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Globe Artichoke (*Cynara cardunculus* L. var. scolymus L. Fiori) Aqueous Extracts Prohibits Growth of Johnson Grass (*Sorghum halepense*) Rhizomes

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Abstract

The allelopathic effects of globe artichoke (*Cynara cardunculus* L.) on growth, lipid peroxidation, and hormonal contents of Johnson grass (*Sorghum halepense*) rhizome were assessed. The experiment was performed on the basis of completely randomized design (CRD) with 5 replicates. Treatments included five concentrations of 20%, 40%, 60%, 80% and 100% of globe artichoke extracts. The globe artichoke aqueous extract was used as the irrigating water. Results showed a drastic reduction in seedling fresh biomass, shoot height, α-amylase activity, indole acetic acid, and gibberellins contents of Johnson grass rhizomes as globe artichoke extract concentrations were increased. The lowest α-amylase activity (1.33 nmol g rhizome min^{-1}), indole acetic acid (74.2 µg g^{-1}), and gibberellins (108.2 µg g^{-1}) obtained in Johnson grass rhizome when 100% aqueous extract of globe artichoke was applied. Malondialdehyde and abscisic acid content reached their highest levels of 0.77 µmol g^{-1} FW and 151.3 µg g^{-1} in the rhizome, respectively, when seedlings were treated with 100% aqueous extract of globe artichoke. There was also a significant negative correlation between globe artichoke total phenolic content with IAA content (r = -0.83), GAs content (r = -0.75), α-amylase activity (r = -0.84) and seedling weight (r =-0.79) in Johnson grass rhizomes. The globe artichoke extract inhibited the Johnson grass rhizome growth by increasing lipid peroxidation and decreasing plant hormonal activities such as IAA and GAs contents.

Keywords: α-*amylase, Cynara cardunculus*, Antioxidant enzymes, Growth, Phenolic compounds, Phytohormones

Introduction

The term allelochemicals include biochemicals produced by some plants that exert their physiological/toxicological actions on other plants and soil microorganisms (Levin, 1976). The allelochemical biosyntheses occur in carbohydrates, fats and amino acids metabolisms via acetate or the shikimic acid pathways (Macías, 2008). Allelopathic compounds extracted from plants include chemicals such as alkaloids, benzoxazinones, cilmamic acid derivatives, cyanogenic compounds, ethylene, and flavonoids (Levin, 1976). These compounds commonly exhibit negative effects on the growth and development of plants species via secreted chemical compounds from the roots of some plants into the soil or released from the decomposition of vegetative parts of dead tissues into the soil (Rice 1984). The negative influences may occur through the serious effects on physiological processes such as cell division and elongation (Bohm et al., 2006) phytohormone induced growth (Kamal, 2011), gas exchange and process of photosynthesis (Farhoudi and Li, 2013), respiration (Lorenzo et al., 2011), membrane permeability (Yu et al.,, 2003), and antioxidants enzyme activates (Oracz et al., 2007). The presence of allelochemicals

has been studied by several researchers in higher plant species and microbes (Bohm et al., 2006, Kamal 2011, Kumar et al., 2013, Oracz et al., 2007; Yu et al., 2003).

α-amylase enzyme which is critical for seed germination through the hydrolysis of large polysaccharides such as starch and glycogen in seed endosperm (Bogatek *et al.,* 2005) can be negatively affected by allelochemicals. Kato-Noguchi and Macias (2008) reported that 6-methoxy-2-benzoxazolinone (MBOA) inhibited germination of some plants such as wheat (*Triticum aestivum*), rice (*Oryza sativa*) and wild oat (*Avena ludoviciana*) via induction of α-amylase inhibition in these seeds. They suggested that the inhibitory effects were associated with increasing allelochemical compound concentrations (Kato-Noguchi and Macias, 2008).

Other evidences also suggest that oxidative stress is stimulated by allelopathic compounds (e.g., Oracz et al., 2007) and directly affects the elevation of reactive oxygen species (ROS) productions in cells during stress conditions such as salinity, drought, heat stresses. Thus, the level of ROS-induced damage increases (Munns, 2002). An increase in ROS can cause a serious disruption in regular metabolisms and cellular homeostasis due to oxidative damage to lipids, protein, phytohormones and nucleic acid (Yu et al., 2003). Moreover, enhanced oxidative stress productions caused by allelopathic substances induce membrane injuries in different plant species (Bogatek et al., 2005; Farhoudi and L, 2013). In contrast, presence of antioxidant enzymes and compounds in plants protect them against the ROS; the ability of plants to tolerate under stress conditions is directly related to the amount of their antioxidant compounds (Munns 2002; Farhoudi and Lee, 2012).

