}	21.5^{c}	35.3^{a}	54.3 c	54.2^{b}	17.8^{a}	3.7	5^{b}	28.7^{b}
	200	39.3^{a}	24.9^{b}	35.8^{a}	64.4^{a}	58.2^{a}	17.9^{a}	3.3	10^{a}	31.7^{a}
	400	34.0^{b}	27.5^{a}	29.8^{b}	59.8^{ab}	58.0^{a}	15.4^{b}	3.7	6^{b}	29.3^{ab}
Bloody Mary	Control	26.1^{c}	15.0^{b}	20.2^{c}	50.8^{c}	61.5^{c}	12.3	3.0	4^{c}	20.9^{b}
	100	32.0^{b}	16.0^{ab}	25.5^{b}	53.8^{a}	64.5^{a}	13.3	3.0	10^{b}	27.3^{a}
	200	27.5^{c}	17.3^{a}	22.0^{c}	52.1^{ab}	62.6^{b}	13.5	3.3	13^{a}	26.4^{ab}
	400	34.1^{a}	13.7^{c}	26.7^{a}	51.2^{b}	63.3^{ab}	13.1	3.3	10^{b}	26.9^{ab}
Yokohama	Control	26.3^{a}	17.2^{c}	19.2^{b}	45.3^{b}	62.8^{a}	15.1^{b}	3.3	3^{b}	24.0^{ab}
	100	25.6^{ab}	18.9^{bc}	19.7^{b}	42.2 c	56.7^{b}	13.0^{c}	3.3	4^{b}	22.9^{b}
	200	26.6^{a}	19.9^{b}	21.6^{a}	50.7^{a}	57.9^{b}	13.7^{c}	3.0	8^{a}	25.2^{a}
	400	24.5^{b}	23.3^{a}	19.3^{b}	45.9^{b}	58.6^{ab}	15.4^{a}	3.7	4^{b}	24.3^{ab}

$^{a–c}$Significant difference between the means with different letters (Duncan) within the error limits of $P < 0.05$.

https://doi.org/10.17221/174/2023-HORTSCI

Flower diameter increased by 13% and 12% in 'Jan Reus' and 'Yokohama' with 200 ppm application compared to the control, respectively. In 'Jan Reus' and 'Yokohama', flower diameter was 4.4% and 6.8% lower than the control at 100 ppm, respectively. In 'Boody Mary', an increase of 5.9% was detected at 100 ppm compared to the control, while the lowest flower diameter increase was obtained from the control (Table 1).

The data obtained showed that control, 200 and 400 ppm treatments had the same effect on length of perianth in 'Jan Reus', while in 'Yokohama', the best results were obtained only from control plants. Again, in 'Jan Reus' and 'Yokohama', the lowest results were obtained from 100 ppm at 7% and 9.7%, respectively. In 'Bloody Mary', 4.9% increase was found at 100 ppm compared to the control, while the lowest result was obtained from control plants (Table 1).

While the control, 100 and 200 ppm treatments had the same effect on leaf length in 'Jan Reus', leaf length increased 10% less than the control in 400 ppm treatment. On the contrary, in 'Yokohama', a 2% increase was detected in 400 ppm application compared to the control, while a 14% lower increase was detected at 100 ppm compared to the control. On the other hand, treatments had no effect on leaf length in 'Bloody Mary'. Similarly, the effect of the treatments on the number of leaves was found to be insignificant (Table 1).

It was determined that the most effective application on the number of flowers in 'Jan Reus', 'Bloody Mary' and 'Yokohama' was 200 ppm, and it was the application that increased the number of flowers the most by 150%, 225% and 167%, respectively, compared to the 200 ppm control. The lowest number of flowers was found in control plants in all three cultivars. However, it was also determined that the number of flowers was quite low compared to the number of bulbs planted for each application (Table 1).

The effects of GA_3 applications on root architectural features in 'Jan Reus', 'Bloody Mary' and 'Yokohama' are given in Table 2. In 'Jan Reus' and 'Yokohama' cultivars, the longest roots were found in control plants. In 'Bloody Mary', 400 ppm increased root length by 16% compared to the control. Again, compared to the control, root length was found to be by 29% lower in 'Jan Reus' at 400 ppm application, 15% lower in 'Bloody Mary' at 200 ppm application, and 31% lower in 'Yokohama' (Table 2, Figure 2).

