 Egypt. J. Hort. **Vol. 51**, No. 2, pp. 161-173 (2024)

Egyptian Journal of Horticulture

https://ejoh.journals.ekb.eg/

Growth, Yield, and Tuber Quality of Potato with Foliar Application of Tryptophan and Its Derivatives

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L-TRYPTOPHAN as an essential amino acid and its derivatives (indole-3-acetic acid and melatonin) have profound impacts on plant growth and development. In the present study, the aim is to investigate the effect of foliar application of tryptophan, indole-3-acetic acid, and melatonin on vegetative growth, mineral content of vegetative growth, SPAD readings, tuber productivity and quality of potato (*Solanum tuberosum* L.) plants cv. Spunta. Tryptophan was used at three concentrations (1, 2, and 4 mM), indole acetic acid at three levels (0.3, 0.6, and 1.2 mM), and melatonin at three concentrations (50, 100 and 200 µM), while water served as a control treatment. The foliar sprayings were applied three times during the growth period of potato plants, 35, 49, and 63 days after planting. The experiment design was a complete randomized block design with three replicates. This work was implemented at the Experimental Farm of the Horticulture Department, Faculty of Agriculture, Ain Shams University, Shoubra El-Kheima, Qalubia Governorate, Egypt for the two consecutive summer seasons of 2021 and 2022. Results showed that foliar application of tryptophan, melatonin, and indole-3-acetic acid enhanced the vegetative growth, mineral content, and tubers yield and quality of potato as compared to the control treatment. Moreover, foliar application of melatonin at 100 and 200 µM, tryptophan at 4 mM, and indole-3-acetic acid at 1.2 mM showed the highest significant increase in growth, yield, and quality of potato. In conclusion, spraying of melatonin at 100 µM or tryptophan at 4 mM or indole-3-acetic acid at 1.2 mM could be used to enhance growth, tubers yield, and quality of potato plants cv. Spunta.

Keywords: *Solanum tuberosum* L., Precursor, Indole-3-acetic acid, Melatonin, Vegetative growth, Tuber yield, Starch, Dry matter.

Introduction

Potato (*Solanum tuberosum* L.) is a substantial crop worldwide, it comes in fourth place, behind wheat, maize, and rice (Khalid and Aftab, 2020). Furthermore, it is a low-cost food for energy with a plentiful content of starch, minerals, amino acids, and vitamins C, and B (Ali et al., 2021). In Egypt, potato cultivation area was 0.2627 million hectares with a total production of 6.90 million tons in 2021 (FAOSTAT, 2023). Foliar application of plant growth stimulators such as tryptophan, indole-3-acetic acid, and melatonin play important roles in improving the growth, yield, and quality of various crops.

L-tryptophan or β-3-indolylalanine is an essential amino acid for living organisms such as plants, animals, humans, and some bacteria. In 1901, it was discovered by the English chemist Frederick Gowland Hopkins (Frankenberger and Arshad, 1991, Mustafa et al., 2018). Additionally, it plays a crucial role in the synthesis of proteins (Jiang et al., 2022). In general, amino acids have N, C, H, and O_2 plus an organic sidechain in their structure, in different amino acids, that characteristic differentiates (Teixeira et al., 2017). Many chemical molecules, including enzymes, vitamins, terpenoids, alkaloids, coenzymes, and purine and pyrimidine bases, are biosynthesized using amino acids. Moreover, amino acids control cell division and differentiation, which further regulates plant growth and development, regulate photosynthesis processes and growth, and are essential for antioxidant defense (Ibrahem, 2016, Ibraheim and Mohsen, 2021). Amino acids are a key mobilizable source of nitrogen and hormone precursors in plants. Also, they participate in various cellular reactions, and thus they have an impact on a number of physiological processes, including plant growth and development,

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(Received 17/10/2023, accepted 06/11/2023)
DOI: 10.21608/EJOH.2023.241425.1263

intracellular pH regulation, the production of metabolic energy or redox power, plus biotic and abiotic stress resistance (Zhao, 2010, Moe, 2013, Hildebrandt et al., 2015, Teixeira et al., 2017). L-tryptophan is a physiological precursor of indole-3-acetic acid (IAA) and melatonin in higher plants (Sarwar and Frankenberger, 1994, Chen et al., 2009, Arnao and Hernández-Ruiz, 2019, Jiang et al., 2022). Tryptophan treatments could improve several biochemical processes by regulating plant growth and differentiation as well as improving water absorption and nutrient uptake. Furthermore, exogenous applications of tryptophan enhanced the growth and yield of various crops grown under normal environmental conditions and likewise under abiotic stresses (Talaat et al., 2005, Dawood and Sadak, 2007, El-Awadi et al., 2017, Sadak and Ramadan, 2021). In addition, previous studies reported that tryptophan foliar applications improved the growth, yield, and quality of some vegetable crops, i.e., snap bean (El-Awadi et al., 2011), chilli pepper (Raza et al., 2014, Rahman et al., 2021), green onion (Abd El-wahed et al., 2016), radish (Nishanthi and Sutharsan, 2017), and lettuce (Ibraheim and Mohsen, 2021).

