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Research article

Effects of gibberellic acid on germination percentage, growth and yield of Jerusalem artichoke

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Abstract

Importance of work: The dormancy of Jerusalem artichoke seed tubers is a major obstacle to breeding progress and production.

Objectives: To examine the effect of gibberellic acid (GA) on the dormancy of Jerusalem artichoke tubers.

Material & Methods: Four GA concentrations (0%, 0.03%, 0.10% and 0.50%) and two varieties of Jerusalem artichoke (JA 89 and HEL 65) were assessed in separate 2×4 factorial experiments using a randomized complete block design and four replications.

Results: Application of GA at the 0.03% concentration had the highest tuber germination percentage, seedling height, seedling diameter, seedling dry weight, tuber fresh weight, tuber dry weight, total dry weight and harvest index in both the Jerusalem artichoke varieties. Application of GA at the 0.03% concentration resulted in uniform germination of both varieties within 7 d after planting. However, GA application at 0.10% and 0.50% concentrations decreased the germination percentage, growth parameters and yield of Jerusalem artichoke, possibly due to toxicity at high concentrations.

Main finding: GA at 0.03% concentration was the most effective at breaking seed tuber dormancy and increasing the growth and yield of Jerusalem artichoke.

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Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is an underutilized crop that is closely related to the sunflower, with only these two species in the genus being cultivated (Kays and Nottingham, 2007). Sunflower is grown mainly for oil seeds, whereas Jerusalem artichoke is primarily cultivated for tubers, which contain inulin—a type of carbohydrate distinct from the starch typically found in other tuber and root crops (Kays and Nottingham, 2007; Wannasutta et al., 2019). Inulin is an important soluble fiber that is not digested by the human digestive system, making it beneficial to human health (Ge and Zhang, 2005). The high fructose content in inulin makes it a valuable raw material for producing high fructose syrup (Chekroun et al., 1996; Prangviset et al., 2018). In addition, the crop can be utilized to produce a variety of value-added products, such as health foods (Kaur and Gupta, 2002), animal feed additives (Seiler and Campbell, 2004) and bioethanol (Denoroy, 1996).

In Thailand, Jerusalem artichoke is grown under rainfed conditions mainly in the early (March–April) and late (August–September) periods during the rainy season. In addition, the crop is grown under irrigation as an off-season crop. Newly harvested seed tubers from the first crop are used as planting material for the subsequent crop. However, seed tuber dormancy can hinder uniform and timely germination and poor tuber germination remains a major limitation for large-scale propagation of Jerusalem artichoke (Ruttanaprasert et al., 2018). In addition, access to Jerusalem artichoke germplasm with a wide range of genetic diversity is important for Jerusalem artichoke breeding. The tuber dormancy of the diverse germplasm causes a problem in germplasm evaluation because it is difficult to obtain uniform germination of the germplasm accessions and breeding materials (Ruttanaprasert et al., 2018). Therefore, breaking tuber dormancy can produce uniform tuber germination and accelerate the progress of Jerusalem artichoke breeding programs.

Other studies have specified that breaking seed tuber dormancy in Jerusalem artichoke can be achieved by storing the seed tubers at 2°C for 2 mth (Kantar et al., 2012) or at 5°C for 2–3 mth (Sennoi et al., 2018). However, this method can be time-consuming and impractical for breeders and farmers. Hence, an alternative approach is the application of gibberellic acid (GA) to overcome seed tuber dormancy. In a comparison with two other plant hormones (ethylene and cytokinin), GA was the best chemical treatment, initiating plant growth within 6.5–11.5 d (Kantar et al., 2012). Ruttanaprasert et al. (2018) reported that Jerusalem artichoke germinated uniformly following GA application at a concentration of 1% at 4.5–8.0 d after planting, while concentrations higher than 1% inhibited germination. Inhibition of the germination percentage due to high application dosages could be caused by GA toxicity; furthermore, high rates of GA application and a long duration of exposure may cause injury to seedlings, with the treated plants having very thin stems because the toxicity affects membrane integrity (Knowles and Knowles, 1990) and the metabolic activity of cell division and elongation (Taiz and Zeiger, 2002). Therefore, lower concentrations of GA may be more effective in achieving the desired results.

