

EFFECT OF GIBBERELIC ACID ON GROWTH, TUBER YIELD AND QUALITY IN POTATOES (*Solanum tuberosum* L.)

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ABSTRACT

The purpose of this study was to determine the effects of different doses of gibberellic acid (GA₃) on growth, tuber yield and some tuber quality traits of potato. The experiment was arranged in a split-plot design with three replicates, cultivars Marabel, Alegria and Agria were arranged in the main plots, and GA₃ doses (0, 25, 50 and 100 mg GA₃ L⁻¹) in the sub-plots. Gibberellic acid was applied to leaves by spraying on the 50th day after planting (during flowering). The effects of GA₃ applications on tuber yield of potato cultivars were varied. GA₃ applications resulted in significant decrease on chlorophyll content (SPAD), tuber dry matter and chips quality of potato. But it caused significant increase on number of tubers and tuber yield plant⁻¹. In 2019 and 2020 years, the highest tuber yield was obtained from Alegria cultivar (62.78 and 50.55 t ha⁻¹ respectively). Total tuber yield values increased from 52.08 t/ha to 65.14 t ha⁻¹ in 2019 and from 42.12 t ha⁻¹ to 53.94 t ha⁻¹ in 2020 with increasing to 100 mg GA₃ L⁻¹ from 0 mg L⁻¹. Overall, increasing doses of GA₃ resulted in a reduction in tuber dry matter and starch ratio. The GA₃ applications caused deformations in tuber shape, the deformations increased with increasing GA₃ doses.

Keywords: Dry matter content, gibberellic acid, *Solanum tuberosum*, SPAD, tuber yield

INTRODUCTION

Potato tubers have a domestic consumption (a few examples are finger, chips, flour, puree, starch, instant soup, etc.) and are also used in the production of alcohol and its derivatives. With industrialization, easy and pre-packaged consumption has a great effect on this usage. Starch is an important industrial raw material that is involved in the production of food, sugar, textiles, paper, glue, alcohol, and spirits, and potato tubers are used directly or as factory residues and animal feed. Tubers and dried stems are also used in animal nutrition (Caliskan et al., 2010).

Organic molecules that can affect the growth, development, and other physiological activity in the plant positively or negatively, can be transported to other parts of the plant and can show their activity in these organs are called hormones (phytohormone-plant growth regulators). Gibberellins (17%), one of the Natural Plant Growth Regulators, are among the most widely used plant hormones in the world (Kumlay and Eryigit, 2011). In plants gibberellins are abundant in buds, embryos, roots, young leaves, flowers, fruits, and cambiums. Among the Gibberellins, GA₃ (Gibberellic acid) is the most widely

used in agriculture. Gibberellins are known to be highly effective in increasing cell growth, breaking seed and bud dormancy, eliminating stunting, eliminating chilling needs, promoting germination, increasing longitudinal growth and branching (Algul et al., 2016).

Tuber formation in potatoes is a complex developmental process in which environmental, biochemical, and genetic factors play a role (Kolomiets et al., 2001). The initiation of stolon formation and the growth of stolons in potatoes is the beginning of tuber formation. After the longitudinal extension of the stolons stops, tuber formation begins and tuber growth continues (Sarkar, 2008). The initiation of stolon formation is associated with the accumulation of carbohydrates in the stems under the soil. However, the levels of carbohydrate accumulation required for the initiation of stolon is lower than that the initiation of tuber formation. Stolon formation is also associated with gibberellin levels in the plant (Abdala et al., 2000). External application of gibberellins promotes stolon growth (Vreugdenhil and Helder, 1992) but prevents tuber formation (Puzina, 2004). Tuber growth and development depend on

sufficient green component to provide adequate water and nutrients and produce the necessary assimilates.

Gibberellic acid promotes the number of stolon that enable tuber formation and it also ensures an increase in number of leaves that will help to provide assimilates required for tuber growth. The economic value of a potato is determined not only by the total tuber yield but also by the tuber size distribution and tuber dry matter content included in tuber quality property. Therefore, studies have been conducted to improve tuber quality, including plant growth regulators (Sarkar, 2008). It has been demonstrated that Gibberellins (GA) stimulate stem growth and stolon growth (Vreugdenhil and Helder, 1992), inhibit or delay tuber initiation (Sarkar, 2008), increase the number of tubers (Mikitzel, 1993; Njoqu et al., 2015), inhibit starch synthesis (Barani et al., 2013), reduce the dry matter and starch ratio, and increase the protein ratio (Javanmardi and Rasuli, 2017).

The purpose of the study was to determine the effects of different concentrations of gibberellic acid on plant growth, tuber formation, tuber yield, and some quality characteristics of some potato genotypes.

MATERIALS AND METHODS

Field experiment was conducted in the Research and Application Area of Nigde Omer Halisdemir University Faculty of Agricultural Sciences and Technologies, Department of Plant Production and Technologies in 2019 and 2020.

