



Breaking Dormancy and Enhancing Germination of *Avena sterilis* L. and *Amaranthus retroflexus* L. Weeds by Gibberellic Acid and Potassium Nitrate to Keep Soil and Crops Healthy

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Abstract

Soils infested with weed seeds are considered hostile lands for crop production. In this context, great wild oat (*Avena* sp.) in winter seasons and redroot pigweed (*Amaranthus* sp.) in summer seasons represent problematic weeds in cropland fields. In a series of laboratory trials, we estimated the effects of gibberellic acid (GA₃) and potassium nitrate (KNO₃) on germination and seedling growth of *Avena sterilis* L. and *Amaranthus retroflexus* L. Different concentrations of GA₃ and KNO₃ were evaluated in randomized complete block design with four replicates. Findings revealed that GA₃ at a rate of 200 mg L⁻¹ along each of 150 and 250 mg L⁻¹ treatment showed the maximum increases in germination percentage, radicle length, plumule length and seedling dry weight of *A. sterilis* L. All applied concentrations of KNO₃ were similar ($p \geq 0.05$) in enhancing seed germination of *A. sterilis* L. exceeding the control treatment. Application of GA₃ at rates of 250, 500 and 750 mg L⁻¹ surpassed the treatments of 0 and 1000 mg L⁻¹ GA₃ for activating *A. retroflexus* L. seeds germination. Addition of 250 and 500 mg L⁻¹ KNO₃ were the potent treatments for stimulating the radicle length of *A. retroflexus* L. It could be concluded that for breaking dormancy efficiently, addition of gibberellic acid or potassium nitrate with *Avena sterilis* L. as well as gibberellic acid with *Amaranthus retroflexus* L. is recommended. Such chemicals could be involved in weed management programs, since distinctive promotion of seed germination for the target weeds was achieved. This undoubtedly will keep the soil and crops healthy.

Keywords Germination stimulants · Gibberellins · Seed dormancy · Weed biology · Weed control

Introduction

Weeds represent one of the biggest obstacles facing agricultural production in the world because of the losses they cause in the productivity and quality of crops. For instance, in cereals, reduction in yields ranging from 50–99% based on the crop specie (El-Metwally and Saady 2009; Saady 2013; Saady and Mubarak 2014; Saady et al. 2021a, b). Furthermore, weeds reduced water use efficiency (El-Met-

wally et al. 2009; Saady and El-Bagoury 2014; Saady and El-Metwally 2022) and nutrient uptakes by crop plants (Saady 2015; Saady and Mubarak 2015; El-Metwally and Saady 2021b). In several legume and oil crops distinctive deterioration in yield and quality were recorded owing to the presence of weeds (Aisa et al. 2019; Saady 2009; El-Metwally and Saady 2021a; Saady et al. 2021c, 2022). On the other hand, dormancy is a strategy of weed survival and persistence threatening continuously crop growers. Weed seed dormancy is one of the most pertinent adaptive properties that give various weeds a good chance of surviving and reproducing in a specific crop system. Seed dormancy is a feature found in many plant species whose adaptive importance is related to the ability to survive in unfavorable environments (Bewley et al. 2012). In croplands, the dormancy level of the weed seed bank in interaction with the predominating ecological conditions will determine the degree and timing of weed emergence (Batlla and Benech-

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Arnold 2010). However, Predicting the timing and extent of weed emergence in the field becomes difficult, when the seed is dormant (Benech-Arnold et al. 2000).

Dormant weeds had the potential to survive compared to the economic crops, especially under harsh conditions, and can germinate at some later time or in some other place (Tran and Cavanagh 1984). Persistence of the weed seed bank and timing of seedling emergence rely on dormancy (Walck et al. 2011; Batlla et al. 2020). Hence, weed seeds can remain in the soil for many years and germinate after experiencing favorable conditions for the survival of seedlings to maturation (Fenner 1985). Such a behavior drives to the accumulation of large seed amounts in the soil, shaping persistent banks which constitute the regenerative tactics developed by several weed species (Fenner 1985).