Plant growth regulators such as gibberellins (GAs), indole acetic acid (IAA) and abscisic acid (ABA) which can also be influenced by allelopathic stresses have significant roles in plant physiological mechanisms (Naqvi, 1999). GAs and IAA involve in stimulation of stem elongation, cell division and seed germination (Kang et al., 2008). ABA, a natural growth inhibitor and well-known "stress hormone", is crucial in the development and survivability of plants under unfavorable conditions (Bogatek et al., 2005). Extracts of sunflower aerial and underground structures containing allelopathic compounds are able to decrease IAA and GAs but increase ABA content in both leaves and roots of young wheat plants (Kamal, 2011). An increase in ABA level was also previously reported because of an allelopathic stress in the radicle of mustard and wheat seedlings (Bernat et al., 2004).

The globe artichoke (*Cynara cardunculus* L. var. *scolymus* L. Fiori) is a perennial plant that belongs to *Asteraceae* family. It is native to the Mediterranean region, and is a botanical variety of a species of thistle cultivated as a food and medicine crop (Ancora, 1986). Previously, the extracts of the aerial part of *Asteraceae* family including Jerusalem artichoke (*Helianthus tuberosus*) were found to possess allelochemical compounds affecting seedling growth of some crops and weedy species such as lettuce, tomato, large crabgrass, and barnyard grass (Tesio et al., 2010; Tesio et al., 2011). However, the allelopathic effects of globe artichoke have not been studied yet.

Johnson grass (*Sorghum halepense, Poaceae*), originated in southern Eurasia, is a perennial herbaceous weed reproduced by rhizomes and seeds which makes it one of the most problematic weeds in most countries around the world (Monaghan 1979; Holm et al., 1977) including Iran (Mousavi 2001, Baghestani et al., 2006). A drastic reduction in the yields of crops such as corn (Ghosheh et al., 1996) and soybean (Williams and Hayes 1984) occurs annually because of the infestations of Johnson grass.

Many studies have investigated the allelopathic effects of plants on growth and development (Yu et al., 2003, Bohm et al., 2006, Lorenzo et al., 2011; Kamal, 2011; Farhoudi and Li, 2013). However, the effects of allelochemicals on the growth of rhizome plants particularly in the early stages of growth and development of the rhizome in which plants are more susceptible to the environmental stresses

have been rarely studied. Thus, the purpose of the present study is to analyze the allelopathic effects of globe artichoke extracts on hormones, lipid peroxidation and antioxidant activities of Johnson grass rhizomes in the seedling stage.

Material and methods

Extract preparations

The experiment was performed on the basis of completely randomized design (CRD) with 5 replicates. Treatments contained five concentrations including 20%, 40%, 60%, 80% and 100% of globe artichoke extracts. Distilled (DI) water was used as a control treatment. The aerial parts of the mature plants were collected from the Medical Plant Garden of Islamic Azad University of Shoushtar located in the southwest of Iran. Samples were dried in ambient temperature and then were finely powdered and sieved. The samples were then stored in sealed centenaries at room temperature. To prepare the 100 % (w/v) stock solution of globe artichoke extract, the amount of 1000 g of the prepared powder was dissolved in 10 L of DI water and incubated for 48 hrs at 24 °C. The solution was filtered and the certain solutions of 20%, 40%, 60%, 80% and 100% strength were prepared according to volumetric method.

Culture conditions

Six rhizomes of Johnson grass were sown in germination boxes (50×50×30 cm) filled with field soil (Table 1). Each plot included two boxes. The rhizomes were grown at temperature range of 22/28°C under 16/8 h light/dark in the greenhouse. The planted rhizomes were irrigated by distill water for the first time. After four days aqueous extract treatments were applied for subsequent irrigations twice a week for 3 weeks. Both rhizomes and seedlings were harvested to study the growth and development. To measure fresh weight, harvested plants were washed, gently blot-dried to remove excess water, and then weighted. Shoot height was measured from three plants per box. To assess the contents of hormones, Malondialdehyde (MDA), α-amylase and antioxidant enzyme activities, the rhizomes were harvested following the first week of the treatment applications.