Therefore, further research is needed to explore the effects of GA concentrations below 1% on the germination, growth and yield of Jerusalem artichoke, as there is currently limited information in the literature. Likewise, as far as our knowledge extends, there have been no reports in the literature on the effects of GA on the growth and yield of Jerusalem artichoke in field conditions. Consequently, this study aimed to investigate the effects of different concentrations of GA on the germination and performance of Jerusalem artichoke genotypes in field conditions. The optimal concentration of GA to promote maximum seed tuber germination as identified in this study could be utilized in both Jerusalem artichoke breeding programs and commercial production.

Material and Methods

Experimental design and treatments

The experiments were conducted at the Department of Plant Science, Textiles and Design, Faculty of Agriculture and Technology, Rajamangala University of Technology Isan Surin Campus, Thailand. Experiment 1 was conducted in plug trays with nursery experimental conditions, while experiment 2 was conducted using pot experimental conditions. The experiments were conducted during September–December 2019. A 4×2 factorial experiment in a randomized complete block design with four replications was used. Factor A consisted of four concentrations of GA (0%, 0.03%, 0.10% and 0.50%), and factor B consisted of two Jerusalem artichoke varieties (JA 89 and HEL 65).

Seed tuber preparation

The plants were harvested at maturity, which was determined by the appearance of defoliation. Only uniformly sized, freshly harvested tubers were selected from each variety. These tubers were washed and then cut into smaller pieces, each containing two buds. Three concentrations of GA (0.03%, 0.10% and 0.50%) were prepared from 2% GA; 0.0% was also included as a control treatment. Each experimental unit for Experiment 1 (nursery) consisted of 50 tuber pieces; with separate tuber pieces being soaked in each GA solution treatment for 2 min.

Crop management

For Experiment 1, charred rice hull was used as the potting medium for seedling preparation. After the tuber pieces had been immersed in the different GA solutions, the tuber pieces were planted in planting trays at a depth of 2.50 cm below the soil surface. All planting trays were placed in a nursery at 25.7–34.9°C. Water was sprayed regularly on the planting trays to avoid drying.

For Experiment 2 (containers in an open environment), the uniform seedlings were transplanted into the containers with a diameter of 35 cm and height of 25 cm. There were two containers in an experimental unit, and there were 64 containers in total. Weeds were manually controlled throughout the experiment. At 30 d after transplanting, a combination of N-P_2O_5-K_2O fertilizers (15-15-15) was applied at a rate of 2 g per container. The crop received a nitrogen application rate equivalent to 150 kg-N/ha. Daily watering was provided to the crops to prevent moisture stress. In order to control stem rot caused by *Sclerotium rolfsii*, Terraclor (quintozene 24% W/V EC) was applied at a rate of 25 mL/20 L of water at intervals of 15 d after transplanting.

Data collection

Data were recorded at the seedling stage and the maturity stage. In the seedling stage, days to germination was recoded from the first day of germination to 7 d after planting, when the germination percentage was higher than 90%. Data were also recorded for germination percentage, seedling height and seedling diameter (both measured in centimeters) and seedling dry weight (measured in milligrams) at 7 d after planting.

At maturity, the data were recorded for plant height (measured in centimeters) and plant dry weight (measured in grams) at 100 d after transplanting. The plants were cut at the soil surface and separated into shoots (above soil surface) and tubers, and roots (below soil surface). The tubers and roots were thoroughly washed in tap water to remove any remaining potting medium and the number of tubers per plant was counted and recorded (Ruttanaprasert et al., 2013). Then, all samples were oven-dried at 80°C for 72 hr (or until a constant weight) and the final weight was recorded in grams. The total biomass was calculated based on the sum of the shoots and tuber dry weights; a harvest index was calculated by dividing tuber dry weight by the total biomass. The total soluble solids of the tuber were recorded using a refractometer.

Weather data were recorded daily from transplanting until crop harvest using a weather station in Surin province, Thailand. Maximum temperature, minimum temperature, rainfall and daily relative humidity were recorded at this experimental station (Fig. 1).