Soil samples were collected from experimental area at 0-30 cm depth before basal fertilizer application to test initial soil characteristics, and soil test results are presented in Table 1. The soil has a clay-loam structure, alkaline character, and a little organic matter content, and soils that are too calcareous have a salt-free character. The total nitrogen content is sufficient, the phosphorus (P_2O_5) content is low and the potassium (K_2O) content is high. The soil in which the study was conducted is sufficient in terms of iron (Fe) and copper (Cu) content, low in manganese (Mn) content, very high in magnesium (Mg) content, and high in calcium (Ca) content. The province of Nigde has a continental climate with hot and dry summers and cold and snowy winters. The daily climatic data were obtained from the General Directorate of Nigde Meteorology Services. The mean values of the climatic date are given in Table 2.

Table 1. Some physical and chemical characteristics of the 0-30 cm soil layer of the experimental site

Properties	Year 2019	Year 2020
Texture	Silt Clay	Silt Clay
pH ^a	8.09	7.95
Electrical conductivity ($\mu S\ cm^{-1}$)	0.027	0.010
CaCO ₃ (g kg ⁻¹)	21.16	21.80
Organic matter (g kg ⁻¹)	1.91	3.15
Total N (g kg ⁻¹)	0.142	0.138
Available P ₂ O ₅ (kg da ⁻¹)	3.16	10.85
Available K (kg da ⁻¹)	159.19	201.19
Fe (mg kg ⁻¹)	5.75	3.25
Cu (mg kg ⁻¹)	1.36	1.21
Mn (mg kg ⁻¹)	4.86	10.35
Zn (mg kg ⁻¹)	1.53	2.15
Mg (mg kg ⁻¹)	403.2	582.1
Ca (mg kg ⁻¹)	5688	5572

pH and Electrical conductivity were determined in saturation extracts.

^b N content was determined with Kjeldahl method.

^c Fe, Cu, Zn, Mg, Ca and Mn contents were determined with DTPA extraction method.

Three different potato cultivars; Marabel early, with ellipse tuber shape, yellow skin color; Alegria mid-early, with ellipse tuber shape, bright yellow skin color and Agria mid-late, with long ellipse tuber shape, yellow skin color were used as plant material. The experimental design was a split plot arrangement of randomized complete block with three replications. Main plots consisted of three cultivars. Sub-plot treatments had four GA₃ doses (0, 25, 50 and 100 mg GA₃ L⁻¹). Each plot consisted of 4 rows of 5.1 meters length and spacing between on the row was 70 × 30 cm. Seed tubers were planted by machine in a depth of 15-18 cm on 19 May 2019 and 20 May 2020. Four levels of GA₃ (0, 25, 50 and 100 mg GA₃ L⁻¹) were sprayed on the foliage of the plants using an atomizer at 50th days after planting. Control plots

were treated with distilled water at the same application time. Approximately 20 days after planting, emergence of plants was visible on the soil surface and emergence times differed according to the cultivars. For weed control, *Metribuzin* was applied to soil at the rate of 800 ml ha⁻¹ in the field before emergence and the plots were maintained as weed-free by hand weeding during growing period. Each plot was applied with a basal dose of phosphorus (P) and potash (K) fertilizers at the rate of 110 kg P + 110 kg K ha⁻¹ at the planting. Nitrogen was applied at the rate of 250 kg ha⁻¹ in split form (half at planting and half at tuber formation period) as a side dress in the form of urea. After planting, a sprinkler irrigation system was installed in the experimental area and regular irrigation was done at intervals of 5-7 days. On the 60th day after the emergence

of the shoots to the soil surface, leaf chlorophyll contents were determined through Minolta SPAD 502 Chlorophyll Meter in each plot. Potatoes were harvested on 01 October 2019 and on 15 September 2020. Ten plants were harvested at maturity from the first and fourth rows of each plot for measuring plant height (cm), number of stems plant⁻¹, number of tubers plant⁻¹, and tuber yield plant⁻¹. After harvesting, the number and weight of tubers over 25 mm and tubers smaller than 25 mm or no use-

value were counted and weighed separately. After the harvest, approximately 2 kg of potato samples were taken from each plot and their specific gravity was measured with the help of PW-2050 Digital Potato Hydrometer and dry matter ratios were calculated as based on specific gravity. Tubers obtained from all plants in the harvest area were weighed and the tuber yields of the plot for each application were determined.

