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Research Article

Allelopathic effects of apricot (*Prunus armeniaca* L.) root on some crops and weeds

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Abstract

Allelopathic effect of apricot (*Prunus armeniaca* L.) root on some crops and weeds was investigated in two independent experiments. First, the effect of concentrations aqueous extract of apricot root (AAR) was assayed on the seed germination of *Cicer arietinum* L., *Phaseolus vulgaris* L., *Triticum aestivum* L., *Zea mays* L., *Amaranthus retroflexus* L., *Secale cereal* L., and *Avena ludoviciana* Durieu. In the second experiment, two pot trials were carried out to investigate the effect of AAR and apricot root powder (ARP) on the seedlings of *P. vulgaris*, *Z. mays*, *S. cereal*, and *A. retroflexus*. The results showed that germination was halted in *T. aestivum*, *C. arietinum*, *A. ludoviciana*, and *S. cereal* under all treatment levels, in *A. retroflexus* under 75 and 100%, and in *P. vulgaris* under 100% of AAR. Also, the results showed that effects of AAR and ARP on the biomass, membrane stability index, chlorophylls, carotenoids, proline, and protein content, and antioxidant enzymes activity were not significant, with a few exceptions. It can be concluded that the allelopathic effect of apricot root is mostly exerted by inhibiting the germination of target plants rather than effect on later stage of plant growth and development.

Keywords: Allelopathy, Crop, Germination, Herbicide, Weed

Introduction

Weeds create the most severe and widespread biological limitations for crops and are undesirable plants that compete with the main plant on nutrients, light, humidity, and space and ultimately reduce its growth and yield quality (Ankita and Chabbi, 2012). Various methods for weed control are recommended, the most important of which is the use of herbicides (Zheng *et al*., 2005). Intense use of herbicides has a number of detrimental impacts on human health and the environment, as well as raising herbicidal tolerance of several weeds (Li *et al*., 2021). Therefore, there is a need to replace herbicides with new compounds. The use of natural substances that prevent the growth of weeds and at the same time do not have adverse effects on crops and the environment is of interest to researchers and beneficiaries. In this regard, natural compounds such as those from plants are a very good option for this goal (Duke *et al*., 2002). It has been shown that extract from allelopathic plants has a potential to be used for reducing seed germination and suppressing the growth of weeds (Jones *et al.*, 2004; Xuan *et al*., 2005).

Allelopathy is any direct and indirect harmful or beneficial effect of living (actively released by plant exudation) or dead (passively produced during the decomposition process of residues) plant materials on the growth and development of recipient through the release of secondary metabolites, namely allelochemicals, into the environment (Huang *et al*., 2020; Schandry and Becker, 2019; Shixing *et al*., 2021). Allelochemicals such as alkaloids, phenolics, terpenoids, flavonoids, volatiles, etc., (Shixing *et al*., 2021) reach the recipient plant through washing, evaporation from leaves, exudation from roots, as well as decomposition of dead parts (Saeedi Pooya *et al*., 2013).

Many researchers evaluate the effect of allelopathy for weed control through aqueous extract of plant tissue. Allelopathic water extracts are utilized as a biological herbicide since they are less harmful to the environment than synthetic herbicides. Water-soluble allelochemical substances are convenient to use and apply without additional wetting agent (Hussain *et al*., 2020).

Apricot (*Prunus armeniaca*) from the family Rosaceae, is a short tree that rarely reaches as high as 6 to 8 meters (Farzad, 2011). Having a wide range of compatibility, it is endemic in tropical and subtropical climates (Emam, 2007). Considering that no study has been done so far on the allelopathic effect of the apricot root, this study was conducted to investigate its effect on the morphological, physiological, and biochemical characteristics of some crops (*Triticum aestivum* L., *Zea mays* L., *Phaseolus vulgaris* L., and *Cicer arietinum* L.), and some widespread weeds (*Amaranthus retroflexus* L., *Secale cereal* L., and *Avena ludoviciana* Durieu).

