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Rationalization of Water Consumption for Taro Plant through the Rationing of Irrigation and Expand the Plant Ability to Resist Stress Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiments were conducted at Horticulture Research Station, El-Kanater El-Khiria, Horticulture Research Institute, Agriculture Research Centre, Egypt during 2016 and 2017 seasons to investigate the effect of different irrigation water levels i.e.,100, 75 and 50% of the crop evapotranspiration (ETc) and foliar application with some stimulant substances i.e., proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1} as well as mulching treatments i.e., black polyethylene plastic, rice straw and sawdust mulches individually or in combination of treatments on vegetative growth characteristics, some bioconstituents, total yield and its components of taro plant under drip irrigation system and results interpreted. The results showed that that increasing water stress level from 75% to 50% of Etc decreased gradually all studied growth characteristics of taro plant (plant height, leaves number $plant^{-1}$, lamina dry weight $plant^{-1}$ and leaf area (cm^2) $plant^{-1}$ in the two seasons. In addition, increasing irrigation water stress resulted in decreasing of photosynthetic pigments (chlorophyll a, b and carotenoids) content in taro

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leaves. Moreover, the increase in water shortage is regularly increased the proline content and antioxidant enzymes activity i.e., superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) in taro leaves compared to the full irrigation level (100% of ETc). Furthermore, different estimated yield characteristics of taro plant i.e., main corm length (cm), main corm diameter (cm), corms number plant^{-1}, corms fresh weight (kg) plant^{-1}, main corm fresh weight (g), corms fresh weight (kg) plot^{-1}, corms fresh yield (ton) fed.$^{-1}$ and corm dry matter % as well as taro corm bioconstituents of N, P, K, crude protein and starch contents decreased by reducing irrigation water levels. In this respect, water stress level at 50% of ETc recorded the highest reductions in different estimated characteristics compared to 75% of ETc level and unstressed plant (100% of ETc).

Regarding, the effect of foliar application with stimulant substances and mulching treatments, proline at 150 mgl^{-1} followed by potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1} as well as black polyethylene plastic mulch were the most effective treatments, respectively.

As for the effect of interaction, the results showed that all the interactions between irrigation water levels and foliar spray with the stimulant materials as well as mulching treatments increased different estimated traits of taro plant i.e., vegetative growth characteristics, bioconstituents, yield and its components as well as water use efficiency compared to the control. In this respect, foliar spray with proline at 150 mgl^{-1} was the most superior treatment followed by putrescine at 10 mgl^{-1} and potassium silicate at 2500 mgl^{-1} under water stress levels i.e., 75 and 50% of ETc when compared with the untreated plants during 2016 and 2017 seasons.

In general, it could be noticed that the applied stimulant substances i.e., proline, putrescine, potassium silicate and black plastic mulch treatments could partially reduce the harmful effects of drought stress on growth, bioconstituents, corms yield and its quality of taro plant.

Keywords: Taro; stress; proline; putrescine; potassium silicate; mulch; growth; yield.

1. INTRODUCTION

With ever increasing population, depleting water resources and an increasing doubt that popular way of age old irrigation cannot assure food security, both researchers and Egyptian government felt the need to introduce drought resistant irrigation practices that could ensure good crop output using water rationing stress induced taro plant cultivation. To achieve this objective the present study has been taken up .Results, given in the subsections bring to light the success of this research initiative.

Taro plant (*Colocasia esculenta* L. Schott) belongs to Araceae family is an important crop with a wide distribution in the tropics and subtropics areas [1]. Taro is a major vegetable in Egypt due to its high economical, nutritional values and a valuable source of essential minerals [2]. It is high in fiber content and vitamins i.e., A, C, E and B_6 contents [3]. There are some factors limiting taro cultivated area such as high quantities of irrigation water and fertilizers, in addition to long duration for cultivation, starting from planting to final harvesting i.e., 7 to 9 months.

The Egyptian taro is planted in the Nile valley, where the method of surface irrigation is in vogue. In this method entire soil surface is flooded without considering the crops actual consumptive requirements. This practice has created the water logging problems and reduced the irrigation efficiency by 30%.

Water is the most important component of life as well as vital commodity for crop production. It constituents 90% of living cells and plays an essential role in plant metabolism on the cellular as well as whole plant levels. Agricultural productivity is dependent upon water and it is essential at every stage from germination to plant maturation [4]. Availability of adequate amount of moisture at critical stages of plant growth not only optimizes the plant cell metabolically process, but also increases the effectiveness of nutrients applied to the crops. Consequently, water stress is producing deleterious effects on plant growth and yield [5].

Nowadays, Egypt is facing water scarcity problem. The irrigation water shortage is the most important factor constraining agricultural production in Egypt.

Water stress is one of the major a biotic stresses, that adversely affects plant growth and yield [6]. Water is the most important limiting factor to taro yield. It is highly sensitive for water deficiency [7,8]. The plant responses to stresses depending on many factors, such as phonological stage, time and stress strength [9,10]. Drought stress is one of the major causes for crop production losses worldwide as well as yield reduction by 50% and over [11]. Also, drought stress causes oxidative damage of the plant cellular components through inducing of reactive oxygen species generation (ROS) [12]. The ROS as O_2^- and H_2O_2 as well as OH^- radicals attack lipids of membranes, degrade protein, inactivate enzymes of metabolism. This negative factor damages nucleic acids leading to cell death [13,14].

For alleviating these oxidative effects, plants have developed a series of enzymatic and non enzymatic systems for protecting cells from oxidative damage and counteracting the ROS radicals [15]. Plants have a wide range of resistance mechanisms for productivity maintenance and ensure survival under drought stress conditions. One of the stress defense mechanisms is presence of antioxidants with low molecular weight (non enzymatic) such as glutathione, tocopherol, ascorbate, phenolic and carotenoids as well as antioxidant enzymes such as superoxide dismutase and peroxidase as well as catalase [16,17].

Proper use of antioxidants is a new method to enhance plant tolerance against adverse environmental conditions and increasing plant growth through protecting plant of any ROS, increasing sub unit of Rubisco, pigments of photosynthesis, thereby increasing photo-synthetic rate and plant productivity [18,19]. So, many strategies have been proposed for alleviating the cellular damage caused by abiotic stress and improve crop drought tolerance. Among them, compatible osmolytes exogenous application such as proline and potassium silicate [20,21,22,23,24]. Several organic compatible solutes which effectively take place in plant stress tolerance include proline, glycine betaine and many others [25]. Proline (an amino acid) is organic osmolytes accumulate in large quantities in response to environmental stress as drought [26,27].

Proline is an osmoprotection and it is involved in the oxidative damage reducing through free radicals scavenging. Also, it plays a role as protein compatible hydrotrope[25]. It support cytoplasmic acidosis and maintain appropriate $NADP^+/NADPH$ ratios suitable for metabolism. After relief from stress, proline rapid breakdown that may give sufficient reducing agents that take part in oxidative phosphorylation of mitochondria and ATP production for retrieval from stress [28]. Many scientists reported proline ameliorative effects in different crops such as wheat [29], tobacco [30] and olive [31]. Proline foliar spray is a shotgun approach for minimizing the stress deleterious effects. In addition, plants show resistance for oxidative damage by inducing antioxidants high levels, organic osmolytes accumulation and the toxic ions reduction. (Hoque et al. [32] and Hayat et al. [33]) reported that increasing of antioxidant enzymes activity as superoxide dismutase, catalase and peroxidase in response to foliar application of proline under stress. (Gamal El-Din and Abd El-Wahed [34]) concluded that foliar spray with proline at 100 mgl^{-1} increased vegetative growth characteristics of chamomile plant. (Ali et al. [35]) found that foliar application with proline at 30 mM was most effective for inducing drought tolerance and enhancing biomass production as well as increasing the rate of photosynthesis of maize plant.

Potassium (K) is essential for several physiological processes such as photosynthesis, metabolism enzymes activation, synthesis of protein, photo-assimilates translocation into sink organs, regulation of stomata opening and closing, plant water-relation, essential for cell structure. It is also important for regulating several metabolic processes as well as increasing drought tolerance [14,36,37].

Silicon (Si) is an environmental friendly and ecologically compatible agent for stimulating plant growth. It was reported that silicon plays a role in reducing the hazard effects of several biotic and a biotic stresses such as drought stress [38,39]. It has emerged as an important mineral for many horticultural crops [38]. It is interact with cell constituents as polyphenols and pectins increases elasticity of the cell wall. Also, increasing of silicon absorption maintain erect leaves for leaf angle to photosynthesis [40]. (Gharib and Hanafy Ahmed [41], Kamenidou and Cavins [42]) stated that foliar spray with silicon significantly increased yield and its components of pea and sunflower plants, respectively. (Sayed et al., [43]) found that globe artichoke plant sprayed with silicon at 2000 mgl^{-1} recorded the highest growth aspects, chlorophylls content, nitrogen, phosphorus, potassium, total sugars and total amino acids concentrations as well as the yield parameters compared with untreated plant. (RemeroAranda et al., [44]) reported that Si improved the storage of water within plant tissues that allows a higher rate of growth.