Table 2. Monthly rainfall, temperature and relative humidity during the growing period of 2019 and 2020

Months	Mean Temperature (°C)			Rainfall (mm)			Relative humidity (%)		
	Long-term	2019	2020	Long-term	2019	2020	Long-term	2019	2020
May	15.1	17.6	16.0	48.7	26.2	21.2	52.7	46.7	52.3
June	19.1	21.3	19.8	27.9	43.4	26.7	51.3	52.3	47.9
July	22.4	22.2	24.6	5.2	8.3	0	39.5	43.9	40.5
August	22.3	22.6	22.5	6.6	6.0	0	40.2	47.0	35.0
September	18.0	18.2	22.0	10.5	6.0	2.4	40.6	47.3	43.5
October	12.2	15.1	12.0	26.7	13.7	0.1	53.6	55.6	40.8

*: Climate data provided from Nigde Meteorology Services General Directorate

The data was analyzed using standard technique of analysis of variance (ANOVA) and treatment means were separated by Least Significant Differences (LSD) at 5% probability level by using SAS statistical software packages version 9.00 as described by Steel and Torrie (1980).

RESULTS AND DISCUSSIONS

Yield and yield components

The variance sources and their statistical significance were shown in Table 3 and 4 for the yield, yield components and tuber quality. Data of variance analysis in Table 3 showed that the effect of the GA₃ applications on SPAD values were statistically significant at 1% probability level. The highest average leaf chlorophyll content was recorded in cultivar Agria (41.72) and the lowest average leaf chlorophyll value was recorded in cultivar Alegria (34.37) in both years (Table 5). The SPAD values of plants sprayed with GA₃ were lower than that of control. Previously, the study of Hou et al. (2018) also observed that the SPAD values were decreased as the amount of GA₃ increased. Similarly, Wang et al. (2018) reported that leaf chlorophyll content was significantly reduced after GA₃ treatments. However, on the contrary Zainaldeen and Rasool (2018) found that the leaf chlorophyll content was increased with the increase of GA₃ in potatoes. In addition, El-Hamady (2017) reported that the increase in the amount of GA₃ enhanced the chlorophyll content in the leaves.

Plant height was significantly ($p < 0.01$) affected by year, cultivar and GA₃ (Table 3). Data recorded on growth parameters of potato revealed that GA₃ increased the plant height of all cultivars i.e., Marabel, Alegria and Agria. The response to the GA₃ varied according to the cultivars. The highest plant height value was measured at cv. Agria

and also plant height increased due to increasing GA₃ doses (Table 6). Therefore, the highest plant height value was obtained from the 100 mg L⁻¹ GA₃ application. Plant height could be affected by several factors. It has been reported that the plant height was influenced by soil fertility, environmental factors, vegetation period (Ekin, 2009), and agricultural activities (Yildirim et al., 2019). The process of plant growth consists of two steps as cell division and cell elongation. The increase in plant height owing to the GA₃ application might be due to GA₃ effect on the elongation of internodes and shoot growth. Reza et al. (2015) recommended that the GA₃ causes increase in cell number and cell size resulting on a significant effect on growth. Chindi and Tsegaw (2019) reported that GA₃ applied on the foliage increased plant growth (8%) as compared to the control, and it may be related to the effect of internodes and shoot growth. The present study is in the agreement with Alexopoulos et al. (2007) and Chindi and Tsegaw (2019) who reported similar results.

The means of the number of stem were presented in Table 3. Analysis of variance given in Table 3 showed that the GA₃ application doses were not significant for number of stem. Cultivar × GA₃ application interaction on stem number plant⁻¹ was statistically significant at the 1% probability level in both years. According to the means given in Table 6, number of stem plant⁻¹ Marabel cultivar was higher than that the other cultivars. Dormancy is an important factor limiting the number of stems in potato. Otrushy (2006) reported that longer stems were obtained with the application of GA₃ in the Marfona potato cultivar, but the number of stems was reduced. During the flowering period, the GA₃ application had no significant affect over the control.

Table 3. Results of variance analysis of the growth and yield components in the experiment conducted in 2019 and 2020

Source of Variation	df	SPAD (Chlorophyll content)	Plant height (cm)	Number of stem plant ⁻¹	Number of tubers plant ⁻¹	Tuber yield plant ⁻¹ (g)
Year (Y)	1	2.42	279.65**	5.17	1.38	181.36**
Cultivar (C)	2	267.60**	581.15**	70.01**	45.45**	42.53**
GA ₃ Doses (G)	2	49.71**	50.20**	0.82	127.86**	28.86**
Y x C	2	0.41	3.12	1.37	0.76	0.68
Y x G	3	0.87	0.11	0.07	0.24	0.07
C x G	6	0.64	2.23	3.63**	1.94	0.51
Y x C x G	6	0.04	0.08	0.21	0.19	0.22
CV (%)	-	3.13	4.48	6.53	8.94	6.18

*P < 0.05, **P < 0.01

Table 4. Results of variance analysis of the yield and tuber quality in the experiment conducted in 2019 and 2020