Materials and methods

Plant culture and treatments: To prepare the aqueous

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extract of the apricot (*P. armeniaca* L.) root (AAR), roots of young tree (2-year-old) cultivar Lasgerdi were crushed into small pieces and then were powdered after drying. To prepare the extract, 30 g of root powder was mixed with 300 ml of distilled water and placed on a shaker for 24 hours. After filtering the mixture, the aqueous extract was accounted for 100% (w/v) and then concentrations of 50 and 75% (w/v) were prepared. For investigating the allelopathic effect of the apricot root, two independent experiments were conducted. In the first experiments, the effect of concentrations 50, 75, and 100% (w/v) of AAR was assayed on the germination properties of the selected species in a factorial experiment based on completely randomized design with three replications. Each experimental unit consisted of a Petri dish (with a diameter of 10 cm) with filter paper, moistened with 10 ml of different concentrations of AAR or polyethylene glycol (PEG) with osmotic potentials equivalent to those of AAR as controls, to eliminate the osmotic potential of each extract. Seeds of selected crops including *C. arietinum* cultivar Pirouz, *P. vulgaris* cultivar Goli, *T. aestivum* cultivar Pishtaz, *Z. mays* cultivar Single Cross 704, and weeds including A. *retroflexus*, *S. cereal*, and *A. ludoviciana* were cultured in the experimental unit after sterilizing by sodium hypochlorite (7% v/v) for 10 minutes, followed by washing with distilled water. Petri dishes were placed under 21 ± 2 ºC condition. Germinated seeds were counted every day and after one week, germination properties were recorded (Hartman *et al*., 1990; Mousavi Kouhi *et al*., 2014).

In the second experiment, the effects of AAR (concentration of 75%) and apricot root powder (ARP) on the physiological and biochemical properties of the *Zea mays*, *Phaseolus vulgaris*, *Amaranthus retroflexus*, and *Secale cereal* seedlings were investigated. For investigating the effects of AAR, seeds were cultured in 0.5 kg pots with garden soil. After germination, seedlings were irrigated with AAR or distilled water (as a control).

To investigate the effect of powder, pots were filled with a mixture of ARP and garden soil (in a ratio of 1 to 30, respectively). Pots containing garden soil without ARP were used as control. This study was conducted as a factorial experiment based on completely randomized design with three replications. In this experiment, 36 experimental units were used and each experimental unit consisted a pot with 10 plants. Before seed culturing, pots were irrigated daily for a week for obtaining a homogeneous mixture. Then, seeds were planted in each pot and irrigated with distilled water.

For both trials, 21 days after planting in a phytotron at 21 ± 2 ºC and 16/8 h light/dark photoperiod, the root of seedlings was carefully removed from the soil and some growth characteristics such as shoot and root length, dry weight of roots, as well as shoot were measured.

Physiological and biochemical measurements: Fresh leaf tissue was used to measure the membrane stability index (MSI).

Two test tubes containing 10 ml of deionized water and 0.1 g of fresh leaf tissue were immersed separately into 40 and 100 ºC water for 30 and 10 min, respectively. After adjusting the temperature, their electrical conductivity (EC) was read with an EC meter and then their MSI was measured according to (Aziz pour *et al*., 2010).

To measure the content of chlorophyll and carotenoid, fresh leaf tissue was homogenized with 80% acetone (v /v). After centrifugation, the volume of the supernatant was reached to a final volume of 25 ml with the same solvent. Finally, absorption of the solution was read at 470, 645, and 663 nm and then, chlorophyll a, b, total chlorophyll, and carotenoid content were calculated according to (Arnon, 1967).

Leaf proline was measured by the method of (Bates *et al*., 1973). To 2 ml of leaf homogenate prepared with 3% sulfosalicylic acid solution, 2 ml of ninhydrin reagent and 2 ml of acetic acid were added. The resulting solution was placed at 100 ºC for 1 hour. After cooling the tubes, 4 ml of toluene was added to each and the absorption of the toluene phase was recorded at 520 nm. Proline content of the samples was determined using a standard curve drawn with different concentrations of proline.

Total protein of leaf was extracted using 0.1 M potassium phosphate buffer with pH = 7.4. The resulting homogenate was centrifuged at 12,000 rpm for 24 min and the supernatant was used to measure protein content and the activity of antioxidant enzymes including superoxide dismutase (SOD) and polyphenol oxidase (PPO) (Guo *et al*., 2004).