Melatonin is also known as N- acetyl- 5-methoxytryptamine and can be found in living organisms (Li et al., 2012, Sadak et al., 2020). Also, it is derived from tryptophan, which was first isolated in 1958 from the bovine pineal gland (Lerner et al., 1958, Nawaz, 2021, Yang et al., 2021). In plants, melatonin was discovered in 1995 (Dubbels et al., 1995, Hattori et al., 1995). It is created in the mitochondria and chloroplast of the roots and leaves of plants, and is then passed on to the meristem, flowers, and fruits (Wang et al., 2016 b, Nawaz et al., 2021). Melatonin is a potential modulator that is crucial for plant's growth and development. In plant cells, melatonin controls a number of physiological and biochemical processes, i.e., shoot and root growth, fruit development, delaying leaf senescence, ion homeostasis, and acting as a stress defender (Li et al., 2012, Sadak, 2020, Sadak and Ramadan, 2021). Foliar applications of melatonin enhanced the growth, yield, and quality of some vegetable crops like potato (El-Yazied et al., 2022), cucumber (Wang et al., 2016 a, Brengi et al., 2022), strawberry (Zahedi et al., 2020), tomato (Ibrahim et al., 2020), and cauliflower (EL-Bauome et al., 2022).

Indole-3-acetic acid (IAA) is an important auxin in higher plants, produced especially in young leaves and, in general, in the meristematic tissues of plants. It is a plant biological regulator that regulates various plant's physiological and developmental processes, i.e., cell division, elongation, differentiation, gametogenesis, embryogenesis, seedling growth, vascular patterning, and flower development, as well as responses to gravity or light stimuli (Zhao, 2010, Waheed et al., 2014, Dhungana and Itoh, 2019, Alam et al., 2020). In plants, the action of IAA on plant growth is dependent on concentration, hence, IAA levels in plants must be kept at optimal levels because high concentrations could have an inhibiting effect (Tanimoto, 2005, El-Mergawi and Abd El-Wahed, 2020). In most tissues, endogenous IAA responded to different amounts of exogenous IAA application (Zhou et al., 2017, El-Mergawi and Abd El-Wahed, 2020). Applications of IAA improved the growth, yield, and quality of some vegetable crops like cowpea (Al-Amri, 2018), and garlic (Abd Elwahed et al., 2019, Lemdor and Deepanshu, 2022).

L-tryptophan and its derivatives, indole-3-acetic acid and melatonin, have profound impacts on plant's growth and development. So, the aim of this study is to assess the influence of foliar application of tryptophan and these two derivatives on growth, mineral content of vegetative growth, SPAD readings, yield, and quality of potato (*Solanum tuberosum* L.) plants cv. Spunta.

Materials and Methods

Experimental site and soil type

At the Experimental Farm of the Horticulture Department located in Faculty of Agriculture, Ain Shams University, Shoubra El-Kheima, Qalubia Governorate, Egypt a field experiment was held during the summer seasons of 2021 and 2022 to assess the influences of tryptophan, indole acetic acid, and melatonin foliar applications on vegetative growth, mineral content, SPAD readings, yield parameters, and tuber quality characteristics of potato plants (*Solanum tuberosum* L.) cv. Spunta.

The soil type was a clay soil with pH of 7.37 and EC of 0.7 mmhos/cm. The electrical conductivity was determined in the extract of saturated soil paste according to the method mentioned by Jackson (1973). The pH values were measured in soil suspension (1:2.5) using pH meter according to the method mentioned by Black et al. (1965).

Experimental design, cultivation, and foliar treatments

The experiment design was a complete randomized block design with three replicates. The tubers were planted on January 27th and 8th, in the 2021 and 2022 seasons, respectively. Each experimental plot contained three rows each of 4 m in length and 75 cm in width with an area of 9 m^2, and potato tubers were planted 30 cm apart (40 plants/plot). All agricultural practices for potato cultivation (irrigation, fertilization, and disease and pest control) were followed as recommended by the Egyptian Ministry of Agriculture and Land Reclamation.

