Growth and Yield Response of Garlic Genotypes to Foliar Application of γ-Aminobutyric Acid

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Abstract: Worldwide, garlic is one of the most important bulb vegetable crops and it has been cultivated from thousands of years ago due to its medicinal and nutritional benefits. The main goal of the current research was to explore the effect foliar application of γ-aminobutyric acid (GABA) on vegetative development and yield traits as well as chemical constitutes of garlic. To achieve this goal, two field experiments were performed during winter seasons of 2015/2016 and 2016/2017. Four concentrations of GABA (0, 1, 2 and 4 mM) were sprayed on two garlic's genotypes (Sids 40 and Egaseed). The results reported that exogenous supplementation of GABA notably improved vegetative growth (plant height and plant fresh weight), yield traits (bulb weight and total yield), and minerals content (N, P, K and Ca), as well as the content of organic compounds (total chlorophyll and total phenols) compared to non-treated plants (control) in both genotypes. It was clearly revealed that 1 mM GABA treatment had achieved the highest morphological traits, yield traits, chemical composition and organic compound content compared to the other GABA treatments. The findings indicate that GABA application has the ability to enhance growth and productivity of garlic through enhancing mineral composition and organic compounds.

Keywords: *Allium sativum* L.*,* GABA, Vegetative growth, Mineral composition

INTRODUCTION

Garlic (*Allium sativum* L.) is a principal member of Alliaceae family. Due to its nutritional and medicinal benefits, garlic is considered to be an important ingredient in the daily diet over the world. Garlic has an important compound known as allicin, which has therapeutic properties. Consequently, garlic is well known for its ability to work as a natural anti-microbial. Also, it contributes positively to human health as anti-cancer, antidiabetic, antimicrobial, anti-inflammatory, immunomodulatory properties, cardio protective and antioxidant (Kumar *et al.*, 2013; Chen *et al.*, 2013; Yun *et al.*, 2014; Martins *et al.*, 2016). World total production of garlic was approximately 27 million tons that were produced from 179534 hectares (FAO, 2016). Egypt is ranked fourth in worldwide garlic production, with an annual production of 280,216 tons from around 11,875 hectares (FAO, 2016). In addition, Egypt is one of the top 10 countries that exported the highest dollar value worth of garlic in 2017 with 0.9% (27 million dollars) of total garlic exports. However, the garlic production in Egypt dramatically fluctuated in last ten years (FAO, 2016). Therefore, getting high yield rather than stable yield is necessary aims for garlic's growers as it is an important crop for local consumption and export.

Several chemicals were introduced to improve the agricultural productivity under favorable and unfavorable environments. One of these promising chemicals is called γ-aminobutyric acid (GABA). It is a four-carbon non-protein amino acid that is generally exists in both animal and plant tissues. It is found in the central nervous system tissues of mammals (Sigel and Steinmann, 2012). Briefly, GABA is resulted from glutamic acid decarboxylation or polyamine degradation (Yang *et al.*, 2013; Ford *et al.*, 1996) and is basically metabolized through a direct pathway consists of three enzymes. Numerous studies have confirmed a positive effect for GABA intake on human health, including decreasing the blood pressure, inhibition cancer cell multiplying, energizing cancer cell apoptosis (Oh and Oh, 2004). Therefore, several attempts were performed out to increase endogenous GABA content in local daily-consumed foods (Nonaka *et al.*, 2017).

In the last few years, the interest in GABA use in plant was increased. Interestingly, several previous studies confirmed the positive results of exogenous GABA application in plants. It is commonly demonstrated that exogenous supplementation of GABA is taking a part in several physiological mechanisms, consequently it causes an improvement in morphological, growth and yield attributes of plants. Once plants encounter abiotic or biotic stress they directly accumulate high amount of GABA (Shelp *et al.*, 2012). This accumulation has been shown to take a part in several important physiological processes in plants. In this regard, it was reported that GABA external supplementation positively improved the drought tolerance in perennial ryegrass and creeping bentgrass, black pepper and black cumin (Krishnan *et al.,* 2013; Vijayakumari and Puthur, 2015; Li *et al.*, 2018; Rezaei-Chiyaneh *et al.*, 2018). Also, it was clearly documented that GABA treatment play a key role in attenuation of damage induced by salt stress in several crop species such, as tomato, melon, wheat and maize (Xiang *et al.*, 2016; Li *et al.*, 2016a; Wang *et al.,* 2017; Cekiç, 2018). In addition, GABA was able to increase winter wheat tolerance to high temperature and had the ability to alleviate the low light stress in pepper seedlings (Wang *et al.*, 2009; Li *et al.*, 2017)

