Asian Journal of Plant Sciences

ISSN 1682-3974

OPEN ACCESS

Asian Journal of Plant Sciences

ISSN 1682-3974
DOI: 10.3923/ajps.2022.66.77

Research Article
Glutathione Stimulates Growth and Productivity of Some Flax Varieties Grown under Sandy Soil

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Abstract

Background and Objective: Linseed is a double purpose plant and propagated as fibre, oil or double purpose plant in different countries. Glutathione is a highly significant and prevailing non-protein thiol produced in plant cells. This investigation was an attempt to evaluate the physiological role of exogenous application of glutathione on growth, some physiological indices and productivity of seven varieties of flax plants grown under sandy soil conditions. **Materials and Methods:** Two field experiments were carried out at the experimental station of the National Research Centre, in the 2018/2019 and 2019/2020 winter seasons, with split-plot design. Foliar applications of different concentrations of glutathione at rates were 50, 100 and 200 mg L^{-1}. **Results:** Data clearly show significant varietal differences among the seven tested flax (Sakha-1, Sakha-2, Sakha-3, Sakha-5, Sakha-6, Giza-11 and Amon) varieties in growth, some biochemical aspects, yield and its components. Results clearly show the superiority of Sakha-5 and Sakha-1 varieties in yield and its components Moreover, results show the enhancing role of glutathione treatments on the growth and yield of the tested flax varieties through improving different physiological aspects Glutathione, 200 mg L^{-1} recorded the highest values of general studied parameters. **Conclusion:** In conclusion, foliar treatments of different flax cultivars with glutathione in different concentrations improved the studied growth, biochemical parameters, yield and quality traits as compared with their corresponding controls of different flax varieties under sandy soil conditions.

Key words: Flax cultivars, glutathione, growth, sandy soil, yield

Citation: Bakry, A.B., M. Sh. Sadak, A.S.M. Younis and T.M. Abd El-Razik, 2022. Glutathione stimulates growth and productivity of some flax varieties grown under sandy soil. Asian J. Plant Sci., 21: 66-77.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Linseed or flax (*Linum usitatissimum* L.) is a useful plant grown as a double purpose plant. It propagated as a fibre, seed or double purposes plant in many countries. Flax seeds contain an extremely potent antioxidant activity and are progressively being recommended as an essential oil and antioxidants source. There is no doubt that the need for conventional edible oils will be increased due to the population growth across the world. Flax seeds are a source of linseed oil. The efficiency of oil is typically valued according to Essential Fatty Acids contents (EFAs)[1]. Omega 3, 6, 9 groups of fatty acids are important for human health. Omega-3 and omega-6 fatty acids are used to create cell walls and hormones which regulate the hormonal cycles. Also, flaxseed has a high ratio of α-linolenic (omega-3) to linoleic (omega-6) fatty acids and it is one of the richest sources of omega-3 fatty acid[2]. Therefore, flax seeds are widely used in the food industry[3] and medicine, while, textiles are used in textile industries[4,5]. Moreover, this unique plant is a source of valuable oil, high-grade vegetable protein, vitamins, microelements and fibre. Seeds contain 30-48% of oil and are rich in unsaturated fatty acids[6]. It is a good precursor for most crops due to a short growing period and resistance to specific pests and diseases. These qualities allow avoiding the use of insecticides and fungicides almost completely[7,8]. However, despite a great demand on the market, world production of flax decreases annually due to great competition with other cost-effective crops. Therefore, increasing flax yield could be occurred via using advanced cultivation technologies and high-yielding varieties or using new reclaimed sandy soil and by improving different soil conditions[9].

The growing of flax plants in sandy soil suffers from low productivity as a result of water shortage, saline water and soil, nutrient deprivation and temperature fluctuations. Thus, to overcome these adverse environmental conditions of sandy soil, external treatments of naturally occurring compounds which present in plant cells. This considered a useful technique that enhances plant tolerance and improves plant growth and productivity. Glutathione (GHS) is one of these compounds. Glutathione (γ-L glutamyl-L-cystinyl-glycine) is one of the highly significant and prevailing non-protein thiol produced in plant cells. The physiological function of glutathione could be split into two categories: Sulfur metabolism and antioxidant impacts. Glutathione was seen as an effectively reduced sulphur pool[10] and enhance absorption of sulfur by root[11]. Glutathione is a potent antioxidant that has a vital effect in regulating the balance between oxidation and antioxidation, it controls different cell vital processes as photosynthesis, biosynthesis and fix of DNA, synthesis of proteins as well as activation and regulation of enzymes in plants. Reduced glutathione the main water-soluble antioxidant in photosynthetic and non-photosynthetic tissues helps preserve the integrity of cell structures and the efficient functions of different metabolic pathways, glutathione can also be included in redox control of cell division[12]. Moreover, glutathione is crucial for biotic and abiotic stress management. It is a pivotal component of the glutathione-ascorbate cycle, a system that reduces poisonous hydrogen peroxide[13]. In addition, it is involved in flower development and plant defence signaling[14].

Thus, this study attempted to observe the effect of different concentrations of glutathione on growth, some biochemical aspects and yield of some flax varieties grown under the sandy soil.

MATERIALS AND METHODS

Study area: Field experiments were carried out at Researches and Production Station of National Research Centre, Al Nubaria district El-Behira Governorate-Egypt, in 2018/2019 and 2019/2020 winter seasons. The soil of the experimental site was sandy. Mechanical, chemical and nutritional analysis of the experimental soil is reported in Table 1[15].