Data analysis

Data were analyzed using two-way analysis of variance and least significant difference (LSD) test was used to compare the means at a significance level of 0.05. The analyses were conducted employing the STATISTIX8 software program (Statistix 8, 2003).

Results

Weather conditions

The maximum temperature (Tmax) and minimum temperature (Tmin) ranges were 25.1 –35.5°C and 11.6–25.0°C, respectively (Fig. 1). The total rainfall was 175.2 mm. The relative humidity was in the range 52.6–96.3%.

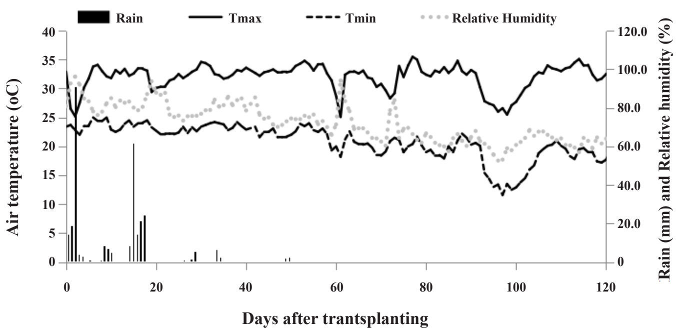

Fig. 1 Maximum temperature (Tmax), minimum air temperatures (Tmin) (°C), rainfall (mm) and relative humidity (%) during study period

Analysis of variance

At 7 d after treatment, the data were recorded for germination percentage, seedling height, seedling diameter and seedling dry weight. The results of the analysis of variance showed that the interaction between variety and GA concentration was significant for germination percentage, but the interactions were not significantly different for seedling height, seedling diameter and seedling dry weight. For the study of traits without and with the interaction of variety and GA concentration are presented with the focus on main effects (Table 1) and a two-way table (Table 4), respectively.

At 100 d after planting, the data were recorded for total soluble solids, plant height, number of tubers per plant, tuber fresh weight, tuber dry weight, shoot dry weight, total dry weight and harvest index. The interaction between variety and GA concentration was not significant for most traits (Table 2, 3) except for the number of tubers per plant (Table 4).

Table 1 Seedling height, seedling diameter and seedling weight of two Jerusalem artichoke varieties treated with four gibberellic acid (GA) concentrations in plug tray experiment evaluated at 7 d after treatment

GA concentration/Variety	Seedling height (cm)	Seedling diameter (cm)	Seedling dry weight (g/plant)
0.00%	0.68±0.76[b]	0.10±0.050[b]	0.01±0.010[b]
0.03%	3.49±0.98[a]	0.15±0.038[a]	0.04±0.014[a]
0.10%	3.94±1.20[a]	0.16±0.017[a]	0.04±0.016[a]
0.50%	4.01±0.95[a]	0.15±0.026[a]	0.03±0.010[a]
F test	**	**	**
Variety			
JA 89	2.99±1.41	0.13±0.041	0.04±0.020[a]
HEL 65	3.07±1.96	0.14±0.043	0.02±0.012[b]
F test	ns	ns	**

Values (mean±SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different.
ns = non-significant ($p \geq 0.05$); ** = highly significant ($p < 0.01$).

Table 2 Total soluble solids, stem diameter and plant height of two Jerusalem artichoke varieties treated with four gibberellic acid (GA) concentrations in pot experiment evaluated at 100 d after transplanting

GA concentration/Variety	Total soluble solids (°Brix)	Stem diameter (cm)	Plant height (cm)
0.00%	26.92±2.27[b]	1.94±0.29	95.75±9.43[a]
0.03%	28.84±2.54[b]	1.71±0.47	73.80±7.77[b]
0.10%	30.82±3.80[a]	1.71±0.36	67.10±31.93[c]
0.50%	28.68±2.39[b]	1.61±0.22	42.60±9.48[d]
F test	**	ns	**
Variety			
JA 89	30.87±2.54[a]	1.59±0.20[b]	80.25±23.40[a]
HEL 65	26.75±1.84[b]	1.89±0.41[a]	59.38±27.93[b]
F-test	**	*	*

Values (mean±SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different.
ns = non-significant ($p \geq 0.05$); * = significant ($p < 0.05$); ** = highly significant ($p < 0.01$).