Putrescine plays an important role in plant protection against several a biotic stresses. It is potent scavenger of ROS and lipid peroxidation inhibitor. The putrescine is alleviating the harmful effects of drought stress by several ways including polyamines involved in scavenging free radicals [45]. Putrescine is a regulator for the antioxidant enzymes and a component for signaling system of stress. It is modulating RNA, DNA functions, proteins synthesis, nucleotide triphosphates and macromolecules protection under stress conditions [46]. Polyamines high accumulation in plant during a biotic stress has been documented and correlated with increasing a biotic stress tolerance [47].

As the world become greatly dependent on the irrigated lands production, it is prudent to make water use efficiency and bring more area under cultivation by introducing advanced irrigation advanced methods and improving practice of apt water managements [48]. The major proportion of irrigation water is lost by evaporation of the surface, deep percolation and other losses resulting in low irrigation efficiency [49]. Mulching is one of the practices of water management for increasing water use efficiency. Mulch is a material spread on the surface of soil for protection from solar radiation or evaporation. Different types of materials such as rice straw, wheat straw, plastic film, wood, grass and sand are used as mulches [50]. Soil surface evaporation may account as much as 50% of the total moisture lost from the soil during the growing season. In this respect, plant residues mulching and synthetic materials is a well-established technique to increase several crops profitability [51]. These effects are contributed to the mulch capacity to conserve moisture of the soil [52]. Moreover, soil temperature is very critical to chemical and biological process, which controls cycling of nutrients [53]. In addition, mulch is improving vegetative growth and roots distribution, thereby increasing nutrients absorption [54]. Also, usage of mulches helps in conservation of moisture and evaporation reduction [55]. (Sharma et al., [56]) concluded that mulch is very beneficial for enhancing moisture and conservation of nutrients resulting in productivity increase and improving soil conditions for better cropping system.

Hence, the present study was conducted to evaluate the effects of different irrigation water levels of crop evapotranspiration (ETc) and foliar spray with some stimulant substances i.e., proline, potassium silicate and putrescine as well as mulching treatments i.e., black polyethylene plastic, rice straw and sawdust mulches individually or in combination of treatments on taro plants have been included as part of the present study to enhance possibility for improving plant tolerance to the harmful effects of water stress and to reduce amount of water used for irrigation.

2. MATERIALS AND METHODS

Two field experiments were conducted during 2016 and 2017 seasons at Horticulture Research Station, El-Kanater El-Khiria, Horticulture Research Institute, Agriculture Research Center, Egypt to investigate individual and combined effects of foliar spray with some stimulant substances i.e., proline, potassium silicate and putrescine as well as mulching treatments i.e., black polyethylene plastic, rice straw and sawdust on growth, biochemical constituents and yield characteristics of taro plant *Colocasia esculenta* L. Schott var. sculenta grown under different irrigation water levels i.e., 100, 75 and 50% of the crop evapotranspiration (ETc).

2.1 Plant Materials and Procedure

After selecting good quality taro seed cormels (*Colocasia esculenta* L. Schott var. *esculenta*) cv. Egyptian during pre planting period. Cormels were planted at the bottom of the ridge at a distance of 30 cm apart on March 27, 2016, and March 12, 2017, respectively. Cormels were irrigated directly after planting. Two weeks later the irrigation procedure was repeated with 10 days interval. All the plots were equally irrigated. The water regime treatments began after two months from planting as shown in Table 3.

The mechanical and chemical analyses of the experiment soil are given in Table 1. Chemical analysis: Calculated as mg/100 g soil and determined in soil: Water extraction. Data in Table 2 show monthly temperature average and relative humidity percentage in the experimental region at Qalyoubia governorate, Egypt during the two seasons of study.

Table 1. Mechanical and chemical analysis of the experimental soil

Mechanical analysis					Chemical analysis							
Texture	Sand %	Silt %	Clay %	EC dS/m	Cations (mg100g^{-1} soil)				Anions (mg100g^{-1} soil)			pH soil
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	$HCO3^-$	
Clay loam	30.67	22.74	46.59	0.19	0.71	0.61	0.25	0.33	0.51	0.51	0.88	**8.30**

Table 2. Average temperatures and relative humidity during the growing seasons 2016 and 2017 under Kaliobia Governorate conditions

Month	Season 2016			Season 2017		
	Temperature (°C)		Relative humidity%	Temperature (°C)		Relative humidity %
	Max.	Min.	Average	Max.	Min.	Average
March	22.6	11.0	50.6	20.1	11.3	53.6
April	27.7	13.5	50.0	25.9	13.0	51.8
May	32.1	16.3	51.3	31.2	15.3	50.0
June	43.8	18.5	53.1	39.3	19.1	52.0
July	40.0	22.3	56.0	38.9	21.7	55.0
August	39.2	23.1	56.0	43.5	24.0	52.0
September	32.3	19.1	56.8	32.0	18.3	56.5
October	30.4	16.4	54.0	29.3	15.6	53.4
November	24.6	12.6	52.0	25.1	10.9	52.5

Metrological authority, Cairo, Egypt

2.2 The Experiment Treatments were as Follows

This experiment included 21 treatments, which were the combination between three irrigation water levels i.e., 50, 75 and 100% of the crop evapotranspiration (ETc) applied using drip irrigation system and 7 treatments of foliar spray with stimulant substances and mulching. The selection of the concentrations of used foliar application treatments is based on the previous studies.

The irrigation levels were calculated using FAO-CROPWAT software version 8 to calculate the crop irrigation water requirements based on the reference crop evapotranspiration as described by (Smith et al., [57]). Evapotranspiration was calculated according to the water balance approach as reported by (James [58]).

The treatments were arranged in split plot design with three replicates; the main plots were assigned to irrigation water levels, while seven treatments of substances foliar spray and mulching treatments were located in subplots. Each sub experimental plot consisted of four ridges; each was 5.84 m in length and 0.8 m in width with an area 14 m^2, since three ridges were planted and the fourth one was left without planting as a guard row for avoiding and preventing the overlapping (interactions of irrigation water). The amount of water applied was increased with increasing of plant growth and declined at the end of the growth season.

All plots received 40 m^3 farm yard manure, 64 kg P_2O_5, 120 kg N and 120 kg K_2O fed.$^{-1}$ Cultivation and all cultural practices except irrigation i.e., weeding, fertilization and pest control etc. were performed according to the Egyptian Agriculture Ministry recommendations.

2.2.1 Irrigation water levels (irrigation water quantity)

Drip irrigation is a highly efficient method of water application, which is also ideally suited for controlling the placement and supply rate of water-soluble fertilizers. Drip irrigation system was used to apply the levels of irrigation water in the experiment. Three irrigation levels of water quantity supply was used i.e., 100% of ETc (the control), 75% of ETc (moderate stress) and 50% of ETc (severe stress), respectively of water requirements of taro plant in the two seasons. Drip tubing (GR type, 0.016 m diameter) with 0.30m emitter spacing built in, each delivering 1.5 L h $^{-1}$ at 1 bar pressure was used (10 drip tubing for each irrigation system). The irrigation water treatments began after two months of planting and continued until harvesting. Such treatments were as follows:

Table 3. Water irrigation levels

Irrigation water levels	% of ETc	Irrigation water quantity applied $m^3 fed.^{-1}$
1-WL_1 full irrigation (control)	100	Irrigation with 4346.5 m^3 water $fed.^{-1}$
2- WL_2 moderate water stress	75	Irrigation with 3259.9 m^3 water $fed.^{-1}$
3- WL_3 severe water stress	50	Irrigation with 2173.3 m^3 water $fed.^{-1}$

The water requirement of taro plant using drip irrigation system is 4346.5 $m^3 fed.^{-1}$ in the same location of soil was taken from the previous study by (Abuzeed [59]).

2.2.2 The foliar spray stimulant treatments were as follows

1. Control (Tap water) 2. Proline at 150 mgl^{-1} 3. Potassium silicate at 2500 mgl^{-1}_4. Putrescine at 10 mgl^{-1}

The foliar spray substances were applied four times using atomizer to completely cover the plant foliage; the first was 70 days after planting date and repeated every month.

2.2.3 The mulching treatments were as follows

1. Black polyethylene plastic sheet 2. Rice straw 3. Sawdust.

The treatments of mulching were applied 60 days from planting on the soil until the season end. Black polyethylene plastic sheet was used to cover soil surface under the plants. The polyethylene plastic sheet was 25 micron in thickness. Rice straw and sawdust mulches with 15 cm thickness were spread out on the soil surface to cover the soil completely. These were spread out for the same period as plastic sheet treatment.

2.3 Sampling and Collecting Data

The growth measurements and the chemical analysis were determined at 180 days after planting.

2.3.1 Vegetative growth characteristics

Different morphological characteristics of taro plants were measured and calculated. Six plants from each treatment were randomly taken and then separated into their organs and the following characteristics were recorded:

Plant height (cm), leaves number $plant^{-1}$, lamina dry weight (g) $plant^{-1}$ and leaf area (cm^2) $plant^{-1}$. The leaf area was determined using the leaf length, width, and a crop coefficient using the following equation: Leaf area = leaf length × leaf width × 0.85 (crop factor) after [60].

2.3.2 Chemical compositions

Chemical analyses were carried out in taro leaves sample at 180 days after planting.