Mechanism of GABA in alleviation the harmful effects resulting from the abiotic stresses depends on plant species and abiotic stress type. However, this mechanism may be due to one or more of these physiological effects: 1) Enhancing water soluble

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Corresponding author e-mail: tohamy_yousef@agri.suez.edu.eg carbohydrates, proline accumulation, total sugars content, chlorophyll content, phenolic substances, photosynthetic capacity, enzyme activities, relative water content and membrane stability, chloroplast structure, as well as function of PSII, level of photochemical efficiency (Krishnan *et al.,* 2013; Vijayakumari and Puthur 2016; Li *et al.* 2017; Rezaei-Chiyaneh *et al.*, 2018). 2) Decreasing malondialdehyde content, electrolyte conductivity, lipid peroxidation and active oxygen species (Xiang *et al*., 2016; Li *et al.,* 2016a; Wang *et al.,* 2017; Cekiç, 2018). 3) Regulating endogenous hormone system (Wang *et al*., 2009)

GABA has also several positive effects during fruit and vegetable storage. For instance, it was apparently declared that GABA application is a helpful tool in reduction of chilling injury during cold-storage in peach and banana fruits through acceleration of endogenous GABA content, proline accumulation and antioxidant system (Shang *et al.,* 2011; Wang *et al.,* 2014). In addition, GABA plays an important role in reducing the browning of fresh-cut potatoes through enhancing the catalase and superoxide dismutase activities, as well as decreasing the polyphenol oxidase activity and reactive oxygen species (Gao *et al.,* 2018). Moreover, GABA has a favorable impacts on unstressed plants, including enhancement of vase-life of rose cut flowers (Mirzaei Mashhoud *et al.,* 2015), increasing growth of citrus plants (Hijaz *et al.,* 2018), enhancement early growth and photosynthesis traits in maize seedlings.

In consonance with the above-mentioned information, the application of GABA can enhance agricultural productivity of several of horticultural crops under favorable condition and under different kinds of abiotic stresses through several physiological processes. So far, little comprehensive information is available about the effect of exogenous GABA treatment on garlic's growth, productivity and quality. Accordingly, goal of this study was to investigate the physiological effects of GABA supplementation on traits of vegetative growth, yield parameters and on chemical composition of garlic under normal conditions.

MATERIALS AND METHODS

Plant materials and treatments

Two field experiments were carried out in winter seasons of 2015/2016 and 2016/2017 at Research Experimental field of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt to study the effect of four concentrations of GABA (0, 1, 2 and 4 mM) on vegetative growth, yield and chemical composition of two of the most garlic's genotypes in Egypt (Sids 40 and Egaseed). The experimental design for the two field experiments was randomized complete blocks design (RCBD) with a split plot arrangement with three replicates. The genotypes were assigned in the main plots, while GABA levels were assigned in the sub-plots.

Soil texture was sandy (85.21% sand, 3.29% clay and 11.50% silt), with pH 7.87, EC 0.47 dSm^{-1}, available N 63 ppm, available P 29.24 ppm, available K 74 ppm, Ca^{+2}1.7 meql^{-1}, Mg^{+2}0.8 meql^{-1}, Na^{+}0.9 meql^{-1}, K^{+} 0.2 meql^{-1}, HCO_3^{-}1.60 meql^{-1}, Cl^{-}1.40 meql^{-1} and SO_4^{-2}0.60 meql^{-1} and CO_3^{-2} 0.00 meql^{-1} organic matter 0.15%, organic carbon 0.083%.