Table 1. Physio – chemical characteristic of pots soil

Soil type	pH	EC	Total Nitrogen	P (P_2O_5)	K
Clay loam	6.7	2.4 ds m^{-1}	0.12 %	7.3 ppm	41.4 ppm

MDA content determination

The quantity of lipid peroxidation was determined through measuring the amount of MDA formation with Thiobarbituric acid method (Health and Parker 1968; Hodges *et al.,,* 1999; Valentovic et al., 2006).

To assess the MDA, 0.2 g of Johnson grass rhizomes tissue was thoroughly mixed with 3 ml of 10% trichloroacetic acid (TCA), centrifuged at 10,000×g for 15min. The supernatant (350 µl) was poured off and mixed with 350µl of 0.6% (w/v) Thiobarbituric acid in a new microtube. The mixture was heated at 95°C for 30 min and then quickly transferred onto ice for 5min to be cooled. After centrifugation at 10,000×g for 10 min at 4°C, the absorbance of the reaction mixture was measured at wavelengths of 450, 532, and 600 nm. The concentration of MDA (µmol L^{-1}) was calculated according to the formula:

$$[MDA] = 6.45 \times (A_{532} - A_{600}) - 0.56 \times A_{450}$$

Where 6.45 and 0.56 are constant coefficients; A_{532}, A_{600}, and A_{450} represent the absorbance of the mixture at 450, 532, and 600 nm, respectively.

Antioxidant enzymes assays

Catalase (CAT: EC:1.11.6), Glutathione Reductase (GR: EC 1.6.4.2) and Guaiacol peroxidase (POD: EC:1.11.1.13) are key antioxidant enzymes scavenging plant cells. CAT and POD were extracted by homogenizing frozen fresh leaf material in ice-cold solution containing 100 Mmol Tris (pH 7.0), 10 Mmol d-isoascorbic acid, 20 g L^{-1} PVP, 1.5 g insoluble PVP, 0.1 Mmol EDTA and 2mL L^{-1} Triton X^{-100} (Chance

and Maehly 1995). CAT activity was determined by monitoring the disappearance of H_2O_2 by measuring the reduction of absorbance at 240 nm of a reaction mixture containing 1.9mL H_2O, 1.0 mL of 5.9 Mmol H_2O_2 in potassium phosphate buffer (pH 7.0), and 1.0 mL extract. POD activity was determined following the protocol of Chanes and Maehly (1995) using guaicol as a reactant, POD activity was measured by monitoring the H_2O_2-dependent oxidation of reduced 2, 3, 6-trichloroindophenol at 675 nm using a UV–vis spectrophotometer (Model U-2001, Hitachi, Tokyo, Japan). GR activity was determined in 800µl of 0.1M potassium phosphate buffer (pH 7.8) containing 0.5mM β-nicotinamide adenine dinucleotide 2′-phosphate, reduced form (2′-NADPH), 10 Mmol glutathione, oxidized form 3 Mmol $MgCl_2$; and 50 µl enzymatic extract. The NADPH oxidation-dependent decline in absorbance was recorded at 340 nm every 30 sec for 6–8 min using a spectrophotometer (Pharma Spec UV-1700; Shimadzu) (Oracz et al., 2007).

α-amylase activity and phytohormones contents assays

The α-amylase was assayed by measuring the rate of generation of reducing sugars from soluble starch (Kato-Noguchi and Macias, 2008). To measure phytohormones contents, the rhizomes and leaves were ground in 80% methanol at 4 °C with antioxidant (butylated hydroxy toluene: BHT); kept for 72 h with change of the solvent each 24 h. The extract was centrifuged and the supernatant was reduced to its aqueous phase using a rotary thin film evaporator. The pH of the aqueous phase was adjusted to 2.5-3.0 and partitioned 4x with 1/3 rd volume of ethyl acetate. The ethyl acetate extract was fully dried using a rotary thin-film evaporator. The dried sample was re-dissolved in 1ml methanol (100%) and analyzed using HPLC (model Agilent 1100, USA). Pure IAA, GAs and ABA were used as standards for identification and quantification of the plant hormones (Zeng et al., 2001).