'Jan Reus' increased root surface area by 17% compared to 100 ppm control. In 'Bloody Mary' and 'Yokohama', the effect of the treatments was lower than the control. Root surface area was found to be 23% lower in 'Jan Reus' at 400 ppm application, and 46% and 48% lower in 'Bloody Mary' and 'Yokohama' at 200 ppm application, respectively, compared to the control (Table 2, Figure 2).

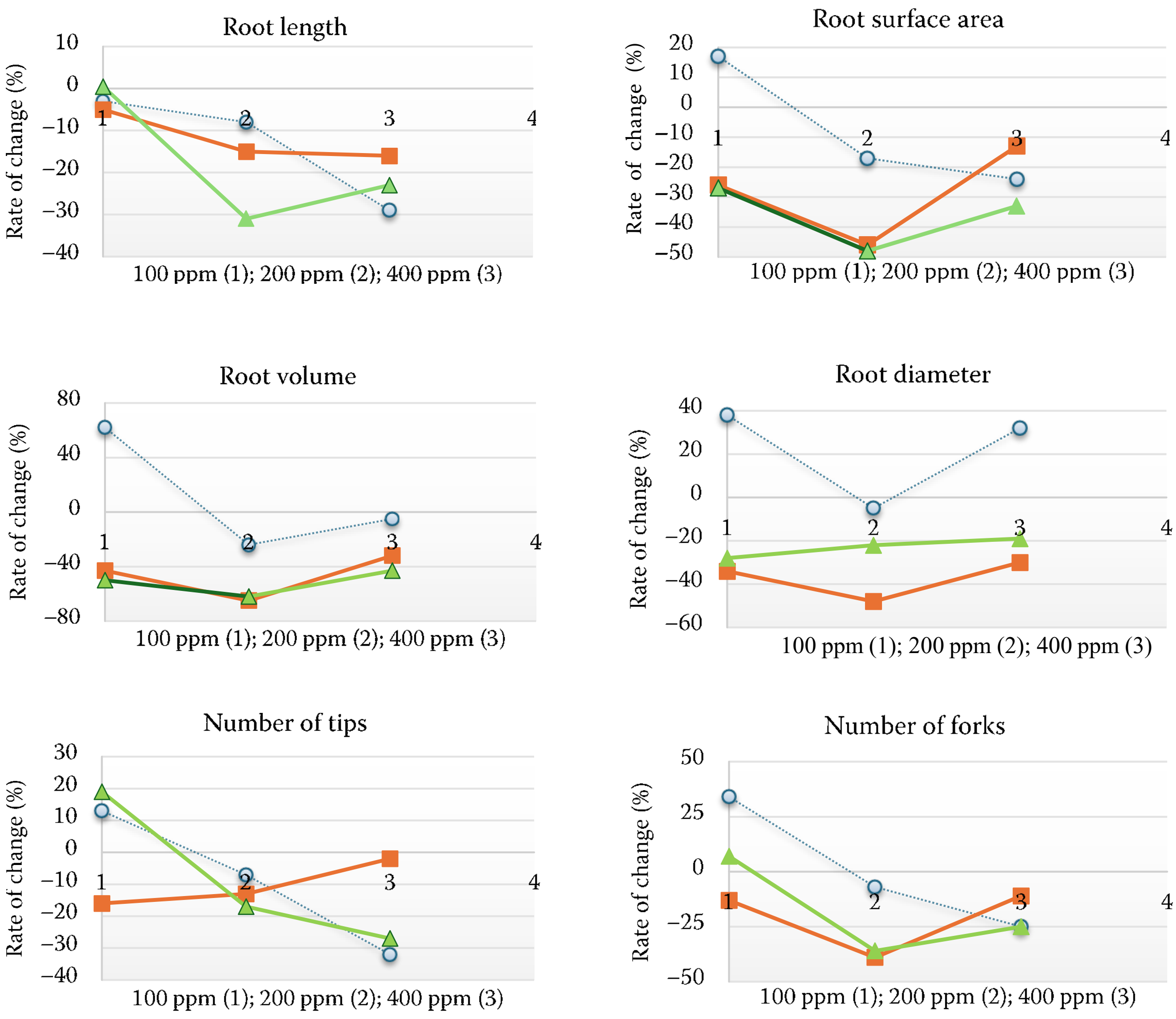
At 100 ppm application in 'Jan Reus', root volume increased by 62% compared to the control. In 'Bloody Mary' and 'Yokohama', the highest root volume was found in control plants. Root volume was found to be 47%, 65% and 62% lower