Table 3 Tuber dry weight, shoot dry weight, total dry weight and harvest index of two Jerusalem artichoke varieties treated with four gibberellic acid (GA) concentrations in pot experiment evaluated at 100 d after transplanting

GA concentration/ Variety	Tuber fresh weight (g/plant)	Tuber dry weight (g/plant)	Shoot dry weight (g/plant)	Total dry weight (g/plant)	Harvest Index
0.00%	132.1±17.00[a]	43.04±8.79[a]	30.11±8.72[a]	73.15±15.98[a]	0.52±0.051[c]
0.03%	144.8±14.80[a]	45.21±7.75[a]	28.36±6.91[b]	73.57±14.21[a]	0.69±0.030[a]
0.10%	99.5±41.58[b]	20.50±3.34[b]	19.00±10.75[c]	39.50±12.41[b]	0.55±0.111[b]
0.50%	69.7±29.33[c]	15.28±11.36[c]	16.82±10.95[d]	32.06±21.12[c]	0.51±0.065[d]
F test	**	**	**	**	**
Variety					
JA 89	118.7±38.40	38.08±14.05[a]	32.17±5.99[a]	70.23±18.28[a]	0.53±0.074[b]
HEL 65	104.3±45.48	23.94±15.02[b]	14.98±8.25[b]	38.91±22.25[b]	0.60±0.055[a]
F-test	ns	**	**	**	**

Values (mean±SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different.
ns = non-significant ($p \geq 0.05$); ** = highly significant ($p < 0.01$).

Table 4 Germination percentage at 7 d after treatment and number of tubers per plant evaluated at 100 d after transplanting of JA 89 and HEL 65 as affected by four gibberellic acid (GA) concentrations

GA concentration	Germination percentage (%)		Number of tubers per plant	
	JA 89	HEL 65	JA 89	HEL 65
0.00%	16.50±13.50^{b}	1.50±1.91^{b}	6.66±1.03^{c}	7.10±0.85^{a}
0.03%	100±0.00^{a}	99.00±2.00^{a}	14.83±3.27^{ab}	4.50±0.41^{b}
0.10%	100±0.00^{a}	95.00±3.46^{a}	16.87±2.66^{a}	7.00±1.25^{a}
0.50%	99.50±1.00^{a}	97.00±3.83^{a}	11.16±1.03^{b}	3.50±0.41^{b}
F test	**	**	*	**

Values (mean±SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different.
ns = non-significant ($p \geq 0.05$); * = significant ($p < 0.05$); ** = highly significant ($p < 0.01$).

Germination percentage, seedling height, seedling diameter and seedling dry weight

There were highly significant differences ($p < 0.01$) among the GA concentrations for seedling height, seedling diameter and seedling dry weight (Table 1). There was an interaction between variety and GA concentration for germination percentage (Table 4). JA 89 had a germination percentage of 16.5% and HEL 65 had a germination percentage of 1.5% for the control treatment. There was 100% germination percentages for JA 89 at the concentrations of 0.03 and 0.10%, while HEL 65 had a highest germination percentage of 99.00% at the 0.03% concentration (Table 4). These results indicated that the application of GA could increase the germination percentage in both JA 89 and HEL 65. However, the optimum concentrations for these varieties seemed to be slightly different.

The seedling height for the control treatment was 0.68 cm, while the seedling heights for the GA treatments ranged between 3.49 cm at the 0.03% rate and 4.01 cm at the 0.05% rate (Table 1). All the GA treatments were significantly higher than the control. The seedling diameter for the control treatment was 0.10 cm and the seedling diameters for the GA treatments ranged between 0.16 cm for the 0.03% rate and 0.16 cm for the 0.10% rate. All the GA treatments were significantly higher than the control. The seedling weight for the control was 0.01 g, whereas the seedling weights for the GA treatments were 0.03 g for the 0.50% rate and 0.04 g for the 0.01% and 0.30% rates, which were significantly higher than for the control.