To measure total protein content, 5 ml of Bradford reagent was added to 100 µl of protein extract, and then the tubes were vortexed rapidly (for 10 seconds). After 20 minutes, the absorbance of the samples was read at 595 nm. The total protein content of each sample was calculated using a standard curve plotted with bovine serum albumin (Bradford, 1976).

Measurement of SOD activity was performed based on the inhibition of Nitro Bluttrazolium (NBT) light reduction at 560 nm (Beauchamp and Fridovich, 1971). PPO activity was done according to (Raymond *et al.*, 1993). The absorption changes at 430 nm per min were recorded and PPO activity was expressed as enzyme unit per mg protein.

Analysis of variance was performed on the data using MINITAB 16 software, and significant differences among treatment means (all morphological, physiological and biochemical traits) were calculated by the use of Duncan's multiple range test ($P \leq 0.05$). Each treatment was analyzed with at least three replicates and a standard deviation (S.D.) was calculated. The data were expressed in mean ± S.D. of three replicates.

Results and discussion

Effect of AAR on germination properties: The results showed that AAR caused a severe and significant

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Table 1. Effect of aqueous extract of the apricot root (AAR) on germination properties of some crops and weeds. Control 1, 2, and 3: Polyethylene glycol with the same concentration of 50, 75, and 100% of AAR. According to Duncan's multiple range test, the means with at least one common letter in each column are not significantly different at 5% level (P ≤0.05).

Plant species	Treatment	Germination percentage (%)	Germination Rate (% day^{-1})	Shoot length (cm)	Root length (cm)
Zea mays	control1	50±10^{a}	22.3±0.5^{a}	6.1±0.4^{a}	18.5±2.9^{a}
	control2	55±5^{a}	22.3±0.5^{a}	6.3±0.1^{a}	21.5±2^{a}
	control3	25±5^{b}	22±0.0^{a}	6.1±0.1^{a}	12.7±3^{b}
	extract50%	30±0.0^{b}	21.6±0.5^{a}	1.9±0.2^{c}	3±0.0^{c}
	extract75%	20±0.0^{b}	22±0.0^{a}	3.1±0.2^{b}	2.2±0.3^{c}
	extract100%	30±10^{b}	22±1^{a}	2.9±0.1^{b}	2.4±0.3^{c}
Phaseolus vulgaris	control1	35±5^{b}	23.6±0.5^{ab}	0.7±0.1^{a}	8.9±1.6^{a}
	control2	35±5^{b}	24.5±0.5^{a}	0.5±0.05^{b}	7.4±0.6^{a}
	control3	57.7±3.8^{a}	22.5±0.5^{bc}	0.6±0.0^{ab}	8.3±0.8^{a}
	extract50%	25±5^{b}	21±1^{c}	0.7±0.07^{ab}	4.9±0.4^{b}
	extract75%	55±5^{a}	22±0.0^{c}	0.6±0.0^{ab}	4.1±0.1^{b}
	extract100%	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{c}	0.0±0.0^{c}
Triticum aestivum	control1	66.5±6.5^{a}	20.3±0.5^{a}	9.2±0.3^{b}	10.5±0.2^{a}
	control2	63±3^{a}	20.3±1.1^{a}	9.6±0.1^{ab}	9.2±0.2^{b}
	control3	53±0.0^{b}	20.3±1.5^{a}	10 ±0.4^{a}	7.9±0.3^{c}
	extract50%	0.0±0.0^{c}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{d}
	extract75%	0.0±0.0^{c}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{d}
	extract100%	0.0±0.0^{c}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{d}
Cicer arietinum	control1	100±0.0^{a}	21±0.0^{a}	4.9±0.1^{a}	12.1±1.1^{a}
	control2	100±0.0^{a}	21±0.0^{a}	4.2±0.1^{b}	11±0.2^{a}
	control3	96.6±5.7^{a}	21.3±0.5^{a}	3.7±0.5^{b}	12.4±0.7^{a}
	extract50%	0.0±0.0^{b}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{b}
	extract75%	0.0±0.0^{b}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{b}
	extract100%	0.0±0.0^{b}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{b}
Avena ludoviciana	control1	59.9±6.6^{b}	18±0.0^{a}	5.3±0.2^{c}	5.6±0.7^{b}
	control2	80±0.0^{a}	19±0.0^{a}	6.8±0.4^{a}	5.3±0.3^{b}
	control3	83.3±10^{a}	18.3±1.1^{a}	6±0.4^{b}	7.5±0.6^{a}
	extract50%	0.0±0.0^{c}	0.0±0.0^{b}	0.0±0.0^{d}	0.0±0.0^{c}
	extract75%	0.0±0.0^{c}	0.0±0.0^{b}	0.0±0.0^{d}	0.0±0.0^{c}
	extract100%	0.0±0.0^{c}	0.0±0.0^{b}	0.0±0.0^{d}	0.0±0.0^{c}
Secale cereal	control1	96.6±5.7^{a}	22.6±0.5^{a}	8.3±0.1^{b}	12.1±1.6^{a}
	control2	80±0.0^{c}	22±1^{a}	9.2±0.1^{a}	14±1.2^{a}
	control3	90±0.0^{b}	22.3±0.5^{a}	8.9±0.6^{ab}	13.1±1.3^{a}
	extract50%	0.0±0.0^{d}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{b}
	extract75%	0.0±0.0^{d}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{b}
	extract100%	0.0±0.0^{d}	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.0^{b}
Amaranthus retroflexus	control1	98.8±1.9^{ab}	19.6±0.5^{a}	1.6±0.05^{b}	2.1±0.1^{a}
	control2	100±0.0^{a}	19±0.0^{a}	1.7±0.0^{b}	2±0.2^{a}
	control3	96.6±0.0^{b}	19.3±0.5^{a}	1.8±0.0^{a}	2.1±0.0^{a}
	extract50%	38.3±1.7^{c}	15.3±0.0^{b}	0.1±0.05^{c}	0.9±0.0^{b}
	extract75%	0.0±0.0^{d}	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{c}
	extract100%	0.0±0.0^{d}	0.0±0.0^{c}	0.0±0.0^{d}	0.0±0.0^{c}