Total Flavonoid and phenolic content determination

Total flavonoid and phenolic contents were determined using a volume of 0.5 ml of 2% $AlCl_3$ ethanol solution added to 0.5 ml of sample solution. After one hour at ambient temperature, the absorbance was measured at 420 nm. The appearance of yellow color indicated the presence of flavonoids. Extract samples were evaluated at a final concentration of 0.1 mg/ml. Total flavonoid content were calculated as quercetin equivalent (Zhuang et al., 2012). Total phenolic compounds in the samples were determined, using Folin–Ciocalteau reagent, and calculated using gallic acid as a standard. Extracts (100 mL) were added to 2 mL of 2% Na2CO3. After 2 min, 50% Folin– Ciocalteau reagent (100 mL) was added to the mixture which was then left to stand for 30 min. Absorbance was read at 750 nm using a spectrophotometer and compared to gallic acid calibration curves (Zhuang et al., 2012). Phenolic and Flavonoid compounds were detected by HPLC according to the method of Shaimaa et al., (2016).

Statistical analysis

One way ANOVA was carried out using MSTATC software. Post hoc tests (Duncan) were performed only if F-test was significant at $p \leq 0.01$.

Results and Discussions

Seedling fresh weight (SFW) and Shoot height (SH) of Johnson grass were significantly influenced by globe artichoke aqueous extracts (Table 2). The highest SFW (0.74 g) and SH (6.16 cm) were obtained from the control treatment while the lowest SFW (0.16 g) and SH (4.6 cm) were occurred at the 100% (w/v) globe artichoke aqueous extract concentration. The number of seedlings produced per rhizome was reduced by the effects of globe artichoke aqueous extracts. Increasing the treatment concentration to 100% caused a serious reduction in the number of seedlings (Table 2). The reduction exhibits the allelochemicals inhibitory effects on physiological processes in plants. The repressive effects of allelopathic

compounds on plant growth may occur via different mechanisms such as diminution of mitotic divisions either in roots or shoots, inhibition of hormonal activities, decrease in ion uptake, reductions of photosynthesis and respiration, disruption to protein formations, decline of cell membrane permeability, and malfunctions of enzyme activities (Kamal 2011, Oracz et al., 2007, Yu et al., 2003). Cardoon (Cynara cardunculus) extract limited germination and growth seedling of *E. crus-galli* and *Brachiaria plantaginea (*Rial et al., 2014).

Table 2. Means comparison of effect of globe artichoke extracts on Johnson grass seedling growth and antioxidant enzymes activity

Globe artichoke extract concentrations (%)	Seedling per rhizome	Seedling fresh weight (g)	Shoot height (cm)	GR activity (nmol NAPDH mg^{-1} protein min^{-2})	CAT activity (nmol H_2O_2 mg^{-1} protein min^{-2})	POD activity (unit mg^{-1} pro)	MDA concentration (nmol g^{-1}FW)
0	7^{a}	0.74^{a}	26.1^{a}	3.7^{c}	1.7^{b}	11.3^{b}	0.003^{d}
20	4^{b}	0.46^{b}	18.2^{b}	2.5^{c}	2.5^{b}	17.0^{b}	0.007^{d}
40	4^{b}	0.29^{c}	14.5^{bc}	12.9^{ab}	4.2^{ab}	37.3^{a}	0.30^{c}
60	4^{b}	0.22^{c}	10.8^{c}	14.0^{a}	6.4^{a}	39.0^{a}	0.66^{b}
80	2^{c}	0.17^{d}	10.6^{c}	10.6^{b}	4.0^{ab}	15.0^{b}	0.67^{ab}
100	2^{c}	0.16^{d}	4.6^{d}	3.7^{c}	1.3^{b}	15.3^{b}	0.77^{a}

Means followed by the same letter (s) are not significantly different at $P < 0.01$ according to Duncan multiple test

Enzymes activity and hormone concentrations

Globe artichoke extracts inhibited the production of α-amylase activity in Johnson grass rhizomes and it was dose-dependent (Figure 1). The lowest α-amylase activity of Johnson grass rhizomes obtained in 100% globe artichoke aqueous extract (1.33 nmol g rhizome^{-1} min^{-1}) followed by 80% extract concentration (2.14 nmol g rhizome^{-1} min^{-1}) while the differences between 20 % extract and control was not significant (Table 2).

