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Potato yield and tuber quality as affected by gibberellic acid and zinc sulphate

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ABSTRACT-Obtaining high potato (*Solanum tuberosum* L.) tuber yield through increasing the number and weight of quality tubers is important for farmers while for food processing industries, quality factors are of more interest. Potato processing industries require high quality tubers having the highest possible dry matter, starch and protein contents. A two-year field study was carried out as a factorial experiment in a randomized complete block design during 2013 and 2014. Gibberellic acid (GA_3 at 0, 100, 200 and 400 mg·L^{-1} levels) and zinc sulfate (at 0, 500, 1000 and 2000 mg·L^{-1} levels) were foliar sprayed on potato plants 20 and 50 days after tuber sprouting, respectively. There was no significant difference in all measured criteria between the two years of experiment. Compared to control, a 38% increase in total tuber yield resulted from treatment with 200 mg·L^{-1} GA_3 and 1000 mg·L^{-1} zinc sulfate. The greatest tuber dry matter content (24.33 g·100g^{-1}fw) was obtained from 200 mg·L^{-1} GA_3 plus 2000 mg·L^{-1} zinc sulfate treatment, while the highest starch content (32.56 % tuber fresh weight) was obtained from sole application of zinc sulfate at 2000 mg·L^{-1}. Application of GA_3 at 400 mg·L^{-1} and zinc sulfate at 2000 mg·L^{-1}resulted in the highest tuber crude protein content of 8.37% tuber dry weight which was over twice as much as that of control treatment. Manipulating plant nutrition and fertilization could be used as a powerful tool to obtain desired quality and quantity of potato tuber.

INTRODUCTION

Obtaining high potato tuber (*Solanum tuberosum* L.) yield through increasing the number and weight of quality tubers is necessary. Potato quality factors including dry matter, starch and protein content are important to food industry. For example, if potato products are to be processed at high temperatures, they should have high and low levels of starch and sugars, respectively (Bent et al., 2012). To this aim, good management practices are a requirement, which eventually lead to adequate canopy formation, assimilate for stolons, tuberization and high quality tuber formation.

Potato tuberization is a complex developmental process requiring interactions of environmental, biochemical, and genetic factors (Kolomiets et al., 2001). It comprises the induction, initiation and growth of stolons, then cessation of stolon longitudinal growth followed by induction, initiation and growth of tubers (Sarkar, 2008). The initiation of stolons is associated with accumulation of carbohydrates in the underground stem, but the level necessary for stolon initiation is lower than the level required for tuberization (Thompson and Kelly, 1957). Stolon formation is linked to gibberellin levels in the plant (Abdala et al., 2000) so that exogenous application of gibberellins promotes stolon growth (Vreugdenhil and Helder, 1992) but inhibits tuberization (Puzina, 2004).

Gibberellins and cytokinins are the two most important phytohormones involved in the regulation of potato tuber formation (Sarkar, 2008). Besides playing a role in the photoperiodic control of tuberization, gibberellins are regulators in tuber formation (Xu et al., 2006). The biochemical process underlying potato tuber formation includes starch synthesis (Tauberger et al., 2000) and accumulation of storage proteins (Taylor et al., 1992). Tuber growth and development is also dependent on the presence of sufficient foliage to produce the necessary assimilates and adequate supplies of water and mineral nutrients. Application of gibberellic acid may stimulate the plant to form more stolons (the more possible positions for tuber formation) and increased foliage which would supply necessary assimilates for supporting stolons and further tubers' growth. It has been stated that zinc would shift the plant indigenous hormonal balance toward the above mentioned phenomena (Puzina, 2004).

Zinc, an essential micronutrient for the normal healthy growth and reproduction of plants, animals and humans, plays a key role as a structural constituent or regulatory co-factor of a wide range of different enzymes and proteins in many important biochemical pathways (Prasad, 2012). These roles include carbohydrate metabolism (both in photosynthesis and in the conversion of sugars to starch), protein metabolism, auxin (growth regulator) metabolism, pollen formation, the maintenance of the integrity of biological membranes and the resistance to infection by certain pathogens (Song et al., 2015).

