EFFECT OF COMMON BUCKWHEAT (*Fagopyrum esculentum* L. Moench) ON THE GERMINATION AND SEEDLING GROWTH OF WHITE MUSTARD (*Sinapis alba* L.)

Nwajei Sunday Ebonka*, Jana Pexová Kalinová

Department of Plant Production, Faculty of Agriculture and Technology, University of South Bohemia, Studentská 1668, 370 05 České Budějovice, Czech Republic

Abstract

A field biotest study was carried out to assess the effect of buckwheat soil exudates on the germination and seedling growth of white mustard. After harvesting of buckwheat, the seeds of white mustard were sown into plots without buckwheat (control) and with soil exudates of buckwheat varieties (Zoe and Harpe) in sole, intercrop with sorghum, mulched with straw and in mixtures with Phacelia + Sinapis to constitute nine treatments laid out in a randomized complete block design with three replicates. Data were collected on germination %, plant height (cm), number of leaves/plant, total leaf area (cm^2)/plant, stem girth (cm), root length (cm) and chlorophyll. Fresh plant weight (kg/ha), dry matter weight (kg/ha), fresh root weight (kg/ha), dry root weight (kg/ha), relative root length (%), germination inhibition rate (%) and root inhibition rate (%) were determined. Data obtained were analyzed using analysis of variance and means were separated using Duncan's Multiple Range Test at 5% level of probability. The results obtained revealed that the treatment without buckwheat exudates had a significant higher germination (100%), plant height (12.69cm) and root length (5.09 cm) than other treatments. The most pronounced inhibitory effects were observed in the Zoe + straw treatment, which resulted in 60% germination and Zoe + Phacelia + Sinapis mixture with the least plant height (6.40cm) and root length (2.13cm) compared to the control. The highest germination (40%) and root (57.99%) inhibition rates were observed in Zoe + straw and Zoe + Phacelia + Sinapis, suggesting a significant negative impact of buckwheat exudates on white mustard germination and root development. Hence, the study suggests that buckwheat be employed as a natural bioherbicide in crop rotations and intercropping systems to reduce weed competition and promote high yields.

Keywords: *buckwheat, exudate, germination, seedling growth, root inhibition, sustainable agriculture*

1. INTRODUCTION

In recent years, weed control is a crucial challenge in modern agriculture as uncontrolled weeds can significantly reduce crop yield via competition for soil moisture, nutrients and light (Xuan & Tsuzuki 2004, Rys et al. 2022). Manual and mechanical weed control were reported to be laborious and cost expensive (Verma et al. 2017). Due to these disadvantages, farmers have relied excessively on the use of herbicides which have raised concerns due to soil degradation, herbicide resistance crops and pollution of the environment (Rys et al. 2022). In light of the above, there is a rise in demand for weed management alternatives that are not only cost effective but sustainable and ecologically friendly.

Crops interact with their environment in various ways, one of which through exudation; a chemical compound secreted into the soil that influences soil microbial activities, nutrient availability, soil aggregation and plant growth (Szwed et al. 2014). This phenomenon, referred to as allelopathy (Uddin et al. 2014). The compounds released as exudates in to the soil can inhibit or stimulate the germination and early seedling growth of neighboring and succeeding plants species, depending on their nature and concentration (Mioduszewska et al. 2013). The use of allelopathic crops in sustainable agriculture is gaining increasing attention as a natural means of weed control and increase yield.

Common buckwheat (*Fagopyrum esculentum* Moench) is a crop in the knotweed family Polygonaceae cultivated for its achenes and as a cover crop or intercrop. Buckwheat has been widely recognized for its weed suppressive ability (Falquet et al. 2015). It is a fast-growing plant that is often incorporated into agricultural systems for weed reduction, soil improvement, and erosion control (Kato-Noguchi et al. 2007). The influence of common buckwheat on other plants has been known for hundreds of years

(Kalinova et al. 2005, Kalinova et al. 2007, Jop et al. 2021). Buckwheat tissues contain numerous compounds with potential allelopathic properties (Golisz et al. 2007, Babineau et al. 2017). It is generally believed that buckwheat residues and root exudates release various phenolic acids, flavonoids and alkaloids that are responsible for inhibitory effects on seed germination and seedling growth of susceptible plants (Kalinova & Vrchotova, 2009, Alli, 2013, Falquet et al. 2015). In addition, it has been reported that the suppression of some weeds is caused by the light competition of rapidly growing buckwheat plants (Björkman & Shail 2013).