Avena fatua L. is a significant and widespread weed worldwide. It is a persistent weed with a combination of dormancy and seed longevity which allow viable seeds to infest agricultural soils for several years (Naylor 1983). Also, *Amaranthus retroflexus* is an important weed, which infests soil in several areas (Holm et al. 1997). Buried seeds of *A. retroflexus* can remain viable for at least 6–10 years (Costea et al. 2004).

Seeds dormancy is controlled by environmental factors that secure concurrence with the optimum growing season (Baskin and Baskin 1989). Breaking dormancy or stimulating germination is affected by several factors such as nitrate, temperature and light (Bouwmeester and Karssen 1993). Various treatments including plant growth regulators and chemicals have been applied to break seed dormancy in different species (Hartmann et al. 2010; Kaur et al. 2020).

It was recorded that gibberellic acid (GA_3) and potassium nitrate (KNO_3) treatments enhanced the germination of two *Papaver* species (Golmohammadzadeh et al. 2015), *Cardaria draba* (L.) Desv. (Rezvani and Zaefarian 2016), *Myagrum perfoliatum* L. (Honarmand et al. 2016), and *Solanum americanum* Mill. (Forte et al. 2019). Moreover, Rezvani and Zaefarian (2016) stated that GA_3 , KNO_3 and pre-chilling activated the germination of hoary cress seeds. GA_3 had stimulation effects for seed germination (Lee et al. 2016; Urbanova and Leubner-Metzger 2018). Seeds soaked in 2% KNO_3 solution recorded approximately 63% increase in seed germination (Narmadha et al. 2020). However, despite the dangerous impacts of *Avena sterilis* L. and *Amaranthus retroflexus* L. in several field crops, their dormancy release was not clearly investigated.

Knowing the effective germination stimulants and their concentration as well as the optimal seedling emergence time has a practicable role in choosing the appropriate tillage time and system, the suitable application time of soil applied herbicides, and the proper crop sowing date. Therefore, the present study aimed to find the best chemi-

cal concentration of GA_3 and KNO_3 on dormancy breaking of *Avena sterilis* L. and *Amaranthus retroflexus* L. seeds. This could help in enhancing emergence potential of these weeds in field crops, which could be crucial in designing effective weed control programs.

Materials and Methods

The present work was carried out in Weed Research Central Laboratory, Agriculture Research Center (ARC), Giza, Egypt (30°01' N, 31°12' E). Four Laboratory experiments were conducted twice in sterilized glass Petri dishes.

Plant Materials and Weed Seeds Preparation

Avena sterilis L. (great wild oat) and *Amaranthus retroflexus* L. (redroot pigweed) weeds were obtained from the Experimental Research Farm of ARC.

In May 2019, *A. sterilis* plants were collected from wheat fields, put within paper bags. After that, plants distributed on lab shelves to air-dried for three days. The spikelets were separated from the plants and stored for a year from the harvesting date under room temperature ($25 \pm 3^\circ C$) to ensure the full maturity of embryo of the grains.

In April 2020 *A. retroflexus* plants were collected from the fields and distributed on lab shelves for four weeks to air-dry. After that, the seeds were separated from the inflorescences and stored under room temperature ($28 \pm 2^\circ C$).