Total soluble solid, stem diameter, plant height and number of tubers

The GA concentrations were highly significantly different ($p < 0.01$) for the total soluble solids and plant height; however, they were not significantly different for the stem diameter, (Table 2). The total soluble solids ranged between 26.92 °Brix for the control to 30.82 °Brix for the 0.10% concentration. The GA concentration at 0.10% was significantly higher than the control.

The stem diameter ranged from 1.94 cm in the control to 1.61 cm in the 0.50% concentration. The differences among the GA concentrations for this parameter were not significant. Plant height was highest (95.75 cm) in the control and lowest (42.60 cm) in the 0.50% concentration. All GA concentrations were significantly lower than the control for plant height.

The two Jerusalem varieties were highly significantly different ($p < 0.01$) for the total soluble solids, stem diameter and plant height (Table 2). JA 89 was significantly higher than HEL 65 for total soluble solids and plant height, whereas HEL 65 was significantly higher than JA 89 for stem diameter.

The two Jerusalem artichoke varieties responded differently to the application of GA regarding the number of tubers per plant (Table 4). JA 89 increased its tuber number for all GA concentrations, whereas HEL 65 had a reduction in tuber number, especially in the 0.03% and 0.50% concentrations. For the control treatment, JA 89 had 6.66 tubers per plant and HEL 65 had 7.10 tubers per plant. In total, 16.87 tubers per plant were produced by JA 89 at a GA concentration of 0.10%, while HEL 65 had 7.00 tubers per plant at the same GA concentration. Application of GA to overcome dormancy increased the total soluble solids and the number of tubers per plant in the Jerusalem artichoke varieties; however, it reduced the stem diameter and plant height. In addition, application at high concentrations could have deleterious effects on the total soluble solids and number of tubers per plant.

Tuber fresh weight, tuber dry weight, shoot dry weight, total dry weight and harvest index

The GA concentrations were highly significantly different ($p < 0.01$) for tuber fresh weight, tuber dry weight, shoot dry weight, total dry weight and harvest index (Table 3).

Application of GA at the 0.03% concentration produced a significantly higher harvest index than the control, but resulted in significantly lower shoot dry weight than the control. In addition, application of GA at the 0.03% concentration produced significantly higher tuber fresh weight, tuber dry weight, shoot dry weight, total dry weight and harvest index than the application of GA at the concentrations of 0.10% and 0.50%.

The two Jerusalem artichoke varieties were highly significantly different ($p < 0.01$) for tuber dry weight, shoot dry weight, total dry weight and harvest index (Table 3). JA 89 was significantly higher than HEL 65 for tuber dry weight, shoot dry weight and total dry weight, whereas HEL 65 was significantly higher than JA 89 for harvest index.

Discussion

Seedling stage

Although true seed can be used as a propagating material in Jerusalem artichoke breeding programs, the seed tuber is generally used in Jerusalem artichoke production and freshly harvested tuber is used for planting the subsequent crop. Tuber dormancy can be released through storage of the seed tubers for 2–3 mth (Sennoi et al., 2018); however, this is not practical for Jerusalem artichoke production because most farmers do not have a cold room to store the seed tubers. Ruttanaprasert et al. (2018) reported that the levels of tuber dormancy in Jerusalem artichoke varied from non-dormancy to high dormancy, depending on the Jerusalem artichoke variety.