Table 2. Effects of different GA_3 applications on plant root architectural features

Cultivar	Aplication	Root length (cm)	Root surface area (cm^2)	Root volume (cm^3)	Root diameter (mm)	Number of tips	Number of forks	Number of crossings	Average
Jan Reus	Control	574^a	275^{ab}	1.05^{ab}	1.52^b	367^{ab}	889^b	63^b	310^b
	100	557^{ab}	321^a	1.70^a	2.10^a	416^a	1188^a	101^a	370^a
	200	529^{ab}	229^b	0.80^b	1.45^b	341^b	824^b	54^b	283^c
	400	406^b	210^b	1.00^{ab}	2.00^a	250^c	66^c	59^b	227^d
Bloody Mary	Control	496^b	285^a	1.37^a	1.90^a	416^a	877^a	65^b	306^a
	100	472^b	210^b	0.78^b	1.25^b	344^b	758^b	79^a	266^b
	200	421^c	154^c	0.48^c	0.99^c	360^b	527^c	38^c	214^c
	400	577^a	249^{ab}	0.93^b	1.33^b	406^a	778^b	55^b	295^{ab}
Yokohama	Control	727^a	344^a	1.38^a	1.60^a	448^b	951^b	72^b	364^{ab}
	100	730^a	252^b	0.69^b	1.15^c	531^a	1016^a	114^a	377^a
	200	498^b	179^c	0.53^c	1.25^b	374^c	612^c	52^c	245^b
	400	561^b	232^b	0.78^b	1.30^b	325^c	710^{bc}	49^c	268^b

[a–d]Significant difference between the means with different letters (Duncan) within the error limits of $P < 0.05$

https://doi.org/10.17221/174/2023-HORTSCI



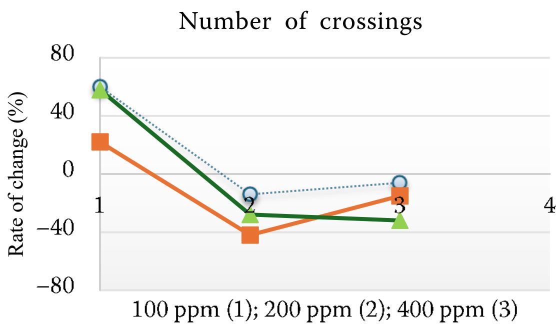


Figure 2. The rate of change of root architectural features compared to the control values of the analysis results after GA_3 applications

in all three species, respectively, in the 200 ppm application compared to the control (Table 2, Figure 2).

In 'Jan Reus', root diameter increased by 38% in 100 ppm treatment compared to the control. In 'Bloody Mary' and 'Yokohama', the highest root diameter was obtained from control plants. Root diameter was 4.6% and 48% lower in 'Jan Reus' and 'Bloody Mary' at 200 ppm treatment and 28% lower in 'Yokohama' at 100 ppm treatment compared to control (Table 2, Figure 2).

In 'Jan Reus' and 'Yokohama', 100 ppm application increased the number of tips by 13% and 18.5%, respectively, compared to the control. In 'Bloody Mary', the effect of the treatments was found to be lower than the control. According to the number of tips control, it was found to be 32% and 27% lower in 'Jan Reus' and 'Yokohama' at 400 ppm applica-

https://doi.org/10.17221/174/2023-HORTSCI

tion, respectively, and 17% lower in 'Bloody Mary' at 100 ppm application (Table 2, Figure 2).

In 'Jan Reus' and 'Yokohama', 100 ppm application was the best application that increased the number of forks by 33.6% and 6.8%, respectively, compared to the control, while in 'Bloody Mary', the effect of the applications remained low compared to the control. According to the number of forks control, it was found to be 25% lower in 'Jan Reus' at 400 ppm application, and 40% and 36% lower in 'Bloody Mary' and 'Yokohama' at 200 ppm application, respectively (Table 2, Figure 2).