Procedures and Treatments

A. sterilis Trials

To test the effect of gibberellic acid (GA_3) and potassium nitrate (KNO_3) on germination and seedlings growth of *A. sterilis* weed, two petri dishes experiments were conducted on weed grains. The first experiment included seven treatments of GA_3 concentrations. The tested concentrations were 150, 200, 250, 500, 750 and 1000 mg L⁻¹ GA_3 , in addition to the control treatment, distilled water, (0 mg L⁻¹ GA_3). Concerning the second experiment, seven treatments of KNO_3 concentrations (150, 200, 250, 500, 750 and 1000 mg L⁻¹ KNO_3 , in addition to the control treatment, distilled water, 0 mg L⁻¹ KNO_3) were applied. In both experiments, the outer surfaces of the spikelets were sterilized by immersing in chlorine 5% for two seconds. Treatments were arranged in randomized complete block design with four replicates. The Petri dishes (9 cm diameter) were lined with a double layer of filter paper (Whatman #1). Both GA_3 and KNO_3 experiments sown two times on 1 March and 29 December 2020, where twenty *A. sterilis* grains (10 sterilized spikelets) were placed in each Petri

dish and moistened with five ml of distilled water or different concentrations of GA₃ or KNO₃ every two days or as need. Seedlings were harvested on 22 March 2020 and 12 January 2021.

A. retroflexus Trials

To investigate the effect of GA₃ and KNO₃ on germination and seedlings growth of *A. retroflexus* weed, two Petri dishes experiments were conducted on weed seeds. The first experiment included five treatments of GA₃ concentrations which were 250, 500, 750 and 1000 mg L⁻¹ GA₃, in addition to the control treatment (distilled water, 0 mg L⁻¹ GA₃). Concerning the second experiment, five concentrations of KNO₃ (250, 500, 750 and 1000 mg L⁻¹ KNO₃, in addition to the control treatment, distilled water, 0 mg L⁻¹ KNO₃) were applied. In both experiments, treatments were arranged in randomized complete block design with four replicates. The Petri dishes (9 cm diameter) were lined with a double layer of filter paper (Whatman #1). Both GA₃ and KNO₃ experiments sown two times on 5 May and 5 July 2020, where twenty *A. retroflexus* seeds were placed in each Petri dish and moistened with five ml of distilled water or different concentrations of GA₃ or KNO₃ every two days or as need. Seedlings were harvested on 26 May 2020 and 26 July 2020.

Assessments

At the end of each experiment, germination percentage was recorded using Eq. 1, where seeds were considered germinating when the radicle emerged through the seed testa with length of longer than 2 mm. The increase in germination percentage in weed seeds under the effect of GA₃ and KNO₃ concentrations (treatment) relative to the control was computed by Eq. 2.

Germination percent =

$$\left(\frac{\text{Total number of seeds germinated}}{\text{Total number of sown seeds}} \right) \times 100... \quad (1)$$

Germination increase % =

$$\left(\frac{\text{Treatment} - \text{control}}{\text{Control}} \right) \times 100... \quad (2)$$

Furthermore, radicle length, plumule length and dry weight of seedlings were measured.

Statistical Analysis

The collected data were subjected to homogeneity test prior to analysis of variance (ANOVA). The outputs proved that the homogeneity and normality of the data are satisfied for running further ANOVA. Thus, combined data of each experiment were undergone to one-way ANOVA according to Casella (2008), using Costat software program, Version 6.303, 2004. Concentration of GA₃ or KNO₃ was considered fixed effect while replications (blocks) were considered random effect. Means were separated using Fisher's protected least significant differences (LSD). Differences were considered significant at the probability level of 5%.

Results

Effect of GA₃ and KNO₃ on Seed Germination and Seedling Growth of *Avena sterilis* L.