Experimental design: The experimental design was a split-plot design with three replicates, where the flax varieties (Sakha-1, Sakha-2, Sakha-3, Sakha-5, Sakha-6, Giza-11 and Amon) distributed randomly in main plots, while, concentrations of glutathione (0.0, 50, 100 and 200 mg L^{-1}) occupied the subplots. Flaxseed varieties were sown on the 20th November in rows 3.5 m long and the distance between rows was 20 cm apart, plot area was 10.5 m^2 (3.0 m in width and 3.5 m in length). The seeding rate was 2000 seeds m^{-2}. Pre-sowing, 150 kg fed^{-1} of calcium super-phosphate (15.5% P_2O_5) were used. Nitrogen was applied after emergence in the form of ammonium nitrate 33.5% at the rate of 75 kg fed^{-1} in five equal doses. Potassium sulfate (48% K_2O) was added at two equal doses of 50 kg fed^{-1}. Watering was done by a new sprinkler irrigation system every 5 days. Foliar application of different treatments of glutathione with 0, 50, 100 and 200 mg L^{-1} concentrations (named as GHS0, GHS1, GHS2 and GHS3) were carried out twice, where plants were sprayed after 30 and 45 days from sowing. At 60 days of age, samples were taken for determining morphological parameters and some biochemical aspects. Growth parameters in terms of plant

Table 1: Mechanical, chemical and nutritional analysis of the experimental soil mechanical analysis

	Sand											
	Course 2000-200 (μ%)			Fine 200-20 (μ%)			Silt 20-0 (μ%)		Clay <2 (μ%)			Soil texture
Mechanical analysis	47.46			36.19			12.86		4.28			Sandy
					Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})			
	pH 1:2.5	EC (dS m^{-1})	$CaCO_3$ (%)	OM (%)	Na^+	K^+	Mg^+	Ca^{++}	CO_3^-	HCO_3^-	Cl^-	SO_4
Chemical analysis	8.25	0.11	0.9	0.9	0.7	0.02	0.1	0.3	0.0	0.2	0.8	0.12
	Available nutrients											
	Macro element (ppm)					Micro element (ppm)						
	N		P	K		Zn		Fe		Mn		Cu
Nutritional analysis	12.9		3.6	52.9		0.12		1.98		0.46		0.06

height (cm) shoot fresh and dry weight (g), roots length (cm), root fresh and dry weight (g). Plant samples were dried in an electric oven with a drift fan at 70°C for 48 hrs to measure chemical analysis. At harvest, flax plants were pulled when signs of full maturity appeared then left on the ground to suitable complete drying. Capsules were removed carefully. Plant height, technical stem length, fruiting zone length, number of fruiting branches/plant, number of capsules/plant, seed yield/plant, biological yield/plant were recorded on random samples of ten guarded plants in each plot. Also, seed yield/fed, straw yield/fed, seed oil% and oil yield/fed), carbohydrates%.

Chemical analysis

Photosynthetic pigments: Chlorophyll a, chlorophyll b and carotenoids were determined using the spectrophotometric method[16]. Indole acetic acid content was extracted and analysed by method[17]. Total phenol content was measured as described previously[18]. Total soluble protein concentration was determined[19]. Proline and free amino acids were extracted[20] and assayed[21]. Free amino acids were estimated[22]. Determination of total carbohydrates of seeds was carried out[23]. The oil of flax seeds was extracted[24].

Statistical analysis: The data were subjected to statistical analysis of variance of split-plot design[24]. Since the trend was similar in both seasons the homogeneity test Bartlet's equation was applied and the combined analysis of the two seasons was done according to the method. Means were compared by using Least Significant Difference (LSD) at 5%.

RESULTS

1-Varietal differences in growth parameters, biochemical constituents, yield and its components of flax

Changes in growth criteria: Different growth criteria (shoot and root length (cm), fresh and dry weight of shoot and root (g)), of 7 flax varieties are presented in Table 2. Data clearly show marked and significant differences between means of Sakha-1, Sakha-2, Sakha-3, Sakha-5, Sakha-6, Giza-11 and Amon flax varieties under study in most growth criteria. Data clearly show that Sakha 5 variety significantly surpassed the rest of all tested varieties in shoot length (64.33 cm), fresh (7.42 g) and dry weight (1.21 g). Meanwhile, Sakha 3 variety surpassed the rest of the varieties in root length (14.17 cm) and root dry weight (0.245 g). Moreover, Amon surpassed them in shoot fresh weight (3.90 g) and Giza 11 variety surpassed the 6 other varieties in root fresh weight (0.719 g).