Szwed et al. (2019) reported that whole buckwheat plant as well as the root residues affected germination, growth, and biomass of several weed species. The stronger allelopathic effect of the buckwheat had roots alone without the aerial parts. They reported that barnyard grass (*Echinochloa crus-galli*), and cleavers (*Galium aparine*) were particularly sensitive to buckwheat root residues in the soil.

Tominaga & Uezu (1995) stated that the inhibition of plant growth by extracts from the soil in which buckwheat grew inhibited root elongation of barnyard grass (*E. crus-galli*) and Purslane (*Portulaca oleracea* L.). Kumar et al. (2008), Gfeller et al. (2018) reported that buckwheat residues in soil suppressed Powell amaranth (*Amaranthus powellii* S. Wats.), pigweed amaranth (*Amaranthus retroflexus* L.), shepherd's-purse (*Capsella bursa-pastoris* L.), and corn chamomile (*Anthemis arvensis* L.).

White mustard (*Sinapis alba* L) is an important member of the Brassicaceae family (Tawaha and Turk, 2003). According to Bicksler & Masiunas, (2009), Björkman and Shail (2013), Björkman et al. (2015), Wiczkowski et al. (2016) white mustard is one species that may be affected by buckwheat root exudates. The crop is commonly used in crop rotations, green manure applications (Tawaha & Turk 2003, Bicksler & Masiunas 2009, Szwed et al. 2019, Mendes Da Silva & Andrade–Vieira 2025). Its early growth stages may be influenced by chemical interactions with neighboring plants such as buckwheat (Szwed et al. 2019). Due to its sensitivity to substances present in the environment, it is one of the recommended species for bioassays evaluating the effects of substances on seedling emergence and seedling growth or vegetative vigour (Mendes Da Silva & Andrade–Vieira 2025). According to Bączek & Halarewicz (2022), common buckwheat strongly inhibits white mustard growth in fields.

A recent study has shown that the presence of another plant species in a location affects the production of root exudates of a given species. When buckwheat recognized the presence of weeds, it changed/increased its production of root exudates in order to impair weed growth. Pigweed seed germination was increased in the presence of buckwheat when they were grown together (Gfeller et al. 2018). Therefore, this study investigated the effect of common buckwheat (*F. esculentum*) grown in post-harvest residues (straw) of wheat, intercropped with grain sorghum (*Sorghum bicolor* (L.) Moench) in a mixture with Lacy phacelia (*Phacelia tanacetifolia*) and white mustard on the germination and seedling growth of white mustard.

2. MATERIALS AND METHODS

2.1 Field experiment with common buckwheat

The field experiment with common buckwheat was carried out from at the Teaching and Research Farm, Faculty of Agriculture and Technology, University of South Bohemia, České Budejovice (48°58′43.15″N and 14°26′54.3″E, 380 m elevation, sandy-loam soil, pH 5.6, average annual temperature 9.7°C, average annual total precipitation 808 mm) during the 2024 cropping season (24th June to 23rd July, 2024).

The treatment involved plots without plants (control), two varieties of common buckwheat (Zoe and Harpe), both varieties intercropped with grain sorghum (variety Ruzrok), mulched with common wheat straw and in mixture with Lacy phacelia and white mustard to give a total 9 treatments. The experiment was laid out in a randomized complete block design with the 9 treatments replicated three times to give a total of 27 plots. The stands were harvested from plots at the late flowering stage of buckwheat.