100 ppm application was found to be the application that increased the number of crossing the most in 'Jan Reus', 'Bloody Mary' and 'Yokohama' by 60%, 22% and 58%, respectively, compared to the control. Number of crossing control was found to be 14%, 42% and 28% lower in all three cultivars, respectively, at 200 ppm application. When the application averages were examined according to species, 100 ppm was the best application in increasing root development in 'Jan Reus' and 'Yokohama', while the effect of the applications in 'Bloody Mary' was lower than the control. Again, while 200 ppm in 'Bloody Mary' and 'Yokohama' was the lowest application in terms of root development, 400 ppm in 'Jan Reus' was the lowest application in terms of root development (Table 2, Figure 2).

Correlation analysis of the relationships between growth and rooting parameters. When Table 3 was examined, it was found that the relationship between applications and root diameter was negative and significant at the $P < 0.05$ level, a positive and insignificant relationship with leaf length, number of blooming flowers, root length, and a negative and insignificant relationship with all other characteristics (Table 3). It was determined that there was a positive correlation between plant height and flower stem length, flower bud diameter, leaf length at $P < 0.01$ level, a significant correlation at $P < 0.01$ level between root length and root surface area and a negative correlation at $P < 0.05$ level between root volume. (Table 3). There was a significant correlation between plant width and leaf length at $P < 0.05$ level. There was a positive and significant correlation at $P < 0.01$ level between flower stem length and flower bud diameter and leaf length, a negative correlation between root length and root surface area and a significant correlation at $P < 0.01$ level (Table 3). A positive and significant relationship at $P < 0.01$ level was determined between flower bud diameter and length of perianth, leaves length, fork and crossing. There was a positive and significant correlation at $P < 0.05$ level between leaf length and fork. A negative insignificant relationship was found between the number of flowers and all root parameters (Table 3). Sarıbaş et al. (2019) found a significant and positive relationship between total root length and surface area in a study on eggplant rootstocks. However, they found a negative relationship between total root length and mean root diameter and volume. Bouma (2000) reported that root length and diameter distribution are important features to consider when describing and comparing root systems. In our study, a significant and negative relationship was found between the applications and the mean root diameter. While it increased the root diameter of the applications in 'Jan Reus', it decreased it in 'Bloody Mary' and 'Yokohama'. The small root diameter is an important indicator of the plant's desire to reach food and water. It is also a measure of the adaptability of these plants. The reduction in root diameter can be explained as follows in this study; GA_3 applied to the plant significantly stimulated the growth of the upper part of the plant. For this reason, the existing assimilates in the plant were used in the development of the above-ground part. As a result, it was concluded that the plant needed more nutrients and therefore, in order to get more nutrients, the root architecture was changed and the root diameters were reduced. The result of this analysis shows that it would be useful to consider root diameter values in studies on root parameters (Table 3).

DISCUSSION

Effect of GA_3 on above-ground vegetative properties. Three different doses of GA_3 were statistically effective in all three types. 200 ppm GA_3 application was the most effective in 'Jan Reus' and 'Yokohama', and 100 ppm GA_3 application was the most effective in 'Bloody Mary'. While the most effective application in increasing plant height in 'Jan Reus' and 'Yokohama' was 200 ppm, it was 400 ppm in 'Bloody Mary'. Again, in 'Jan Reus' and 'Yokohama', a lower growth was detected in the 400 ppm application compared to 200 ppm in plant height. On plant width, 200 ppm was more effective in 'Bloody Mary' and 400 ppm in 'Jan Reus' and 'Yokohama'. In terms of flower stem length, 200 ppm was found to be more effective in 'Jan Reus' and 'Yokoha-

Table 3. Correlations between vegetative features and root architectural features