reduction in germination percentage in the tested plants. At the concentration of 75% AAR, the germination percentage in *Z. mays* was decreased by 63% compared to the control. No germination was observed in *P. vulgaris* under 100% AAR, in *A. retroflexus* under 75% and 100% AAR, and in *T. aestivum*, *C. arietinum*, *S. cereal*, and *A. ludoviciana* under none of AAR concentrations. Among the species that showed germination under AAR, the germination rate in *Z. mays* did not show any significant change but in *P. vulgaris* it was decreased significantly. In *A. retroflexus* which showed germination only under 50% AAR, the germination rate was significantly reduced (Table 1). Other studies also reported seed germination rate was decreased by the increased concentration of white cabbage post-harvest leaves extractions, which were made with different concentrations of aqueous and methanol extracts (30, 40, and 50%). The methanol extract was found to be more effective in germination (Kural and Ozkan, 2020). In another study, allelochemicals may poison weak seeds, impede nutrient absorption, and hinder seedling growth and development (Cheng *et al*., 2021).

It has been reported that the allelopathic effect on *P. oleraceae* resulted in reduction of metabolic enzymes activities, protein, carbohydrate, as well as nucleic acid contents. (El-Shora, 2022). Delay or stop of the movement of the food storages during germination can lead to respiration disturbance and limitation of metabolic energy and ultimately reducing germination