The experiment included ten treatments: tryptophan was used at three concentrations (1, 2, and 4 mM), indole acetic acid at three levels (0.3, 0.6, and 1.2 mM), and melatonin at three concentrations (50, 100, and 200 µM), plus water served as a control treatment. The foliar sprayings were applied three times during the growth period of potato plants, 35, 49, and 63 days after planting. By using hand-held sprayer, applications were implemented before sunset and the plants were treated with the spraying solutions till the plant foliage was completely covered.

Data recorded

Vegetative growth parameters

After 80 days of cultivation, three plants were taken as a random sample from each experimental plot was measure the vegetative growth characteristics, i.e., plant length, number of branches and leaves per plant, shoot fresh and dry weight per plant, and leaf area. Leaf area was measured using the fully expanded fourth leaf from the plant top as a relation between the area and the fresh weight of leaves according to the following equation as indicated by Koller (1972).

$$\text{Leaf area (cm}^2\text{)} = \frac{\text{Disk area x No.of disks x fresh weight of leaves}}{\text{Fresh weight of disks}}$$

Mineral analysis of vegetative growth and SPAD readings

An electric oven was used to dry samples of vegetative growth at 70 Celsius degrees till a constant weight. Then the samples were grounded to a fine powder in a high-speed stainless steel mill, and a half gram of dry powdered samples was taken and wet digested. In the acid digested solution, total nitrogen was estimated by the micro-Kjeldahl method, according to Jackson (1973). Phosphorus concentration was determined spectrophotometrically, as described by Watanabe and Olsen (1965). Potassium was assayed using a flame photometer, according to Jackson (1973). Versenate (EDTA) was used to assay calcium and magnesium as described by Cheng and Bray (1951). While, zinc was estimated by using atomic absorption spectroscopy, according to Beaty and Kerber (1978).

The fourth leaf from the top of the plant that was fully expanded was selected to measure the leaf greenness of the plant by a portable chlorophyll meter (SPAD–502, Konica Minolta Sensing, Inc., Japan), according to Khan et al. (2003).

Yield components and tuber quality

Tubers were harvested 110 days after planting. Tuber number/plant, average tuber weight, tuber weight/plant, and total yield/hectare were determined. The total yield/hectare was calculated using the following equation:

$$\text{Total yield (ton ha}^{-1}\text{)} = \frac{\text{tuber weight per plant (kg)x 44,000}}{1000}$$

where 44,000 is the number of plants/ha, and 1000 is the metric conversion calculator from kg to ton.

Samples of tubers were washed, chopped, and mixed, then 200 g from each unit were taken and dried in an electric oven at 70 Celsius degrees till a constant weight was reached. The ratio between dry and fresh weight was calculated as the dry matter content, according to AOAC (1990):

$$\text{Dry matter (\%)} = \frac{\text{sample weight after dry}}{\text{sample weight before dry}} \text{x } 100$$

Tuber-specific gravity (SG) was calculated by the ratio of tuber density to water. The starch content was estimated, according to Burton (1948):

$$\text{Starch (\%)} = 17.546+199.07\ (\text{SG} - 1.0988).$$

Statistical analysis

CoStat package program (Version 6.303, CoHort Software, USA) was used to apply the statistical analysis. Data were analyzed using to one-way-ANOVA analysis of variance. Duncan's multiple range test compared the differences among means of data (Waller and Duncan, 1969). All statistical calculations were implemented at a 5% level of probability.

Results and Discussion

Vegetative growth parameters

Data in Table (1) obviously show that all applied foliar treatments caused significant increases in plant length, except for the IAA treatment at 1.2 mM, while spraying melatonin at 100 µM and IAA at 0.6 mM exhibited the highest values of this trait in the 2021 and 2022 growing seasons. There are no significant differences between both treatments of 100 µM melatonin and 0.6 mM IAA in both seasons. In contrast, all treatments significantly increased the number of leaves/plant, leaf area/plant and shoot dry weight (Table 2), except for the treatment of tryptophan at 1 mM, while applications of melatonin at 100 and 200 µM showed the highest values of the aforementioned parameters without significant differences among them in both growing seasons. In addition, all foliar treatments induced significant increments in number of branches/plant, except tryptophan at 1 mM and IAA at 0.3 and 1.2 mM, while tryptophan at 4 mM, melatonin at 100 and 200 µM and IAA at 0.6 mM revealed the highest values of this character without any significant differences among them in the 2021 and 2022 growing seasons. Additionally, all applied treatments significantly increased shoot fresh weight, while melatonin at 100 and 200 µM and IAA at 0.6 and 1.2 mM exhibited the highest values of this parameter in 2021 and 2022 growing seasons (Table 2). However, the control treatment revealed the lowest significant values of all the vegetative growth metrics in the 2021 and 2022 growing seasons.