Changes in photosynthetic pigments: Data presented in Table 2 demonstrated the effect of varieties on photosynthetic pigments contents (chlorophyll a, chlorophyll b, carotenoids and total pigments). Data clearly show significant differences between flax varieties (Sakha 1, Sakha 2, Sakha 3, Sakha 5, Sakha 6, Giza 11 and Amon) on photosynthetic pigments contents. Moreover, data clearly show that Sakha 5 variety surpassed the other 6 mentioned flax varieties as it gave the highest contents of photosynthetic pigments constituents (Chlorophyll a (1.687 mg g^{-1} fresh wt.), Chlorophyll b (0.903 mg g^{-1} fresh wt.), carotenoids (0.631 mg g^{-1} fresh wt.) and total pigments (3.221 mg g^{-1} fresh wt.)), followed by Sakha 3 and Amon varieties (Chlorophyll a (1.629 and

Table 2: Effect of varietal differences on growth parameters, biochemical constituents, yield, its components and nutritional value, antioxidant compounds and antioxidant activity of seed yields (Data are means of two seasons)

	Flax varieties							
Characters	Sakha-1	Sakha-2	Sakha-3	Sakha-5	Sakha-6	Giza-11	Amon	LSD 5%
Shoot length (cm)	56.75	51.33	62.83	64.33	59.67	61.92	56.83	2.10
Shoot fresh weight (g)	3.63	3.61	4.39	7.42	4.27	5.51	3.90	0.22
Shoot dry weight (g)	1.20	0.81	0.78	1.21	0.92	1.00	1.05	0.073
Root length (cm)	13.17	10.25	14.17	11.08	12.42	10.58	11.08	0.52
Root fresh weight (g)	0.708	0.406	0.584	0.506	0.457	0.719	0.549	0.062
Root dry weight (g)	0.199	0.120	0.245	0.131	0.166	0.178	0.089	0.046
Fresh weight (mg g^{-1})								
Chlorophyll a	1.152	1.203	1.629	1.687	0.868	1.026	1.409	0.016
Chlorophyll b	0.713	0.633	0.845	0.903	0.542	0.652	0.885	0.014
Carotenoids	0.342	0.316	0.566	0.631	0.348	0.365	0.520	0.003
Total pigments	2.21	2.152	3.04	3.221	1.76	2.04	2.81	0.021
Fresh weight (mg/100 g)								
Phenols	34.74	32.16	57.54	64.18	35.40	37.10	52.89	0.29
IAA	39.61	36.67	65.61	73.19	40.37	42.31	60.31	0.33
Dry weight (mg/100 g)								
TSP	110.37	102.17	182.82	203.93	112.49	117.89	168.06	0.19
Proline	29.99	27.76	49.68	55.42	30.57	32.03	45.67	0.25
Free amino acids	170.80	158.11	282.92	315.58	174.07	182.43	260.08	1.41
Plant height (cm)	81.42	63.58	74.58	72.67	72.33	77.42	79.17	2.73
Fruiting zone length (cm)	26.17	23.08	20.92	21.08	25.92	22.00	22.33	5.49
Technical stem length (cm)	55.25	40.50	53.67	51.58	46.42	55.42	56.83	6.47
No of fruiting branches/plant	4.33	4.50	4.17	4.58	4.58	4.42	4.58	0.74
No. of capsules/plant	15.33	16.25	16.33	17.75	14.42	13.08	17.17	3.25
Seed yield/plant (g)	0.490	0.36	0.45	0.57	0.51	0.40	0.36	0.07
Biological yield/plant (g)	2.92	2.14	2.37	2.93	2.46	2.61	2.48	0.55
Seed yield (kg fed^{-1})	362.39	371.77	367.15	455.22	399.97	332.84	329.26	18.87
straw yield (t fed^{-1})	2.811	2.639	2.628	2.620	2.760	2.764	2.712	0.113
Biological yield (t)	3.173	3.011	2.995	3.076	3.160	3.097	3.041	0.105
Oil (%)	30.04	34.85	32.62	32.26	33.29	35.52	30.90	0.36
Oil yield (kg fed^{-1})	109.49	130.19	120.18	147.70	133.29	119.50	102.75	5.65
Carbohydrates (%)	33.11	32.18	33.77	31.52	31.76	30.95	30.19	0.44

1.409 mg g^{-1} fresh wt.), Chlorophyll b (0.845 and 0.885 mg g^{-1} fresh wt.), carotenoids (0.566 and 0.520 mg g^{-1} fresh wt.) and total pigments (3.040 and 2.81 mg g^{-1} fresh wt.).

Changes in phenols, IAA, total soluble protein (TSP), proline and free amino acids: The results reported in Table 2 also showed that there are significant differences between different tested varieties on phenols, IAA, TSP, proline and free amino acids contents of flax plants grown under the sandy soil. Sakha 5 variety surpassed the other 6 varieties on phenolic, IAA, TSP, proline and free amino acids contents. It gave 64.18 mg/100 phenolic, 73.19 IAA, 203.93 TSP, 55.42 and 315.58 free amino acids. Followed by Sakha 3 variety, it gave 57.54 mg/100 phenolic, 65.61, IAA, 182.82 TSP, 49.68 and 282.92 free amino acids.

Changes in seed yield and its components: Table 2 showed the effect of varieties on seed yield, yield components, oil% and carbohydrate% of the seven tested varieties. Data clearly show the presence of marked differences between varieties in seed yield and yield parameters. Sakha 5 variety surpassed the other varieties in the number of fruiting branches (4.58) and capsules (17.75), seed yield (0.57 g plant) and biological yield (2.93 g plant^{-1}) and seed yield (455.22 kg fed^{-1}). Meanwhile, Sakha 1 variety surpassed the other varieties in plant height (81.42 cm), fruiting zone length (26.17 cm), technical stem length (55.25 cm), biological yield g plant (2.92 g) and straw (2.811 t fed^{-1}) and biological yield 3.173 t fed^{-1}. Sakha 5 variety surpassed significantly the other varieties in oil%, oil yields/fed and total carbohydrates%.