Since gibberellic acid and zinc play important roles in potato plant growth, development and tuberization, we aimed to determine how the combination of those compounds at different physiological stages would affect plant growth pattern, tuber formation, yield and the content of some quality factors of potato.

MATERIALS AND METHODS

Site Description

The study was carried out in 500 m^2 of a commercial potato field area in Bukan-Iran, located in N 36°31' and E 46°12' at an altitude of 1370 m above sea level. The regional annual mean precipitation is 350-450 mm, relative humidity is 50-75% and the mean monthly minimum and maximum temperatures are 15 and 32°C during the growing season, respectively. Soil samples were analyzed by a certified soil and water laboratory. The soil was well-drained and had a deep loamy texture with EC of 2.41 $mhos \cdot m^{-1}$ and a pH of 7.6 (soil extract 1:2). Pre-plant fertilization was applied according to soil test results and recommendation for potato production.

Plant Culture

Potato seed tubers cv. Agria, were planted in a 500-m^2 area early June during two successive years of 2013 and 2014. Each experimental plot (3 × 2 m) was planted with 25 medium sized tubers (70-80 g) at a 60 × 40 cm spacing. The field was under furrow irrigation. Irrigation was based on crop evapotranspiration estimates from tensiometers placed in production beds. Plants were subjected to the same cultural practices in both years.

Treatments

Twenty days after emergence (plants at 15-20 cm height), plants were treated with gibberellic acid (GA_3) (Valent Biosciences Co., Walnut Creek, CA) at 0, 100, 200 and 400 $mg \cdot L^{-1}$ as the first foliar treatment. Zinc sulfate (Merck, Darmstadt, Germany) at 0, 500, 1000 and 2000 $mg \cdot L^{-1}$ were applied as the second foliar treatment, 30 days after the GA_3 application. Control plants were treated with distilled water at the same application times.

The study was arranged with two factors (4 × 4) in a randomized complete block design with 3 replicates (blocks or plots), each of which consisted of 25 plants. The total number of 48 plots (4 × 4 × 3) consisted of 1200 plants (48 × 25). To eliminate the marginal effects, nine central plants plots were used for all data recordings. Yield components including tuber number, tuber fresh weight (total yield) and seed tuber yield (40-70 g tubers) were determined. Then, the following were measured: the percentage of tuber dry matter, starch content using Anthrone method (Saini et al., 2001), total N using the Kjeldal method (AOAC, 1984), tuber crude protein content (Van Gelder, 1981) and zinc content (Saini et al., 2001) using Shimadzu AA-670G atomic absorption spectrophotometer.

Statistics

The data were subjected to the analyses of variance for a factorial experiment with GA_3 level, zinc sulfate level and year as factors using SAS 9.1 (SAS Institute Inc., Cary, NC) computer software for Windows. If interactions were significant, they were used to explain the results. If the interactions were not significant, means were separated using Least Square Means test.

RESULTS AND DISCUSSION

Combined analysis of two years of experiment showed no significant differences for year and interaction of year with GA_3, zinc sulfate and their interaction. Therefore, the analyses were performed for the means of the data of two years of experiment for all measured characteristics (Table 1).

Seed Tuber and Total Tuber Number

Application of gibberellic acid and zinc sulfate affected the number of seed tubers (40-70 g) and tubers over 70 g per plant (Table 1). Irrespective of zinc sulfate concentration, the number of seed tubers (40-70 g) increased by increasing GA_3 concentration but the number of tubers over 70 g showed a reverse trend (Table 2). Potato seed tuber is used as a propagation material. Greater seed tuber number obtained in higher GA_3 treatments is likely due to more stolons (Javanmardi and Rasuli, 2010) and more tuber formation which are sinks for limited assimilates. Stolon formation is associated with high levels of gibberellins (Pont Lezica, 1970). Exogenous application of GAs promotes stolon growth (Vreugdenhil and Helder, 1992) through providing the more possible positions for tuber formation. Endogenous GA content during elongation of stolons is high but is reduced during tuber development (Xu et al., 1998).