After soil clearing, ploughing and harrowing, organic manure and superphosphate (15.5% P_2O_5) were added at 20 m^3/fad and 150 kg/fed, respectively. Later, drip irrigation system was used. Uniform and healthy cloves of both genotypes were selected and soaked in running water for 24h. In the next day, the wetted cloves were sown by hands at 10 cm between the plants and 100 cm between the rows. The planting was performed on 15 of October in both seasons. Experimental unit area (plot) was 3 m x 3 m in size (three rows).

The GABA treatments were given to the plants five times through the whole season on the whole foliage in the morning (10 a.m.) with a manual pump. The plants of both genotypes received the first GABA treatment after one month from planting date and with 2 weeks intervals. The control plants of both genotypes were sprayed with only distilled water. The volume of treatments solution was ranged from156 to 468 L per Feddan each time, according to plant size. The other normal agricultural treatments were performed according to recommendation of Ministry of Agriculture.

Vegetative growth and yield parameters

Ten mature plants, when older leaves turned yellowish green and started withering, were harvested (end of March) from each replicate to measure the following parameters:

- Plant height (cm).
- Plant fresh weight (g).
- Bulb fresh weight (g): It was estimated after removing the foliage at neck zone.
- Bulbing ratio: It was estimated according to the formula described by Mann, (1952) as follow: Bulbing ratio = (bulb neck diameter (cm)/bulb diameter (cm)). Both bulb diameter and neck diameter were measured using a precision caliper 0/0001 m.
- Roundness: It was calculated by dividing the bulb length/bulb width. Both of bulb length and bulb width were measured using a precision caliper 0/0001 m.

Total Yield

Total yield (Kg/Feddan): Plants of each experimental plot were harvested after 180 days from sowing, weighted and total yield of whole plants was calculated.

Chemical composition parameters

Organic compounds

The chlorophyll content (SPAD value) in the leaf samples was assessed by a SPAD-502 meter (Minolta Co. Ltd., Osaka, Japan).

- Total phenols (mg/g FW) were determined according to Mazumdar and Majumder, (2003).

- Total sugars (mg/g FW) were determined according to Dubois *et al*. (1956).
- Soluble solid content (SSC, %) was measured by a digital refractometer (Atago N1, Japan).

Minerals determination

Two bulbs from each replicate were dried at 70ºC till constant weight. Later, they were grounded into powder. 0.5 g of fine ground materials was digested with sulfuric acid and hydrogen peroxide mixture and then with distilled water the final volume was adjusted to 100 ml with for determination of the following elements:

- Total nitrogen (mg/g DW): it was measured using semi-micro-kjeldahl method as described by Ling (1963).
- Phosphorus (mg/g DW): it was analyzed as described by Jackson (1973).
- Potassium and calcium (mg/g DW): they were determined using a Perkin-elmer, Flame photometer (Page, 1982).

Statistical analysis

All statistical procedures including analysis of variance (ANOVA) and Duncan's test for that collected data was performed out using CoStat version 6.303 1998–2004 CoHort software, 798 Lighthouse Ave, PMP 320, Monterey, CA 93940, USA. Duncan’s test was applied at 1% significance level to compare the means of treatments.

RESULTS

Effect of GABA on vegetative growth, bulb and yield traits

Table (1) shows the main effect of genotype, GABA and their interaction on vegetative growth and yield traits. The results demonstrated that there was a highly significant difference between the two genotypes for most of the studied traits in both seasons, except roundness trait as well as bulbing ratio and total yield in 2016/2017 season. Egaseed cultivar achieved the highest values compared to Sids 40 for all studied traits (Table 1). The main effect of GABA significantly affected growth, bulb and yield traits. GABA treatments clearly achieved higher plant growth, bulbing and yield compared to control plants in both genotypes and seasons, except roundness trait. Among GABA treatments, the treatment at 1 mM GABA, followed by 2 mM GABA, was more efficient than the remaining GABA levels: 4 mM GABA and the 0 mM GABA (control). The treatment by 4 mM also positively improved the studied traits; however, this improvement was not necessarily significant. Inconsiderable effect of GABA application was recorded for the roundness trait in both genotypes and seasons. In 2015/2016 season, the foliar spray by 1 mM GABA improved the bulb weight and total yield by 30.01% and 27.29% over the two genotypes, respectively. In season of 2016/2017, it improved the bulb weight and total yield by 29.63% and 30.00% over the two genotypes, respectively. In addition, Table (1) shows the interaction effects between genotype and GABA treatments. It shows that Egaseed plants that were sprayed with 1 mM GABA had the highest plant growth, bulb and yield traits compared to other combinations. The exogenous application of GABA at 1 mM to Egaseeds plants increased bulb weight and total yield of Egaseeds cultivar by 37.27% and 24.50%, respectively, over the two growing seasons.