2.2 Test with white mustard

The study was carried out in plots when the common buckwheat was growing before A seed of white mustard was sown in minimally prepared beds with a spacing of 10 × 20 cm, both inter- and intra-row, 30 days after harvest. A total of 50 plants/plot were involved. The individual testing plot size of 1 × 1m was measured with 1m between plots and replicates. Plantng took place on 2nd August, 2024 when rains were fully established. At 21 days after planting (at stage of fifth true leaves) data were given followng data collected.

2.2.1 Germination count (%)

The germination of the white mustard seeds was evaluated using the formula below:

$$Germination\ count\ (\%) = \frac{\boldsymbol{Number\ of\ germinated\ seeds}}{\boldsymbol{Number\ of\ seeds\ sown}} \text{x} \frac{\mathbf{100}}{\mathbf{1}}$$

2.2.2 Physiological parameters

In each plot, a total of ten plants from two middle rows per plot were tagged for data collection. The parameters measured were:

Plant height (cm)

Plant height was measured with a measuring tape from the soil surface to the apex of the crop where the youngest leaf branches.

Number of leaves/plant

The number of leaves/plant was visually counted.

Total leaf area/plant (cm^2)

The total leaf area/plant was measured from leaves at the middle canopy (fifth fully expanded leaf) using Petiole Pro plant leaf area meter app (Breskinaa & Chuyana 2021) and the value was multiplied by total number of leaves/plant (Nwajei et al. 2019).

Stem girth (cm)

Stem girth per plot was determined using a digital vernier caliper (at 2 cm) above the ground level.

Root length (cm)

After harvesting the plants at 2cm above ground, the root was carefully unearthed and a measuring tape was used to take the length of root from the root tip to the base of the shoot (root- shoot junction).

Chlorophyll determination

The dark green colour index (DGCI) was measured non-destructively, with a hand-held chlorophyll meter (Petiole Pro app) in twenty repetitions per plot from a representative leaf from the middle canopy of the white mustard plant (fifth fully expanded leaf) as Described by Breskinaa & Chuyana (2021).

2.3 Yield

The following yield parameters were measured as follow:

Fresh biomass yield

The fresh biomass yield of the ten plants per plot was determined by harvesting the whole plant at 2 cm above the ground level and weighed. The forage yield was calculated using the formula described by Omoregie and Nwajei (2015), as stated below:

$$\text{Fresh biomass yield (kg/ha)} = \frac{Fresh\ \text{weight (g)}}{\text{Harvested plot area (m}^2)} \times \frac{10000\ (\text{m}^2)}{1000}$$

Dry matter yield

The dry matter weight of the harvested ten plants per plot was determined by oven-drying the plants at 70^0C to a constant weight according to Saifullah et al. (2011) and the values were calculated to kg/ha using the same formula as that used for forage yield.

Fresh root yield

The fresh weight of roots from ten plants per plot was taken using a weighing balance and the weight was further extrapolated to kg/ha according to formula described by Nwajei and Omoregie (2017).

Dry root yield

The dry root yield of the harvested ten plants per plot was determined by oven-drying the fresh roots at 70^0C to a constant weight according to the method of Saifullah *et al*. (2011) and the values calculated to kg/ha.

2.4 Inhibition rate

The inhibitory effect was expressed as relative root length (RRL), germination and root growth inhibition rates as described by (Oueslati et al. 2023). These are expressed mathematically as:

$$Relative\ root\ length\ (\%) = \frac{Root\ length\ in\ treatment}{Root\ length\ inin\ control} \times \frac{100}{1}$$

$$Germination\ inhibition\ rate\ (\%) = \frac{Germination\ in\ control - Germination\ in\ treatment}{Germination\ in\ control} \times \frac{100}{1}$$

$$Root\ inhibition\ rate\ (\%) = \frac{Mean\ root\ length\ in\ treatment\ (cm)}{Mean\ root\ length\ in\ control\ (cm)} \times \frac{100}{1}$$

2.5 Data analysis

All data obtained were analysed using the analysis of variance (ANOVA) using GenStat (2009) 12th edition computer software program. Duncan's Multiple Range Test (DMRT) at 5% level of probability was employed for the post-hoc test when the F – ratio proves significant.

