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Review

The potential of Si and Se as biostimulants to enhance resistance to climatic conditions and improve yields in common and Tartary buckwheat

Mateja GERM[1], Aleksandra GOLOB[1], Katarina VOGEL MIKUŠ[1,2], Matevž LIKAR[1], Jure MRAVLJE[1,2], Paula PONGRAC[1,2], Anja MAVRIČ ČERMELJ[1], Cheol Ho PARK[3], Min Ook PARK[4], Jacek KWIATKOWSKI[5], Marjana REGVAR[1]

[1] *Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia*
[2] *Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia*
[3] *Korea Buckwheat Research Institute and [4] Department of Smartfarm Agriculture & Industries, Kangwon National University, Korea 24341*
[5] *Department of Genetics, Plant Breeding and Bioresource Engineering, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, Plac Łódzki 3, 10-724 Olsztyn, Poland*
* *Corresponding author: Mateja Germ, Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia, Tel: +38613203334; mateja.germ@bf.uni-lj.si;*

E-mail addresses of authors: mateja.germ@bf.uni-lj.si (MG); aleksandra.golob@bf.uni-lj,si (AG); katarina.vogelmikus@bf.uni-lj.si (KVM); matevz-likar@bf.uni-lj.si (ML); jure.mravlje@bf.uni-lj.si (JM); paula.pongrac@bf.uni-lj.si (PP); anja.mavric@bf.uni-lj.si (AMČ); chpark@kangwon.ac.kr (CHP); koonim67@gmail.com (MOP); jacekkw@uwm.edu.pl (JK); marjana.regvar@bf.uni-lj.si (MR)

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ABSTRACT

Common buckwheat and Tartary buckwheat are pseudocereals and grow worldwide. Due to the high concentration of flavonoids, buckwheats are potential sources of smart food. Tartary and common buckwheat are traditionally grown in mountain regions of China, Korea, the northern parts of India, Bhutan, and Nepal. Plants that grow in high elevations are exposed to intense UV radiation, which can harm susceptible sites in the plants. Plants defend themselves against intense radiation by synthesising UV-absorbing compounds. Drought will probably become more frequent and intense due to climate change. UV radiation and drought are environmental parameters that present stress to the plants. These impacts can be synergistic or antagonistic. Selenium (Se) and silicon (Si) can protect plants exposed to UV radiation or drought since Se acts as an antioxidant. Silicon is an abundant element in Earth's crust. It is present as a liquid or an amorphous or crystalline solid phase in the soil. Selenium and silicon are not essential elements for vascular plants, but they may positively affect plants. Thus, they can be added to the growth media to improve crop yield and quality, enhance resistance to abiotic and biotic stress and improve plant growth.

1 INTRODUCTION

Species of the genus buckwheat (*Fagopyrum* spp.) are assigned as pseudocereals and grow worldwide, as they have strong adaptability to many different environments (Ge and Wang, 2020) and are stress resistant (Jha et al., 2024). Due to flavonoids, buckwheat is also considered a smart food (Jha et al., 2024). Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) (Figures 1,2,3) originates in the Himalayan region. It expanded its distribution area to the southeast with the Yi people's migration. This is a minority in Southwestern China with a long history of cultivating Tartary buckwheat (He et al., 2024c). It was recently reported that, based on the whole-genome resequencing of many germplasm samples, two domestications occurred in southwestern and northern China. This led to diverse characteristics of modern Tartary buckwheat varieties (Zhang et al., 2021). Tartary and common buckwheat (*Fagopyrum esculentum* Moench) (Figures 1,4) are cultivated in the mountain regions of China, Korea, northern parts of India, Bhutan, and Nepal (Ohnishi, 1998; Zhang et al., 2017) and several European countries, USA, Canada, Brazil, Australia and recently in some countries in Africa.

Plants that grow in high elevations are subjected to intense UV radiation. Ultraviolet radiation can damage the vulnerable tissue in plants. That is why plants protect themselves by synthesising UV-absorbing substances, making a shield from UV radiation. Protective substances mainly belong to polyphenols, with aromatic rings of six carbon atoms, double ties, and groups bound to carbon atoms, frequently with attached OH or sugar components (Kreft et al., 2022).

Plants will probably be exposed to diverse environmental constraints in the future (Bernal et al., 2015). Due to climate change, extreme events, such as drought, are expected to become more frequent and intense (Pachauri and Meyer, 2014). Water limitation will have substantial negative impacts on crop production, affecting the mechanisms and growth of the plants (Aubert et al., 2021). UV radiation and drought may pose stress to the plants, which can be synergistic or antagonistic.