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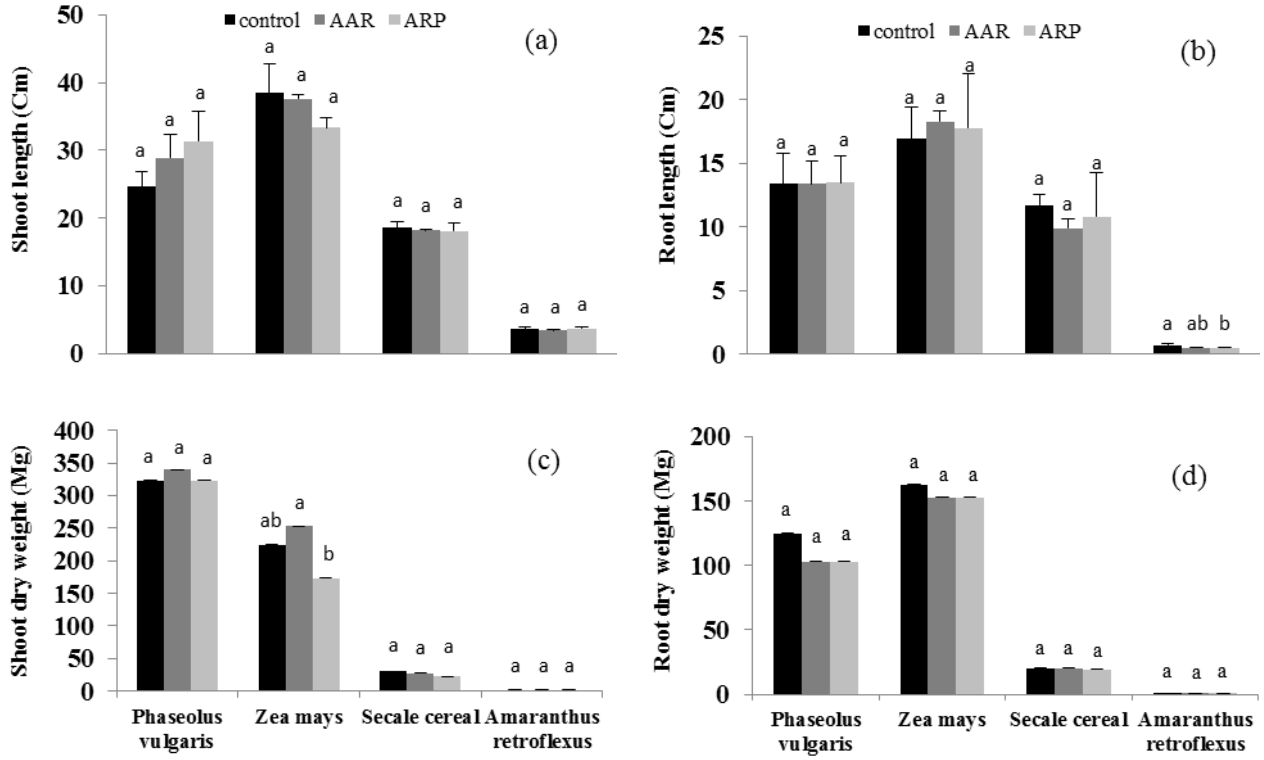

Figure 1. Effects of aqueous extract of the apricot root (AAR) and apricot root powder (ARP) on Shoot length (a), Root length (b), Shoot dry weight (c), Root dry weight (d). Similar letters indicate that there is no significant difference among the means ($P \leq 0.05$).

and seedling growth (Bogatek *et al*., 2005; Taiz *et al*., 2015).

The results showed that under AAR, there was a significant reduction in the roots and hypocotyl length of germinated species. Under 50% AAR, the Hypocotyl length was reduced 68 and 93% in *Z. mays* and *A. retroflexus*, respectively. In *P. vulgaris*, *A. retroflexus*, and *Z. mays* which showed germination under 50% AAR, root length was decreased 44, 57, and 83%, respectively. It has been shown that allopathic compounds can inhibit plant root elongation and cell division, change cell structure, and interfere with plant growth and development. For instance, an investigation on the allopathic effect of *Sicyos deppei* G. don on *P. vulgaris* showed that the root tip cells were deformed and the organization and differentiation of cells were slightly irregular (Cruz and Anaya, 1998). In another study, coumarin, as one of the allopathic compounds, was found to significantly inhibit the elongation of the roots of *Lactuca sativa* L., increased the thickness of cortical cells, whereas decreased cellular activity and the number of Golgi apparatus (Li *et al*., 2010).