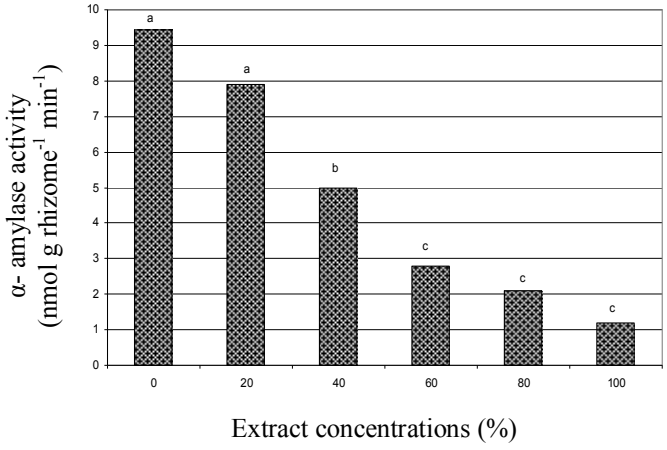

Figure 1. Effect of globe artichoke extract on α-amylase activity of on Johnson grass rhizome (the same letter indicates that the treatments is not significantly differed based on Duncan multiple range test $p \leq 0.01$)

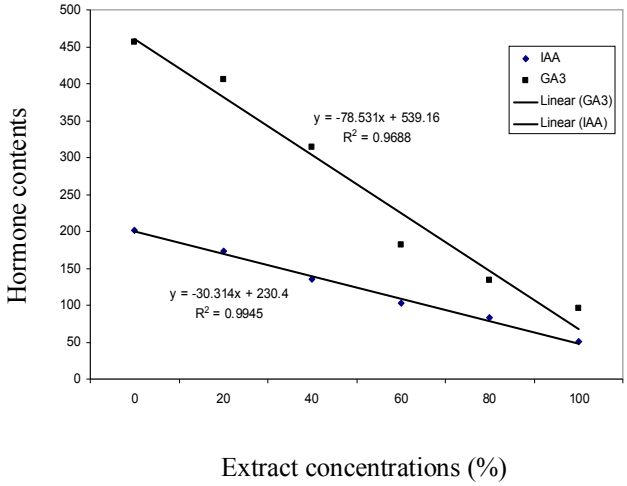

Figure 2. Effect of globe artichoke extracts on IAA (µg g^{-1}) and GA3 (µg g^{-1}) contents of Johnson grass rhizome

Table 3. The phenolic and flavonoid profiles of globe artichoke 100% extract

Phenolic compounds	Rate (mg GA/100 g^{-1} DW)	Flavonoid compounds	Rate (mg CE/100 g^{-1} DW)
Gallic acid	13.8	Apigenin	4.7
Benzoic acid	13.2	Kaempferol	4.2
Vanillin	10.4	Luteolin	3.6
Catechin	9.7	Quercetin	2.5
Salicylic	8.3		
Luteolin	6.4		

The negative effects of allelochemical stresses on α-amylase activity and seedling growth have been reported in bean (*Phasaeolous vulgaris*) and corn (*Zea mays* L.) seedlings (Cruz-Ortega et al., 2002) that can support our findings. As α-amylase has a substantial role in degradation of reserve carbohydrate to soluble the sugars during germination, it is possible that phytotoxins inhibit α-amylase production and activity during the germination processes. The inhibition of the germination and seedling growth processes could have taken place by either influencing on the cell divisions and elongations that are vital mechanisms at this stage or interfering with enzymes involving in the mobilizations of essential nutrients for the germination and seedling growth (Kato-Noguchi and Macias 2008, Macías et al., 2008). Gradual increase in concentrations of globe artichoke aqueous extracts reduced the GAs and IAA contents while caused an increase in ABA contents in Johnson grass rhizomes. The lowest GAs content reached to 124.7 µg g^{-1} after applying 100% (w/v) extract (Figure 2). Moreover, the treatments exhibited negative influences on IAA content of the Johnson grass rhizomes (Figure 2). The highest extract concentration that caused the occurrence of the lowest IAA content had a significant difference with the other extract concentrations (Table 2 and Figure 2). Growth hormones, such as GA and IAA are vital in plant growth and development. Physiological characteristics such as stimulation of root initiation, seedling growth, and early development of seedling are dependent on these hormones, whereas ABA reduces seedling growth under stress condition (Bellanmine 1998). The syntheses of these hormones can be affected by environmental stresses including allelopathical effects, and the variations in IAA, GA, and ABA concentrations can be used as indicators of plants responding to unfavorable conditions (Naqvi 1999, Yu et al., 2003). Benzoic acids, as well as