Effect of GABA on SSC, total chlorophyll, total sugars and total phenols

Table (2) shows the main effects of genotype, GABA treatments and their interaction on SSC, total chlorophyll content, total sugars and total phenols. It shows that there was a significant difference between the two genotypes for all traits, except SSC content in 2015/2016 season. Egaseed had the highest SSC, total chlorophyll, total sugars and total phenols in both seasons. There were significant differences among GABA treatments in Table (2). The highest total chlorophyll and total phenol content were observed in plants treated by 1 mM and 2 mM GABA in both genotypes and seasons. The exogenous application by 1 mm GABA increased total chlorophyll and total phenol content by 13.90% and 72.62% over the both genotypes and seasons. In contrast to the previous results, these treatments significantly decreased both SSC and total sugars compared to non-treated plants in both genotypes and seasons. The foliar application by 1 Mm decreased total SSC and total sugars content by 5.36% and 26.88% over the both genotypes and seasons. Interestingly, the exogenous application by 4 mM did not dramatically increase or decrease the studied traits in comparison to the control plants. Regarding the interaction effect between genotype and GABA treatments, the results revealed that Egaseed plants sprayed with 1 mM and 2 mM GABA had the highest chlorophyll content and total phenols in comparison with other combinations.

Effect of GABA on mineral content.

Table (3) shows the main effects of genotype, GABA treatments and their interaction on mineral content: N, P, K and Ca. It shows that there were significant differences between the genotypes in both seasons for all studied traits, except phosphorus content in season 2016/2017. The results indicated that Egaseed cultivar had the significant highest nitrogen, phosphorus, potassium and calcium content in both seasons. Concerning the main effect of GABA treatments overall genotypes, there were highly significant differences among GABA treatments. It clearly indicates that four GABA concentrations positively improved nitrogen, phosphorus, potassium and calcium content in both seasons compared to un-treated plants. However, the application of GABA at 1 mM gave the highest nitrogen, phosphorus, potassium and calcium in both seasons compared to the other GABA treatments. In addition, Table (3) shows the interaction effects between genotype and GABA treatments. It shows doubtless that the combination of Egaseed and GABA 1 mM recorded the significant highest nitrogen, phosphorus, potassium and calcium in both seasons. This combination was flowed by the combination of Egaseed and 2 mM GABA in season 2015/2016. However, the best combination was followed by another combination (Sids 40 and 1 mM) in season of 2016/2017.

Table (1): Main effects of genotype, GABA treatment and their interactions on vegetative growth and yield traits of garlic during 2015/2016 and 2016/2017 seasons