2.3.2.1 Leaves photosynthetic pigments and proline determinations

The photosynthetic pigments i.e., chlorophyll a, b. and carotenoids were determined and calculated as mgg^{-1} fresh weight during 2016 and 2017 growth seasons according to (Wettstein [61]). Free proline content was determined calorimetrically using the method of (Bates et al., [62]) during 2017 season.

2.3.2.2 Determination of oxidative enzyme activities

0.5 g of taro leaves was homogenized in 10 mM potassium phosphate buffer with pH 7.0 containing 4% polyvinyl pyrrolidone, the homogenates were centrifuged at 12 000 × g at 4°C for 15 min and the supernatants were immediately used for determination of enzymes activity. Peroxidase activity was estimated according to the method described by (Nakano and Asada [63]). Catalase was assayed spectrophoto chemically according to (Velikova et al. [64]), superoxide dismutase activity was estimated according to the method described by (Beauchamp and Fridovich [65] and Dhindsa et al., [66]) during 2017 season only.

2.3.2.3 Corms bioconstituents determination

At harvest stage, total nitrogen was determined in the digested corms dry matter using microkjeldahl method as described by (Horneck and Miller [67]), then the crude protein was calculated according to (AOAC [68]). Phosphorus was determined colorimtrically according to the method of (Sandell [69]). Potassium was determined by the flame photometer model Carl-Zeiss according to the method described by (Horneck and Hanson [70]). Starch was determined according to (Dubois et al. [71]).

2.3.3 Yield and its components

At harvest time i.e., 240 days after planting in 2016 and 2017 seasons, corms yield of ten randomly plants from each experimental plot were taken for estimating the following characteristics: main corm length (cm), main corm diameter (cm), corms number plant^{-1}, corms fresh weight (kg plant^{-1}), corms fresh weight (kg plot^{-1}), corms fresh yield (ton fed.$^{-1}$) and main corm fresh weight (g). The samples of corms were dried in the oven-dried for 48 h in 75°C to a constant weight and then corms dry matter percentage was calculated. These dry samples of corms were kept for chemical analysis.

2.3.4 Water use efficiency (WUE)

Water use efficiency is used to describe the correlation between production and the amount of irrigation water used (kg yield/m^3 water) as follow:

$$WUE = \frac{\text{Crop yield kgfed.}^{-1}}{\text{Water m}^3\text{fed.}^{-1}}$$

2.3.5 Statistical analysis

Data of morphological and bioconstituents (except proline and antioxidant enzymes activity) as well as yield characteristics were statistically analyzed and the means compared using Least Significant Difference (LSD) test at 5% according to (Snedecor and Cochran [72]).

3. RESULTS AND DISCUSSION

3.1 Vegetative Growth Characteristics

Data in Table 4 show that increasing water regime levels i.e., 75 and 50% of ETc have significantly decreased vegetative growth parameters of taro plants gradually compared to the full irrigation level (control 100% of ETc). In addition, the same results show that the highest water stress level at 50% of ETc was the most effective treatment that gave the highest reductions in the vegetative growth aspects of taro plant during the two growing seasons. This reduction in the growth characteristics were explained by (Hussain et al., [73]) they indicated that drought stress caused impaired mitosis, cell elongation and expansion resulted in reducing of both growth and yield traits. Also, (Farooq et al. [74]) concluded that water deficit stress reduced leaf growth and in turn the plant leaf areas.

Such decrements in all studied growth aspects as a result for decreasing the irrigation water amount may be attributed to the roles of water in increasing macro and micro nutrients absorption from the soil and in turn affect plant growth. Moreover, this effect may be due to the role of water as the main constituent in photosynthetic process which consequently affects on the plant growth. It could be concluded that the sequence of events in the plant tissue subjected to drought stress may be due to: A. The growth of plant depends on cell division, enlargement and differentiation. All of these events are affected by water stress and required photosynthetic assimilates for formation of cells and tissues. Cells and tissues are affected by water stress. This process in turn affect on all morphological parameters of growing [6,75]. B. Water stress greatly suppresses expansion of the cell and plant growth due to the low turgor pressure [76]. C. Drought stress may lead to an imbalance between antioxidant defense and ROS amount, causing ROS accumulation which induces oxidative damage to the components of the cell [14,77]. D. Water stress inhibits enlargement of the cell more than cell division. Water stress reduces plant growth by affecting several physiological and biochemical processes as photosynthesis, translocation, respiration, carbohydrates, ion uptake, metabolism of nutrients and promoters of growth [10,78,79]. E. Water stress causes a change in balance of hormones including increases of ABA and reduces the extensibility of the cell wall, thereby causing leaf elongation decline [80]. Several studies have indicated that soil moisture level depletion reduced growth parameters (Farooq et al., [74]) on common bean; (Gadalla [22]) on soybean and (Abd-Ellatif [23]) on snap bean. These results are in agreement with those reported by researchers [6,20,73,81,82, 83].

Concerning the effect of foliar application with stimulant substances and mulching treatments, data clearly indicate that all vegetative growth parameters were increased to reach the level of significance with different applied treatments during 2016 and 2017 seasons. In this respect, proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1}, putrescine at 10 mgl^{-1} followed by sawdust and black polyethylene mulches were the most effective treatments, respectively. Moreover, increasing number of formed leaves and lamina dry weight on a growing plant could be reversed upon

Table 4. Effect of irrigation water levels, foliar application substances and mulching treatments as well as their interactions on vegetative growth parameters plant^{-1} of taro during first (1st) and second (2st) growing seasons

Treatments \ Characteristics	Plant height (cm)		Leaves number		Lamina dry weight (g) plant^{-1}		Leaf area (cm^2)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation water levels [a]								
WL1	148.29	163.90	4.35	6.04	61.19	74.90	2938.22	3682.40
WL2	142.19	154.86	4.25	5.86	53.34	63.75	2548.69	3461.85
WL3	107.71	129.90	3.42	4.90	38.41	42.96	1794.28	2458.92
L.S.D. at 5%	8.19	15.84	0.60	0.48	6.24	9.54	394.45	378.62
Foliar spray with stimulants and mulching treatments [b]								
Control	109.78	127.67	3.41	4.44	40.80	45.29	1510.38	1726.82
Proline 150 mgl^{-1}	148.56	165.11	4.27	6.11	56.37	71.26	3169.26	4211.78
Potassium silicate 2500 mgl^{-1}	141.33	158.44	4.14	5.68	56.44	67.74	2303.74	2996.91
Putrescine 10 mgl^{-1}	139.67	152.78	4.25	5.85	54.88	63.06	3107.80	3706.22
Black polyethylene	133.22	155.00	4.01	5.87	50.23	61.78	2351.74	3990.94
Rice straw	135.44	148.67	3.94	5.50	49.60	59.01	2423.12	3159.46
sawdust	121.11	139.22	4.00	5.77	48.55	55.60	2123.41	2615.26
L.S.D. at 5%	6.01	12.47	0.49	0.35	4.92	5.43	250.88	310.44
The interaction between irrigation water levels [a] and stimulants foliar spray as well as mulching treatments [b]								
WL1 Control	129.67	141.00	3.75	5.00	49.38	51.85	1726.51	2105.28
Proline 150 mgl^{-1}	153.33	183.00	4.66	7.00	66.54	86.87	3969.90	5718.04
Potassium silicate 2500 mgl^{-1}	157.33	176.33	4.33	6.00	67.67	85.77	2958.35	3839.35
Putrescine 10 mgl^{-1}	159.67	172.00	4.66	6.33	64.67	79.94	3257.26	3844.56
Black polyethylene	145.00	166.33	4.39	6.16	62.23	77.44	2970.95	3944.13
Rice straw	155.00	157.00	4.16	5.83	57.06	75.00	2805.41	3990.00
sawdust	138.00	151.67	4.50	6.00	60.81	67.45	2879.21	2335.43
WL2 Control	114.33	125.33	3.50	4.27	41.43	46.63	1627.63	1615.29
Proline 150 mgl^{-1}	158.00	169.00	4.33	6.16	56.67	72.17	3460.41	3789.07
Potassium silicate 2500 mgl^{-1}	157.33	168.33	4.50	6.05	59.38	71.61	2362.53	3097.51
Putrescine 10 mgl^{-1}	147.00	158.00	4.44	6.05	60.49	68.55	3326.16	4250.75
Black polyethylene	138.33	160.67	4.33	6.11	52.42	66.04	1986.00	4893.45
Rice straw	150.67	155.00	4.33	6.33	52.99	61.27	2795.80	3357.06
sawdust	129.67	147.67	4.36	6.05	50.04	59.99	2282.34	3229.80
WL3 Control	85.33	116.67	3.00	4.05	31.60	37.41	1177.00	1459.88
Proline 150 mgl^{-1}	134.33	143.33	3.83	5.16	45.90	54.74	2077.49	3128.22
Potassium silicate 2500 mgl^{-1}	109.33	130.67	3.61	5.00	42.29	45.85	1590.34	2053.89
Putrescine 10 mgl^{-1}	112.33	128.33	3.66	5.16	39.50	40.70	2740.00	3023.36
Black polyethylene	116.33	138.00	3.33	5.33	36.04	41.88	2098.27	3135.24
Rice straw	100.67	134.00	3.33	4.33	38.77	40.78	1668.17	2131.32
sawdust	95.67	118.33	3.16	5.27	34.81	39.37	1208.67	2280.55
L.S.D. at 5 %	10.40	21.59	0.85	0.61	8.52	9.40	434.52	537.68

Where WL1: 100% of ETc, WL2: 75% of ETc and WL3: 50% of ETc

many other characteristics such as leaf area, dry weights and finally the corms yield. Such increments in plant growth aspects as a result for using the tested foliar application and mulching treatments may be due to the main role of the foliar spray materials on reactions of metabolism enzymes in plant and its role in catching and binding as well as scavenging of the reactive oxygen species (ROS) which affect on plant metabolism, vigor and consequently plant growth increasing or may be attributed to increase of the photosynthetic pigments and the mineral nutrients absorption that affect positively on plant growth.