Source of Variation	df	Marketable tuber ratio (%)	Unmarketable tuber ratio (%)	Total tuber yield (ton ha ⁻¹)	Dry matter content (%)	Specific gravity (g/cm ³)	Chips Quality (L)
Year (Y)	1	1.32	13.21**	90.04**	0.10	0.01	19.15**
Cultivar (C)	2	0.96	9.78**	11.67**	12.23**	11.44**	12.67**
GA ₃ Doses (G)	2	62.65**	19.66**	23.88**	51.57**	29.35**	3.35*
Y x C	2	5.82**	9.81**	0.84	0.14	0.17	11.77**
Y x G	3	0.42	1.56	0.10	0.03	0.29	0.39
C x G	6	0.87	0.48	0.44	4.25	4.03	1.32
Y x C x G	6	1.35	2.11	0.31	0.18	0.13	1.33
CV (%)	-	1.75	47.99	8.60	2.53	0.26	5.87

*P < 0.05, **P < 0.01

Variation for the GA₃ application for tuber number plant⁻¹ was statistically significant at 1% probability level (Table 3). When the means of over the two years are evaluated, the highest number of tubers plant⁻¹ was obtained from Alegria (Table 5). The GA₃ treatments resulted in significant increases in tuber number plant⁻¹ as compared with control. The 100 mg L⁻¹ GA₃ application was highly stimulatory in increasing the number of tubers plant⁻¹. Bandara et al. (1998) mentioned that when plants were applied once with GA during the early growth stage, the number of tubers plant⁻¹ were increased, but this effect is critically dependent on the time of the GA₃ application (Alexopoulos et al., 2007). Caldiz (1996) reported that foliar applied GA₃ significantly increased tuber number plant⁻¹ and the effect of GA₃ application on tuber number was mainly due to an increase in the length and branching of the main stolon. The increase in tuber number might be due to the stimulated stolon production and increased photosynthetic activity. Otrshy (2006) determined that the highest and lowest amount of GA₃ had a significant effect on tuber number, and El-Hamady (2017) determined that the application of GA₃ to tubers before planting increased number of tubers plant⁻¹.

Highly significant difference was observed among the GA₃ treatments with regard to tuber yield plant⁻¹ (Table 3). It has been determined that there was the significant (1%) difference between years, cultivars and the GA₃ applications for average tuber yield plant⁻¹. The highest tuber yield plant⁻¹ was obtained from the Alegria cultivar while the lowest was obtained from Marabel (Table 6). The tuber yield plant⁻¹ increased when the GA₃ doses were

increased, and the mean of two years was 1101.0 g at the 0 mg L⁻¹ GA₃ (Control) application but increased up to 1318.9 g at the 100 mg L⁻¹ GA₃ application. The best effect of GA₃ application on tuber yield plant⁻¹ was at the concentration of 100 mg L⁻¹ GA₃ applications followed by the 50 mg, and 25 mg application respectively (Table 6). Previous studies have shown that the GA₃ application increases tuber yield plant⁻¹ and tuber yield (Barani et al., 2013; Dahshan et al., 2018). However, Mikitzel (1993) reported that the application of GA₃ to seed tubers before planting did not affect tuber yield. Sharma et al. (1998) reported that the application of GA₃ in potatoes delayed tuber formation and also reduced tuber yield. Chindi and Tsegaw (2019) found that 750 and 1000 ppm GA₃ applications increased had tuber yield plant⁻¹ by approximately 26% and 45%, respectively as compared to the control (562.80 g). In comparison other studies, supporting results were obtained in this study indicator the GA₃ applications increased tuber yield plant⁻¹.

The GA₃ applications decreased on average marketable tuber rate as compared to control, and significant differences were also obtained for GA₃ (Table 4). GA₃ applications of 100 mg L⁻¹ decreased marketable tuber ratio by 6,8 % as compared to the control (Table 7). Karaat (2011) reported that increasing GA₃ doses decreased the tuber size in potato tuber. Sharma et al. (1998) observed that foliar application of GA₃ caused deformed tubers and some of tubers were sickle-shaped. Likewise, Jackson (1996) reported that the GA₃ encouraged stolon growth and caused the tubers to be more elongated and elliptical than normal type. It has been

demonstrated that spray application of GA₃ to leaf during the growing period and seed tuber before planting promotes size distribution ratio among tubers from largest tuber to smallest tuber (Struik et al., 1989; Karaat, 2011).

In this study, the average marketable tuber yield decreased as compared to control with increase of GA₃ doses similar to other studies (Karaat, 2011).

Table 5. Means of over two years for chlorophyll content SPAD, number of tuber plant⁻¹, total tuber yield (ton/ha⁻¹), dry matter content and specific gravity of three potato cultivars evaluated under different GA₃ doses.