	Plant width (cm)	Flower stem length (cm)	Flower bud diameter (mm)	Length of perianth (mm)	Leaf length (cm)	Number of leaves	Number of flowers	Root lenght (cm)	Root surface area (cm^2)	Root volume (cm^3)	Root diameter (mm)	Number of tips	Number of fork	Number of crossings
Applications	–0.036	–0.005	–0.02	–0.265	0.016	–0.139	0.286	0.400	–0.089	-0.117	–0.311*	–0.099	–0.228	–0.257
Plant height (cm)	0.202	0.950**	0.501**	0.271	0.584**	–0.044	0.049	–0.631**	–0.628**	0.342*	0.263	0.032	0.290	0.040
Plant width (cm)		0.259	0.273	0.051	0.348*	0.120	–0.198	0.015	0.097	0.152	0.126	–0.189	–0.042	–0.108
Flower stem length (cm)			0.476**	0.145	0.636**	0.039	0.055	–0.640**	–0.646**	0.321	0.288	–0.080	0.231	0.000
Flower bud diameter (mm)				0.573**	0.486**	–0.011	–0.056	–0.048	–0.059	0.223	–0.052	0.252	0.541**	0.473**
Length of perianth (mm)					0.173	–0.049	0.042	0.010	0.055	0.141	–0.093	0.120	0.239	0.115
Leaf length (cm)						–0.005	–0.127	–0.147	–0.130	0.253	0.118	0.126	0.386*	0.222
Number of leaves							–0.229	0.000	0.009	0.142	–0.006	0.112	0.201	0.087
Number of flowers								–0.549	–0.565	–0.234	–0.168	–0.135	–0.204	–0.329

**$P < 0.01$; *$P < 0.05$

https://doi.org/10.17221/174/2023-HORTSCI

ma', while 400 ppm was found to be more effective in 'Bloody Mary'. In terms of flower diameter, 200 ppm was more effective in 'Jan Reus' and 'Yokohama', and 100 ppm was more effective in 'Bloody Mary'. The effects of GA_3 on length of perianth were found to be different in each variety. In the research conducted by Zengin and Kelen (2016), the highest plant height, flower height, flower stem length and flower diameter of 'Cafe noir' and 'Conqueror' tulip cultivars were determined in 300 ppm GA_3 application. In our study, cultivars responded differently to the applications. This situation supports studies reporting that different species and varieties respond differently to applications. As a matter of fact, it has been reported that the responses of plant species to chemical applications vary (Jones, MacMillan 1985).

Masud (1995) reported that GA_3 increased leaf proliferation and the highest number of leaves per plant was obtained from cloves treated with 100 and 200 ppm GA_3. However, in this study, GA_3 applications did not have any effect on the number of leaves.

In the literature, it has been observed that GA_3 generally causes an increase in the number of flower buds or the number of flowers or panicles. In his study on 'Apeldoorn' and 'Golden Apeldoorn' tulip cultivars, Suh (1997) determined that he kept the cultivars at 5 °C for 6, 9 and 12 weeks and injected GA_3, GA_{4+7} and promalin into the bulbs before planting. It was observed that promalin and gibberellins increased flowering in both cultivars. Since the highest number of flowers was obtained at 200 ppm dose in all three cultivars in this study, it can be said that 200 ppm dose is the optimum dose in terms of flower number. It was determined that the number of flowers was lower in the 400 ppm application compared to the 200 ppm dose. In the study conducted by Zengin and Kelen (2016) on 'Conqueror' and 'Cafe noir' cultivars, the flowering rate was obtained from a dose of 300 ppm, but it was determined that the flowering rate decreased in the application of 700 ppm GA_3. It is known that this situation is probably due to the high dose of 700 ppm application. Rossi et al. (2004) also reported that some plants, in particular, may be negatively affected by high dose applications. According to the results of this study, it was determined that in the application of doses higher than the GA_3 doses determined as the optimum dose, plant property values were lower than the values obtained at the optimum dose, similar to the findings of the researchers (Table 1, Figure 2). In addition, the lowest flowering rates in all three cultivars were determined in the control application. Hormone doses appear to significantly increase flowering rates. This situation is thought to be related to the fact that GA_3 application is effective in meeting the cooling need of tulip bulbs and ultimately increases the flowering rate. In this regard, the findings are similar to the findings of (Vanbragt, Zijlstra 1971; Zengin, Kelen 2016), who reported that the flowering rate decreased or no flowers were formed in tulip bulbs that were not adequately cooled (Table 1).