Parameters	GABA	2015-2016			2016-2017		
		Genotype		Mean	Genotype		Mean
		Egaseed	Sids 40		Egaseed	Sids 40	
Plant height (cm)	0 mM	49.40d	43.80e	**46.60D**	54.80bcd	49.30D	**52.05C**
	1 mM	65.60a	62.60b	**64.10A**	61.20a	55.80ABC	**58.50A**
	2 mM	61.00b	54.80c	**57.90B**	57.90ab	54.00BCD	**55.95AB**
	4 mM	50.50d	48.20d	**49.35C**	51.30cd	53.50BCD	**52.40BC**
	Mean	**56.63A**	**52.35B**		**56.30A**	**53.15B**	
Fresh weight (g/plant)	0 mM	79.40e	72.20f	**75.80D**	83.90c	77.30d	**80.60C**
	1 mM	111.20a	101.10b	**106.15A**	106.30a	102.80a	**104.55A**
	2 mM	91.50c	94.90c	**93.20B**	102.40a	96.50b	**99.45B**
	4 mM	80.70de	84.10d	**82.40C**	85.30c	82.30c	**83.80C**
	Mean	**90.70A**	**88.08B**		**94.48A**	**89.73B**	
Bulb weight (g/Bulb)	0 mM	60.40d	55.20e	**57.80C**	49.30e	65.10c	**57.20C**
	1 mM	79.00a	71.30b	**75.15A**	70.10b	78.20a	**74.15A**
	2 mM	66.30c	65.90c	**66.10B**	64.90c	76.70a	**70.80B**
	4 mM	64.60cd	62.20cd	**63.40B**	54.30d	64.20c	**59.25C**
	Mean	**67.57A**	**63.65B**		**71.05A**	**59.65B**	
Bulbing ratio	0 mM	0.22bc	0.17d	**0.19B**	0.20b	0.19b	**0.19B**
	1 mM	0.27a	0.24ab	**0.26A**	0.28a	0.27a	**0.28A**
	2 mM	0.25ab	0.24ab	**0.24B**	0.27a	0.25a	**0.26A**
	4 mM	0.22bc	0.19cd	**0.21B**	0.22b	0.21b	**0.21B**
	Mean	**0.24A**	**0.21B**		**0.24A**	**0.23A**	
Roundness	0 mM	0.91a	0.86a	**0.89A**	0.95a	0.85a	**0.90A**
	1 mM	0.89a	0.84a	**0.86A**	0.87a	0.81a	**0.84A**
	2 mM	0.90a	0.84a	**0.87A**	0.85a	0.84a	**0.85A**
	4 mM	0.93a	0.84a	**0.88A**	0.89a	0.82a	**0.86A**
	Mean	**0.91A**	**0.84A**		**0.89A**	**0.83A**	
Total yield (kg/Fed)	0 mM	4832de	4315f	**4573.5C**	5208c	3944e	**4576C**
	1 mM	6320a	5322c	**5821.0A**	6256a	5608b	**5932A**
	2 mM	5850b	5372c	**5611.0A**	6136a	5192c	**5664B**
	4 mM	5168cd	4573ef	**4870.5B**	5136c	4344d	**4740C**
	Mean	**5542.50A**	**4895.50B**		**5684.00A**	**4772.00A**	

Values are the means of three replicates. Values followed by the same letters within a column for each genus are not significantly different at the 1% level of probability according to Duncan's multiple range test

Table (2): Main effects of genotype, GABA treatment and their interactions on SSC, total cholorphyll, total sugars and total phenols of garlic

Parameters	**GABA**	**2015-2016**			**2016-2017**		
		Genotype		**Mean**	**Genotype**		**Mean**
		Egaseed	**Sids 40**		**Egaseed**	**Sids 40**	
SSC %	0 mM	40.20ab	40.80ab	**40.50A**	42.00a	40.70abc	**41.35A**
	1 mM	36.10d	39.60abc	**37.85B**	39.30bc	39.90abc	**39.60B**
	2 mM	37.55cd	38.80bc	**38.18B**	40.20abc	38.80c	**36.50B**
	4 mM	41.80a	39.40abc	**40.60A**	41.40ab	39.30bc	**40.35AB**
	Mean	**39.91A**	**39.65A**		**40.73A**	**39.68B**	
Total Chlorophyll (SPAD value)	0 mM	54.80b	46.30c	**50.55C**	56.70c	48.50e	**52.60C**
	1 mM	70.60a	58.60b	**64.60A**	65.20a	61.50ab	**63.35A**
	2 mM	58.70b	52.90b	**55.80B**	62.80a	53.60cd	**58.20B**
	4 mM	56.50b	47.00c	**51.75C**	58.00bc	49.40de	**53.70C**
	Mean	**60.15A**	**51.20B**		**60.68A**	**53.26B**	
Total Sugars (mg/g FW)	0 mM	200.02a	176.63b	**188.32A**	176.63a	185.02a	**180.83A**
	1 mM	148.89c	133.66de	**141.27B**	138.66c	118.89d	**128.77C**
	2 mM	150.69c	143.42cd	**147.06B**	131.61cd	125.69cd	**128.65C**
	4 mM	168.22b	131.60e	**149.91B**	158.43b	133.22cd	**145.82B**
	Mean	**166.95A**	**146.33 B**		**151.32A**	**140.71B**	
Total phenols (mg/100 g FW)	0 mM	23.92c	14.41d	**19.16C**	19.92de	14.41f	**17.17C**
	1 mM	33.22a	31.96a	**32.59A**	28.22ab	31.96a	**30.09A**
	2 mM	29.02ab	27.11bc	**28.07B**	24.02bcd	23.11cd	**23.57B**
	4 mM	24.59bc	16.63d	**20.61C**	25.09bc	16.63ef	**20.86B**
	Mean	**27.69A**	**22.53B**		**24.31A**	**21.53B**	