Table 1. Effect of tryptophan, melatonin, and indole acetic acid (IAA) foliar spraying on plant length, number of leaves and branches per plant, and leaf area of potato plants cv. Spunta in 2021 and 2022 seasons.

Treatments		Plant length (cm)		Number of leaves/plant		Number of branches/plant		Leaf area (cm^2)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control		68.44 d	53.55 d	39.33 e	43.56 g	2.56 d	2.56 f	127.4 f	133.3 e
Tryptophan	1 mM	71.22 c	56.78 c	40.33 e	50.11 ef	2.67 d	2.77 ef	130.0 ef	145.5 d
	2 mM	73.78 b	60.00 b	49.22 b	52.00 de	3.44 bc	3.11 cde	134.2 d	153.7 c
	4 mM	73.44 b	56.33 c	48.00 bc	48.67 f	4.22 a	3.55 ab	152.3 b	154.6 c
Melatonin	50 µM	72.67 bc	59.33 b	48.56 b	54.22 bc	3.38 c	3.00 cde	132.2 de	165.6 b
	100 µM	77.56 a	63.67 a	52.67 a	60.56 a	3.89 ab	3.72 a	155.4 a	172.7 a
	200 µM	73.89 b	56.33 c	52.55 a	59.44 a	3.78 abc	3.33 abc	153.7 ab	168.3 ab
IAA	0.3 mM	71.78 c	63.55 a	46.44 c	52.56 cd	4.22 a	2.89 def	142.6 c	151.8 c
	0.6 mM	77.00 a	64.45 a	52.67 a	55.22 b	4.11 a	3.33 abc	152.2 b	168.2 ab
	1.2 mM	61.22 e	60.22 b	43.11 d	56.11 b	2.67 d	3.22 bcd	155.1 ab	164.6 b

Means within a column followed by the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

Table 2. Effect of tryptophan, melatonin, and indole acetic acid (IAA) foliar spraying on shoot fresh and dry weights, and leaf SPAD readings of potato plants cv. Spunta in 2021 and 2022 seasons.

Treatments		Shoot fresh weight (g)		Shoot dry weight (g)		SPAD readings	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Control		267.04 f	325.44 e	41.18 e	50.58 e	52.77 a	56.49 a
Tryptophan	1 mM	298.17 e	346.34 cd	42.41 e	63.48 d	53.60 a	56.99 a
	2 mM	310.67 d	344.52 d	49.85 d	65.86 c	52.40 a	55.77 a
	4 mM	319.33 c	349.11 bcd	51.08 d	67.59 bc	53.99 a	58.06 a
Melatonin	50 µM	316.40 cd	350.22 bcd	62.26 b	67.62 bc	50.63 a	55.73 a
	100 µM	337.50 a	359.78 ab	67.90 a	73.07 a	50.96 a	55.92 a
	200 µM	336.40 a	364.52 a	64.84 ab	72.20 a	52.59 a	56.99 a
IAA	0.3 mM	324.20 bc	357.78 abc	48.66 d	65.70 cd	50.68 a	55.82 a
	0.6 mM	330.44 ab	359.26 abc	56.94 c	68.58 b	52.97 a	56.02 a
	1.2 mM	329.43 ab	366.33 a	63.28 b	73.48 a	53.57 a	57.13 a

Means within a column followed by the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

Similar stimulatory effects of tryptophan, melatonin, and IAA treatments on vegetative growth attributes were stated in snap bean (El-Awadi et al., 2011), chilli pepper (Raza et al., 2014, Rahman et al., 2021), sweet pepper (Shahen et al., 2019), potato (Kumari, 2022, El-Yazied et al., 2022), tomato (Ibrahim et al., 2020, Khan et al., 2022), cucumber (Wang et al., 2016 a, Brengi et al., 2022), cauliflower (EL-Bauome et al., 2022), garlic (Abd Elwahed et al., 2019), onion (Abd El-wahed et al., 2016), okra (Mustafa et al., 2016), radish (Nishanthi and Sutharsan, 2017), and lettuce (Ibraheim and Mohsen, 2021).