Effect of concentrations on growth parameters, biochemical constituents, yield and its components of flax

Changes in growth criteria: Table 3 showed the effect of concentrations on the growth criteria of the flax plant. Data clearly show that different concentrations (50, 100 and 200 mg L^{-1}) significantly increased different growth criteria (shoot length, shoot fresh and dry weight as well as root

Table 3: Effect of glutathione concentrations on growth parameters, biochemical constituents, yield, its components and nutritional value, antioxidant compounds and antioxidant activity of seed yield (Data are means of two seasons)

	Glutathione concentrations (mg L^{-1})				
Characters	0.0	50	100	200	LSD 5%
Shoot length (cm)	50.57	63.05	62.29	60.48	1.28
Shoot fresh weight (g)	2.61	5.49	5.48	5.14	0.24
Shoot dry weight (g)	0.51	1.28	1.20	1.04	0.05
Root length (cm)	10.38	11.90	12.81	12.19	0.64
Root fresh weight (g)	0.221	0.797	0.645	0.583	0.038
Root dry weight (g)	0.093	0.210	0.171	0.170	0.033
Fresh weight (mg g^{-1})					
Chlorophyll a	1.173	1.222	1.341	1.392	0.013
Chlorophyll b	0.696	0.701	0.759	0.799	0.010
Carotenoids	0.400	0.422	0.462	0.482	0.003
Total pigments	2.269	2.344	2.562	2.674	0.015
Fresh weight (mg/100)					
Phenol	40.66	42.85	46.93	48.98	0.283
IAA	46.37	48.86	53.52	55.86	0.322
Dry weight (mg/100 g)					
TSP	129.20	136.16	149.13	155.64	0.90
Proline	35.11	37.00	40.52	42.29	0.24
Free amino acids	199.94	210.70	230.78	240.86	1.39
Plant height (cm)	66.33	80.43	76.43	74.62	2.12
Fruiting zone length (cm)	18.19	25.24	24.33	24.52	2.70
Technical stem length (cm)	48.14	55.19	52.10	50.10	2.65
No of fruiting branches/plant	4.10	4.29	4.48	4.95	0.37
No. of capsules/plant	11.24	16.52	16.95	18.33	1.90
Seed yield/plant (g)	0.26	0.50	0.50	0.53	0.05
Biological yield/plant (g)	1.12	3.18	2.81	3.12	0.39
Seed yield (kg fed^{-1})	239.64	363.04	417.72	475.94	13.07
Straw yield (t fed^{-1})	2.021	2.573	2.934	3.292	0.083
Biological yield (t fed^{-1})	2.260	2.936	3.352	3.768	0.084
Oil (%)	31.17	32.88	34.00	33.08	0.26
Oil yield (kg fed^{-1})	74.38	119.42	142.06	157.33	4.59
Carbohydrates (%)	29.68	31.65	33.40	32.96	0.27

length, fresh and dry root weight) of flax plant compared with untreated control plant (0.0). The most effective concentration was 50 mg L^{-1} on all studied growth criteria except root length the most effective concentration was 100 mg L^{-1} compared with the other used concentrations. The obtained data were shoot length, 63.29 cm, shoot fresh wt, 5.49 g, shoot dry wt, 1.28, root fresh wt, 0.797 and root dry wt, 0.210, while at 100 mg L^{-1} it was 12.81 cm.

Changes in photosynthetic pigments contents: The effect of different used concentrations (50, 100 and 200 mg L^{-1}) on photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids and total pigments) are presented in Table 3. Different concentrations increased gradually and significantly different photosynthetic pigments constituents as compared with untreated control plants. 200 mg L^{-1} was the most effective concentration over the other concentrations (50 and 100 mg L^{-1}). The obtained data was, Chlorophyll a, 1.392, chlorophyll b, 0.799, carotenoids, 0.482 and total pigments, 2.674 (mg g^{-1} fresh wt.).

Changes in phenols, IAA, Total Soluble Protein (TSP), proline and free amino acids: Table 3 showed the effect of different concentrations on phenols, IAA, TSP, proline and free amino acids of the flax plant. Treatment of flax plants with different concentrations increased significantly the above mentioned studied parameters as compared with untreated control plants. Data also show that increasing concentrations caused gradual increases with increasing concentrations. Moreover, 200 mg L^{-1} gave the highest increases in different studied biochemical contents. This concentration (200 mg L^{-1}) gave 48.98 (mg/100 g fresh wt.) of phenol contents, 55.86 (mg/100 g fresh wt.) of IAA, 155.64 (mg/100 g dry wt) of TSP, 42.29 mg/100 g dry wt.) of proline and 240.86 (mg/100 g dry wt.) of free amino acids contents.

Changes in seed yield and its components: Seed yield and its components of flax plants treated with different concentrations are presented in Table 3. Data showed that foliar treatments of flax plants with different concentrations increased significantly seed yield and its components as

Table 4: Effect of interaction between varieties and different concentrations (0.0, 50, 100 and 200 mg L^{-1}) of glutathione on growth criteria of flax plant grown under sandy soil (Data are means of two seasons)