Values are the means of three replicates. Values followed by the same letters within a column for each genus are not significantly different at the 1% level of probability according to Duncan's multiple range test

Table (3): Main effects of genotype, GABA treatment and their interactions on N, P, K and Ca of garlic

Parameters	**GABA**	**2015-2016**			**2016-2017**		
		Genotype		**Mean**	**Genotype**		**Mean**
		Egaseed	**Sids 40**		**Egaseed**	**Sids 40**	
N (mg/g DW)	0 mM	26.76bc	14.60d	**20.68C**	20.46cd	21.23cd	**20.84C**
	1 mM	44.46a	31.64b	**38.05A**	34.16a	31.64ab	**32.90A**
	2 mM	43.10a	23.52c	**33.31B**	30.80ab	23.52c	**27.16B**
	4 mM	21.18c	25.40c	**23.29C**	26.88bc	15.55d	**21.22C**
	Mean	**33.88A**	**23.79B**		**28.08A**	**22.98B**	
P (mg/g DW)	0 mM	7.51abc	4.78d	**6.14B**	6.51ab	5.28b	**5.89B**
	1 mM	9.87a	7.39abcd	**8.64A**	7.87a	7.39a	**7.63A**
	2 mM	8.81ab	7.39abcd	**8.10A**	6.81ab	7.39a	**7.10AB**
	4 mM	5.38cd	7.17bcd	**6.28B**	6.67ab	5.88ab	**6.28B**
	Mean	**7.89A**	**6.88B**		**6.96A**	**6.49A**	
K (mg/g DW)	0 mM	18.86bcd	16.68cd	**17.77B**	16.46d	16.68cd	**16.56C**
	1 mM	24.46a	20.54bc	**22.50A**	25.56a	21.04b	**23.30A**
	2 mM	21.21ab	16.20d	**18.71B**	19.31bc	16.08d	**17.69BC**
	4 mM	17.58bcd	18.58bcd	**18.08B**	19.61b	19.20bc	**19.40B**
	Mean	**20.53A**	**17.99B**		**20.23A**	**18.25B**	
Ca (mg/g DW)	0 mM	6.30bc	5.20c	**5.75B**	6.20b	5.00b	**5.60B**
	1 mM	9.30a	5.00c	**7.15AB**	8.20a	6.40ab	**7.30A**
	2 mM	8.00ab	7.90ab	**7.95A**	6.40ab	5.00b	**5.70B**
	4 mM	7.40ab	5.00c	**6.20B**	5.05b	5.00b	**5.03B**
	Mean	**7.75A**	**5.78B**		**6.46A**	**5.35B**	

Values are the means of three replicates. Values followed by the same letters within a column for each genus are not significantly different at the 1% level of probability according to Duncan's multiple range test

DISCUSSION

The result of the current research undoubtedly reported that the foliar supplementation of GABA significantly enhanced vegetative and yield parameters in the two garlic's genotypes compared to un-treated plants. GABA treatments improved plant height, fresh plant weight, bulb weight and total yield per Feddan (Table 1). These outcomes compatible with the findings of Li *et al.* (2016b), who found that exogenous supplementation of GABA significantly enhanced the vegetative growth; shoot fresh weight and seedlings length in three maize cultivars. Also, Kathiresan *et al.* (1998) found that the GABA supplementation improved the stem elongation in *Stellaria longipes*. There are several scientific theories that explain GABA's mechanism in improving the plant growth and alleviation of the negative effects resulting from the abiotic stress. Previous studies illustrated that GABA-induced enhancement in several agricultural crops probably attributed to enhanced of water soluble cabohydartes, proline accumulation, total sugars content, chlorophyll content, phenolic substances, photosynthetic activity, antioxidant enzyme activities, relative water content and membrane stability (Krishnan *et al.,* 2013; Vijayakumari and Puthur, 2015; Li *et al.,* 2016; Li *et al.,* 2017; Rezaei-Chiyaneh *et al.,* 2018).