Selenium (Se) and silicon (Si) can protect plants exposed to UV radiation or drought (Mavrič Čermelj et al., 2022). Selenium can act as an antioxidant under abiotic and biotic stress (Feng et al., 2013; Hashem et al., 2022) and most often exists as organic selenium like selenoprotein, selenium polysaccharide and inorganic selenium like elemental selenium, selenate (Se(VI)) and selenite (Se(IV)) (Niu et al., 2020). However, the incorporation of SeCys and SeMet instead of Cys and Met, results in the

Figure 1. *Tartary buckwheat, cv. Zlata (left plot) and common buckwheat, cv. Darja (plot to the right, behind), grown at an elevation of 1100 m a.s.l. (above sea level) (Javorje, Črna na Koroškem, Slovenia).*

Figure 2. *Inflorescence of Tartary buckwheat, cv. Zlata, grown at the elevation of 1100 m a.s.l. (Javorje, Slovenia).*

Figure 3. *Tartary buckwheat, cv. Zlata, grown at the elevation of 1100 m a.s.l. (Javorje, Slovenia, photo Franc Stopar).*

production of non-functional proteins in plants, which is why the tolerance curve is very narrow, and Se can be toxic for plants already in low concentrations. Nevertheless, SeMet and SeCys are very efficiently utilised by the animal/human body (Srikanth Lavu et al., 2016). Silicon composes 28.8% of the continental crust and is an abundant element (Wedepohl, 1995). It is present in different forms and can be found in a liquid or an amorphous or

Figure 4. *Common buckwheat, cv. Darja, grown at the experimental field of Biotechnical Faculty, in Ljubljana, Slovenia, 300 m a.s.l.*

crystalline solid phase in the soil (Mavrič Čermelj et al., 2022). Silicon is not an essential element for vascular plants, except for horsetail (Equisetaceae), but it is an essential element for the diatom algae (Bacillariophyceae) (Chen and Lewin, 1969). Silicon has a positive effect on stress-exposed plants as well as on stress-free plants. Foliar addition of Si induced Si accumulation in shoots and grain production in soybean and rice (Felisberto et al., 2021). According to the results of the study on barley, it was reported that plants were stressed due to Si deficiency (Mavrič Čermelj et al., 2022). Biostimulants are different formulations of compounds, substances, and microorganisms that can be added as catalysts to the media for improving crop yield, quality, tolerance, and resistance to abiotic and biotic stress (Azad et al., 2021), enhancing plant growth (Szparaga et al., 2018).

2 RESPONSES OF BUCKWHEAT TO ENVIRONMENTAL PARAMETERS

2.1 Drought

Drought is a more and more common stressor for plants, including crops like buckwheat. There is little research regarding the effects of drought on buckwheat. Aubert et al. (2021) grew common buckwheat and Tartary buckwheat in a greenhouse under two water regimes: control and water stress. Common buckwheat and Tartary buckwheat responded differently to water stress. The vegetative growth was affected in the former but not in the latter. Water stress negatively affects growth parameters and stomatal conductance, transpiration rate, and photosynthesis rate in common buckwheat but not in Tartary buckwheat. The content of chlorophyll increased in water-stressed common buckwheat and Tartary buckwheat. Water stress affected the reproductive phase in both species (Table 1). According to the results, authors concluded that Tartary buckwheat is more resistant to water stress than common buckwheat. The research of Defalque et al. (2025) showed a greater impact of drought and high temperatures on generative development compared to vegetative growth in common buckwheat plants. Both species also have different strategies to cope with water limitations. Common buckwheat exhibited traits with drought avoidance characteristics, while Tartary buckwheat had drought tolerance characteristics (Aubert et al., 2021). The response to stress within a species may partially depend on the genotype/variety/cultivar (Yuan et al., 2024; Defalque et al., 2025). Recently Martínez-Goñi et al. (2024) stated that common buckwheat showed higher water-use efficiency and photosynthesis under drought than wheat and suggested this species as an alternative crop to wheat in the future. Recently, the effects of drought during the flowering phase on Tartary buckwheat's carbon and nitrogen metabolism were studied (He et al., 2024b). The authors found out that the treatment increases the antioxidant enzyme activities and activities of enzymes of carbon and nitrogen metabolism (Table 1) that increases the ca-

Table 1. *The effect of drought on morphological, physiological and biochemical properties of common (CB) and Tartary buckwheat (TB) (According to Aubert et al., 2021)*

Parameter	/Stress factor/species	CB	TB
Leaf production	drought	↓	–
Leaf FW	drought	↓	–
Leaf DW	drought	↓	–
Stomatal conductance	drought	↓	–
Transpiration rate	drought	↓	–
Photosynthesis	drought	↓	–
Chlorophyll fluorescence	drought	–	–
Chlorophyll content	drought	↑	↑
Antioxidant content	drought	–	↑
N of inflorescences	drought	↓	↓
Pollen production	drought	↓	↓

– No response ↑ increased ↓ decreased

pability of Tartary buckwheat to drought stress and also increases plant yield.