The stimulatory effects on vegetative growth parameters may be attributed to the fact that melatonin is readily soluble in both water and fats and can readily transfer to any aqueous portion. So, melatonin acts primarily as an antioxidant. Thus, melatonin can improve the growth of plants. It controls physiological and biological plant processes like photosynthetic activity, root growth, and plant hormones synthesis, i.e., ethylene, cytokinin, gibberellins, IAA, and brassinosteroids (Sharif et al., 2018, Arnao and Hernández-Ruiz, 2018). Also, it could be potentially due to improving the genes expression that are involved in metabolism, cell division, and photosynthesis activity and efficiency, also it can increase the enzyme activity levels (Ibrahim et al., 2020). Additionally, melatonin shared IAA and tryptophan in the structure and functions (Herna´ndez-Ruiz et al., 2005, Pelagio-Flores et al., 2012). IAA promotes cell elongation, enhances cell division, increases cell expansion, and stem elongation. Also, the enhancements in the vegetative growth could be correlated to the beneficial influence of tryptophan on enhance protein synthesis, and production of phytohormones such as IAA (El-Awadi et al., 2017). Additionally, IAA may promote plant growth by altering the activity of the enzymes involved in carbohydrate metabolism. Also, IAA starts a signal transduction pathway that produces secondary messengers that activate pre-existing H+-ATPases and increases the expression of a number of genes correlated to plant's growth and development. Furthermore, IAA inhibits gibberellins (GA) deactivation and stimulates the production of GA. In addition, IAA stimulates the upregulation of gibberellin biosynthesis gene and the production of new wall polysaccharides so that growth can last for extended durations (Damian et al., 2002, Khandaker et al., 2018). Moreover, amino acids may directly or indirectly improve a variety of physiological plant's growth and development processes through their regulatory impacts on gibberellin production in plant tissues, nutrients uptake, and metabolism in treated plants, all of which are essential for enhancing plant growth (Zewail, 2014, El-Kenawy, 2022). Furthermore, the enhancement in plant growth may be due to the beneficial impact of tryptophan on the cell division throughout the development process (Muneer et al., 2009). Also, the increase in plant's growth is presumably due to the function of tryptophan in regulating gene expression to provide the particular macromolecules necessary for constant cell elongation (Ahmed et al., 2017). Additionally, tryptophan as an amino acid serves as a source of nitrogen in plant tissue, which has a direct role in plant growth (Ibraheim and Mohsen, 2021). Also, IAA has an inhibitory effect on ethylene action (Kim et al., 2001).

SPAD readings

Data in Table (2) indicate that foliar applications of tryptophan, melatonin, and IAA had no significant effects on the SPAD readings of the potato plants compared to the control treatment in both growing seasons. The indicated results are in good accordance with those indicated by Abou Dahab and Abd El-Aziz (2006) who found that tryptophan treatments had no significant influence on the chlorophyll contents in 2021 and 2022 growing seasons.

Mineral analysis of vegetative growth

Data in Tables (3 and 4) reveal that all treatments significantly increased nitrogen percentage, except tryptophan at 1 mM and melatonin at 50 µM, while melatonin at 100 and 200 µM and IAA at 0.6 and 1.2 mM revealed the highest values of nitrogen without significant differences in both growing seasons. Additionally, all treatments caused significant increases in phosphorus percentage, however tryptophan treatment at 4 mM and IAA at 1.2 mM gave the highest values of phosphorus in 2021 and 2022 growing seasons. There are no significant differences between tryptophan at 4 mM and IAA at 1.2 mM in phosphorus percentage in both seasons. In addition, all foliar treatments caused significant increases in potassium percentage, except IAA treatment at 0.3 mM while tryptophan at 2 and 4 mM, melatonin at 200 µM and IAA at 1.2 mM exhibited the highest values of potassium without significant differences in both growing seasons. Also, all treatments significantly increased magnesium percentage, except tryptophan at 1 mM, melatonin at 50 µM and IAA at 0.3 and 0.6 mM, however tryptophan at 4 mM, melatonin at 100 and 200 µM and IAA at 1.2 mM revealed the highest values of magnesium without significant differences in both seasons. Also, all treatments significantly increased calcium percentage, while tryptophan at 4 mM, melatonin at 100 µM and IAA at 0.6 mM showed the highest values of calcium without significant differences in both growing seasons. Additionally, all treatments caused significant increases in zinc content, except tryptophan at 1 mM, while tryptophan at 2 and 4 mM and melatonin at 100 µM showed the highest values of zinc in 2021 and 2022 growing seasons. Furthermore, the lowest significant values of all mineral were recorded with the control treatment in the growing seasons of 2021 and 2022.

Table 3. Effect of tryptophan, melatonin, and indole acetic acid (IAA) foliar spraying on nitrogen, phosphorus, and potassium percentages in vegetative growth of potato plants cv. Spunta in 2021 and 2022 seasons.