For proline, it is considered an agent of osmoprotection. It is involved in the oxidative damage reducing through free radicals scavenging. Also, it plays a role as protein compatible hydrotrope [25]. Many scientists reported that proline has ameliorative effects in different crops such as wheat [29], tobacco [30] and olive [31]. Proline foliar spray minimize the stress deleterious effects. In addition, plants show resistance for oxidative damage by inducing antioxidants high levels, organic osmolytes accumulation and the toxic ions reducing. (Gamal El-Din and Abd El-Wahed [34]) concluded that foliar spray with proline at 100 mgl^{-1} increased vegetative growth characteristics of chamomile plant. (Ali et al. [35]) found that foliar application with proline at 30 mM was most effective for inducing drought tolerance and enhancing biomass production as well as increasing the rate of photosynthesis of maize plant.

Increasing plant growth aspects as a result of foliar spray with potassium silicate may be due to the role of potassium as a macro element in plant nutrition and its effects on different plant physiological and chemical reactions which affect positively on plant growth [14,36]. Also, Adequate levels of K nutrition enhanced plant drought tolerance and plant growth under drought conditions. This improvement was attributed to the K role in improving stability of cell membranes and the ability of osmotic adjustment. (Egilla et al., [84]) reported that an adequate supply of K is essential for enhancing drought tolerance by increasing root elongation. For silicon, it was reported that silicon plays a role in reducing the hazard effects of drought stress [38,39]. (RemeroAranda et al. [44]) reported that Si improved the storage of water within plant tissues that allows a higher rate of growth.

Putrescine, it is playing an important role in plant protecting against several a biotic stresses. It is a potent scavenger of ROS and lipid peroxidation inhibitor. The putrescine is alleviating the harmful effects of drought stress in plant by several ways including free radicals scavenging [45]. Putrescine is a regulator for the antioxidant enzymes and it is a component for signaling system of stress. It is modulating RNA, DNA functions, proteins synthesis, nucleotide triphosphates and macromolecules protection under stress conditions [46].

High accumulation of polyamines in plant during a biotic stress has been documented and it is correlated with increasing a biotic stress tolerance [47].

Regarding, increasing plant growth characteristics as a result of mulching treatments could be explained by that mulching is one of the practices of water management for increasing water use efficiency and protection it from solar radiation or evaporation. Different types of materials such as rice straw, wheat straw, plastic film, wood, grass and sand etc. are used as mulches to increase crops profitability [50,51]. These effects are contributed to the mulch capacity to conserve moisture of the soil [52,55,56]. Moreover, soil temperature is very critical to chemical and biological process which control cycling of nutrients [53,56]. In addition, mulch is improving vegetative growth and roots distribution, thereby increasing nutrients absorption [54].

Regarding the interactions effect, it was clear that the combinations of drought stress levels, foliar spray stimulants and mulching treatments had significant effects on different studied vegetative growth characteristics of taro plant. Foliar application treatments with proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1} as well as putrescine at 10 mgl^{-1} treatments in combination with either water stress level at 75 or 50 % of ETc gave the highest growth aspects compared to the control and other treatments application during the two seasons.

In this respect, the growth promoting effects of foliar spray treatments, especially under water regime levels i.e., 75 and 50% of ETc may be due for enhancing the antioxidant capacity. In this regard, the interaction of drought stress and antioxidant treatments showed that the applied antioxidants enhanced growth parameter of soybean under drought stress compared with control [22].

The above mentioned results evidently indicated that the applied treatments greatly increased the ability of taro plant tolerance against the water stress adverse effects. Also, it was obvious from the same data that control plant was physiologically stressed, resulting in decreasing its morphological growth aspects.

3.2 Leaves Chemical Compositions

Data in Tables 5 and 6 indicate the effect of tested irrigation water levels i.e.,100, 75 and 50% of ETc, foliar application substances i.e., proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1} and mulching i.e., black polyethylene plastic sheet, rice straw and sawdust mulches) individually or in combination of treatments on the photosynthetic pigments (i.e., chlorophyll A, B and carotenoids). Proline content as well as antioxidant enzymes activity has been noticed in taro plant leaves at 180 days after planting during both seasons of 2016 and 2017.

3.2.1 Photosynthetic pigments content

As shown in Table 5 data clear the effect of water regime levels, foliar spray materials and mulching treatments individually or in combination on photosynthetic pigments (i.e., chlorophyll a, b, a+b and carotenoids) content are noticed in taro leaves.

Regarding, the effect of water stress levels, data show that increasing water stress levels from 75 to 50% of ETc have decreased concentration of photosynthetic pigments (i.e., chlorophyll a, b, a+b and carotenoids) gradually compared to full irrigation level (100%). In this respect, water stress level at 50% of ETc gave the highest reduction in chlorophyll a, b and carotenoids in taro leaves. Similarly, water stress decreased the content of the photosynthetic pigments in snap bean [23], cotton plants [85] and soybean [22] it directly related to plant biomass and yield. Also, (Mafakheri et al., [86]) reported that drought stress significantly decreased chlorophyll a, chlorophyll b and total chlorophyll contents in chickpea. In addition, the decrease in chlorophyll content under drought stress has been considered a typical symptom of oxidative stress and may be the result of pigment photo-oxidation and chlorophyll degradation. (Wahid et al.,[87]) stated that carotenes are a key part of the antioxidant defense system in plant.

Concerning the effect of stimulants foliar spray and mulching treatments, as shown in Table 5 different applied treatments increased each of chlorophyll a, b and carotenoids in taro leaves. Also, it could be noticed that maximum increases of all these pigments in taro leaves were existed in cases of proline at 150 mgl^{-1}, black polyethylene plastic mulch and potassium silicate at 2500 mgl^{-1} followed by putrescine at 10 mgl^{-1} treatments. Since, proline at 150 mgl^{-1} was the most effective treatment which led to maintain the highest concentrations of the determined photosynthetic pigments.

As for the effect of interaction, data in Table 5 clearly show that all the interactions between water stress levels and foliar applications as well as mulching treatments increased the concentration of chlorophyll a, b and carotenoids in taro leaves compared to the control plants. Also, proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1} gave the highest concentration of chlorophyll a, b and carotenoids in taro leaves under water stress levels at 75 and 50% during 2016 and 2017 seasons.

Our results are in harmony with those reported by (Ali et al. [35]) who found that the foliar application with proline at 30 mM was most effective for inducing drought tolerance and increasing the rate of photosynthesis of maize plant. In this respect, the stimulation of photosynthetic pigments formation could be attributed to the vigorous growth obtained in Table 4. Also, increasing of chlorophylls and carotenoids contents may be due for enhancing photosynthesis efficiency through photosynthetic apparatus by protecting plant of any ROS, increasing sub unit of Rubisco, pigments of photosynthesis, thereby increasing photosynthetic rate and plant productivity [18]. So, many strategies have been proposed for alleviating the cellular damage caused by abiotic stress and improving crop drought tolerance. Among them are compatible osmolytes exogenous application [20,21,22,23, 24]. On the other hand, to alleviate these oxidative effects, plants have developed a series of enzymatic and non enzymatic systems for protecting cells from oxidative damage and counteracting the ROS radicals [15]. Plants have a wide range of resistance mechanisms for productivity maintaining and ensure survival under drought stress conditions. One of the stress defense mechanisms is consisting of antioxidants with low molecular weight (non enzymatic) such as glutathione, tocopherol, ascorbate, phenolic and carotenoids as well as antioxidant enzymes such as superoxide dismutase and peroxidase as well as catalase [14,16,17]. In addition, (Egilla et al., [84]) suggested that increasing K^+ concentrations in plant cells with an excess K^+ supply could prevent inhibition of photosynthesis under drought stress.

An adaptive K requirement for drought-stressed plants could be related to the role of K in enhancing photosynthetic CO_2 fixation and transport of photosynthates into sink organs and inhibiting the transfer of photosynthetic electrons to O_2, thus reducing ROS production [88]. Also, this increment of photosynthetic pigment contents in response to putrescine and potassium may be due to its action as antioxidants and enhancing antioxidant enzymes activities for protecting chloroplast and photosynthetic system from oxidative damages by free radical [6]. Our results are agreed with those reported by earlier researchers [89,90,91]. Also, (Sayed et al., [43]) found that spraying globe artichoke plants with 2000 mgl^{-1} silicon recorded the highest increasing in chlorophylls content compared with untreated plants.