Sytar et al. (2023) emphasised in their study regarding drought effects on two common buckwheat cultivars that the impact of drought on phenolic compound substances encompasses the complexity of metabolic responses to environmental constraints. They also concluded that the studies, including genotype x environment interaction, are very important. Dziedzic et al. (2025) observed a slight decrease in most phenolic compounds in leaves, stems, seeds and husk of Tartary buckwheat exposed to drought stress.

We can conclude that common and Tartary buckwheat have different strategies for coping with drought and that drought affects the synthesis of phenolic substances in both buckwheat species.

2.2 UV and drought

Plants growing under natural conditions are continuously exposed to multiple environmental stressors. Climate change increasing the frequency and seriousness of droughts, so combination of high UV-B irradiance and drought particularly at mid to low latitudes is a big concern (Barnes et al., 2023). In the future, plants will probably be exposed to increased UV radiation and limited water supply simultaneously. Thus, Germ et al. (2013) studied the effect of the combination of enhanced UV-B radiation and water limitation on common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat (*Fagopyrum tataricum*) in semi-controlled conditions. The negative effect of elevated UV-B radiation on growth parameters in common buckwheat was highly significant in watered plants but less pronounced in plants exposed to water limitation. However, in Tartary buckwheat, UV-B radiation mitigated the adverse effects of water limitation, resulting in increased biomass production (Table 2). We can conclude that UV radiation and drought interfere with the response of both buckwheats.

At higher elevations, environmental conditions are harsher and impose constraints on the plants. Golob et al. (2022) cultivated common and Tartary buckwheat at different elevations (300, 600, and 1100 m a.s.l.). They reported that in common buckwheat grown at the high-

Parameter	/Stress factor/species	CB	TB
Chlorophyll content	Drought	↓	–
Chlorophyll content	Enhanced UV	↓	↓
Chlorophyll content	Drought x UV	↑	–
UV absorbing compounds	Drought	↑	↑
UV absorbing compounds	Enhanced UV	↑	–
Fv/Fm	Drought	–	–
Fv/Fm	Enhanced UV	–	–
ΔF/Fm’	Drought	↑	↓
ΔF/Fm’	Enhanced UV	–	↓
ΔF/Fm’	Drought x UV	–	↓
Stomata	Enhanced UV	↓ (closing stomata)	↓ (closing stomata)
Stomata	Drought	↓ (closing stomata)	↓ (closing stomata)
Biomass of seeds	Enhanced UV	↓	–
Biomass of seeds	Drought	↓	↓

– No response ↑ increased ↓ decreased

Table 2. *The effect of drought, enhanced UV radiation and combination on common (CB) and Tartary buckwheat (TB) (According to Germ et al. (2013)). Fv/Fm – potential quantum yield of photosystem II; deltaF/Fm’ – quantum yield of PSII II*

est elevation, plants increased investment in secondary metabolism and decreased in primary metabolism; the synthesis of UV-absorbing compounds increased while the amounts of chlorophylls and carotenoids decreased. The amounts of UV-absorbing compounds and photosynthetic pigments were similar in plants grown at different elevations in Tartary buckwheat. The authors assume that this is because of the better adaptation of this species to conditions at higher elevations.

3 THE EFFECT OF BIOMINERALS ON BUCKWHEATS

3.1 Selenium

Another combination for the research is also interesting: UV radiation, which increases the formation of free radicals but is also an important environmental factor that regulates plant growth and development, and Se, an antioxidant that increases plant tolerance to various environmental constraints (Golob et al., 2018). Thus, the authors exposed hybrid buckwheat plants to full (+UV) and reduced (−UV) ambient UV radiation without (−Se) and with (+Se) foliar Se treatment (10 mg L^{-1} sodium selenate). Plants exposed to ambient UV radiation and Se treatment experienced a trade-off between primary and secondary metabolism. It means high levels of protective substances like anthocyanins, UV-absorbing compounds, and low levels of photosynthetic pigments. All plants grown in ambient UV radiation were shorter than those under the reduced UV, while biomass production was highest for plants without the addition of Se and under ambient UV radiation and lowest for ambient and Se-exposed plants. The authors found out that the addition of Se and conditions under ambient UV radiation separately positively affects the growth and production of hybrid buckwheat, while the combination of the addition of Se treatment and ambient UV leads to lower yields. It was concluded that under Se treatment and ambient UV radiation, the hybrid buckwheat had good protection against the different environmental constraints due to climate changes.