Total tuber number (including seed tubers and tubers over 70 g) was affected by GA_3 concentrations (Table 2). This means that exogenous GA_3 induces plant to produce more tuber formation sites (stolons) but the plant potential for supporting induced tubers is not affected, resulting in a greater number of smaller tubers due to limited assimilates. This could be advantageous for seed tuber producers to apply GA_3 at 400 $mg \cdot L^{-1}$for greater seed tuber number.

Tuber Fresh Weight

As expected from the result of total tuber number, the highest total tuber fresh weight per plant was not affected significantly by GA_3 regardless of zinc sulfate concentration (Table 2). However, there was approximately 38% greater total tuber yield over the control which obtained in 200mg·L^{-1} GA_3 and any concentration of zinc sulfate (Table 2). Stolon formation and branching is stimulated by GA_3 (Ewing, 1997) and potato tuber growth is increased but tuberization is delayed (Ewing, 1995; Abdala et al., 2000). Zinc affects the ratio of hormones toward tuberization, and zinc sulfate negates apical dominance but increases tuber weight due to their increased number of cork cell layers (Puzina, 2004). We found delayed tuberization with application of GA_3 in early growth; however, the number and growth of stolons increased. Application of zinc sulfate at early flowering stimulated tuberization at the end of stolons so that numbers of tubers increased (200 mg·L^{-1} GA_3 and 1000 mg·L^{-1} zinc sulfate). The increased number of seed tubers may be explained by: 1) application of zinc sulfate coincided with shortening days (which normally stimulates tuberization); delayed tuberization following GA application and full tuber growth were shortened by the end of the season, cold weather, and 2) there were more branched stolons with more possible positions for tuber formation due to GA application. With increasing numbers of tubers, each would receive less nutrients. Our results agree with Alexopoulos et al. (2006) who reported increased number of seed tubers after GA_3 application.

Tuber Dry Matter Percentage

The greatest tuber dry matter percentage was obtained in 0 mg·L^{-1} GA_3, regardless of zinc sulfate. It showed a decreasing trend in tuber dry matter percentage with increasing GA_3 concentration. Tuber dry matter content increased by increasing zinc sulfate concentration when combined with GA_3. The greatest dry matter content was obtained in 2000 mg·L^{-1} zinc sulfate and 200 mg·L^{-1} GA_3 (Table 2). Previous studies reported that exogenous application of GAs increased photosynthesis, carbohydrates level and dry weight (Sharma et al., 1998).

Tuber Starch Content

The main effect of increasing GA_3 was reduction in starch content regardless of zinc sulfate application. Although higher starch content in tubers was observed in plants treated by higher zinc sulfate concentrations, its ability to increase tuber starch content could not compensate for the decreasing impacts at higher GA_3 concentrations (Table 2). This means GA_3 had a stronger impact on lowering starch accumulation than increasing the effect of zinc sulfate.

Table 1. Analysis of variance for potato tuber quality and quantity characteristics

Source of variation	Degree of freedom	Mean squares						
		Seed tuber number	Over 70 g tuber number	Total tuber number	Tuber fresh weight	Tuber dry matter content	Tuber starch content	Tuber crude protein
GA_3	3	8.49^{**}	4.06^{**}	2.69^{*}	2.56^{ns}	7.84^{**}	78.22^{**}	5.90^{**}
Zinc sulfate	3	1.01^{*}	0.88^{ns}	3.67^{ns}	1.25^{ns}	6.36^{*}	10.93^{*}	0.32^{ns}
GA_3 × Zinc sulfate	9	9.53^{*}	4.60^{*}	6.163^{*}	3.79^{ns}	8.30^{*}	148.49^{*}	74.38^{*}
Error	32	0.261	0.193	0.209	0.163	0.238	0.708	0.197

ns, *, ** non-significant, significant at p≤0.05 and p≤0.01, respectively

Table 2. Effects of GA_3 and zinc sulfate on potato tuber quantity and quality factors