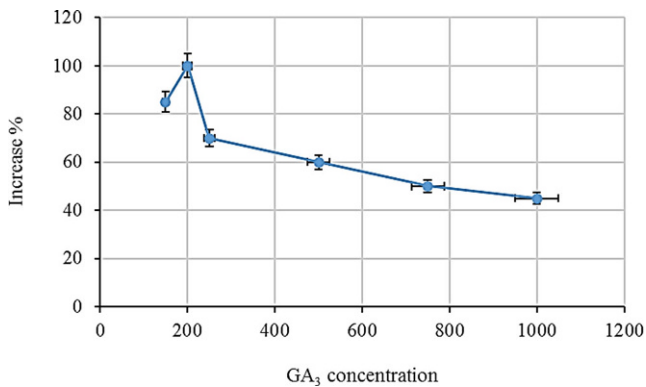
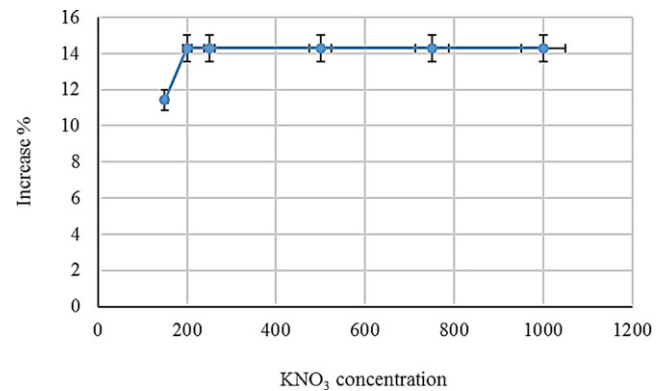
GA₃ (Table 1) and KNO₃ (Table 2) concentrations had significant ($p \leq 0.05$) effects on seed germination and seedling growth traits of *A. sterilis* L. Concerning GA₃ effect, all tested concentrations of gibberellic acid caused increases in germination percentage higher than the control. Application of GA₃ at a rate of 200 mg L⁻¹ along with 150 and 250 mg L⁻¹ showed the maximum germination percentages. Increases in germination percentage due to different GA₃ concentrations are illustrated in Fig. 1. Furthermore, GA₃ at a rate of 200 mg L⁻¹ along with 150 and 250 mg L⁻¹ treatments showed the maximum increases in radicle length, plumule length and seedling dry weight, surpassing the other treatments, except 500 and 750 mg L⁻¹ GA₃ treatments for radicle length.

Table 1 Germination and seedling growth traits of *Avena sterilis* L. as affected by gibberellic acid (GA₃) concentration

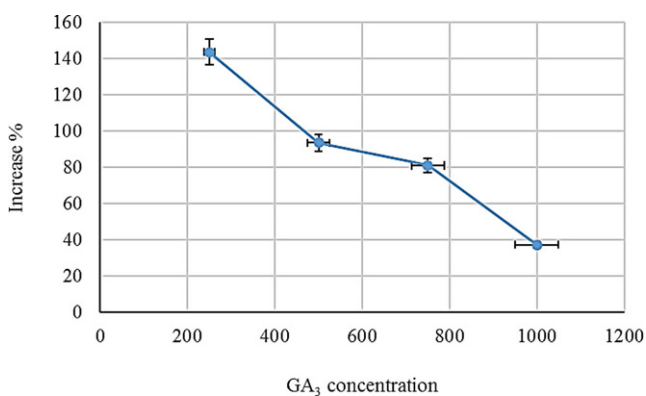
GA ₃ treatment (mg L ⁻¹)	Germination %	Radicle length (cm)	Plumule length (cm)	Seedling dry weight (g)
1000	72.50	10.60	12.00	0.075
750	75.00	12.05	12.45	0.077
500	80.00	12.30	12.87	0.095
250	85.00	12.55	14.82	0.100
200	100.00	16.17	15.30	0.132
150	92.50	16.02	14.95	0.107
Control	50.00	6.72	11.85	0.062
LSD _{0.05}	20.13	4.86	1.41	0.036

Table 2 Germination and seedling growth traits of *Avena sterilis* L. as affected by potassium nitrate (KNO_3) concentration

KNO_3 treatment ($mg\ L^{-1}$)	Germination %	Radicle length (cm)	Plumule length (cm)	Seedling dry weight (g)
1000	100.00	12.57	14.85	0.110
750	100.00	12.62	15.40	0.135
500	100.00	13.22	16.10	0.145
250	100.00	11.75	13.25	0.092
200	100.00	8.75	11.12	0.097
150	97.50	6.37	10.25	0.075
Control	87.50	4.12	8.12	0.070
$LSD_{0.05}$	9.12	5.04	2.93	ns