Table 5. Effect of irrigation water levels, foliar application substances and mulching treatments as well as their interactions on photosynthetic pigments content (mgg^{-1} F.W.) of taro plant leaves during first (1st) and second (2st) growing seasons

Characteristics / Treatments		Chlorophyll (a)		Chlorophyll (b)		Chlorophyll (a + b)		Carotenoids	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation water levels [a]									
WL1		1.05	1.16	0.72	0.74	1.78	1.91	1.06	0.99
WL2		0.85	1.04	0.61	0.63	1.46	1.68	0.80	1.06
WL3		0.79	0.94	0.48	0.48	1.27	1.42	0.78	0.95
L.S.D. at 5 %		0.15	0.13	0.17	0.12	0.26	0.31	0.35	0.13
Foliar spray with stimulants and mulching treatments [b]									
Control		0.79	0.91	0.45	0.55	1.24	1.46	0.75	0.78
Proline 150 mgl^{-1}		0.97	1.16	0.68	0.65	1.65	1.81	1.16	1.06
Potassium silicate 2500 mgl^{-1}		0.94	1.05	0.61	0.59	1.56	1.65	0.95	0.94
Putrescine 10 mgl^{-1}		0.85	1.17	0.61	0.64	1.46	1.81	0.82	1.11
Black polyethylene		0.96	1.07	0.65	0.71	1.61	1.78	0.92	1.00
Rice straw		0.87	0.89	0.59	0.57	1.48	1.46	0.79	1.12
sawdust		0.90	1.08	0.63	0.61	1.53	1.69	0.77	0.97
L.S.D. at 5 %		0.03	0.08	0.05	0.10	0.13	0.15	0.03	0.12
The interaction between irrigation water levels [a] and stimulants foliar spray as well as mulching treatments [b]									
WL1	Control	0.85	1.07	0.53	0.67	1.38	1.74	0.83	0.67
	Proline 150 mgl^{-1}	1.16	1.31	0.88	0.79	2.04	2.10	1.83	1.14
	Potassium silicate 2500 mgl^{-1}	1.20	1.14	0.81	0.70	2.01	1.84	1.26	1.05
	Putrescine 10 mgl^{-1}	0.98	1.36	0.66	0.74	1.64	2.10	0.82	1.13
	Black polyethylene	1.15	1.06	0.87	0.93	2.02	1.99	1.17	0.98
	Rice straw	0.93	0.81	0.62	0.58	1.55	1.39	0.72	0.94
	sawdust	1.12	1.40	0.70	0.81	1.82	2.21	0.84	1.03
WL2	Control	0.74	0.87	0.46	0.55	1.20	1.42	0.64	0.89
	Proline 150 mgl^{-1}	0.93	1.05	0.71	0.63	1.64	1.68	0.85	1.08
	Potassium silicate 2500 mgl^{-1}	0.81	1.09	0.55	0.62	1.36	1.71	0.78	0.90
	Putrescine 10 mgl^{-1}	0.78	1.13	0.62	0.71	1.40	1.84	0.92	1.21
	Black polyethylene	0.96	1.29	0.67	0.70	1.63	1.99	0.89	1.15
	Rice straw	0.95	0.90	0.56	0.69	1.54	1.59	0.81	1.23
	sawdust	0.81	0.97	0.70	0.57	1.51	1.54	0.71	0.96
WL3	Control	0.79	0.81	0.37	0.43	1.16	1.24	0.78	0.79
	Proline 150 mgl^{-1}	0.83	1.13	0.45	0.54	1.28	1.67	0.81	0.97
	Potassium silicate 2500 mgl^{-1}	0.82	0.94	0.49	0.46	1.31	1.40	0.82	0.89
	Putrescine 10 mgl^{-1}	0.79	1.02	0.57	0.49	1.36	1.51	0.74	1.01
	Black polyethylene	0.77	0.86	0.41	0.52	1.18	1.38	0.71	0.88
	Rice straw	0.75	0.97	0.60	0.45	1.35	1.42	0.86	1.19
	sawdust	0.79	0.87	0.49	0.47	1.28	1.34	0.77	0.92
L.S.D. at 5 %		0.05	0.13	0.08	0.17	0.22	0.25	0.05	0.20

Where WL1: 100% of ETc, WL2: 75% of ETc and WL3: 50% of Etc

As for putrescine (Kaur-Sawhney and Galston [92]) reported that polyamines are important factor for stabilizing chloroplasts thylakoid membranes and retarding chlorophyll degradation. (Zeid [93]) indicated that application of putrescine at 10^{-2} mM increased leaves chlorophyll a, b and carotenoids contents in stressed bean seedlings.

3.2.2 Proline content

Results in Table 6 reflect the effect of irrigation water levels and foliar spray with stimulant materials as well as mulching treatments individually and their interaction treatments on proline content in taro leaves at 180 days after planting during 2017 season.

As regards to the water regime levels, it could be noticed that by increasing water stress levels from 75% to 50% of ETc, the proline content was gradually increased comparing with the full irrigation level i.e.,100% of ETc. The highest water stress level at 50% gave the highest value of determined proline content in taro leaves. In this connection, under drought stress, the maintenance of leaf turgor could be achieved by osmotic adjustment in response to proline accumulation, sucrose, soluble carbohydrates, glycine betaine, and other solutes in cytoplasm improving water uptake from drying soil. The process of accumulation of such solutes under drought stress is known as osmotic adjustment which strongly depends on the rate of water stress. In this respect, increasing leaves proline content with decreasing of available water is an efficient mechanism for osmotic regulation, stabilizing of sub cellular structures and cellular adaptation to water stress [94,95]. Also, high proline content in plants under water stress was recorded by other researchers [96,97,98].

Concerning the effect of stimulants foliar spray and mulching treatments the same data Table 6 show that putrescine at 10 mgl^{-1}, proline at 150 mgl^{-1} and black polyethylene plastic mulching treatments gave the highest proline content in leaves of taro plant compared to the control.

The consequences also, show the effect of interaction between water regimes and foliar spray with stimulant substances as well as mulching treatments on proline content in taro leaves. In this regard, both of exogenous application substances and mulching treatments significantly increased proline content of taro leaves under water deficit conditions. Since, black polyethylene plastic mulch, putrescine at 10 mgl^{-1}, proline at 150 mgl^{-1} and potassium silicate at 2500 mgl^{-1} gave the highest concentrations under water stress level at 50% when compared to the control and other treatments. Such accumulation in osmolyte components is osmotic adjustment and osmoregulation under water stress conditions, the disturbance in plant osmotica under stress conditions could be attributed to the metabolic processes imbalance, i.e., photosynthesis, respiration, transpiration, hormones and activity of enzymes as well as protein synthesis. This results could be explained by that amino acid proline is known to occur widely in higher plants and normally accumulates in large quantities in response to environmental stresses [25]. Proline is one of the commonly occurring compatible solutes and plays a crucial role in osmotolerance and osmoregulation, it protects membranes and proteins against the dehydration destabilizing effects under a biotic stress. In addition, it has ability for scavenging free radicals generated under stress conditions.

Also, (Zeid [93]) found that exogenous putrescine treatment at 10^{-2} mM significantly increased bean seedlings content of proline under stress compared to the control plant. Moreover, several mechanisms have been adopted by drought tolerant plants to adapt water stress including osmolytes accumulation [89]. The osmolytes accumulated include amino acids such as proline, glutamate, glycine betaine and sugars. These compounds are playing a key role in preventing membrane disintegration and enzyme inactivation under water stress conditions. Many strategies have been proposed for alleviating the cellular damage caused by a biotic stress and improving crop drought tolerance. Among them, compatible osmolytes exogenous application such as proline, potassium silicate are noteworthy [20,21,22, 23,24].

3.2.3 Antioxidant enzymes activity

Plant cells possess several defense mechanisms against the oxidative injury caused by drought stress. Such mechanisms including antioxidant enzymes, namely, superoxide dismutase, peroxidase and catalase which degrade superoxide radicals and H_2O_2, respectively. Many non enzymatic antioxidants, as the polyphenolic compounds also play an important role [16].

In this respect, our obtained data in Table 6 clearly show that those treatments of water regimes, foliar application with stimulant substances as well as mulching treatments and their interactions affected the antioxidant enzymes activity i.e., superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) in taro leaves at 180 days after planting during 2017 season.

Regarding to irrigation water levels the presented results in Table 6 indicate that all water stress levels increased the activity of the antioxidant enzymes i.e., SOD, POD and CAT in taro leaves. Also, water stress level at 50% of ETc gave the highest values of the activity of those enzymes when compared to the control (100% ETc).

These results are in harmony with those reported by many researchers. They stated that plants have a wide range of resistance mechanisms for maintaining of productivity and ensure survival under drought stress conditions [14,16,17,99]. One of the stress defense mechanisms consist of antioxidant enzymes such as superoxide dismutase (SOD) and peroxidase (POD) as well as catalase (CAT). Superoxide radicals are scavenged by superoxide dismutase, while the resulting H_2O_2 is reduced to H_2O by CAT and POD.