Verities	Glutathione concentrations (mg L^{-1})	Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Root length (cm)	Root fresh weight (g)	Root dry weight (g)
Sakha-1	0.0	50.67	1.90	0.41	11.33	0.17	0.05
	50	61.00	3.30	2.41	12.67	1.36	0.38
	100	57.33	5.52	1.13	14.67	0.85	0.23
	200	58.00	3.81	0.85	14.00	0.45	0.14
Sakha-2	0.0	47.00	1.50	0.28	7.67	0.11	0.04
	50	52.00	4.31	1.02	9.33	0.57	0.16
	100	53.33	4.03	0.86	12.00	0.41	0.12
	200	53.00	4.61	1.10	12.00	0.53	0.16
Sakha-3	0.0	49.33	2.06	0.64	12.67	0.23	0.15
	50	68.00	5.49	0.91	14.67	0.70	0.21
	100	66.67	6.12	2.58	15.00	0.89	0.35
	200	67.33	3.91	0.96	14.33	0.52	0.27
Sakha-5	0.0	53.67	1.94	0.35	8.33	0.11	0.03
	50	59.67	3.98	0.63	11.00	0.42	0.14
	100	65.67	5.06	1.08	13.00	0.79	0.17
	200	59.67	4.62	1.06	12.00	0.70	0.18
Sakha-6	0.0	56.00	2.21	0.49	11.67	0.15	0.05
	50	69.00	5.69	1.14	12.00	0.57	0.16
	100	68.33	3.74	0.84	13.67	0.40	0.13
	200	64.00	5.46	1.21	12.33	0.72	0.18
Giza-11	0.0	55.67	4.45	0.80	9.67	0.33	0.10
	50	69.33	6.96	1.53	11.67	1.22	0.34
	100	63.33	4.51	0.74	10.33	0.54	0.11
	200	59.33	6.14	0.91	10.67	0.78	0.16
Amon	0.0	41.67	4.20	0.63	11.33	0.45	0.08
	50	62.33	8.67	1.30	12.00	0.73	0.07
	100	61.33	9.37	1.13	11.00	0.64	0.10
	200	62.00	7.46	1.16	10.00	0.38	0.10
	LSD 5%	3.39	0.63	0.13	1.69	0.10	0.09

compared with untreated controls. The most effective concentration was 50 mg L^{-1} on increasing shoot length (80.43 cm), fruiting zone length (25.24 cm) and technical shoot length (55.19 cm) and consequently Biological yield/plant (3.18 g) over the other used concentrations. On the other hand, 200 mg L^{-1} concentration was the most effective concentration on an increasing number of fruiting branches (4.95) and capsules per plant (18.33), seed yield /plant (0.53 g) as well as seed (475.94 kg fed^{-1}), straw (3.22 ton fed^{-1}), biological (3.768 ton fed^{-1}) and oil yields/fed (157.33 kg fed^{-1}) comparing with the other tested concentrations, Meanwhile, oil% (34.0%) and carbohydrates% (33.40) was in response to 100 mg L^{-1} glutathione treatment in seeds comparing with the other tested concentrations.

Effect of interaction between flax varieties and different glutathione concentrations

Changes in growth criteria: The effect of foliar treatment of glutathione with different concentrations (0.0, 50, 100 and 200 mg L^{-1}) on growth criteria of 7 varieties of flax plant grown under sandy soil are presented in Table 4. Data clearly show that different concentrations of glutathione increased significantly different studied growth criteria of the seven varieties (Sakha-1, Sakha-2, Sakha-3, Sakha-5, Sakha-6, Giza-11 and Amon) as compared with their corresponding untreated controls (0.0 GSH).

Changes in photosynthetic pigments: The changes in photosynthetic constituents in different varieties of flax plants in response to different glutathione concentrations are presented in Fig. 1. Data clearly show that foliar treatment of glutathione with different concentrations (0, 50, 100 and 200 mg L^{-1}) caused significant increases in photosynthetic pigment constituents (chlorophyll a, chlorophyll b, carotenoids and total pigments). Increasing glutathione concentrations increased gradually different constituents of photosynthetic pigments of the seven studied varieties.

Changes in phenols, IAA, Total Soluble Protein (TSP), proline and free amino acids: Figure 2 and 3 showed the effect of different concentrations of glutathione different concentrations on phenols, IAA, TSP, proline and free amino acids of different varieties of the flax plant. Foliar treatment with different concentrations of glutathione increased

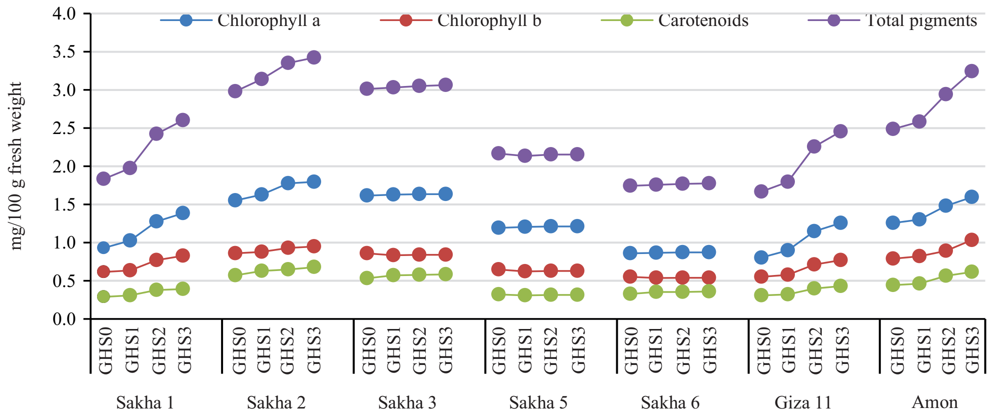

Fig. 1: Effect of interaction between varieties and different concentrations (0.0, 50, 100 and 200 mg L^{-1}) of glutathione on photosynthetic pigments (mg g^{-1} fresh wt.) of flax plants grown under sandy soil