Application of GA at 2% concentration could release dormancy in most Jerusalem artichoke varieties except for JA 318F (Kantar et al., 2012). Dormancy breaking was correlated with weight loss and an increase in the respiration rate of tubers during seedling emergence. A series of bisections of the tubers after GA application to the point of detachment from the stolon indicated that longitudinal movement GA within the tuber had an effect on sprouting. Application of GA caused increases in starch breakdown and α-glucosidase activity in the bud, and it also increased the RNA content, especially in the tip of the buds, prior to sprouting (Alexopoulos et al., 2008). A study in Thailand reported that application of GA at 1% concentration could overcome dormancy in all Jerusalem artichoke varieties, including JA 89, HEL 65 and JA 102 × JA 89(8) (Ruttanaprasert et al., 2018). A GA concentrations of 1% inhibited the germination percentage and growth parameters, possibly due to toxicity at high concentrations. However, using concentrations of GA lower than 1% for dormancy breaking in Jerusalem artichoke has not been reported elsewhere. The current study was conducted to fine-tune GA concentrations lower than 1% (0%, 0.03%, 0.10% and 0.50%) for dormancy breaking of Jerusalem artichoke tuber. Application of GA at the 0.03% concentration produced the highest germination percentages in the two studied Jerusalem artichoke varieties (JA 89 and HEL 65). The 0.03% concentration reported in this study might be the lowest GA concentration that is the most effective for dormancy breaking in Jerusalem artichoke.

The significant interaction between Jerusalem artichoke variety and GA concentration for germination percentage indicated differential responses of Jerusalem artichoke varieties to varying concentrations of GA. The current results revealed that JA 89 and HEL 65 had different responses to GA concentrations of 0.03%, 0.10% and 0.50%, as were their responses to a GA concentration of 0%, with JA 89 having an initial germination percentage of 16.50% and HEL 65 having an initial germination percentage of 1.50%. JA 89 and HEL 65 are considered dormant varieties because their initial germination percentages were low. Ruttanaprasert et al. (2018) found that the initial germination percentage of a Jerusalem artichoke tuber could be as high as 95%, and application of GA to the varieties with high initial germination percentages would result in a reduction in germination percentages.

JA 89 and HEL 65 had similar values for seedling height and seedling diameter. However, JA 89 was significantly higher than HEL 65 for seedling dry weight. All the GA treatments had significantly higher seedling height, seedling diameter and seedling weight than the control, indicating that the application of GA at all the studied concentrations increased the seedling height, seedling diameter and seedling weight of Jerusalem artichoke.

For all GA treatments, application of GA at 0.03% concentration significantly lowered seedling height compared to the applications of GA at concentrations of 0.10% and 0.50%, whereas it was similar to the concentrations of 0.10% and 0.50% for seedling diameter and seedling weight. An empirical study by Ruttanaprasert et al. (2018) reported that some varieties of Jerusalem artichoke showed a significant increase in seedling height when treated with concentrations of 1%, 2% and 3% of GA. Application of GA at high concentrations reduced seedling height. According to Bryan (1989), when young stems of potato were treated with 1% paste of GA after emergence above the soil, there was increased stem elongation; however, it reduced days to flowering. Application of GA at a rate lower than 20 mg/l was effective in breaking dormancy and promoting sprouting of potato tubers (Van Ittersum, 1992; Shibairo et al., 2006). The differences between the results in the current study with such previous study could have been due mainly to differences in the concentration of GA and plant variety. The results in the current study indicated that germination percentage was the most appropriate parameter for determining seedling quality because it could better separate differences in GA treatments from the untreated control. A GA concentration at 0.03% was the best optimal concentration for Jerusalem artichoke to achieve an optimal balance between disruption of dormancy and stimulation of normal shoot growth.

Harvest stage

Other studies reported the effects of GA on the germination and seedling quality parameters of Jerusalem artichoke (Kantar et al., 2012; Ruttanaprasert et al., 2018). The application as a foliar spray of 50 ppm of GA at vegetative stage (75, 90 and 105 days after sowing) increased tuber yield, number of tuber/plant and tuber diameter (Ahmed et al., 2020). However, the effects of GA (tuber seed soaked in GA solution) at harvest have not been reported in Jerusalem artichoke. GA has been widely used to break dormancy in various crops, including potatoes (Alexopoulos et al., 2008). Several methods are used to break tuber dormancy including physical methods such as pre-chilling and wounding, and chemical methods, such as the application of ethylene, ethephon, gibberellic acid and other growth regulators. Wounding of seed tubers or seed stalks is generally practiced to break bud dormancy in cassava, potato and Jerusalem artichoke and is effective enough in cases of low dormancy (Deligios et al., 2020). However, a growth regulator treatment is still required to break deep dormancy, with this type of dormancy classified as endo-dormancy, where the crops do not germinate in a favorable environment (Yang et al., 2021).