Treatments		Nitrogen (g/100 g DW)		Phosphorus (g/100 g DW)		Potassium (g/100 g DW)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Control		2.88 e	3.29 c	0.59 c	0.58 e	1.60 d	1.84 d
Tryptophan	1 mM	3.06 d	3.38 bc	0.62 b	0.66 cd	1.79 b	2.02 ab
	2 mM	3.11 bcd	3.52 a	0.69 a	0.72 bc	1.86 a	2.04 a
	4 mM	3.08 cd	3.53 a	0.70 a	0.80 a	1.87 a	1.99 ab
Melatonin	50 µM	2.90 e	3.56 a	0.62 b	0.64 d	1.71 c	1.93 c
	100 µM	3.14 ab	3.48 ab	0.64 b	0.67 cd	1.77 b	1.96 bc
	200 µM	3.12 abc	3.53 a	0.64 b	0.66 cd	1.86 a	2.01 ab
IAA	0.3 mM	3.11 bcd	3.47 ab	0.64 b	0.69 cd	1.80 b	1.87 d
	0.6 mM	3.17 a	3.58 a	0.68 a	0.68 cd	1.88 a	1.96 bc
	1.2 mM	3.14 ab	3.52 a	0.70 a	0.75 ab	1.86 a	2.05 a

Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Table 4. Effect of tryptophan, melatonin, and indole acetic acid (IAA) foliar spraying on magnesium, calcium percentages and zinc content in vegetative growth of potato plants cv. Spunta in 2021 and 2022 seasons.

Treatments		Mg (g/100 g DW)		Ca (g/100 g DW)		Zn (mg/kg DW)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Control		1.85 c	1.68 d	1.14 f	1.12 d	96.02 e	69.63 g
Tryptophan	1 mM	1.88 c	1.78 c	1.44 d	1.20 bc	97.39 de	122.53 b
	2 mM	2.00 b	1.88 a	1.56 b	1.27 a	109.71 a	124.32 a
	4 mM	2.10 a	1.91 a	1.58 ab	1.28 a	108.02 ab	124.25 a
Melatonin	50 µM	1.91 c	1.78 c	1.38 e	1.22 b	107.33 b	114.63 f
	100 µM	2.08 a	1.92 a	1.58 ab	1.27 a	109.62 a	123.73 ab
	200 µM	2.11 a	1.87 ab	1.53 c	1.29 a	104.94 c	116.63 e
IAA	0.3 mM	1.86 c	1.78 c	1.56 b	1.18 c	99.19 d	120.38 c
	0.6 mM	1.92 c	1.82 bc	1.60 a	1.28 a	108.00 ab	122.73 b
	1.2 mM	2.10 a	1.89 a	1.53 c	1.29 a	108.40 ab	119.02 d

Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

The same results were reported by Mahdi and Saeed (2019), Ibraheim and Mohsen (2021), El-kenawy (2022) which found that exogenous application of tryptophan showed the highest values of potassium, phosphorus, and magnesium. Also, Zahedi et al. (2020) on strawberry indicated that melatonin foliar sprays at 100 and 200 µM increased the leaf concentrations of potassium, magnesium and calcium. In addition, Zahedi et al. (2021) stated that 200 µM melatonin had better impacts on potassium and calcium. Shahen et al. (2019) indicated that foliar application of IAA revealed the highest values of nitrogen, phosphorus, and potassium percentages. The increments in plants of nutrients are probably due to foliar application of tryptophan, melatonin, and IAA were significantly enhanced the vegetative growth parameters of potato plant as shown in Tables 1 and 2, and these increases in plant growth led to an increment in nutrients uptake. Furthermore, exogenous treatment of melatonin enhances the production of IAA. Also, IAA and melatonin enhances root growth (Murch et al., 2001, Wang et al., 2016 c, Sharif et al., 2018). Thus, it was accompanied by increased water and nutrients uptake for vegetative growth.

Yield components and tuber quality

As shown in Table (5) treatments of tryptophan at 4 mM and melatonin at 100 and 200 µM gave the highest and most significant values of the number of tubers/plant in both seasons. There were insignificant differences among the above-mentioned treatments on the number of tubers/plant in both seasons. Further, all foliar applications caused significant increases in the average tuber weight, except tryptophan at 1 mM, melatonin at 50 µM and IAA at 0.3 mM, while tryptophan at 2 and 4 mM and IAA at 0.6 and 1.2 mM showed the highest values of average tuber weight without significant differences among them in both growing seasons. Additionally, all treatments significantly increased tubers weight/plant and total tuber yield, except tryptophan at 1 mM and IAA at 0.3 mM, however tryptophan at 4 mM, melatonin at 50 and 100 µM and IAA at 0.6 and 1.2 mM gave the highest values of these parameters without significant differences in both seasons. Additionally, the lowest significant values of all parameters were recorded with the control treatment in both seasons.

Table 5. Effect of tryptophan, melatonin, and indole acetic acid (IAA) foliar spraying on yield components of potato plants cv. Spunta in 2021 and 2022 seasons.