Impact on root architecture features of GA_3. In this study, GA_3 applications had an increasing effect on the root architectural features of 'Jan Reus' such as root surface area, root volume, root diameter, number of forks and number of crossings, while its effect on root length remained low compared to the control. While root length and number of crossings increased in 'Bloody Mary', its effect on root surface area, root volume, root diameter, number of tips and number of forks remained low compared to the control. As for 'Yokohama', while the number of tips, number of forks and number of crossings increased, its effect on root length, root surface area, root volume and root diameter remained low compared to the control. (Table 2, Figure 2). According to the results, it was determined that the reactions of different cultivars to the applications were different. In fact, it is known that the morphology of a root system can be complex and vary greatly even within a species (Hodge 2009; Sarı, Çelikel 2021).

These results reveal two results when compared with the studies of previous researchers;

It suggests that external application of GA_3 limits root growth by blocking the effect of auxin. As a matter of fact, this situation confirms the information that GA_3 is synthesized in the root and transported to a large extent from the root to the above-ground organs, and that it is responsible for regulating the activity of auxin, which is carried only from the above-ground organs to the root in the root region. It was determined that polar auxin transport plays an important role in the development of lateral roots (Casimiro et al. 2001). It was reported that removal of apical tissues or application of polar transport inhibitors inhibits lateral root development (Reed et al. 1998). Rahim and Alamgir (1995) reported that GA_3 inhibited root growth in *Colocasia esculenta*. However, the absence of GA_3 in the root zone was found to cause a decreased root elongation

https://doi.org/10.17221/174/2023-HORTSCI

rate. This is an indication that there is a minimum requirement for GA for cell growth in plant roots (Tanimoto 1991). Indeed, Barlow (1992) determined that the root meristems of the 9ib-1 mutant of the GA-deficient tomato displayed shorter and wider meristematic cells compared to the root meristems of wild types. It was reported that this indicates that GAs are involved in the morphogenetic control of root development. Baluška (1993) similarly reported that low gibberellin concentration in root tissues causes root thickening. In this study, plant root diameters of 'Bloody Mary' and 'Yokohama', except for 'Jan Reus', were found to be higher in control plants than those treated with GA_3 (Table 2, Figure 2). This was also expressed by Ud-Deen and Kabir (2011), where GA_3 treated roots were thinner than water-treated plants. According to Rahman et al. (2006), the number of roots in carnations was the highest at 250 ppm, and it decreased with further increase in GA_3, and they reported that the differences in optimum concentration might be due to cultivar characteristics. Again, in this study, although it varied depending on the variety, as the dose increased, the development of the architectural features of the root was found to be lower than the optimum dose (Table 2, Figure 2).

In tulip cultivars, very low doses of GA_3 promote root growth with auxin. If a higher dose than the optimum dose is applied externally, this negatively affects root growth. This issue was explained by arguing that GAs control the growth of stem cells at lower concentrations than in above-ground shoot organs (Tanimoto 1991). Gibberellins applied to intact root systems appear to have highly variable effects. It was reported that gibberellins promote root growth in some plant species but inhibit it in others (Feldman 1984). These facts indicate that roots, like auxins, require extremely low levels of gibberellin for their normal growth; therefore, very low concentrations of gibberellins may be sufficient for root growth. It is also supported by current results that normal growth of roots requires a much lower level of gibberellin than the development of above-ground organs. Roots synthesize gibberellins that are transported to shoots, although there is insufficient data on how much GA_3 is absorbed by the roots and transported to the aerial parts. Therefore, it was reported that gibberellins can regulate normal root growth at a much lower concentration range than shoot growth by cooperating with low levels of auxins (Tanimoto 1987). When this study was evaluated according to these results, it was concluded that giberalins produced by the plant did not limit root growth. Because the plant produces as much as it needs. For this reason, externally given gibberellins adversely affected root development in tulip cultivars as it would increase the optimum dose in the plant. In addition, it was revealed in this study that less amount of giberalin should be applied from the stem for root elongation (Table 2, Figure 2). Again, reduction of endogenous GA levels by treating plants with Paclobutrazol (PAC, a GA biosynthesis inhibitor) was reported to result in reduced root growth rate (Ubeda-Tomás et al. 2009). Thus, supporting and maintaining the increase in root growth rate through control of root meristem size. In the research, the GA_3 application with the lowest development of root architectural features compared to control plants was determined as 400 ppm (27%) in 'Jan Reus' and 200 ppm (30% and 33%) in 'Bloody Mary' and 'Yokohama' (Table 2, Figure 2). As a matter of fact, it was reported that natural gibberellins, like auxins, can be inhibitory at superoptimal concentrations. In addition, excessive GA producing mutations and exogenous GA applications in poplar (*Populus tremula*) and rice (*Oryza sativa*), led to suppression of lateral and incidental root formation (Gou et al. 2010; Lo et al. 2008). This study results were supported by the findings of the researchers.