Treatment	SPAD (Chlorophyll content)	Number of tubers plant ⁻¹	Total tuber yield (ton ha ⁻¹)	Dry matter content (%)	Specific gravity (g/cm ³)
Cultivar (C)					
Agria	41.72 a	10.50 b	52.63 b	19.08 b	1.0740 b
Alegria	34.37 c	12.90 a	56.66 a	19.47 a	1.0769 a
Marabel	35.77 b	10.48 b	50.36 b	18.79 c	1.0731 b
LSD _(0.05)	0.67	0.58	26.57	0.28	0.0017
GA ₃ Doses (G)					
0	39.31 a	8.28 d	47.10 d	19.99 a	1.0790 a
25	38.31 b	9.93 c	51.39 c	19.62 b	1.0762 b
50	36.64 c	12.67 b	54.85 b	18.55 c	1.0728 c
100	34.89 d	14.28 a	59.54 a	18.29 c	1.0707 d
LSD _(0.05)	0.78	0.67	3.06	0.32	0.0019

Tubers smaller than 25 mm in diameter, green, damaged and deformed were accepted as unmarketable tubers and they were used as animal food. But high rate of unmarketable tubers is not desirable in potato production. Unmarketable tuber content rate was significantly ($p < 0.01$) affected by year, cultivar, GA₃ application and the year x cultivar interaction (Table 4). When the data of the two years are evaluated, unmarketable tuber content rate decreased as GA₃ dose was increased, and the unmarketable tuber content rate, which was 0.81% for control application, increased to 3.06% at the 100 mg L⁻¹ GA₃ application (Table 7). The GA₃ application at the time of tuber initiation (50 days after planting) increased the yields in the smaller classes (smaller than 25 mm diameter), while reducing the yields of the marketable tuber. Struik et al. (1989) reported that the maximum effect was obtained when the GA was applied on the day of 40. Dahshan et al. (2018) found that the GA₃ applications reduced the rate of unmarketable tuber. Karaat (2011) reported that GA₃ applications have significantly increased average unmarketable tuber rate. Increasing GA₃ doses increased the rate of unmarketable tubers while average unmarketable tuber rate was 7.9% non GA₃ application, and it was 56.3% in the 150 mg L⁻¹ GA₃ application.

The total tuber yield of potato was significantly affected by year, cultivar and GA₃ applications (Table 4). Tuber yield significantly varied among cultivars and GA₃ application. The highest total tuber yield was obtained from Alegria with 62.78 ton ha⁻¹ in 2019. Also effect of GA₃ applications were significant on tuber yield. The highest tuber yield was obtained from the 100 mg L⁻¹ dose 65.14 ton ha⁻¹ in 2019 (Table 5). Generally, in our study, tuber yields in 2019 were higher than those of the 2020. The main reason for this difference was due to different environmental factors of growing seasons. In potato, high temperatures promote vegetative growth, but reduce tuber

growth. Menzel (1984) reported that the reduction in tuber growth by the GA was accompanied by a promotion of haulm weight and high temperatures strongly reduced tuber number and harvest index. In the 2019 growing season, mean temperatures (°C) were higher than that the other experiment year in our study (Table 2). Therefore, total tuber yield reduced due to the high temperature especially during tuber formation stage in 2020. Total tuber yield was affected significantly by the GA₃. In 2019 and 2020 years, the 100 mg L⁻¹ GA₃ application caused an increase in tuber yield as compared to the control and increase in total tuber yield was approximately 25% and 28% in 2019 and 2020, respectively. Sillu et al. (2012) informed that tuber yield in the GA₃ application to seed tuber during planting was higher than that the foliar application of the GA₃ and foliar application of plant growth regulator with better penetration into leaves increased the leaf chlorophyll content increasing in the photosynthetic rate and in turn increased the growth of plants this resulting in higher yield attributes and yield than that of the seed treatment method. Studies conducted by Njoqu et al. (2015) revealed that the application of GA₃ during planting on seed tubers accelerated shoot formation and emergence resulting in higher tuber yield. Dahshan et al. (2018) found that the GA₃ applications increased total tuber yield as compared to the control. In our study, all cultivars responded positively to increasing GA₃ doses so increased total tuber yield resulted in.

Tuber quality characteristics

Potato quality traits including dry matter content, specific gravity and starch content are important in food industry and directly affect the quality and processing quality of the final product. Variances given in Table 4 showed that the effect of GA₃ application on dry matter content of tuber was statistically significant. The highest dry matter content was obtained from Alegria as 19.47%.

It was observed that tuber dry matter content was decreased with increasing GA₃ doses in our study and there was a negative relationship between the GA₃ doses and dry matter content. In 2019 and 2020 years, it was observed that mean tuber dry matter content was 19.99% in control, while it was 18.29% in the 100 mg L⁻¹ GA₃ application (Table 5). Javanmardi and Rasuli (2017) reported that the tuber dry matter rate decreased due to an increase in the GA₃ concentration. Alexopoulos et al. (2007) explained that the GA₃ caused a significant reduction in the dry matter content of tubers, while the rate of respiration (measured 10 day after harvest) was significantly higher. The reduction in tuber dry matter content following the GA₃ application could be due to a decline in starch content which was a result of sucrose interception by the shoots, and restricted sucrose supply to the tubers (Sharma et al., 1998).