Allelopathic effects of AAR and ARP in the seedling stage: Allopathic plants can stop the growth of target plants and consequently reduce their growth criteria such as length and biomass. For example, allopathic chemical compounds in the extracts of the stem and tuber of *Cyperus rotundus* L. have been shown to inhibit seedling length and biomass of *Eleusine coracana* Gaertn (Kavitha *et al*., 2012). However, in the present study, the results showed that AAR and ARP had no significant effect on root and shoot length and dry weight of these organs in the studied species, except for a significant reduction in root length of *A. retroflexus* and shoot dry weight of *Z. mays* under ARP (Figure 1).

The pigments content including to chlorophyll a, chlorophyll b and total chlorophyll with the exception of carotenoids significantly decreased in ARP treatment compared with the control. The effect of AAR on pigments contain of all evaluated plants was not significant (Figure 2). However, it has been reported that plants with allopathic effects can reduce the content of photosynthetic pigments in target plants. For instance, under aqueous extracts of *Achillea biebersteinii* Afan. the content of chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, and proteins were significantly reduced in *Capsicum annuum* L. (Abu-Rommanand, 2011). Other research showed that total chlorophyll content of *N. wightii* was significantly reduced in all plants treated with both aqueous seed and leaf extracts of *D. stramonium* (Kong *et al*., 2021). In another study, RNA-Seq analysis and key gene detection analysis indicated that *A. argyi* inhibited the germination and growth of weed via multi-targets and multi-paths while the inhibiting of chlorophyll synthesis of target plants was one of the key mechanisms (Li *et al*., 2021).

In the present study, proline content in *S. cereal* was significantly increased by about 66% under AAR

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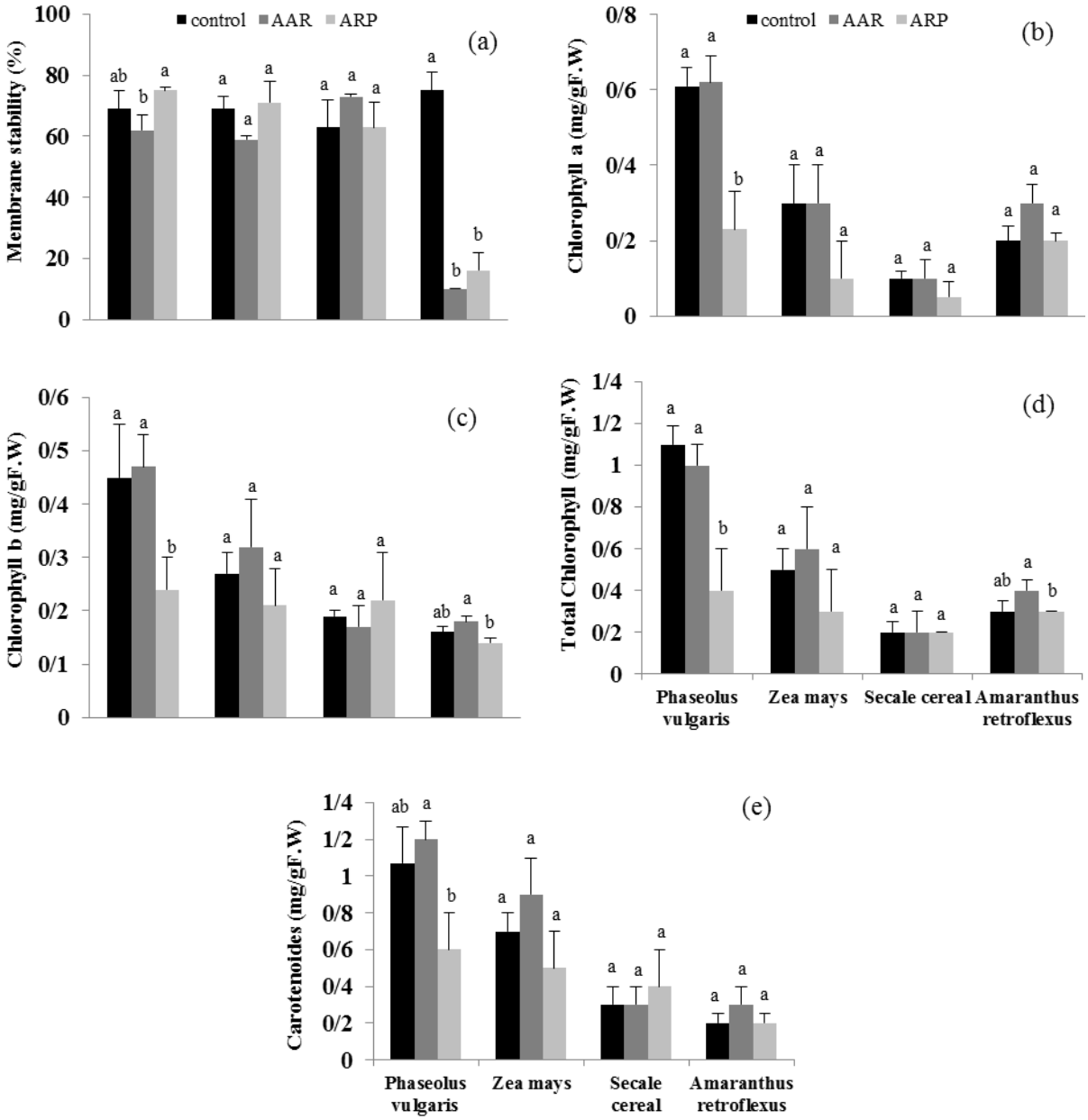