Treatments		Number of tubers/plant		Average tuber weight (kg)		Tuber yield /plant (kg)		Total tuber yield/ha (Ton)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Control		4.78 d	5.05 d	0.17 b	0.17 d	0.80 e	0.84 d	30.2 e	32.0 d
Tryptophan	1 mM	5.00 cd	5.56 cd	0.18 b	0.17 d	0.87 e	0.93 cd	33.2 e	35.3 cd
	2 mM	5.66 a-d	5.44 cd	0.23 a	0.21 a	1.28 bc	1.15 abc	48.6 bc	43.7 abc
	4 mM	6.00 abc	6.55 ab	0.22 a	0.20 ab	1.33 abc	1.34 a	50.7 abc	50.9 a
Melatonin	50 µM	5.56 bcd	6.95 a	0.22 a	0.17 cd	1.21 cd	1.18 ab	45. 9 cd	44.9 ab
	100 µM	6.11 abc	6.81 ab	0.23 a	0.19 bc	1.43 abc	1.27 ab	54.4 abc	48.2 ab
	200 µM	6.67 ab	6.83 ab	0.23 a	0.19 bc	1.53 ab	1.27 ab	58.1 ab	48.4 ab
IAA	0.3 mM	5.33cd	6.22 abc	0.18 b	0.17 cd	0.95 de	1.08 bc	36.2 de	41.0 bc
	0.6 mM	5.67 a-d	6.67 ab	0.23 a	0.20 ab	1.30 abc	1.36 a	49.3 abc	51.7 a
	1.2 mM	6.78 a	6.00 bcd	0.23 a	0.21 a	1.59 a	1.26 ab	60.4 a	47.9 ab

Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Data in Table (6) show that exogenous applications of tryptophan at 2 and 4 mM, melatonin at 100 µM, and IAA at 1.2 mM significantly increased dry matter percentage, while tryptophan at 2 mM, melatonin at 100 µM, and IAA at 1.2 mM revealed the highest significant values of dry matter in both seasons. There were no significant differences among these treatments in this character in both seasons. In addition, tryptophan at 2 mM, melatonin at 100 and 200 µM and IAA at 1.2 mM exhibited the highest and most significant values of tuber specific gravity and starch percentage in both growing seasons without significant among these treatments. Meanwhile, the lowest significant values of all cases were recorded with the control treatment in both growing seasons.

Table 6. Effect of tryptophan, melatonin, and indole acetic acid (IAA) foliar spraying on dry matter, specific gravity and starch content of potato tubers cv. Spunta in 2021 and 2022 seasons.

Treatments		Dry matter (%)		Specific gravity		Starch (%)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
Control		15.46 d	19.17 e	1.05 b	1.05 d	7.83 b	8.49 d
Tryptophan	**1 mM**	19.05 c	19.20 e	1.07 ab	1.07 abc	11.15 ab	12.48 abc
	2 mM	21.11 ab	20.70 abcd	1.09 a	1.08 ab	15.13 a	13.14 ab
	4 mM	18.82 c	20.97 ab	1.07 ab	1.07 bc	11.15 ab	11.15 bc
Melatonin	**50 µM**	18.10 c	19.60 cde	1.06 b	1.06 cd	9.82 b	10.49 cd
	100 µM	21.59 a	20.80 abc	1.08 a	1.08 ab	14.47 a	13.14 ab
	200 µM	20.52 b	20.50 a-e	1.09 a	1.07 abc	15.13 a	12.48 abc
IAA	**0.3 mM**	18.17 c	19.40 de	1.06 b	1.06 cd	9.16 b	10.49 cd
	0.6 mM	18.27 c	19.80 bcde	1.07 ab	1.06 cd	11.81 ab	10.49 cd
	1.2 mM	21.30 ab	21.20 a	1.09 a	1.08 a	15.13 a	14.47 a

Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

Similar results were reported by (El-Awadi et al., 2011) on snap bean, (Raza et al., 2014) on chilli pepper, (Mustafa et al., 2016) on okra, (Nishanthi and Sutharsan, 2017) on radish, (Ibraheim and Mohsen, 2021) on lettuce, (Rahman et al., 2021) on chilli, (Ibrahim et al., 2020) on tomato, (Zahedi et al., 2020) on strawberry, (EL-Bauome et al., 2022) on cauliflower, (Brengi et al., 2022) on cucumber, (El-Saeid, 2010, Al-Amri, 2018) on cowpea, (Aldesuquy et al., 2018) on pea, (Kumari, 2022) on potato, (Shahen et al., 2019) on sweet pepper, and (Abd Elwahed et al., 2019, Lemdor and Deepanshu, 2022) on garlic.