**Fig. 1** Change in germination percentage increase of *Avena sterilis* L. seeds under different concentrations of gibberellic acid (GA_3)**Fig. 2** Change in germination percentage increase of *Avena sterilis* L. seeds under different concentrations of potassium nitrate (KNO_3)**Table 3** Germination and seedling growth traits of *Amaranthus retroflexus* L. as affected by gibberellic acid (GA_3) concentration

GA_3 treatment ($mg\ L^{-1}$)	Germination %	Radicle length (cm)	Plumule length (cm)	Seedling dry weight (g)
1000	27.50	3.45	3.75	0.042
750	36.25	4.25	4.25	0.052
500	38.75	4.27	4.25	0.052
250	48.75	4.42	4.87	0.060
Control	20.00	2.87	3.50	0.032
$LSD_{0.05}$	17.83	ns	ns	ns

**Fig. 3** Change in germination percentage increase of *Amaranthus retroflexus* L. seeds under different concentrations of gibberellic acid (GA_3)

All applied concentrations of potassium nitrate (KNO_3) were similar ($p \geq 0.05$) in germination percentages exceeding the control treatment (Table 2). Increases in germination percentage due to different KNO_3 concentrations are depicted in Fig. 2. KNO_3 at a rate of 500, 750 or 1000 $mg\ L^{-1}$ (for radicle length and plumule length), in addition to 200 and 250 $mg\ L^{-1}$ (for radicle length) recorded the highest values. Non-significant ($p \geq 0.05$) response was obtained in seedling dry weight owing to the different KNO_3 concentrations.

Effect of GA_3 and KNO_3 on Seed Germination and Seedling Growth of *Amaranthus retroflexus* L.

As shown in Table 3, seed germination of *A. retroflexus* L. significantly ($p \leq 0.05$) affected by GA_3 concentration,

Table 4 Germination and seedling growth traits of *Amaranthus retroflexus* L. as affected by potassium nitrate (KNO_3) concentration

KNO_3 treatment (mg L ⁻¹)	Germination %	Radicle length (cm)	Plumule length (cm)	Seedling dry weight (g)
1000	40.00	3.57	4.75	0.030
750	50.00	3.67	4.75	0.037
500	52.50	4.15	5.00	0.052
250	50.50	4.45	5.50	0.060
Control	37.50	3.55	4.75	0.025
LSD _{0.05}	ns	0.58	ns	ns

while radicle length, plumule length and seedling dry weight did not affect ($p \geq 0.05$). The maximum values of germination percentage were recorded with application of GA_3 at rates of 250, 500 and 750 mg L⁻¹ surpassing the control (0 mg L⁻¹) and the high concentration (1000 mg L⁻¹). Germination percentage increases of *A. retroflexus* L. seeds due to various concentrations of GA_3 are shown in Fig. 3.

Regarding the effect of KNO_3 on *A. retroflexus* L., data presented in Table 4 revealed that there were no significant ($p \geq 0.05$) variations among different KNO_3 concentrations on germination percentage, plumule length and seedling dry weight. Unlike, radicle length significantly responded to KNO_3 levels producing the higher values with 250 and 500 mg L⁻¹ of KNO_3 .

Discussion

Since weeds compete with crop plants for environmental factors, they should be eliminated. Due to weed competition, the availability of water and nutrients to the economic plants remarkably reduced (Saady et al. 2020; El-Metwally et al. 2022a). Hence, quantitative and qualitative traits of the final product were significantly decreased (Saady and Abd-Elmomen 2009; Saady and El-Metwally 2009; El-Metwally et al. 2022b).