cinnamic acids, as putative allelochemicals, have been reported to influence on IAA contents via catalyzing or inhibiting the degradation of IAA in acceptor plants (Robinson 1983). The ABA content found its maximum at 100% globe artichoke extract with 151.3 µg g^{-1} followed by 80% extracts with 142.8 µg g^{-1} while the lowest ABA content was obtained in control treatment with 52.5 µg g^{-1} ABA (Figure 3). The ABA content is increased under abiotic environmental stresses such as salinity and drought (Munns 2002, Saeedipour 2013). Our results also show that the ABA is influenced under allelopathic condition.

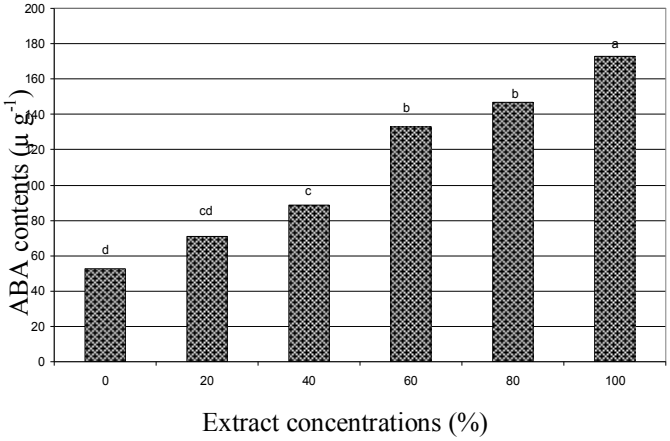

Figure 3. Effect of globe artichoke extract on ABA content of Johnson grass rhizome (the same letter indicates that the treatments is not significantly differed based on Duncan multiple range test $p \leq 0.01$)

In addition, we have found that the globe artichoke extract could impose the hormonal imbalances among ABA, GA and IAA that is considered as the factors controlling germination, growth, and development in plants. Although it is not clearly understood, a higher ABA content may increase a plant resistance to allelopathic. The increased level of ABA in Johnson grass rhizomes, correlates well with the changes described above in the seedling growth, seedling germination and α-amylase activity (Table 2 and Figure 1).

Table 4. Correlations of biochemical compounds of globe artichoke 100% extracts and physiological characteristic in Johnson grass seedling

Biochemical compounds	Seedling per rhizome	Seedling fresh weight	α-amylase activity	MDA concentration	ABA content	GA content	IAA content
phenolic	-0.73**	-0.79**	-0.84**	0.85**	0.92**	-0.75**	-0.83*
flavonoid	-0.61**	-0.59*	-0.89*	0.89**	0.83**	-0.79**	-0.75*

** and *: significant in 1% and 5% probability level, respectively.

Allelochemicals induce oxidative stresses causing production of ROS and activation of cellular antioxidant system (Bais et al., 2003, Romero-Romero et al., 2005). These stresses were significantly increased in cucumber (*Cucumis sativus*) roots subjected to phytotoxic compounds (Yu et al., 2008). In plant cells, one of the primary physiological processes of oxidative stresses is lipid peroxidation, a free-radical transfer chain leading to the degradation of poly-unsaturated fatty acids increasing the presence of MDA in the membranes resulting in severe damage to the cells (Valentovic et al., 2006). Our findings reveal that lipid peroxidation is enhanced in Johnson grass rhizomes by applications of globe artichoke aqueous extracts (Table 2). The highest MDA concentration (0.77 nmol g^{-1} FW) was

belonged to 100 % extract treatment. The concentration of 20 % (w/v) of globe artichoke extract did not have any effects on MDA concentration in Johnson grass rhizomes compared with the control group. Our data indicate that the loss of seedling growth of Johnson grass is associated with enhanced lipid peroxidation. Other studies have also reported an increased level of lipid peroxidation in the presence of aqueous extract of beautyberry *(Callicarpa acuminate)* and *Sicyos deppei* (*Cucurbitaceae*) in tomato, bean, and corn roots (Cruz-Ortega *et al.,,* 2002; Romero-Romero *et al.,,* 2005). Indeed, the cell membranes exposed to the allelochemicals can be damaged via a direct interaction of the membrane components with the phytotoxins which can be detrimental to vital metabolic processes, maintaining the membrane functions.