CONCLUSION

Based on the current findings, it has been determined that GA_3 applications are effective in improving the above-ground parts and root architectural features of plants, but GA_3 application at higher than the effective dose can suppress the development of these features. While it was seen that the application that increased the above-ground properties of the plant the most was 200 ppm in 'Jan Reus' and 'Yokohama' and 100 ppm GA_3 in 'Bloody Mary', the application that increased the root properties the most was generally 100 ppm in 'Jan Reus' and 'Yokohama', while the application in 'Bloody Mary' was 100 ppm. The effect was found to be lower than the control. It was determined that 200 ppm GA_3 was the application with the lowest root architectural properties. In addition to these effects of GA_3, 200 ppm significantly increased flowering in tulip cultivars used as ornamental plants. This strengthens

https://doi.org/10.17221/174/2023-HORTSCI

the assumption that 200 ppm GA_3 application may be the optimum dose to increase flowering by meeting the chilling need in tulip cultivars. However, this cannot be said for the development of root architectural features. It is thought that GA_3, produced by the plant itself, may be sufficient for the development of root architectural features in 'Bloody Mary' or may be effective at much lower dose applications. It was found that the results obtained varied according to the cultivars. According to these results, recommended to apply GA_3 spray at a dose of 200 ppm to ensure flowering by providing cooling in tulip varieties and cut flower cultivation. High doses of GA_3 are not recommended for root development. Moreover, more detailed studies are needed for root development in tulips.

REFERENCES

Bach A., Sochacki D. (2013): Ornamental geophytes from basic science to sustainable production; phsiology and management systems. Ornamental Geophytes. From Basic Science to Sustainable Production. CRC Press.

Bouma T.J., Nielsen K.L., Koutstaal B.A.S. (2000): Sample preparation and scanning protocol for computerised analysis of root length and diameter. Plant and Soil, 218: 185–196.

Bucksch A., Burridge J., York L. M., Das A., Nord E., Weitz J.S., Lynch J.P. (2014): Image-based high-throughput field phenotyping of crop roots. Plant Physiology, 166: 470–486.

Casimiro I., Marchant A., Bhalerao R.P., Beeckman T., Dhooge S., Swarup R., Bennett M. (2001): Auxin transport promotes Arabidopsis lateral root initiation. The Plant Cell, 13: 843–852.

Da Silva Vieira M.R., Citadini V., Lima G.P.P., de Souza A.V., de Souza Alves L. (2010): Use of gibberellin in floriculture. African Journal of Biotechnology, 9: 9118–9121.

Feldman L.J. (1984): Regulation of root development. Annual Review of Plant Physiology, 35: 223–242.

Gou J., Strauss S.H., Tsai C.J., Fang K., Chen Y., Jiang X., Busov V.B. (2010): Gibberellins regulate lateral root formation in Populus through interactions with auxin and other hormones. The Plant Cell, 22: 623–639.

Hodge A., Berta G., Doussan C., Merchan F., Crespi M. (2009): Plant root growth, architecture and function. Plant and Soil, 321: 153–187.

Judd L.A., Jackson B.E., Fonteno W.C. (2015): Advancements in root growth measurement technologies and observation capabilities for container-grown plants. Plants, 4: 369–392.

Kılıç Ö. (2018): Bulbs Surface-Sterilization Protocol for *Tulipa julia* C. Koch from Turkey. Central European Journal of Botany, 4: 7–11.

Kul R., Ekinci M., Turan M., Ors S., Yildirim E. (2020): How abiotic stress conditions affects plant roots. IntechOpen: 6–10.