Concentration (mg·L^{-1})		Means						
GA_3	Zinc sulfate	Zinc sulfate	Tubers number (over 70 g)	Totaltuber number	Tuber fresh weight (kg/plant)	Tuber dry matter (g/100g fw)	Tuber starch(% fw)	Tuber crude protein(% dw)
0	0	4.26	7.00	11.26	0.97	21.59	24.07	4.06
	500	3.80^{ns}	7.33^{ns}	11.13^{ns}	0.98^{ns}	22.57^{ns}	27.48^{ns}	4.39^{ns}
	1000	6.10^{*}	7.26^{ns}	13.70^{**}	1.09^{*}	23.06^{*}	30.72^{**}	4.68^{*}
	2000	6.23^{ns}	7.38^{ns}	13.93^{ns}	1.11^{ns}	23.36^{ns}	32.56^{ns}	4.87^{ns}
100	0	6.23	6.26	12.50	1.04	18.08	21.16	5.68
	500	8.13^{*}	6.06^{ns}	14.20^{**}	1.15^{ns}	21.77^{ns}	22.62^{ns}	6.25^{*}
	1000	8.06^{ns}	6.20^{ns}	14.26^{ns}	1.15^{ns}	22.63^{*}	23.61^{*}	6.47^{ns}
	2000	7.83^{ns}	6.33^{ns}	14.16^{ns}	1.15^{ns}	23.16^{ns}	25.15^{ns}	6.95^{ns}
200	0	6.76	5.40	12.16	1.03	19.42	18.54	7.06
	500	9.20^{*}	6.13^{ns}	15.30^{**}	1.33^{**}	20.41^{*}	19.32^{ns}	7.22^{*}
	1000	9.00^{ns}	6.80^{ns}	15.80^{ns}	1.37^{ns}	21.14^{ns}	19.76^{ns}	7.27^{ns}
	2000	8.96^{ns}	6.40^{ns}	15.36^{ns}	1.34^{ns}	24.33^{**}	21.68^{*}	7.54^{ns}
400	0	9.26	3.13	12.23	1.02	18.31	15.85	7.58
	500	9.50^{ns}	4.40^{ns}	13.90^{**}	1.11^{ns}	19.33^{*}	15.98^{ns}	7.81^{ns}
	1000	8.56^{ns}	4.86^{ns}	13.26^{ns}	1.06^{ns}	20.54^{*}	17.34^{ns}	7.89^{*}
	2000	8.90^{ns}	4.65^{ns}	13.48^{ns}	1.07^{ns}	23.36^{**}	17.93^{ns}	8.37^{**}

ns, *, ** non-significant or significant at P≤0.05 or P≤0.01, Least Squares Means analysis.
fw: fresh weight; dw: dry weight

The greatest starch content was obtained in 0 mg·L^{-1} of GA_3 and 2000 mg·L^{-1} of zinc sulfate which was over 35% as great as that of control (Table 2). This could be explained by the fact that the application of GA_3 to potato shoots reduces export of photosynthates to tubers, decreases starch accumulation, increases sugar level and results in cessation of tuber growth (Tsegaw, 2006).

It was reported that by increasing GA_3 concentration, activity and specific activity of amylase in chickpea (*Cicer arietinum* L.) increased (Kaur et al. 1998). Therefore, starch reduction in the plant, especially tubers (as a source of starch) is explainable. It has been stated that increased level of sugar reduction occurred with the application of GA so that suggested GAs may reduce starch-synthesizing capacity by reducing ADP-Glc-pyrophosphorylase activity (Mares et al., 1981).