Significant differences were found with regard to specific gravity among different GA₃ doses (Table 4). Increasing GA₃ doses caused a decrease in tuber specific gravity and it varied between 1.0707 and 1.0790 in all treatments (Table 5). It was defined that if the tuber

specific gravity values are less than 1.077 was Low, if it is between 1.077 and 1.086 was Medium and it was defined as high if it is more than 1.086. The specific gravity of potatoes was very different and ranged from 1.050 to 1.106. Specific gravity values of potatoes determined the intended use of tubers. Chindi and Tsegaw (2019) reported that high rates of the GA₃ application in potatoes had higher specific gravity and dry matter rate than those of non-application tubers. Therefore, there was a significant and positive relationship between specific gravity and dry matter content. Likewise, Degebasta (2010) explained that the haulm application of GA₃ increased specific gravity by about 2% and dipping seed tubers in 50 ppm of GA₃ solution increased the tuber specific gravity of the next generation by 1.3% as compared to the control application. On the contrary, the GA₃ application decreased tuber specific gravity in potatoes in both years in this study Alexopoulos et al. (2007) found that application of the GA₃ at a more mature stage of plant growth, i.e. at 60 days after planting had no effect on tuber dry matter content, when the tuberization and presumably starch synthesis was virtually complete.

Table 6. Means of the plant height, number of stem plant⁻¹ and tuber yield plant⁻¹

Treatment	Plant height (cm)			Number of stem plant ⁻¹			Tuber yield plant ⁻¹ (g)		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
Cultivar (C)									
Agria	91.48a	80.98a	86.23a	6.11a	5.71a	5.91a	1290.3b	1083.0b	1186.6b
Alegria	80.00b	64.98b	72.51b	4.95b	4.86b	4.90b	1435.5a	1185.1a	1310.3a
Marabel	60.98c	48.76c	54.87c	6.11a	6.00c	6.06a	1239.9b	998.6b	1114.2c
LSD _(0.05)	5.36	1.09	1.85	0.45	0.13	0.21	98.37	59.9	43.2
GA ₃ Doses (G)									
0	71.12b	59.16d	65.14d	5.62	5.48	5.55	1222.8c	979.2c	1101.0d
25	74.98b	62.52c	68.75c	5.67	5.47	5.57	1282.7bc	1037.9c	1160.3c
50	80.13a	67.22b	73.67b	5.77	5.53	5.65	1350.5b	1118.9b	1234.7b
100	83.76a	70.73a	77.25a	5.83	5.62	5.72	1431.6a	1206.2a	1318.9a
LSD _(0.05)	13.40	1.26	2.14	0.76	0.15	0.24	119.1	69.2	49.9

Table 7. Means of the marketable and unmarketable tuber ratio (%) and chips quality (L)

Treatment	Marketable tuber ratio (%)			Unmarketable tuber ratio (%)			Chips quality (L)		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
Cultivar (C)									
Agria	94.00	94.20a	94.10	1.59	1.69b	1.64 b	62.53a	60.54b	61.54a
Alegria	93.56	94.31a	93.94	1.71	1.85b	1.77 b	58.79b	64.42a	61.60a
Marabel	94.61	92.33b	93.47	1.64	3.97a	2.80 a	53.48c	60.77b	57.13b
LSD _(0.05)	1.63	1.05	0.95	0.97	0.65	0.57	2.61	3.39	2.05
GA ₃ Doses (G)									
0	97.43a	97.37c	97.40a	0.73c	0.89c	0.81 c	60.27	63.71	61.99a
25	95.57a	95.07b	95.31b	1.37bc	1.93b	1.65 b	58.96	61.27	60.11ab
50	92.48b	91.34a	91.91c	2.11ab	3.44a	2.78 a	57.62	62.40	60.01ab
100	90.75b	90.67a	90.71d	2.38a	3.74a	3.06 a	56.27	60.27	58.25b
LSD _(0.05)	1.88	1.21	1.10	0.93	0.75	0.66	4.62	3.91	2.36

Variation for chips quality (L) of potato was significantly for year, cultivar, GA₃ application and year x cultivar interaction. The L value was changed between

56.27 and 63.71 in two years (Table 7). The highest L value was obtained from Agria in 2019 and Alegria in 2020. The highest values for chips quality were obtained

from the control with non GA₃ application. Therefore, increasing the GA₃ doses decreased the chips quality. Burton (1989) stated that the color of chips in potatoes is a characteristic of cultivar, but changeable depending on the cultural practices during the growing period, the maturity of the potato tubers and the storage conditions. The amount of reducing sugar in the tuber varied according to the applied cultural practices fertilization (Yildirim, 2019), growth conditions, storage, stress conditions during growth, cultivar, frying temperature and slice thickness of the potatoes to be fried (Burton, 1989). In addition, Javanmardi and Rasuli (2017) explained that increased level of sugar reduction with the application of GA₃. GA₃ may reduce starch-synthesizing capacity by reducing ADP-Glc-pyro phosphorylase activity by the decrease in starch synthesis (Mares et al., 1981). In this study, considering changes of the dry matter contents of the tuber with in GA₃ applications, the chips quality would vary with the GA₃ applications.