Lo S.F., Yang S.Y., Chen K.T., Hsing Y.I., Zeevaart J.A., Chen L.J., Yu S.M. (2008): A novel class of gibberellin 2-oxidases control semidwarfism, tillering, and root development in rice. The Plant Cell, 20: 2603–2618.

Masud A. (1995): Effects of planting date, growth regulators and cold treatments on the growth and yield of garlic [M.S. Thesis]. Department of Horticulture, Bangladesh Agricultural University.

Praveen N., Manohar S.H., Naik P.M., Nayeem A., Jeong J.H., Murthy H.N. (2009): Production of androghrapholide from adventitious root cultures of Andrographis paniculata. Current Science, 96: 5–10.

Rahim M.A., Alamgir M. (1995): Effect of paclobutrazol and gibberellic acid on the growth of late planted mukhi kachu (*Colocasia esculenta*). Progressive Agriculture, 6: 39–46.

Rahman M.H., Haque M.S., Karım M.A., Ahmed M. (2006): Effects of gibberellic acid (GA_3) on breaking dormancy in garlic (*Allium sativum* L.). International Journal of Agriculture and Biology, 2: 4.

Reed R.C., Brady S.R., Muday G.K. (1998): Inhibition of auxin movement from the shoot into the root inhibits lateral root development in Arabidopsis. Plant Physiology, 118: 1369–1378.

Rossi A.D., Rufato L., Giacobbo C.L., Gomez F.R.C., Fachinello J.C. (2004): Use of Promalin on one-year old tree of the apple cv. "Catarina". Acta Horticulturae (ISHS), 636: 145–149.

Saniewski M., Okubo H., Miyamoto K., Ueda J. (2010): The role of endogenous gibberellin in tulip stem growth induced by IAA and IBA: Relevance to inhibitors of gibberellin biosynthesis. In XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on Plant, 932: 397–403.

Ömer S., Çelikel, F.G. (2021): Determination of root properties of saplings belong to two boxwood species (*Buxus sempervirens* and *Buxus balearica*) by image processing technique. Turkish Journal of Food and Agriculture Sciences, 3: 20–24.

Sarıbaş S., Balkaya A., Kandemir D., Karaağaç O. (2019): The phenotypic root architectures and rooting potential of local eggplant rootstocks (*Solanum melongena* × *Solanum aethiopicum*). Black Sea Journal of Agriculture, 2: 137–145.

Sochacki D. (2013): The occurrence of the viruses in tulip crops in Poland. Journal of Horticultural Research: 21.

Suh J.K., Cho H.J. (1997): Stem elongation and flowering response to temperature treatment at various growth stage of tulip. Journal of the Korean Society for Horticultural Science, 38: 739–743.

https://doi.org/10.17221/174/2023-HORTSCI

Tanimoto E. (1987): Gibberellin-dependent root elongation in *Lactuca sativa*: recovery from growth retardant-suppressed elongation with thickening by low concentration of GA_3. Plant and Cell Physiology, 28: 963–973.

Tanimoto E. (1991): Gibberellin requirement for the normal growth of roots. In: Takahashi N., Phinney B.O., MacMillan J. (eds) Gibberellins. Springer, New York.

Ud-Deen M.M., Kabir G. (2009): Effects of growth regulators on root tip cells of onion. Bangladesh Journal of Botany, 38: 99–102.

Vanbragt J., Zijlstra F.A. (1971): Effects of gibberellins on flowering of tulip cv 'Apeldoorn'. Zeitschrift fur Pflanzenphysiologie, 64: 139–144.

Zang Y.X., Chun I.J., Zhang L.L., Hong S.B., Zheng W.W., Xu K. (2016): Effect of gibberellic acid application on plant growth attributes, return bloom, and fruit quality of rabbiteye blueberry. Scientia Horticulturae, 200: 13–18.

Zengin G., Kelen M. (2016): Lale yetiştiriciliğinde büyüme, gelişme, kalite ve erkencilik üzerine gibberellik asit (GA_3) uygulamalarının etkileri, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 20: 206–214.

Received: November 28, 2022
Accepted: December 19, 2023
Published online: September 11, 2024