Furthermore, environmental stresses including allelopathy cause disruptions in the cellular homeostasis via production of ROS (Maffei 1999, Romero-Romero et al., 2005). ROS products are considered as toxic molecules in plant physiology, the accumulation of these molecules lead to cell injuries, disturbances in seedling development and restriction in growth processes (Bailly 2004). Under stress conditions, plants utilize some defensive mechanisms including activations antioxidants such as CAT, POD, SOD and GR. An increase in superoxide dismutases (SOD) (Yu *et al.,,* 2003) and CAT (Maffei et al., 1999) activity was reported in cucumber roots and seedlings exposed to allelochemicals. Our results suggest that globe artichoke aqueous extracts increased CAT, POD and GR activities up to 60% in Johnson grass rhizomes compared with the control group; however, 80% and 100% concentrations decreased POD, CAT and GR activities compared with the 60% treatment (Table 2). Antioxidant enzymatic activities were decreased in Johnson grass rhizomes treated with 80% and 100% globe artichoke extracts indicating the damage in enzymatic activities. Although activations of the cellular antioxidant systems are detected rapidly after allelopathic treatments, it seems that they do not sufficiently function to avoid cellular damages. This indicates that the antioxidants activities are reduced as suggested in wild barley (*Hordeum spontoneum)* and wild oat (*Avena ludoviciana)* seedlings exposed to sunflower extracts (Farhoudi and Lee 2013). This is in agreement with our results as CAT, POD and GR are reduced in 80% and 100% extract treatments (Table 2).

Phenolics and flavonoid constitute one of the major groups of compounds acting as allelopathical effect on growth of plants (Bellanmine et al., 1998). In 100% aqueous extract of globe artichoke, major phenolic compounds were gallic acid, vanillin, benzoic acid, catechin, salicylic acid, and luteolin (Table 3). The major flavonoid compounds were apigenin, kaempferol, luteolin and quercetin (Table 3). Total phenolic content was 22.1 mg GA/100 g^{-1} DW and total flavonoids was 2.32 mg CE /100 g^{-1} DW (data not shown here). Allelopathical extracts composing of phenolic compounds decreased germination and seedling growth in soybean (Bohm *et al.,,* 2006). As shown in Table 4 the globe artichoke total phenolic content was highly correlated with MDA concentration ($r=0.85$) and ABA content ($r=0.92$) ($p<0.05$). Also, there were strong correlations between globe artichoke flavonoid content and each of MDA concentration and ABA content. A significant negative correlation was observed between globe artichoke total phenolic content and IAA content ($r = -0.83$), GA content ($r = -0.75$), α-amylase activity ($r = -0.84$) as well as seedling weight ($r = -0.79$) in Johnson grass rhizomes.

Conclusion

Johnson grass rhizomes growth was responded differently to globe artichoke extract concentrations in terms of POD, GR, CAT activities and MDA content. Allelochemicals secreted by globe artichoke inhibited Johnson grass rhizomes germination and reduced the level of GA, IAA hormones, α-amylase activity, shoot length, and seedling fresh weight. Conversely, the ABA content, antioxidants

enzymes activity, and MDA contents increased. Inhibition of Johnson grass rhizomes germination by globe artichoke extracts was correlated with phenolic and flavonoid compounds enhancing membrane lipid peroxidation. The germination reductions can be related to the elevation of ABA and reduction of IAA, GA as well as α-amylase activity. As a result, the globe artichoke extracts can be suggested as weed control agents. However, more investigations are required to determine the effects on other weedy species and also determine the target areas of selected plants which are likely more susceptible to these toxic substances. Our findings could eventually lead researches to discover a biological integrative control method to deal with selected weeds, resulting in an extreme reduction of herbicide consumptions.

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