Certainly, emergency of weed plants from soil help the crop growers to distinguish the weed flora infested their fields. Thus, determination and planning tactics for weed control are becoming more easily. On the contrary, the presence and abundance of dormant weed seeds within soil represent a great challenge in weed management programs. Accordingly, obtaining germination stimulators is considered a remarkable tool for improving weed control methods, especially before crop planting to reduce weed infestation, hence plants grow in clean medium. The current work subjected to the dormancy as a critical issue of two important weeds, i.e. *A. sterilis* L. and *A. retroflexus* L. Findings exhibited that GA_3 and KNO_3 had motivative effect for *A. sterilis* L. weed germination and seedling growth. While, GA_3 alone was efficient for enhancing germination and seedling growth of *A. retroflexus* L. weed. Low and medium concentrations of GA_3 (150, 200 and 250 mg L⁻¹) and KNO_3

(250 and 500 mg L⁻¹) were more effective in this respect than the control or higher concentration (1000 mg L⁻¹). For promoting false jagged-chickweed seed germination rate, a KNO_3 concentration of 30 μ mol and a GA_3 concentration of 144 μ mol were the best treatments (Moeini et al. 2021).

In a wide range of plant species, due to its physiological role in induction of hydrolytic enzymes, GA_3 released the seed dormancy and promoted the germination (Rogis et al. 2004; Zhang et al. 2006) and can eliminate the natural chilling requirement of the dormant seeds (Gashi et al. 2012). Gibberellic acid could remove dormancy in *Amaranthus retroflexus* seeds and the dormancy release by GA_3 involved ethylene biosynthesis and action (Kępczyński et al. 2003). Sensitivity to GA_3 increases with the progress of dormancy release (Cadman et al. 2006; Finch-Savage and Leubner-Metzger 2006). The greatest germination percentage of *Thlaspi arvense* was obtained in seeds treated with 150 ppm GA_3 (Karimmojeni et al. 2014). A concentration range of GA_3 (288–1152 μ molar) increased germination of *Erica andevalensis* (Rossini Oliva et al. 2009). Applying pre-chilling with GA_3 provided the highest germination percentage in *Helianthus tuberosus* L. (Puttha et al. 2014).

Also, KNO_3 used for breaking seed dormancy and stimulating seed germination (Shim et al. 2008). In this respect, Chauhan et al. (2006) clarified that the germination rate of *Sisymbrium orientale* seeds increased in direct proportion to increasing concentrations of KNO_3 , although only up to 0.02 M, after which it reduced. Stimulation and inhibition of seed germination at low and high concentrations of KNO_3 have previously been documented (Foley and Chao 2008; Wei et al. 2010). Potency of KNO_3 for breaking dormancy varied based on weed specie, since *A. retroflexus* L. was less affected than *A. sterilis* L. Potassium nitrate partly increased germination potential in *Malcolmia africana* seeds, which initially were less dormant than those of *Thlaspi arvense* and *Descurainia Sophia* (Karimmojeni et al. 2014). Various concentrations of KNO_3 promoted germination of false jagged-chickweed (Moeini et al. 2021) and other weed species such as *Solanum rostratum* and *Cardaria draba* (Rezvani and Zaefarian 2016; Wei et al. 2010).

Conclusion

Findings of the current research proved that the dormancy effectively broken by treating *Avena sterilis* L. seeds with gibberellic acid or potassium nitrate as well as *Amaranthus retroflexus* L. seeds with gibberellic acid. Generally, application of 150–250 mg L⁻¹ gibberellic acid and 250–750 mg L⁻¹ potassium nitrate regarded as the optimal dosages, since the highest increases in germination percentage and seedling growth traits were observed. Certainly, enhancing the germination of soil banked seeds of weeds especially prior crop planting will support the efficacy of weed control methods such as herbicides usage and false seed bed preparation. Thus, the crop competitiveness against weeds will improve, hence keeping soil and plant healthy.

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Conflict of interest T.Y. Rizk, A.S. Othman kholousy, H.S. Saady, Sh.S. Sultan and S.H.A. Abd-Alwahed declare that they have no competing interests.

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