CONCLUSION

Foliar application of GA₃ affects not only plant growth, tuber yield and yield component, but also the tuber quality characters such as dry matter content, specific gravity and chips quality of the tubers. Three potato cultivars tested had significant differences for growth, yield, yield parameters and some quality traits. Number of tuber plant⁻¹, tuber yield plant⁻¹, total tuber yield, dry matter content, specific gravity and chips quality of Alegria cultivar that is mid-early were enhanced by GA₃ treatments and gave the highest values compared to other cultivars. Increasing gibberellic acid doses reduced the chips quality, dry matter content and specific gravity of potato tuber. In contrast, total tuber yield increased with increasing GA₃ doses from 0 mg/L⁻¹ to 100 mg/L⁻¹, besides, unmarketable tuber ratio has also increased. Storage of potatoes is an important stage of the potato production and cultural practices during the growing period affect the storage period. Therefore, it could be beneficial to conduct further research on the post-harvest storage life of tubers treated with the GA₃ application.

LITERATURE CITED

- Abdala, G., G. Castro, O. Miersch and D. Pearce. 2000. Changes in jasmonate and gibberellin levels during development of potato plants (*Solanum tuberosum* L.). *Plant Growth Regulators* 36(2): 121-126.
- Alexopoulos, A.A., G. Aivalakis, K.A. Akoumianakis and H.C. Passam. 2007. Effect of foliar applications of gibberellic acid or daminozide on plant growth, tuberisation, and carbohydrate accumulation in tubers grown from true potato seed. *J. Hort. Sci. Biotechnol.* 82: 535–540.
- Algul, B.E., F.E. Tekintas and G.G. Dalkilic. 2016. The use of plant growth regulators and applications to increase the biosynthesis of internal hormones. *Adnan Menderes Uni. Journal of Agriculture Faculty*, 13(2): 87-95 (in Turkish).
- Bandara, M.S., K.K. Tanino and D.R. Waterer. 1998. Effect of pot size and timing of plant growth regulator treatments on growth and tuber yield in greenhouse-grown Norland and Russet Burbank potatoes. *J. Plant Growth Regul.* 17: 75–79.
- Barani, M, N. Akbari and H. Ahmadi. 2013. The effect of gibberellic acid (GA₃) on the size and sprouting of potato tubers (*Solanum tuberosum* L.). *African Journal of Agriculture Research* 8(29): 3899-3903.
- Burton, W.G. 1989. *The potato*. Third edition, John Wiley and Sons, Inc New York, NY. P. 742.
- Caldiz, D.O. 1996. Seed potato (*Solanum tuberosum* L.) yield and tuber number increase after foliar applications of cytokinins and gibberellic acid under field and glasshouse conditions. *Plant Growth Regul.* 20: 185-88.
- Caliskan, M.E., H. Onaran and H. Arioglu. 2010. Overview of the Turkish potato sector: Challenges, achievements and expectations. *Potato Research* 53:255-266.
- Chindi, A. and T. Tsegaw. 2019. Effect of gibberellic acid on growth, yield and quality of potato (*Solanum tuberosum* L.) in central highlands of Ethiopia. *Journal Horticulture Sci. For.* 1(2): 1-10.
- Dahshan, A.M.A., H.E.M. Zaki, Y.M.M. Moustafa, Y.T. Abdel-Mageed and M.A.M. Hassan. 2018. Effect of some growth regulators and natural extracts on yield and quality of potato. *Minia Journal of Agriculture Research and Development* 38(2): 271-295.
- Degebasta, A.C. 2010. Effect of Gibberellic acid on tuber dormancy breaking, subsequent growth, yield quality of potato (*Solanum tuberosum* L.). MSc Thesis, School of Graduate Studies Department of Plant Science, Haramaya University, 1-78.
- Ekin, Z. 2009. Determination of yield and quality properties of some potato (*Solanum tuberosum* L.) varieties in Ahlat ecological conditions. *Harran University Journal of Agriculture Faculty* 13(3): 1-10 (in Turkish).
- El-Hamady, M.M. 2017. Growth and yield of potato *Solanum tuberosum* L. as influenced by soaking in GA₃ and potassium fertilizer rates. *Canadian Journal of Agriculture and Crops* 2(1): 50-59.
- Hou, K., J.W. Chen, J.Y. Li, H. Shen, L. Chen and W. Wu. 2018. Effect of gibberellic acid and chlormequat chloride on growth, coumarin content and root yield of *Angelica dahurica* var. *formosana*. *J. Agr. Sci. Tech.* 15: 1415-1423.
- Jackson, S.D. and S. Prat. 1996. Control of tuberization in potato by gibberellins and phytochrome B. *Physiol. Plant.* 98:407-412.
- Javanmardi, J. and F. Rasuli. 2017. Potato yield and tuber quality as affected by gibberellic acid and zinc sulphate. *Iran Agricultural Research* 36(2): 7-12.
- Karaat, F.E. 2011. Effects of different growth regulators applications on plant growth and tuber yield and quality in early and main product potato growing. MSc Thesis. Hatay Mustafa Kemal University, Graduate School of Natural and Applied Sciences, p: 90 (in Turkish)
- Kolomiets, M.V., D.J. Hannapel, H. Chen, M. Tymeson and R.J. Gladon. 2001. Lipoxygenase is involved in the control of potato tuber development. *The Plant Cell Online.* 13(3): 613-626.
- Kumlay, A.M. and T. Eryigit. 2011. Substances Regulating Growth and Development in Plants: Plant Hormones. *Igdir University Journal of Science Institute* 1(2):47-56.
- Mares, D.J., H. Marscfaner and A. Krauss. 1981. Effect of gibberellic acid on growth and carbohydrate metabolism of developing tubers of potato (*Solanum tuberosum*). *Physiologia Plantarum* 52(2): 267-274.
- Menzel, C.M. 1984. Potato as a potential crop for the lowland tropics. *Tropical Agriculture* 61(3): 162-166.
- Mikitzel, L.J. 1993. Influencing seed tuber yield of Ranger Russet and Shepody potatoes with Gibberellic acid. *American Potato Journal* 70: 667-676.