LSD @5% Chlorophyll a: 0.033, Chlorophyll b: 0.027, Carotenoids: 0.007, Total pigments: 0.039

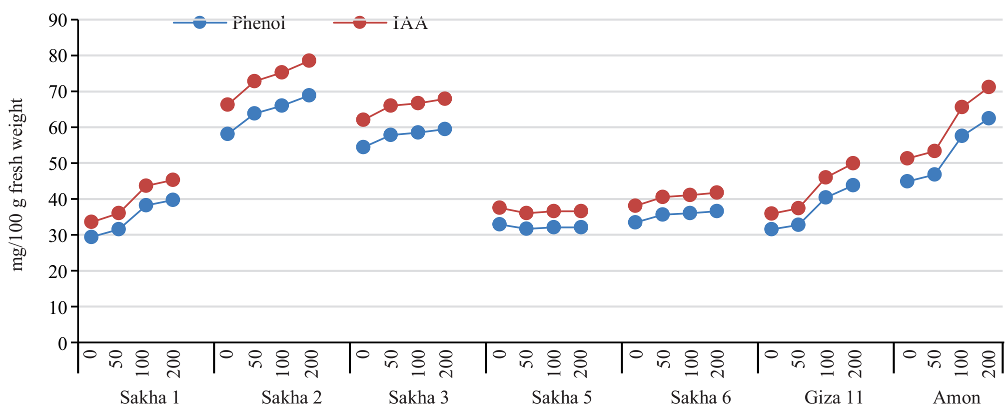

Fig. 2: Effect of interaction between varieties and different concentrations (0.0, 50, 100 and 200 mg L^{-1}) of glutathione on phenols and IAA of flax plants grown under sandy soil

LSD @5%, Phenol: 0.748, IAA: 0.853

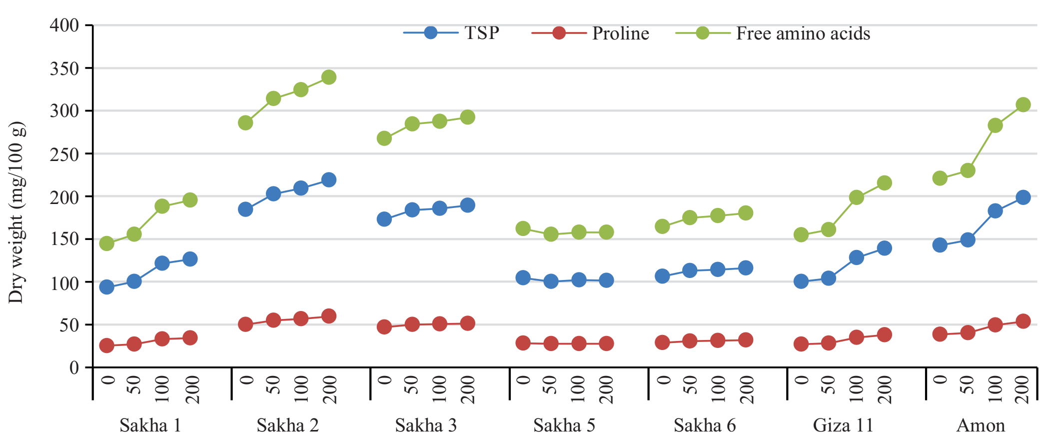

Fig. 3: Effect of interaction between varieties and different concentrations (0.0, 50, 100 and 200 mg L^{-1}) of glutathione on Total Soluble Protein (TSP), proline and free amino acids of flax plants grown under sandy soil

LSD @5%, TSP: 02.38, Proline: 0.65, Free amino acids: 3.68

Table 5: Effect of interaction between varieties and different concentrations (0.0, 50, 100 and 200 mg L^{-1}) of glutathione on different major parts of flax plants grown under sandy soil (Data are means of two seasons)

Varieties	Glutathione concentrations	Plant height (cm)	Fruiting zone length (cm)	Technical length (cm)	Number of fruiting branches/plant	Number of capsules/plant
Sakha-1	0.0	67.67	21.67	46.00	4.3	8.3
	50	91.67	36.67	55.00	4.4	10.7
	100	81.00	26.67	54.33	4.7	18.3
	200	73.67	19.67	54.00	4.9	24.0
Sakha-2	0.0	57.00	18.67	38.33	4.0	10.7
	50	58.33	20.00	38.33	5.0	17.3
	100	68.67	26.67	42.00	5.7	20.0
	200	73.00	30.00	43.33	5.8	26.0
Sakha-3	0.0	68.67	13.67	55.00	3.7	11.7
	50	79.33	19.00	60.33	4.0	24.0
	100	75.00	19.00	56.00	4.7	15.7
	200	75.33	22.00	53.00	4.3	19.7
Sakha-5	0.0	65.33	20.00	45.33	4.0	15.0
	50	70.33	21.33	48.67	4.7	16.3
	100	71.00	21.67	50.33	4.7	15.0
	200	76.33	23.67	52.67	4.7	19.0
Sakha-6	0.0	58.33	18.00	40.33	4.7	14.7
	50	69.00	23.00	46.00	3.7	10.7
	100	70.33	30.00	40.33	5.0	19.0
	200	72.67	32.67	40.00	5.0	13.3
Giza-11	0.0	66.00	19.33	46.67	4.0	10.3
	50	93.00	20.00	73.00	4.3	11.3
	100	84.67	19.33	65.33	5.0	14.0
	200	82.00	29.33	52.67	4.3	16.7
Amon	0.0	72.00	15.67	56.33	4.0	8.0
	50	76.33	20.67	55.67	4.3	12.0
	100	84.67	23.33	61.33	5.3	20.3
	200	83.67	29.67	54.00	4.7	28.3
LSD 5%		5.60	7.14	7.01	n.s	5.03