Figure 2. Effects of aqueous extract of the apricot root (AAR) and apricot root powder (ARP) on Membrane stability index (a), Chlorophyll a (b), Chlorophyll b (c), Total Chlorophyll (d), Carotenoids (e). Similar letters indicate that there is no significant difference among the means (P ≤ 0.05).

treatment. However, the effects of AAR and ARP on the proline content of other species were not significant (Figure 3a). It has been reported that the increase of proline content in plants under stress conditions, is one of the acclimation mechanisms to overcome these conditions (Manivannan *et al*., 2007). Other research showed that proline has different functions under stress conditions, such as creating osmotic balance, preservation of protein structure and cell membrane, stabilization of the intracellular structure, and removal of free radicals (Ain-Lhout *et al.*, 2001).

Mean comparison data showed that the effect of AAR and ARP on protein content and MSI of the studied species were not significant, except for MSI in *A. retroflexus*, which decreased by 80 and 70% compared to the control, respectively (Figure 2a). The activity of SOD and PPO enzymes under AAR and ARP treatment were not significantly different in the studied plants, except for PPO activity in *S. cereal* which increased by 68 and 72%, compared to the control, respectively (Figure 3c and 3d). In another study, POD and PPO activity in lettuce *Lactuca sativa* L. was increased as concentration of *Citrus sinensis* L. hexane, chloroform, and methanol fractions increased to maximal concentrations. (Nunes *et al.*, 2015). Other research showed that some antioxidant enzymes such as catalase (CAT), PPO, ascorbate peroxidase (APX) were increased in response to paraxanthine that might be