In the current study, the Jerusalem artichoke varieties were significantly different in total soluble solids, stem diameter, plant height, number of tubers per plant, tuber dry weight, shoot dry weight, total dry weight and harvest index; however, there as no significant difference in tuber fresh weight. Their responses to varying concentrations of GA were also similar for most characters except for stem diameter. There was only a significant interaction for the number of tubers per plant between GA concentration and variety. Application of GA at all the studied concentrations increased the number of tubers per plant in JA 89, whereas application of GA at all the concentrations reduced the number of tubers per plant in HEL 65. The reductions in the number of tubers per plant were more evident at a GA concentration of 0.50% in HEL 65 and a similar reduction was found for the GA concentration of 0.50% in JA 89 after producing the highest number of tubers per plant at a GA concentration of 0.10%.

The reduction in the number of tubers per plant could have been due to GA toxicity at high concentrations. The application of GA at 0.5% concentration was too high and produced toxicity in the crop. Ruttanaprasert et al. (2018) demonstrated that the use of GA concentrations exceeding 1% could damage the terminal bud during the seedling stage of Jerusalem artichoke. Notably, extended exposure to high doses of GA may result in seedling injury.

The GA concentration had not significant effect on stem diameter. However, it significantly reduced plant height and shoot dry weight with as little as 0.03% GA concentration, with the reductions being most severe at the 0.50% concentration. Application of GA increased tuber fresh weight, tuber dry weight, total dry weight and harvest index at the concentration of 0.03%, and it reduced tuber dry weight, total dry weight and harvest index at the concentrations of 0.10% and 0.50%.

Conclusion

This study examined the effect of low concentrations of GA, ranging from 0.00% to 0.50% on the germination percentage, seedling height, seedling diameter and seedling dry weight of Jerusalem artichoke seedlings and evaluated the effects of GA on total soluble solids, stem diameter, plant height, number of tubers per plant, tuber fresh weight, tuber dry weight, shoot dry weight, total dry weight and harvest index at 100 d after transplanting of the seedlings. At the seedling stage, the results showed that applying GA at a concentration of 0.03% resulted in the highest tuber germination percentage, as well as increased seedling height, diameter, and seedling dry weight. Furthermore, at harvest, GA application at a concentration of 0.03% produced the highest values for tuber fresh weight, tuber dry weight, total dry weight and harvest index in both the JA 89 and HEL 65 varieties. It was observed that the application of GA at concentrations of 0.10% and 0.50% led to the inhibition of germination percentage, growth parameters, and yield, possibly due to the toxicity associated with high concentrations of GA. The current findings support the application of GA at a concentration of 0.03% as being the most effective dose to break seed tuber dormancy and enhance growth and yield in Jerusalem artichoke.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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References

Ahmed, H.S., Ragab, M.E., Arafa, M.M., Shahin, S.I. 2020. Response of Jerusalem artichoke growth, yield, quality and disease detection to some foliar application treatments. 2020. J. Hort. Sci. Ornamen. Plants 12: 237-248.

Alexopoulos, A.A., Aivalakis, G., Akoumianakis, K.A., Passam, H.C. 2008. Effect of gibberellic acid on the duration of dormancy of potato tubers produced by plants derived from true potato seed. Postharvest Biol. Technol. 49: 424–430. doi.org/10.1016/j.postharvbio.2008.02.009

Bryan, J.E. 1989. Breaking Dormancy of Potato Tubers. CIP Research Guide 16. International Research Center Lima. Lima, Peru.

Chekroun, M.B., Amzile, J., Mokhtari, A., El Haloui, N.E., Prevost, J., Fontanillas, R. 1996.