Table 6: Effect of interaction between varieties and different concentrations (0.0, 50, 100 and 200 mg L^{-1}) of glutathione on yield and its components of flax plants grown under sandy soil (Data are means of two seasons)

	Concentrations	Seed yield/ plant (g)	Biol. yield/ plant (g)	Seed yield kg/fed	Straw yield (t/fed)	Biol. yield (t/fed)	Oil (%)	Oil yield (kg/fed)	Carbohydrate (%)
Sakha 1	GHS0	0.64	1.28	272.67	1.986	2.259	28.19	76.84	29.79
	GHS1	0.97	2.60	345.33	3.315	3.122	30.08	103.93	32.92
	GHS2	0.91	3.87	402.67	3.166	3.569	31.40	126.43	35.38
	GHS3	1.03	3.93	428.89	2.177	3.744	30.48	130.75	34.35
Sakha 2	GHS0	0.54	0.78	213.50	1.990	2.204	33.52	71.57	30.34
	GHS1	0.69	2.77	360.22	2.447	2.807	34.92	125.82	32.41
	GHS2	0.78	3.43	421.78	2.853	3.274	36.32	153.23	33.42
	GHS3	0.88	3.57	491.57	3.269	3.760	34.63	170.14	32.54
Sakha 3	GHS0	0.49	0.71	204.00	1.953	2.157	31.77	64.80	31.11
	GHS1	0.67	2.07	396.83	2.632	3.029	33.06	131.20	33.68
	GHS2	0.76	2.63	412.22	2.876	3.288	33.14	136.59	35.68
	GHS3	0.87	3.07	455.56	3.053	3.508	32.51	148.13	34.62
Sakha 5	GHS0	0.76	1.75	314.22	1.985	2.299	30.58	96.10	29.36
	GHS1	0.71	2.63	433.33	2.247	2.680	32.35	140.23	30.57
	GHS2	0.95	3.57	505.56	2.828	3.333	33.68	170.28	32.48
	GHS3	1.01	3.77	567.78	3.422	3.990	32.45	184.19	33.65
Sakha 6	GHS0	0.63	1.30	266.56	2.095	2.362	32.34	86.27	30.52
	GHS1	0.73	1.87	344.44	2.662	3.007	33.79	116.39	31.36
	GHS2	0.86	3.27	444.44	2.902	3.346	34.42	152.99	33.56
	GHS3	1.02	3.40	544.44	3.380	3.924	32.60	177.50	31.58
Giza 11	GHS0	0.41	1.02	191.89	2.228	2.419	33.05	63.44	28.87
	GHS1	0.74	2.26	337.79	2.591	2.928	35.47	119.83	30.22
	GHS2	0.77	3.03	379.44	2.953	3.332	37.14	140.90	31.67
	GHS3	0.86	3.47	422.22	3.284	3.706	36.44	153.83	33.05
Amon	GHS0	0.47	1.04	214.67	1.908	2.123	28.76	61.67	27.77
	GHS1	0.68	2.73	323.33	2.653	2.976	30.49	98.56	30.42
	GHS2	0.68	3.00	357.94	2.961	3.319	31.87	114.02	31.63
	GHS3	0.81	3.17	421.11	3.325	3.746	32.48	136.77	30.96
LSD 5%		0.14	1.024	34.59	0.210	0.223	0.69	12.14	0.72

significantly and gradually the above studied the above-mentioned parameters as compared with their corresponding untreated control plants. Data also show that increasing concentrations caused gradual increases with increasing concentrations.

Changes in seed yield and yield components: Foliar treatment of glutathione with different concentrations (50, 100 and 200 mg L^{-1}) caused significant increases in seed yield and its components, oil% and carbohydrates% of different varieties of flax plants grown under sandy soil conditions in Table 5 and 6 as compared with their corresponding control plants. The most effective treatment on seed yield (567.78 kg fed^{-1}), biological yield (3.990 t fed^{-1}) and straw yield (3.422 t fed^{-1}) were obtained by the interaction between Sakha-5 variety with 200 mg L^{-1} glutathione foliar treatment than other interactions.

DISCUSSION

The collected data showed the significant effect of varieties on different growth parameters (shoot and root length (cm), fresh and dry weight of shoot and root (g)) (Table 2) and photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids and total pigments) (Table 2) phenolic, IAA, TSP, proline and free amino acids as well as yield and its components, oil% and carbohydrate% of the seven tested varieties (Table 2). These differences might be due to the differed rate of quenching of chlorophyll fluorescence, which markedly affects plant biomass. Moreover, the superiority of Sakha 5 and Sakha 1 varieties in yield components over the other five tested varieties might be due to the superiority in plant height, fruiting zone length, branches and capsules number/plant, seed yield/plant. The superiority of the Sakha 5 variety in oil yields/fed reflected in its increased number of fruiting branches, number of capsules, the weight of capsules, seed yield /plant. In addition, Sakha 1 surpassed significantly the other varieties in the biological and straw yield superiority, contents plant height, technical stem length, biological yield/ plant. Such results are in agreement with those obtained by other investigators[8,25-28]. They found that the flax varieties differed in yield components and seed productivity, Moreover, the variability among flax varieties may be expected because of the differences of these varieties in origin and growth habit, where, these flax varieties are grown for double purpose crop oil and fibres under the conditions of this trails. Moreover, these obtained results were following those obtained[9, 29-32] on different plant species in many regions of the world.