With regard to stimulants foliar spray and mulching treatments, results show that all applied treatments also increased the activity of antioxidant enzymes i.e., SOD, POD and CAT. Black polyethylene mulch and proline at 150 mgl^{-1} were the most effective treatments in this respect when compared to the control.

From the details given above, it is clear that the applied treatments induced the synthesis of antioxidant enzymes as a defensive system. Generally, it could be concluded that different applied treatments were mostly effective, which induced an active metabolism case and an effective antioxidantal mechanism of internal defense.

The effect of interaction between water regimes and foliar spray with stimulant substances as well as mulching treatments on antioxidant enzymes activity i.e., SOD, POD and CAT in taro leaves. In this regard, both of substances foliar application and mulching treatments increased the activity of the antioxidant enzymes under water deficit conditions. Putrescine at 10 mgl^{-1} ranked the first followed by potassium silicate at 2500 mgl^{-1} and proline at 150 mgl^{-1} especially under water stress level at 50% ETc when compared to the control and other treatments.

The presented results indicate that, the foliar application of putrescine, potassium silicate and proline on taro plant under water stress regulate the level of antioxidant enzymes which involved in scavenging ROS. Also, these results may be attributed to the potential effect of foliar applied substances, which act as free radical scavenger.

The above discussed results evidently indicated that the applied treatments were greatly increased the ability tolerance of taro plant against the water stress adverse effects. Also, it was obvious from the same data that control plants were physiologically stressed. They developed with no or weakly mechanism by which they protected against the prevailing water stress and its probable inducible oxidative nature.

Table 6. Effect of irrigation water levels, foliar application substances and mulching treatments as well as their interactions on proline content (mgg^{-1} F.W.) and antioxidant enzymes activities (unit min^{-1} mg^{-1} protein) of taro plant leaves during second (2^{st}) growing season

Characteristics / Treatments	Proline			Superoxide dismutase			Peroxidase			Catalase		
	WL1	WL2	WL3	WL1	WL2	WL3	WL1	WL2	WL3	WL1	WL2	WL3
Control	0.65	0.72	0.93	0.38	0.56	0.48	0.60	0.64	0.82	0.69	0.71	1.07
Proline 150 mgl^{-1}	0.73	0.76	0.96	0.49	0.59	0.52	0.74	0.81	0.85	0.66	0.76	0.91
Potassium silicate 2500 mgl^{-1}	0.68	0.69	0.94	0.45	0.50	0.57	0.78	0.77	0.87	0.69	0.72	0.80
Putrescine 10 mgl^{-1}	0.73	0.76	1.12	0.46	0.49	0.58	0.86	0.83	1.09	0.88	0.97	1.12
Black polyethylene	0.85	0.66	1.06	0.51	0.55	0.62	0.68	0.76	0.83	0.68	0.60	1.09
Rice straw	0.64	0.81	0.91	0.43	0.41	0.58	1.17	0.72	0.68	0.63	0.64	0.87
sawdust	0.72	0.81	0.92	0.41	0.61	0.47	1.05	0.65	1.06	0.70	0.75	0.85

Where WL1: 100% of ETc, WL2: 75% of ETc and WL3: 50% of Etc

These results are in harmony with those given by the specialists [17,99,100]. Plants protect cellular and sub cellular system from the cyto-toxic effects of active oxygen radicals with anti-oxidative enzymes such as SOD, POX and CAT as well as metabolites like glutathione, ascorbic acid, tocopherol and carotenoids [101]. Proline plays a regulatory role in function and activity of catalase, peroxidase and superoxide dismutase enzymes in plant cells and in their participation in development of metabolic responses for environmental conditions [26].

3.3 Yield and its Components

3.3.1 Effect of applied treatments on taro corms yield

Data presented in Tables 7 and 8 clearly show the effect of tested irrigation water levels (i.e.,100, 75 and 50% of ETc), foliar spray with the stimulant substances (i.e., proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1}) and mulching treatments (i.e., black polyethylene plastic sheet, rice straw and sawdust mulches) individually or in combination treatments on different estimated yield characteristics of taro plant i.e., main corm length (cm), main corm diameter (cm), corms number $plant^{-1}$, corms fresh weight (kg) $plant^{-1}$, main corm fresh weight (g), corms fresh weight (kg) $plot^{-1}$, corms fresh yield (ton) $fed.^{-1}$ and corm dry matter % as well as water use efficiency kg corms / m^3 water during 2016 and 2017 seasons.

With regard to irrigation water treatments, one could notice that different yield traits of taro corms were significantly decreased gradually with increasing water stress levels from 75 to 50% of ETc compared to the full irrigation level (100% ETc) during the two growth seasons. Also, water regime level at 50% ETc gave the highest reduction in all yield characteristics of taro during 2016 and 2017, when compared to water stress level at 75% ETc and full irrigation level 100% ETc (the control). These results are in agreement with reports about decreasing irrigation water level resulted in decreasing yield characteristics compared to the control plant (100% WL) by earlier researchers [23, 81,102,103].

It could be concluded that this reduction in yield and its components due to increasing water stress level was accompanied by decreasing growth parameters Table 4 and photosynthetic pigments Table 5 as well as antioxidant enzymes activity Table 6.

Our results agree with those reported by (Turner [4]) who concluded that water is the most important component of life as well as vital commodity for crop production. Agricultural productivity is dependent upon water and it is essential in every stage from germination to plant maturation. Consequently, any degree of water stress produce deleterious effects on plant yield [5,6]. Drought stress is one of the major causes for crop production losses worldwide as well as yield reducing [11].

As for the effect of foliar spray with stimulant substances and mulching treatments on taro corms yield characteristics, it was clear that different applied treatments were significantly increased all yield characteristics of taro corms and water use efficiency comparing with the control plant during the two seasons of growth. It was obvious from the same data in Tables 7 and 8 that proline at 150 mgl^{-1} ranked the first for increasing the corms yield parameters followed by putrescine at 10 mgl^{-1}, potassium silicate at 2500 mgl^{-1} and black polyethylene plastic mulch when compared with the control and other treatments.

Regarding the interaction effect between different water regimes and foliar application with stimulants as well as mulching treatments on corms yield characteristics and water use efficiency, the obtained results show that foliar spray with stimulants and mulching treatments increased corms yield characteristics as well as water use efficiency to reach the level of significance compared to the control plant. Since, one could notice that the highest increasing in yield characteristics were existed with proline at 150 mgl^{-1} followed by potassium silicate at 2500 mgl^{-1}, putrescine at 10 mgl^{-1} and black polyethylene plastic mulch treatments under irrigation water levels at 75 and 50% ETc when compared to the untreated plants.

The same results presented in Table 8 reveal that irrigation water levels at 75 and 50% of ETc combined with proline at 150 mgl^{-1} followed by potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1} treatments gave the uppermost outcomes yield (corms kg /m^3 of irrigation water).

The above mentioned results evidently indicated that the applied treatments greatly increased the tolerance ability of taro plant against the water stress adverse effects. Also, it was obvious from the same data that control plants have been physiologically stressed. They developed with nil or weak mechanism by which they have been protected against the prevailing water stress and its probable inducible oxidation.

Table 7. Effect of irrigation water levels, foliar application substances and mulching treatments as well as their interactions on yield characteristics of taro plant during first (1st) and second (2st) growing seasons