Tuber Crude Protein Content

Increasing GA_3 and zinc sulfate concentration increased tuber crude protein content (Table 2). The greatest crude protein content in tubers was obtained at 400 mg·L^{-1} GA_3 and 2000 mg·L^{-1} zinc sulfate which was over twice as much as that of control. This could be concluded because increasing the effect of GA_3 on tuber protein content synergistically increased with zinc sulfate application; however, there was no significant differences among zinc sulfate concentrations at each GA_3 concentration. The positive effect of GAs on nitrate reductase (NR) activity is known; NR activity is the primary enzyme for nitrate assimilation and protein synthesis (Premabatidevi, 1998). Our results agree with Cao and Shannon (1997) who reported increased protein content with increasing GA level in cell suspension culture of maize (*Zea mays* L.), as well as Shah and Ahmad (2007) with GA foliar application on *Nigella sativa* L.. Zinc is required by a large number of proteins (Cakmak et al., 2010).

CONCLUSIONS

The results of this research could be useful for both potato seed tuber producers and potato food processing industry. To obtain higher yields, producers should use 200 mg·L^{-1} GA_3 and at least 500 mg·L^{-1} of zinc sulfate. Food processing industries require high dry matter content and enhanced nutritional quality of tubers. The main nutritional quality factors of potato for food industry are the highest possible starch and protein content. It is possible to improve yield and/or tuber quality with application of GA_3 and suitable zinc sulfate level to manipulate potato plant toward the desired quality.

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تأثیرجیبرلیک اسید و سولفات روی برعملکرد و کیفیت ژوخه سیب‌زمینی

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نشاسته

پروتئین خام غده

غده‌زایی

چکیده-بدست آوردن عملکرد بالا در سیب زمینی (*Solanum tuberosum*L.) از طریق افزایش تعداد و وزن غده‌های با کیفیت، از موارد بسیار با اهمیت برای کشاورزان است در حالی‌که ویژگی‌های کیفی غده‌ها بیشتر برای صنایع غذایی و فرآوری مطرح هستند. صنایع فرآوری سیب‌زمینی نیازمند غده‌هایی با کیفیت بالا یعنی بالاترین درصد ماده خشک، نشاسته و پروتئین هستند. پژوهشی به‌صورت آزمون فاکتوریل در قالب طرح بلوک کامل تصادفی طی دو سال زراعی ۱۳۹۲ و ۱۳۹۳ صورت پذیرفت. جیبرلیک اسید (GA_3) در غلظت‌های صفر، ۱۰۰، ۲۰۰ و ۴۰۰ میلی‌گرم در لیتر و سولفات روی در غلظت‌های صفر، ۵۰۰، ۱۰۰۰ و ۲۰۰۰ میلی‌گرم در لیتر به صورت محلول‌پاشی برگی به ترتیب ۲۰ و ۵۰ روز پس از جوانه‌زنی غده‌ها مورد استفاده قرار گرفتند. نتایج، تفاوت معنی‌داری را از نظر اثر سال بر صفات مورد ارزیابی نشان نداد. در مقایسه با تیمار شاهد، افزایش ۳۸ درصدی در عملکرد کل غده در تیمار با ۲۰۰ میلی‌گرم GA_3 و ۱۰۰۰ میلی‌گرم سولفات روی مشاهده شد. بیشترین محتوای ماده خشک غده‌ها به میزان ۲۴/۳۳ گرم در ۱۰۰ گرم وزن تر از تیمار ۲۰۰ میلی‌گرمGA_3 و ۲۰۰۰ میلی‌گرم سولفات روی بدست آمد در حالی‌که بیشترین محتوای نشاسته به میزان ۳۲/۵۶ درصد وزن تر از کاربرد ۲۰۰۰ میلی‌گرم سولفات روی به تنهایی حاصل شد. کاربرد ۴۰۰ میلی‌گرم GA_3 و ۲۰۰۰ میلی‌گرم سولفات روی بیشترین پروتئین خام غده‌ها را به میزان ۸/۳۷ درصد وزن خشک غده ایجاد نمود که بیش از ۲ برابر تیمار شاهد بود. به‌طور کلی ایجاد تغییرات در تغذیه و کوددهی می‌تواند به عنوان ابزاری قدرتمند برای بدست آوردن مقادیر و کیفیت‌های مورد نظر در سیب‌زمینی محسوب شود.