The improvement in plant growth and yield in the current study for GABA treatments in both tested garlic genotypes and seasons may have been associated with increasing the total chlorophyll content during vegetative growth. Our results clearly indicated that the GABA treatments: 1mM and 2 mM improved the total chlorophyll content in treated plant compared to control and 4 mM treated plants (Table 2). In this regard, exogenous GABA supplementation significantly increased chlorophyll parameters: a and b content by 6.2% and 19.2%, respectively, and improved the structure and function of photosystem II in black cumin, muskmelon and pepper subjected to abiotic stress: water deficit, low light and salinity-alkalinity (Xiang *et al.,* 2016; Li *et al.,* 2017; Rezaei-Chiyaneh *et al.,* 2018). Moreover, GABA treatments reduced the chlorophyll degradation and improved the synthesis of carotenoids in black pepper and maize, thus improved photosynthetic system (Vijayakumari *et al.,* 2015; Wang *et al.,* 2017). In sum, the improvement in yield of garlic in current study might be attributed to the increase in the photosynthesis traits including cholorphyll content.

Phenolic compounds have important roles in the defense mechanism of higher plants through prevention lipids oxidation and eliminating the deleterious effects of reactive oxygen species (ROS) induced by abiotic stress (Pennycooke *et al*., 2005; Petridis *et al.,* 2012). The result of our study clearly reported that GABA treatments significantly promoted the endogenous total phenols in garlic (Table 2). In the same context, exogenous GABA promoted the accumulation of phenolic substances in banana fruits, wheat and tomato plants under several types of abiotic stress (Wang *et al.,* 2014; Farooq *et al.,* 2017; Cekiç, 2018). Taken together, positive effect of GABA in increasing the agricultural productivity and mitigation of harmful effect of abiotic stresses probably due to accumulation of total phenols that improves antioxidant defense system, thus improving yield and efficiency of water-use (Farooq *et al*., 2017). Phenylalanine ammonia lyase (PAL) is one of the essential enzymes associated with phenols biosynthesis. GABA treatment promoted PAL activity and recorded high content of total phenolics compared to untreated fruit (Wang *et al*., 2014). Our results suggest that GABA treatment might involve in acceleration of PAL activity in garlic bulbs and total phenolic content, leading to high total yield per Feddan in both garlic's genotypes.

The results proved that significant higher total sugars and TSS content connected with non-GABA treated plants (Table 2). These findings are not in harmony with the outcomes of Vijayakumari and Puthur (2015) and Rezaei-Chiyaneh *et al.* (2018), who found a positive correlation between GABA application and higher contacting of total sugars in black cumin and black paper plants, respectively. However, this result might be referred to increasing the vegetative growth and bulb size. It is obvious from the result of this study that GABA has a positive effect on elements content including N, P, K and Ca (Table 3). The highest mineral content: N, P, K and Ca was achieved in GABA treated plants that were sprayed with 1 and 2 mM GABA in both genotypes and growing seasons. Further increase of GABA to 4 mM did not increase the previous mentioned parameters. This novel result shows that GABA has supportive effect on the mineral composition of garlic bulb. Subsequently, GABA can increase garlic productivity through enhancing elements absorption from the soil, which can reduce the amount of the applied fertilizers. However, further studies are required to study effect of GABA on translocation of the macro elements such as N, P and K.