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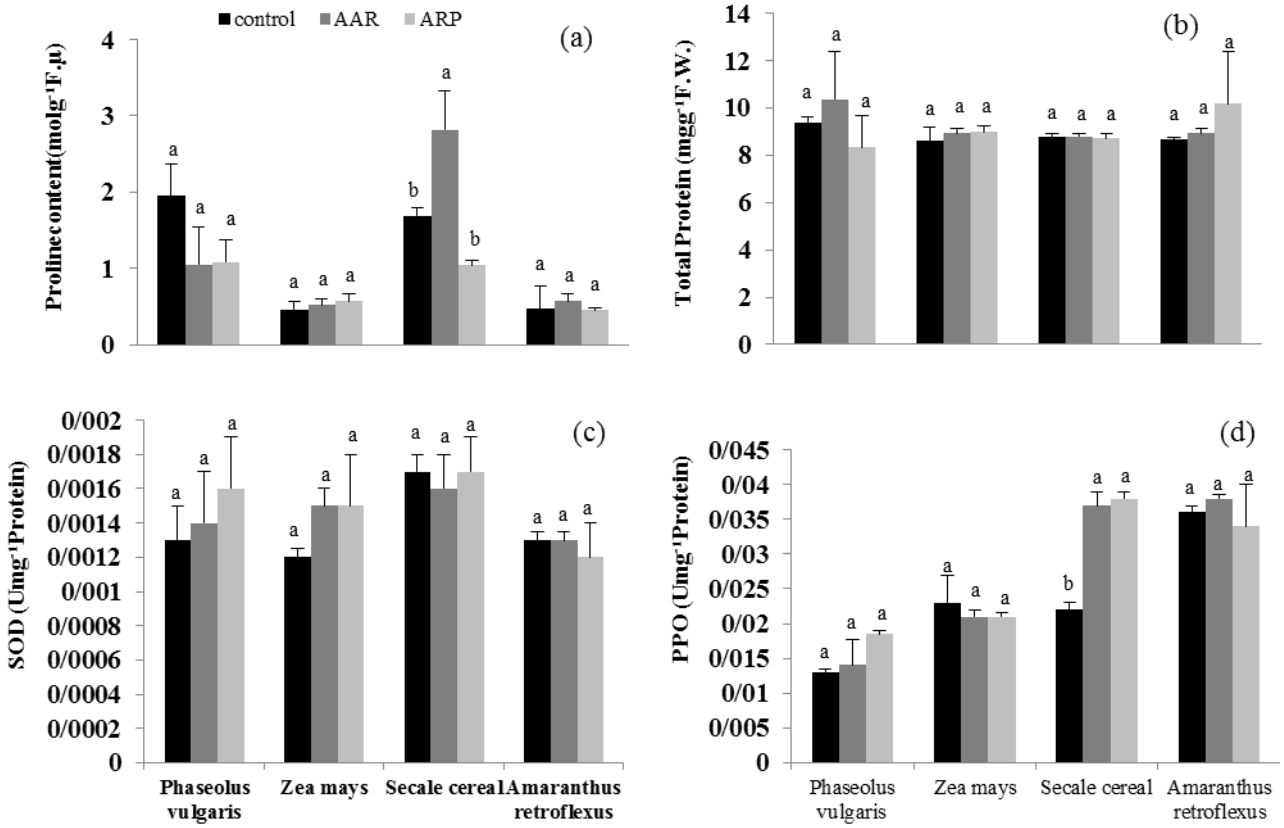

Figure 3. Effects of aqueous extract of apricot root (AAR) and apricot root powder (ARP) on Proline content (a), Total protein (b), Superoxide dismutase (SOD) (c), Polyphenol oxidase (PPO) (d). Similar letters indicate that there is no significant difference among the means (P ≤ 0.05).

tendto minimize paraxanthine created oxidative stress. Paraxanthin is a group of purine alkaloids, secondary metabolites of plants, this compound is made up of the caffeine metabolism found in plants such as tea, coffee and cocoa (Asadi and Razavi, 2022).

Comparison between results of germination and seedling stage: Corresponding results of AAR effect on growth variables such as length and biomass of roots and shoots in germination and seedling stage of the studied crop and weeds showed that this effect was much greater in the germination stage so that in most of the studied plants, growth was stopped completely. Changes in physiological and biochemical variables under AAR and ARP in the studied crops and weeds did not indicate a trend that can be considered as an allopathic effect. However, on a case-by-case basis, this effect was more noticeable on weeds. Overall, the results obtained from both stages indicated that the effect of apricot root on weeds is more than crops.

Conclusions

Regarding the severe effect of AAR on germination properties of the studied plants (*C. arietinum*, *P. vulgaris*, *T. aestivum*, *Z. mays*, *A. retroflexus*, *S. cereal*, and *A. ludoviciana*) and on the other hand, inconsiderable effect of AAR and ARP on different growth, physiological and biochemical characteristics of selected plants (*Z. mays*, *P. vulgaris*, *A. retroflexus*, and *S. cereal*) in the seedling stage, it seems that the allelopathic effect of the apricot root is mostly done by preventing the germination of target plants rather than the effect on the later stage of plant growth and development. Therefore, the apricot extract has the potential to be used as an inhibitor of the germination of undesirable plants in the target field.

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Conflict of interest

The authors declare that they have no conflict of interest.

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