Characteristics / Treatments		Main corm length (cm)		Main corm diameter (cm)		Corms No. plant^{-1}		Corms F.W. (kg) plant^{-1}		Main corm F.W. (g)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation water levels [a]											
WL1		14.63	16.34	11.18	13.13	3.53	4.45	1.68	1.77	979.03	1294.40
WL2		13.43	14.97	10.39	12.51	3.31	4.00	1.51	1.70	898.62	946.85
WL3		13.03	13.39	9.75	10.64	2.69	3.51	1.11	1.27	615.23	837.66
L.S.D. at 5%		0.21	0.25	0.16	0.27	0.52	0.45	0.24	0.27	83.21	94.25
Foliar spray with stimulants and mulching treatments [b]											
Control		13.12	13.45	9.34	10.83	2.75	3.46	0.87	1.25	441.06	732.39
Proline 150 mgl^{-1}		14.50	15.25	10.99	13.14	3.55	4.38	1.70	1.84	1010.78	1235.67
Potassium silicate 2500 mgl^{-1}		13.57	15.66	10.90	12.42	3.33	4.35	1.58	1.74	833.33	1077.89
Putrescine 10 mgl^{-1}		13.96	14.46	11.05	12.67	3.00	3.81	1.66	1.74	959.84	1234.40
Black polyethylene		13.55	15.67	10.47	12.22	3.01	3.83	1.49	1.58	1047.94	1092.06
Rice straw		13.60	14.47	10.11	11.52	3.43	4.22	1.34	1.41	657.37	855.00
sawdust		13.61	15.34	10.22	11.87	3.14	3.87	1.39	1.50	866.39	956.72
L.S.D. at 5 %		0.11	0.14	0.13	0.15	0.43	0.58	0.19	0.22	52.51	46.87
The interaction between irrigation water levels [a] and stimulants foliar spray as well as mulching treatments [b]											
WL1	Control	13.83	14.13	9.93	11.43	3.33	3.83	1.11	1.49	632.17	904.33
	Proline 150 mgl^{-1}	15.33	17.00	11.76	14.23	4.33	5.27	1.95	1.96	1115.67	1565.33
	Potassium silicate 2500 mgl^{-1}	15.06	17.16	11.65	13.66	3.16	4.72	1.88	1.93	1075.00	1383.33
	Putrescine 10 mgl^{-1}	14.06	16.96	11.65	13.56	3.33	4.33	1.99	2.06	1136.37	1805.17
	Black polyethylene	14.00	17.10	11.21	13.46	3.50	4.16	1.60	1.83	1344.00	1266.50
	Rice straw	15.16	16.06	10.93	13.13	3.72	4.33	1.53	1.47	803.33	1173.33
	sawdust	15.00	16.00	11.10	12.46	3.33	4.50	1.73	1.62	746.67	962.83
WL2	Control	12.70	13.66	9.26	11.50	2.66	3.50	0.97	1.25	390.00	712.17
	Proline 150 mgl^{-1}	13.66	14.80	11.11	13.43	3.50	3.66	1.93	2.02	1216.67	1266.67
	Potassium silicate 2500 mgl^{-1}	13.53	16.53	11.05	13.20	3.83	4.50	1.71	1.97	975.00	1125.33
	Putrescine 10 mgl^{-1}	14.53	15.06	11.00	13.03	3.00	4.11	1.64	1.8	934.83	813.53
	Black polyethylene	13.40	15.56	10.45	12.40	3.00	3.83	1.57	1.69	912.33	964.67
	Rice straw	13.23	13.86	9.78	11.53	3.83	4.50	1.41	1.57	875.00	811.23
	sawdust	13.00	15.33	10.10	12.53	3.33	3.94	1.31	1.63	986.50	934.33
WL3	Control	12.83	12.56	8.83	9.56	2.25	3.05	0.53	1.02	301.00	580.67
	Proline 150 mgl^{-1}	14.50	13.96	10.10	11.76	2.83	4.22	1.23	1.53	700.00	875.00
	Potassium silicate 2500 mgl^{-1}	12.13	13.30	10.00	10.40	3.00	3.83	1.15	1.30	450.00	725.00
	Putrescine 10 mgl^{-1}	13.30	11.36	10.50	11.43	2.66	3.00	1.35	1.37	808.33	1084.50
	Black polyethylene	13.25	14.36	9.76	10.80	2.55	3.50	1.28	1.21	887.50	1045.00
	Rice straw	12.40	13.50	9.63	9.89	2.75	3.83	1.08	1.20	293.77	580.43
	sawdust	12.83	14.70	9.47	10.63	2.77	3.16	1.13	1.25	866.00	973.00
L.S.D. at 5 %		0.19	0.24	0.22	0.25	0.11	0.09	0.34	0.38	90.94	81.17

Where WL1: 100% of ETc, WL2: 75% of ETc and WL3: 50% of Etc

Table 8. Effect of irrigation water levels, foliar application substances and mulching treatments as well as their interactions on yield parameters and water use efficiency (WUE kg corms/m^3 water) of taro plant during first (1st) and second (2st) growing seasons

Characteristics / Treatments		Corms fresh weight(kg) plot^{-1}		Corms fresh yield (ton)fed.$^{-1}$		Corm dry matter %		Water use efficiency	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation water levels [a]									
WL1		60.60	63.55	17.31	18.16	24.91	27.33	3.97	4.17
WL2		54.19	61.31	15.48	17.51	24.11	25.11	4.74	5.37
WL3		39.78	45.66	11.37	13.05	22.74	23.06	5.22	5.99
L.S.D. at 5 %		4.81	5.59	1.68	1.29	0.86	1.22	0.65	0.78
Foliar spray with stimulants and mulching treatments [b]									
Control		31.28	44.98	8.94	12.85	22.11	23.54	2.72	4.08
Proline 150 mgl^{-1}		61.35	66.19	17.53	18.91	25.01	25.95	5.50	6.08
Potassium silicate 2500 mgl^{-1}		56.81	62.46	16.23	17.84	24.58	26.11	5.08	5.64
Putrescine 10 mgl^{-1}		59.69	62.66	17.05	17.90	24.36	25.60	5.41	5.66
Black polyethylene		53.46	56.73	15.27	16.21	23.80	25.26	4.93	5.12
Rice straw		48.16	50.84	13.76	14.53	24.07	25.09	4.38	4.75
sawdust		49.92	54.03	14.26	15.44	23.52	24.60	4.51	5.04
L.S.D. at 5 %		5.89	6.13	1.03	1.15	0.35	1.16	0.43	0.52
The interaction between irrigation water levels [a] and stimulants foliar spray as well as mulching treatments [b]									
WL1	Control	39.83	53.48	11.38	15.28	23.34	25.84	2.61	3.51
	Proline 150 mgl^{-1}	70.29	70.63	20.08	20.18	25.78	28.35	4.61	4.64
	Potassium silicate 2500 mgl^{-1}	67.73	69.65	19.35	19.90	25.31	28.03	4.45	4.57
	Putrescine 10 mgl^{-1}	71.59	74.06	20.45	21.16	25.67	27.93	4.70	4.86
	Black polyethylene	57.48	65.80	16.42	18.80	24.44	27.80	3.77	4.32
	Rice straw	55.13	52.92	15.75	15.12	25.23	27.18	3.62	3.47
	sawdust	62.15	58.31	17.76	16.66	24.62	26.14	4.08	3.83
WL2	Control	35.05	44.87	10.01	12.82	21.98	23.69	3.07	3.93
	Proline 150 mgl^{-1}	69.65	72.80	19.90	20.80	25.48	25.74	6.10	6.38
	Potassium silicate 2500 mgl^{-1}	61.43	70.90	17.55	20.26	25.37	25.65	5.38	6.21
	Putrescine 10 mgl^{-1}	58.89	64.66	16.83	18.47	24.33	25.50	5.16	5.66
	Black polyethylene	56.67	60.77	16.19	17.36	24.06	25.03	4.96	5.32
	Rice straw	50.61	56.38	14.46	16.11	24.22	25.09	4.43	4.94
	sawdust	47.04	58.82	13.44	16.80	23.35	25.03	4.12	5.15
WL3	Control	18.96	36.58	5.42	10.45	21.03	21.10	2.49	4.80
	Proline 150 mgl^{-1}	44.10	55.13	12.60	15.75	23.77	23.76	5.79	7.24
	Potassium silicate 2500 mgl^{-1}	41.27	46.84	11.79	13.38	23.07	24.64	5.42	6.15
	Putrescine 10 mgl^{-1}	48.59	49.27	13.88	14.08	23.08	23.36	6.38	6.47
	Black polyethylene	46.23	43.61	13.21	12.46	22.92	22.95	6.07	5.73
	Rice straw	38.75	43.23	11.07	12.35	22.75	23.00	5.09	5.68
	sawdust	40.56	44.97	11.59	12.85	22.59	22.62	5.33	5.91
L.S.D. at 5 %		10.20	14.51	1.87	2.66	0.60	2.00	0.74	1.34

Where WL1: 100% of ETc, WL2: 75% of ETc and WL3: 50% of Etc

The negatively effects of high water stress level on yield and its components may be due to the decrease in the number of leaves and leaf area plant^{-1}, resulting in supply reduction of photosynthates because of the decrease in the net photosynthetic rate. Limited photosynthesis and sucrose accumulation in the leaves may hamper the rate of sucrose export to the sink organs and ultimately affect the reproductive development [74]. Drought stresses not only limits the size of the source and sink tissues, but also the phloem loading and assimilate translocation to reproductive sinks. Yield can be limited by availability of assimilate translocation and biomass accumulation [74]. Drought stress reduces yield by 40-55% [104,105].

In addition, such increases effects of proline, putrescine, potassium silicate and mulching treatments on yield and its components in these results may be attributed to their roles in enhancing many physiological and developmental processes in plant under abiotic stress [47,106]. Different scientists reported ameliorative effects of proline in different crops like wheat [29], tobacco [30] and olive [31]. (Gamal El-Din and Abd El-Wahed [34]) concluded that foliar application of proline minimizes deleterious effects of stress. Foliar spray with proline at 100 mgl^{-1} increased yield characteristics of chamomile plant.

Potassium (K) is an essential element for many physiological processes such as translocation of photosynthetic material into sink organs in plants. This process increases drought tolerance [14,36,37].

Silicon was reported to reduce the hazard effects of various abiotic and biotic stresses. (Gharib and Hanafy Ahmed [41]) reported that foliar application of pea plants with silicon significantly increased yield traits $fed.^{-1}$. (Sayed et al., [43] indicated that globe artichoke plant sprayed with silicon at 2000 mgl^{-1} recorded the highest increasing in yield parameters compared to untreated plant.

Polyamines high accumulation in plant during a biotic stress has been documented and it is correlated with increasing a biotic stress tolerance [47].

Mulching with plant residues and synthetic materials is a well established technique for increasing the profitability of many horticultural crops [51]. Also, mulch is improving roots distribution and their nutrients absorption as well as plant yield [54,55]. (Sharma et al., [56]) found that mulching is very beneficial for enhancing moisture and nutrient conservation, resulting in productivity increase.