Regarding the effect of foliar treatment of glutathione with different concentrations (0.0, 50, 100 and 200 mg L^{-1}) on growth criteria of the 7 varieties of flax plant grown under the sandy soil. Data clearly show that different concentrations of glutathione increased significantly different studied growth criteria of the seven varieties (Sakha 1, Sakha 2, Sakha 3, Sakha 5, Sakha 6, Giza 11 and Amon) as compared with their corresponding untreated controls (Table 4). These results are in harmony with these obtained earlier[33] on tomato. This enhancing role of glutathione could be due to its effect in integrating into primary metabolism and its role on the processing of signal transduction pathways by upregulating the redox state of cells[34]. Moreover, the increased growth in flax plants treated with glutathione could be due to increased photosynthetic pigments[35].

Figure 1 showed that increasing glutathione concentrations increased gradually different constituents of photosynthetic pigments of the seven studied varieties, In agreement with this enhancement effect[33-36] on different plant species. In this concern, Anjum *et al.*[13] stated that glutathione plays an important role in maintaining and controlling the intercellular redox system. Moreover, the efficient regulation role of glutathione might be particularly in the metabolism of a chloroplast as it provides the redox buffering capacity necessary for efficient photosynthesis and thus used in processing the oxidizing which are inevitably formed as a result of light capture and subsequent electron transport[37].

Foliar treatment with different concentrations of glutathione increased significantly and gradually phenols, IAA, TSP, proline and free amino acids as compared with their corresponding untreated control plants Fig. 2 and 3. These obtained results are in agreement with that obtained previously[38]. The increases in phenols contents might be due to that, phenolic compounds are secondary metabolites used in the protection of plants against adverse environmental conditions and have an antioxidant property[39]. Also, Huang *et al.*[40] reported that phenol was regarded as an antioxidant defensive compound that scavenges ROS radicals as a consequence of their high reactivity as hydrogen or electron donors. This can stabilize and delocalize the unpaired electron (chain-breaking function) and from their ability to chelate transition metal ions. Moreover, phenols have an efficient mechanism in the regulation of plant metabolic processes and consequently overall plant growth[41].

Moreover, the increases of IAA contents are congruent with the increases in the growth rate of flax varieties confirming the physiological role of IAA in increasing growth through promoting cell division and/or cell enlargement[42]. These increases in IAA could be occurred through retarding the biosynthesis of hormone derivative enzymes and/or repressing their activities or through preventing the transformation of these active substances into inactive forms. Concerning TSN, proline and free amino acids contents of the flax plant, it is well known that the accumulation of high levels of compatible osmolytes causing osmotic adjustment in plant cells. Proline is an important amino acid that has vital roles in osmotic adjustment, stabilization and protection of enzymes, proteins and membranes[43]. Moreover, these increases in proline contents might be due to increased proline biosynthesis or increasing key enzymes of proline biosynthesis and low activity of the oxidizing enzymes[44].

Foliar treatment of glutathione with different concentrations (50, 100 and 200 mg L^{-1}) caused significant increases in seed yield, its components, oil% and carbohydrates% of different varieties of flax plant grown under sandy soil conditions (Table 5 and 6) as compared with control plants. The improving role of glutathione foliar treatment on seed yield of flax plants is in agreement with the earlier results obtained[33-35] and on different plant species. Glutathione improved photosynthetic activities and chlorophyll biosynthesis or retard chlorophyll degradation and integrated into primary metabolism as well as it can influence the functioning of signal transduction pathway by modulating cellular redox state thus return in increasing crop yiel[45]. It is worthy to mention that there is a close relationship between the enhancement effects of different treatments on acidic growth regulators (IAA) which appeared in enhancement growth parameters which reflected on the increase in yield[44]. These increments could be partially or attributed to the physiological roles of glutathione as growth regulators and antioxidants as well as having the power to increase the amount of assimilates and increasing their translocations from leaves to fruits[42]. Regarding the increment in oil% and oil yield (kg fed^{-1}) and total carbohydrates with foliar treatments of glutathione these increases may be due to the increase in vegetative growth and nutrients uptake.

CONCLUSION

It could be concluded that there are varietal differences between tested flax varieties in growth, some biochemical aspects and yield components. Foliar application of the seven tested varieties with different concentrations of glutathione could improve growth and yield quantity and quality via increasing photosynthetic pigments, phenol, IAA, TSN contents as well as, proline and free amino acids of plants, under sandy soil conditions. In general, the flax varieties were significantly differed in their seed and oil yields due to the application of these glutathione treatments.

SIGNIFICANCE STATEMENT

This study discovered the effective role of glutathione that can be beneficial for improving the growth and productivity of seven varieties of flax plants via improving different biochemical and physiological metabolic processes. So, this study will help the researchers to uncover the critical areas of the physiological effect of glutathione on flax plants under the sandy soil that many researchers were not able to explore.

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