- Njoqu, M.K., G.K. Gathungu and P.M. Daniel. 2015. Comparative effects of foliar application of gibberellic acid and benzylaminopurine on seed potato tuber sprouting and yield of resultant plants. *American J. of Agriculture and Forestry* 3(5): 192-201.
- Otroshy, M. 2006. Utilization of tissue culture techniques in a seed potato tuber production scheme. PhD Thesis, Wageningen University. p: 1-264.
- Puzina, T.I. 2004. Effect of zinc sulfate and boric acid on the hormonal status of potato plants in relation to tuberization. *Russian Journal of Plant Physiology* 51(2): 209-215.
- Reza, M., M. Islam, A. Hoque, R.K. Sikder, H. Mehraj and A.F.M. Jamal Uddin. 2015. Influence of Different GA Concentrations on Growth and Yield of Broccoli. *American-Eurasian Journal of Scientific Research* 10 (5): 332-335.
- Sarkar, D. 2008. The signal transduction pathways controlling in planta tuberization in potato: an emerging synthesis. *Plant Cell Reports* 27(1): 1-8.
- Sharma, N., N. Kaur and A.K. Gupta. 1998. Effects of gibberellic acid and chlorocholine chloride on tuberization and growth of potato (*Solanum tuberosum* L.). *J. Food Sci. Agric.* 78: 466-470.
- Sillu, M., N.M. Patel, H.S. Bhadoria, and V.R. Wankhade. 2012. Effect of plant growth regulators and methods of application on growth and yield of potato (*Solanum tuberosum* L.) cv. KUFRI BADSHAH. *Advance Research Journal of Crop Improvement* 3(2): 144-147.
- Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw Hill, New York.
- Struik, P.C., G. Kramer and N.P. Smit. 1989. Effects of soil applications of gibberellic acid on the yield and quality of tubers of *Solanum tuberosum* L. cv. Bintje. *Potato Research* 32(2): 203-209.
- Vreugdenhil, D. and H. Helder. 1992. Hormonal and metabolic control of tuber formation. In: CM. Karssen L.C. van Loon and D. Vreugdenhil (eds.), *Progress in Plant Growth Regulation*. The Netherlands, Kluwer Academic Publishers.
- Wang, C. C., X.Y. Wang, K.C. Wang, J.J. Hu, M.X. Tang, W. He and P. Vander Zaag. 2018. Manipulating aeroponically grown potatoes with gibberellins and calcium nitrate. *American Journal of Potato Research* 95(4): 351-361.
- Yildirim, M. 2019. The Effects of Animal and Chemical Manure Applications on Plant Growth Yield and Quality in Potato (*Solanum tuberosum* L.)", MSc Thesis, Nigde Omer Halisdemir University. Graduate School of Natural and Applied Sciences, Nigde (in Turkish).
- Zainaldeen, M.A. and I.J. Abdul Rasool. 2018. Effect of foliar application of gibberellin and nutrients on growth and yield of potato var. "Burren". *Iraqi Journal of Agricultural Sciences* 49(2): 168-176.