These improvements in yield components and quality may be as a consequence of increases in the vegetative growth attributes as shown in Tables 1 and 2. Also, may be due to increases of nutrients in vegetative growth of potato as mentioned in Tables 4 and 5. Furthermore, the increase in yield components is probably due to the positive effect of tryptophan on production of phytohormones e.g., IAA (Abbas, 2013, El-Awadi et al., 2017). Additionally, IAA has a direct role on cell elongation, cell division and changes in the activities of carbohydrate metabolism enzymes (Khandaker et al., 2018). In addition, melatonin has a valuable role in controlling plant physiological and biological processes such as photosynthetic activity, root growth, and can be regulate plant hormones (Sharif et al., 2018). Additionally, the enhancement of yield might be due to the stimulatory effect on increased number of leaves/plant, expansion of leaf area as shown in Table 1, and photosynthetic activity which raised the amount of carbohydrates in leaves, increasing the yield of potato plants as a consequence. Furthermore, the increment in transpiration rate and transfer of the photosynthetic assimilates by IAA are most likely responsible for improving yield characteristics (Al- Amri, 2018).

Conclusion

Currently, it could be concluded that foliar applications of tryptophan, melatonin, and indole-3-acetic acid can be used to enhance and increase the plant productivity. In addition, foliar application melatonin at 100 µM or tryptophan at 4 mM or indole-3-acetic acid at 1.2 mM were the most efficient and effective treatments, which enhanced growth, yield, and quality of potato plants cv. Spunta.

Acknowledgment

Thanks to my supervisors at Department of Horticulture, Faculty of Agriculture, Ain Shams university, Egypt for their continuous help and valuable advice during carrying out this study.

Funding statements

This research was technically supported by the Faculty of Agriculture, Ain Shams University, Egypt.

Conflict of interest

The authors declare that they have no competing interests.

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نمو ومحصول وجودة درنات البطاطس بالرش الورقي بالتربتوفان ومشتقاته

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الحمض الأميني التربتوفان ومشتقاته (اندول حمض الخليك، والميلاتونين)، لهم تأثيرات إيجابية على نمو وتطور النبات. أجريت تجربة حقلية خلال الموسمين المتتالين ٢٠٢١ و٢٠٢٢ في المزرعة التجريبية الخاصة بقسم البساتين، كلية الزراعة، جامعة عين شمس، محافظة القليوبية، مصر بهدف دراسة تأثير تطبيق الرش الورقي بمستويات مختلفة للتربتوفان واندول حمض الخليك والميلاتونين على النمو الخضري، ومحتوى العناصر، وقراءات (SPAD) كمؤشر لإخضرار الأوراق، ومحصول وجودة درنات البطاطس صنف سبونتا. تم إستخدام التربتوفان بثلاثة تركيزات (١ و٢ و٤ ملليمول)، واندول حمض الخليك بثلاثة تركيزات (٠,٣ و٠,٦ و١,٢ ملليمول)، والميلاتونين بثلاثة تركيزات (٥٠ و١٠٠ و٢٠٠ ميكرومول)، بالإضافة إلى الرش الورقي بالماء كمعاملة مقارنة وتم الرش ثلاث مرات خلال موسم النمو. صممت التجـربة فى تصميم القطاعات كاملة العشوائية من ثلاث مكررات. أوضحت النتائج المتحصل عليها أن معاملة الرش الورقي للحمض الأميني التربتوفان والميلاتونين واندول حمض الخليك قد أدى إلى تحسين النمو الخضري، ومحتوى العناصر في المجموع الخضري، ومحصول وجودة نباتات البطاطس، مقارنة بمعاملة الرش بالماء. بالإضافة إلى ذلك، الرش الورقي بالميلاتونين بتركيز ١٠٠ و٢٠٠ ميكرومول، والتربتوفان بتركيز ٤ ملليمول، واندول حمض الخليك بتركيز ١,٢ ملليمول سجلوا أعلى زيادات معنوية في قراءات النمو الخضري ومحصول وجودة درنات البطاطس. من هذه الدراسة يُستنتج أنه يمكن إستخدام الرش الورقي بالميلاتونين بتركيز ١٠٠ ميكرومول، أو التربتوفان بتركيز ٤ ملليمول، أو اندول حمض الخليك بتركيز ١,٢ ملليمول للحصول على أعلى محصول وجودة لنباتات البطاطس صنف سبونتا.

الكلمات الدالة: *Solanum tuberosum* L.، Precursor، اندول حمض الخليك، الميلاتونين، النمو الخضري، محصول الدرنات، النشا، المادة الجافة.