Similarly Breznik et al. (2005) in their experiment, exposed common (*Fagopyrum esculentum*) - CB and Tartary (*Fagopyrum tataricum*) - TB buckwheat to three levels of UV-B radiation and the addition of selenium. Plants grew outdoors from sowing to ripening. At week 7, they were foliarly sprayed with a solution containing 1 g (Se) m^{-3}. Elevated UV-B radiation, corresponding to a 17% reduction of the ozone layer, induced the production of UV-absorbing compounds. In both buckwheat species, the amounts of chlorophyll a were also lowered. In Tartary buckwheat, this negative effect was more evident when selenium was added. The effective quantum yield of PSII was reduced in both buckwheat species due to UV-B radiation, but the addition of Se ameliorated this effect. The content of UV-B absorbing compounds in leaves did not differ much between buckwheat species. Common buckwheat and Tartary buckwheat have similar potential to cope with stress due to UV-B radiation since the amount of UV-B and UV-A absorbing compounds was similar. The addition of Se treatment alleviated the stunting effect of UV-B radiation and lowering the biomass in common buckwheat. UV-B radiation and the addition of Se interfere with mechanisms of metabolic pathways that affect growth and development in common buckwheat and Tartary buckwheat.

3.2 Silicon

Silicon is a biostimulant with positive effects on plants, especially when exposed to stress conditions (Mavrič Čermelj et al., 2022). She et al. (2018) recorded that adding Si reduced the lodging degree in common buckwheat. Azad et al. (2021) showed that Si significantly influenced the growth and bioactive compound accu-

Table 3: *The effect of Si addition on common (CB) and Tartary buckwheat (TB) according to Azad et al. (2021).*

Parameter	Silicon	Species	
		CB	TB
Total phenolic content	Low dose	↑	↑
Total phenolic content	High dose	↑	↑
Total flavonoid content	Low dose	↑	↑
Total flavonoid content	High dose	↑	↑
Rutin	Low dose	↑	↑
Rutin	High dose	↑	↑
Plant fresh weight	Low dose	↑	↑
Plant fresh weight	High dose	↑	↑

↑ increased

mulation in both buckwheat species. Additionally, it was found that lower doses of Si enhanced the growth characteristics, total and single phenolic substances, total flavonoids, rutin, quercetin content, and antioxidant capacity in common buckwheat. Higher doses of Si had a similar effect on Tartary buckwheat (Table 3) (Azad et al., 2021). Qi et al. (2024) proved that Si alleviates the toxic effect of Al on buckwheat plants by limiting its accumulation in roots and increasing the activity of antioxidant enzymes (POD and APX), phenolic (flavonoid) content and free radical scavenging capacity (DPPH and ABTS). It can be concluded that the addition of Si enhanced the fitness of buckwheat in stress and in no stress conditions.

4 CONCLUSIONS

Common and Tartary buckwheat originate from high altitudes and contain high levels of secondary substances that protect them from UV radiation. Plants will be even more exposed to UV radiation and drought in the future because of climate changes. Research aimed at identifying and understanding the molecular mechanism of buckwheat tolerance to drought stress provides an opportunity to limit the effects of stress in new cultivars (He et al., 2024a; Li et al., 2025). Biostimulants such as Se and Si can protect plants. The addition of Se ameliorated negative effects of UV radiation in buckwheats. The addition of Si enhanced growth and bioactive compound accumulation in both buckwheat species.

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IZVLEČEK

Odziv navadne in tatarske ajde na okoljske parametre in dodajanje mineralov

Ključne besede: navadna ajda, tatarska ajda, UV sevanje, suša, elementi

Navadna ajda in tatarska ajda sta vrsti ajde, ki rasteta po vsem svetu. Zaradi visoke koncentracije flavonoidov je ajda živilo, ki ima pozitivne vplive na ljudi. Tatarsko in navadno ajdo tradicionalno pridelujejo v gorskih območjih držav, kot so Kitajska, Koreja, severni deli Indije, Butan in Nepal. Rastline, ki rastejo na visokih nadmorskih višinah, so izpostavljene močnemu UV-sevanju, ki lahko poškoduje občutljiva mesta v njihovih tkivih. Pred močnim sevanjem se

rastline branijo s sintezo UV-absorbirajočih spojin. Zaradi podnebnih sprememb bodo suše verjetno postale pogostejše in intenzivnejše. UV-sevanje in suša sta stres za rastline, vplivi so lahko sinergistični ali antagonistični. Selen (Se) in silicij (Si) lahko zaščitita rastline, izpostavljene UV-sevanju ali suši, saj Se deluje kot antioksidant. Silicij je eden najbolj razširjenih elementov v Zemljini skorji. Prisoten je v tleh v tekoči, amorfni ali kristalinični trdni fazi. Silicij ni esencialni element za višje rastline, vendar ima pozitiven učinek tako na rastline, izpostavljene stresu, kot tudi na rastline, ki niso izpostavljene stresu. Biostimulante, kot sta Se in Si, dodajajo gojitvenemu mediju za izboljšanje kakovosti pridelka, za povečanje odpornosti na abiotski in biotski stres ter za spodbujanje rasti rastlin.