Generally, GABA treatments improved all studies traits, except SSC and total sugars in the current study (Table 1, 2 and 3). However, this improvement in growth and yield parameters in two garlic genotypes is dose-dependent. Where, the highest vegetative growth (plant height and plant fresh weight), bulb traits (bulb weight, bulbing ratio) yield, mineral content (N, P, K, and Ca) and organic content (total chlorophyll and total phenols) were achieved in GABA treated plants that were sprayed with 1 and 2 mM GABA. Interestingly, increase of GABA to 4 mM tended to decrease or does not improve the previous mentioned parameters. Several recent researches declared that low concentrations of GABA were more effective in improving plant growth than the high concentrations. In accordance with our findings, Farooq *et al.* (2017) reported that foliage applied GABA at 100 mg/L was more competent than another concentration 150 mg/L in alleviation of drought stress in two cultivars of bread wheat. Also, Krishnan *et al.* (2013) found that GABA supplementation at 50 mM was reported to be more practical than 70 mM in mitigation the damage in perennial ryegrass grown under water deficit condition.

Also, Li *et al*. (2016a) reported that exogenous of GABA partially at 0.5 mM enhanced photosynthetic trait and antioxidant enzyme actions in the NaCl-treated plants of wheat compared to other GABA treatment (0.25 mM and 1mM). Taken together, the ideal GABA concentration significantly vary between the plants and it depends on the crop species itself and abiotic stress type and this point should be taken into account to get positive response on growth and productivity parameters.

CONCLUSION

The result of the current study reported that significant highest vegetative growth and yield parameters as well as chemical composition parameters: organic and non-organic were associated with Egaseed than Sids 40 over all GABA treatments. It also showed that GABA treatments gave higher values for all studies traits, except total sugars and SSC than un-treated plants. Generally, GABA treated-garlic plants with 1 mM and 2 mM gave the significant highest values for all studies traits, except total sugars and SSC compared to another GABA treatment (4 mM). This result suggests that the positive GBAB effect is dose-dependent and it must be taken into account for the different agricultural crops in order to ensure high yield and productivity. The superior combination treatment for vegetative growth, yield and chemical composition parameters was Egaseed and foliar spray with GABA treatments at 1 mM. Based on the findings of this research, exogenous GABA application can increase the garlic growth and productivity under normal conditions through enhancing the mineral composition (N, P, K and Ca) and organic compounds (total phenols and total chlorophyll).

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إستجابه نمو ومحصول أصناف الثوم للرش الورقي بحامض جاما امينو بيوتريك

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يعتبر الثوم واحد من أهم محاصيل الخضر البصلية ويزرع من آلاف السنين نظراً لفوائده الطبية والغذائية. كان الهدف من الدراسة هو دراسة تأثير الرش بحامض جاما أمينو بيوترك على النمو الخضري وخصائص المحصول وكذلك المحتوى المعدني. لتحقيق هذا الهدف تم إجراء تجربتين حقليتين في موسم الشتاء لعامي ٢٠١٥/ ٢٠١٦ و ٢٠١٧/٢٠١٦م. تم رش نباتات الثوم لصنفي سيدس ٤٠ وايجاسيد بأربعة تركيزات من حامض جاما أمينو بيوترك (٠ و ١ و ٢ و ٤ ملليمول). أوضحت نتائج هذه الدراسة أن الرش بحامض جاما امينو بيوترك أدى إلى تحسين كلاً من صفات النمو الخضري (ارتفاع النباتات ووزن النبات الطازج) والمحصول (وزن الأبصال والمحصول الكلى) وكذلك المحتوى المعدني (نيتروجين – فوسفور – بوتاسيوم – كالسيوم) والعضوي (محتوى الكلورلوفيل والمواد الفينولية) لنباتات الثوم في كلا الصنفين تحت الدراسة بالمقارنة بالنباتات غير المعاملة. كما أظهرت نتائج هذه الدراسة أن المعاملة بتركيز ١ ملليمول حققت أعلى قيم في كلاً من صفات النمو الخضري والمحصول والمحتوى المعدني والعضوي مقارنة بباقي المعاملات. تشير نتائج هذه الدراسة إلى أن حامض جاما أمينو بيوترك لديه القدرة على تحسين نمو وإنتاجية الثوم عن طريق زيادة المحتوى المعدني وكذلك تحسين محتوى النباتات من المواد العضوية.