3.3.2 Effect of applied treatments on some bioconstituents of taro corms

Results in Table 9 illustrate the effect of irrigation water levels (i.e.,100, 75 and 50% of ETc) and foliar application with the stimulant materials (i.e., proline at 150 mgl^{-1}, potassium silicate at 2500 mgl^{-1} and putrescine at 10 mgl^{-1}) and mulching treatments (i.e., black polyethylene plastic sheet, rice straw and sawdust mulches) individually or in combination treatments on some bioconstituents of taro corms i.e., N, P, K, protein and starch % during 2016 and 2017 seasons.

With regard to water regime levels, data clearly indicate that different water stress levels i.e., 75 and 50% of ETc decreased the content of N, P, K, crude protein and starch in corms of taro plants compared with the full irrigation level (100% ETc). Also, the water stress level at 50% of ETc gave the highest reduction in the determined bioconstituents. These results are in agreement with those reported that drought stress reduces the availability, uptake, translocation, metabolism of nutrients and efficiency of their utilization [74].

Concerning the effect of stimulants foliar spray and mulching treatments, the obtained data clearly indicate that all applied treatments effectively increased the concentration of N, P, K, crude protein and starch in taro corms of treated plants compared to those of the control. The most effective treatment which maintained the highest concentrations of the determined bioconstituents was proline at 150 mgl^{-1} followed by potassium silicate at 2500 mgl^{-1}, putrescine at 10 mgl^{-1} and black polyethylene plastic mulch, respectively.

In this respect, increasing of total carbohydrate with different applied treatments consider as a direct result of increasing both photosynthesis rate and efficiency. Also, that was preceded with large photosynthetic area Table 4 and high content of photosynthetic pigments Table 5 as with a result of different applied treatments.

In other words, such promotional effect of applied treatments on determined minerals, protein and carbohydrate concentrations could be due to their similar effect on photosynthetic pigments and number of leaves i.e., surfaces of photoassimilation thereby, the capacity of Co_2 fixation and carbohydrates synthesis. In addition, increment of determined bioconstituents in taro corms with different applied treatments considered a direct result of the obtained vigorous growth that being accompanied with high photosynthesis efficiency.

Regarding the effect of interaction, data presented in Table 9 clearly show that foliar spray with stimulants and mulching treatments significantly increased N, P, K, protein and starch contents in taro corms under different irrigation water levels compared to the untreated plants. Since, it is noticed that the highest increasing of the determined bioconstituents were existed with proline at 150 mgl^{-1} followed by potassium silicate at 2500 mgl^{-1}, putrescine at 10 mgl^{-1} and black polyethylene plastic mulch treatments under irrigation water levels i.e., 75 and 50% ETc when compared to untreated plants during the two seasons of growth.

Table 9. Effect of irrigation water levels, foliar application substances and mulching treatments as well as their interactions on some bioconstituents % of taro corms yield during first (1^{st}) and second (2^{st}) growing seasons

Characteristics / Treatments	N		P		K		Protein		Starch	
	1^{st}	2^{nd}	1^{st}	2^{nd}	1^{st}	2^{nd}	1^{st}	2^{nd}	1^{st}	2^{nd}
Irrigation water levels [a]										
WL1	1.575	1.519	0.565	0.582	2.791	2.831	9.845	9.491	50.02	53.70
WL2	1.548	1.499	0.554	0.568	2.744	2.784	9.672	9.371	48.29	50.07
WL3	1.462	1.436	0.508	0.530	2.513	2.586	9.137	8.978	45.45	46.08
L.S.D. at 5 %	0.041	0.020	0.017	0.012	0.040	0.098	0.191	0.083	2.14	2.81
Foliar spray with stimulants and mulching treatments [b]										
Control	1.055	1.037	0.440	0.444	2.530	2.599	6.592	6.480	44.03	46.75
Proline 150 mgl^{-1}	1.674	1.652	0.603	0.617	2.730	2.784	10.463	10.323	49.72	51.13
Potassium silicate 2500 mgl^{-1}	1.666	1.633	0.582	0.611	2.819	2.809	10.415	10.209	49.61	51.77
Putrescine 10 mgl^{-1}	1.627	1.541	0.583	0.603	2.743	2.779	10.167	9.634	48.64	50.64
Black polyethylene	1.540	1.529	0.526	0.558	2.642	2.728	9.623	9.557	47.91	50.41
Rice straw	1.600	1.472	0.560	0.560	2.692	2.740	9.998	9.203	48.13	49.63
sawdust	1.536	1.529	0.500	0.526	2.621	2.698	9.601	9.554	47.37	49.30
L.S.D. at 5 %	0.091	0.018	0.015	0.033	0.038	0.047	0.122	0.069	2.08	2.15
The interaction between irrigation water levels [a] and stimulants foliar spray as well as mulching treatments [b]										
WL1 Control	1.146	1.112	0.471	0.476	2.788	2.838	7.161	6.951	46.34	50.34
Proline 150 mgl^{-1}	1.711	1.684	0.639	0.649	2.813	2.879	10.694	10.526	51.55	54.71
Potassium silicate 2500 mgl^{-1}	1.719	1.673	0.606	0.630	2.920	2.894	10.742	10.456	51.29	55.40
Putrescine 10 mgl^{-1}	1.671	1.564	0.596	0.639	2.809	2.862	10.445	9.775	51.01	54.87
Black polyethylene	1.565	1.573	0.545	0.577	2.740	2.793	9.780	9.832	49.54	54.94
Rice straw	1.659	1.466	0.586	0.575	2.754	2.794	10.369	9.162	50.47	53.36
sawdust	1.556	1.558	0.512	0.528	2.713	2.762	9.726	9.737	49.90	52.27
WL2 Control	1.078	1.084	0.459	0.456	2.788	2.743	6.738	6.774	43.96	47.39
Proline 150 mgl^{-1}	1.705	1.682	0.609	0.622	2.769	2.803	10.654	10.511	50.73	50.82
Potassium silicate 2500 mgl^{-1}	1.699	1.658	0.606	0.623	2.828	2.830	10.617	10.364	50.74	50.96
Putrescine 10 mgl^{-1}	1.638	1.546	0.604	0.608	2.770	2.794	10.239	9.661	48.76	50.66
Black polyethylene	1.538	1.516	0.528	0.560	2.697	2.793	9.615	9.472	48.35	50.40
Rice straw	1.623	1.467	0.572	0.573	2.691	2.772	10.146	9.170	48.44	49.85
sawdust	1.551	1.543	0.499	0.534	2.667	2.757	9.695	9.643	47.03	50.40
WL3 Control	0.940	0.914	0.390	0.399	2.015	2.216	5.877	5.715	41.78	42.53
Proline 150 mgl^{-1}	1.606	1.589	0.562	0.581	2.608	2.671	10.040	9.931	46.88	47.86
Potassium silicate 2500 mgl^{-1}	1.582	1.569	0.534	0.579	2.710	2.703	9.886	9.807	46.80	48.95
Putrescine 10 mgl^{-1}	1.571	1.514	0.550	0.563	2.650	2.683	9.816	9.464	46.16	46.39
Black polyethylene	1.516	1.499	0.505	0.538	2.490	2.599	9.475	9.367	45.83	45.90
Rice straw	1.517	1.484	0.523	0.530	2.632	2.655	9.479	9.277	45.49	45.67
sawdust	1.501	1.485	0.490	0.518	2.484	2.575	9.383	9.282	45.18	45.23
L.S.D. at 5 %	0.157	0.031	0.025	0.057	0.065	0.081	0.211	0.119	3.60	3.72

Where WL1: 100% of ETc, WL2: 75% of ETc and WL3: 50% of Etc

Generally, results indicate that different applied treatments i.e., proline, potassium silicate, putrescine and mulching play a defensive protective role against adverse effects of water stress level via it's antioxidant and regulatory functions, especially at water stress level 50% compared to that of 100% from water requirements.

It was reported that foliar application of proline minimizes stress deleterious effects. Moreover, plants show resistance to drought oxidative damage by organic osmolytes accumulation such as sugars [32,33 ,89].

Spraying globe artichoke plant with silicon at 2000 ppm increased nitrogen, phosphorus, potassium and total sugars contents compared to the control plant [43].

Polyamines can modulate proteins synthesis and protect macromolecules under stress conditions [46]. High accumulation of polyamines in plants during abiotic stress has been well documented and is correlated with increased tolerance to a biotic stress [47].

Also, mulching improved roots absorption of nutrients [54]. Furthermore, (Sharma et al., [56]) reported that mulching is very beneficial for enhancing moisture and nutrient conservation, resulting in productivity increase.

4. CONCLUSION

The results from the present study confirm that spraying taro plant grown under water stress levels i.e., 75 and 50% of ETc with proline at 150 mgl^{-1} or potassium silicate at 2500 mgl^{-1} or putrescine at 10 mgl^{-1} as well as black polyethylene plastic mulch, respectively improved plant tolerance to the harmful effects of water stress and reduced the amount of water used for irrigation, especially at 75 of ETc level without significant decreasing in taro yield compared to the full irrigation level (100% ETc).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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