Comparison of fructose production by 37 cultivars of Jerusalem artichoke (*Helianthus tuberosus* L.). N.Z.J. Crop Hortic. Sci. 24: 115–120. doi.org/10.1080/01140671.1996.9513943

Deligios, P.A., Rapposelli, E., Mameli, M.G., Baghino, L., Mallica, G.M., Ledda, L. 2020. Effects of physical, mechanical and hormonal treatments of seed-tubers on bud dormancy and plant productivity. Agronomy 10: 33. doi.org/10.3390/agronomy10010033

Denoroy, P. 1996. The crop physiology of *Helianthus tuberosus* L.: A model oriented view. Biomass Bioenergy 11: 11–32. doi.org/10.1016/0961-9534(96)00006-2

Ge, X.-Y., Zhang, W.-G. 2005. A shortcut to the production of high ethanol concentration from Jerusalem artichoke tubers. Food Technol. Biotechnol. 43: 241–246.

Kantar, M., Betts, K., Hulke, B.S., Stupar, R.M., Wyse, D. 2012. Breaking tuber dormancy in *Helianthus tuberosus* L. and interspecific hybrids of *Helianthus annuus* L. × *Helianthus tuberosus*. Hort Sci. 47: 1342–1346. doi.org/10.21273/HORTSCI.47.9.1342

Kaur, N., Gupta, A.K. 2002. Applications of inulin and oligofructose in health and nutrition. J. Biosci. 27: 703–714. doi.org/10.1007/BF02708379

Kays, S.J, Nottingham, S.F. 2007. Biology and Chemistry of Jerusalem Artichoke *Helianthus tuberosus* L. CRC Press. Boca Raton, FL, USA.

Knowles, L.O., Knowles, N.R. 1990. Changes in fatty acid composition of phospholipids from different ages of potato seed-tubers during sprouting. Ann. Bot. 65: 217–223.

Prangviset, K., Songpim, M., Yodsuwan, N., Wannawilai, S., Dejsungkranont, M., Changlek, P., Sirisansaneeyakul, S. 2018. Fructose production from Jerusalem artichoke using mixed inulinases. Agr. Nat. Resour. 52: 132-139.

Ruttanaprasert, R., Jogloy, S., Vorasoot, N., Kesmala, T., Kanwar, R.S., Holbrook, C.C., Patanothai, A. 2013. Photoperiod and growing degree days effect on dry matter partitioning in Jerusalem artichoke. Int. J. Plant Prod. 7: 393–416.

Ruttanaprasert, R., Jogloy, S., Kanwar, R.S., Gleason, M.L. 2018. Gibberellic acid effect on tuber dormancy of Jerusalem artichoke under greenhouse conditions. Pak. J. Bot. 50: 741–748.

Seiler, G.J., Campbell, L.G. 2004. Genetic variability for mineral element concentrations of wild Jerusalem artichoke forage. Crop Sci. 44: 289–292. doi.org/10.2135/cropsci2004.2890

Sennoi, R., Poonpinyo, T., Sapsiri, S. 2018. Tuber germination of four Jerusalem artichoke varieties after storage at difference duration. Thai Sci. Technol. J. 26: 1141–1149. [in Thai]

Shibairo, S.I., Demo, P., Kabira, J.N., et al. 2006. Effect of gibberellic acid (GA3) on sprouting and quality of potato seed tubers in diffused light and pit storage conditions. J. Biol. Sci. 6: 723–733. doi: 10.3923/jbs.2006.723.733

Statistix 8. 2003. Statistix 8: Analytical Software User's Manual. Tallahassee, FL, USA.

Taiz, L., Zeiger, E. 2002. Plant Physiology. Sinauer Associates. Sunderland, MA, USA.

Van Ittersum, M.K. 1992. Variation in duration of tuber dormancy within a seed potato lot. Potato Res. 35: 261–269. doi.org/10.1007/BF02357706

Wannasutta, R., Boonlue, S., Jogloy, S., Mongkolthanaruk, W. 2019. Identification of endophytic actinobacteria from Jerusalem artichoke and examination of inulinase gene and enzyme properties. Agr. Nat. Resour. 53: 555-565.

Yang, Q., Gao, Y., Wu, X., Moriguchi, T., Bai, S., Teng, Y. 2021. Bud endodormancy in deciduous fruit trees: Advances and prospects. Hortic. Res. 8: 139. doi.org/10.1038/s41438-021-00575-2