3. RESULTS

3.1 Germination (%)

The results obtained showed that buckwheat root exudates had significantly suppressed the germination of white mustard (Figure 1). Although the control had 100% germination, however, all treatments with buckwheat soil exudates reduced germination. The least was observed in Zoe + straw (60%), representing 40% reduction compared to the control. Other treatments reduced the germination of white mustard from 30.67% (Sole Harpe) to 36.67% (Sole Zoe and Harpe + Sorghum).

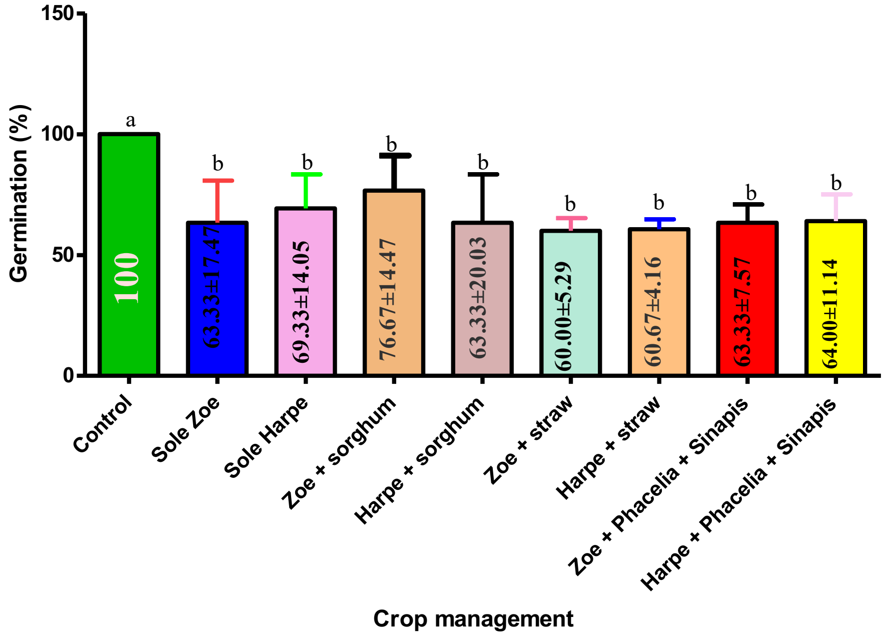


Fig. 1. Effect of buckwheat on germination % of white mustard. Error bars denote the standard deviation. Bars with same letter(s) are not significantly different using DMRT at 5% level of probability.

3.2 Physiological parameters

Plant height (cm)

*Buckwheat had significant negat*ive effect on the plant height of white mustard (Figure 2). The mean height varied from 6.40-12.69cm. The control had the highest plant height (12.69 cm) while Zoe + *Phacelia* + *Sinapis* (6.40 cm) gave the least which indicates the highest reduction of 49.6% shorter than control. Zoe + Sorghum also resulted in a 38.7% white mustard height reduction compared other treatments.

Number of leaves/plant

Data on number of leaves/plant of white mustard showed significant decline from control to the treatment which indicate a stress-induced growth suppression (Figure 2). The control had higher number of leaves/plant (8.97) than the buckwheat treatment. Zoe + *Phacelia* + *Sinapis* (4.87), had a higher reduction (45.7%) of the number of leaves/plant than other treatments with values which varied from 32% to 42%.

Total leaf area/plant (cm^2)

Buckwheat had significant strong inhibitory effects on the total leaf area/plant of white mustard (Figure 3). The control gave a higher total leaf area/plant (78.36 cm^2) while Zoe + *Phacelia* + *Sinapis* (9.62 cm^2) gave the least. This showed a higher reduction of 87.7% in the total leaf area compared to the control.

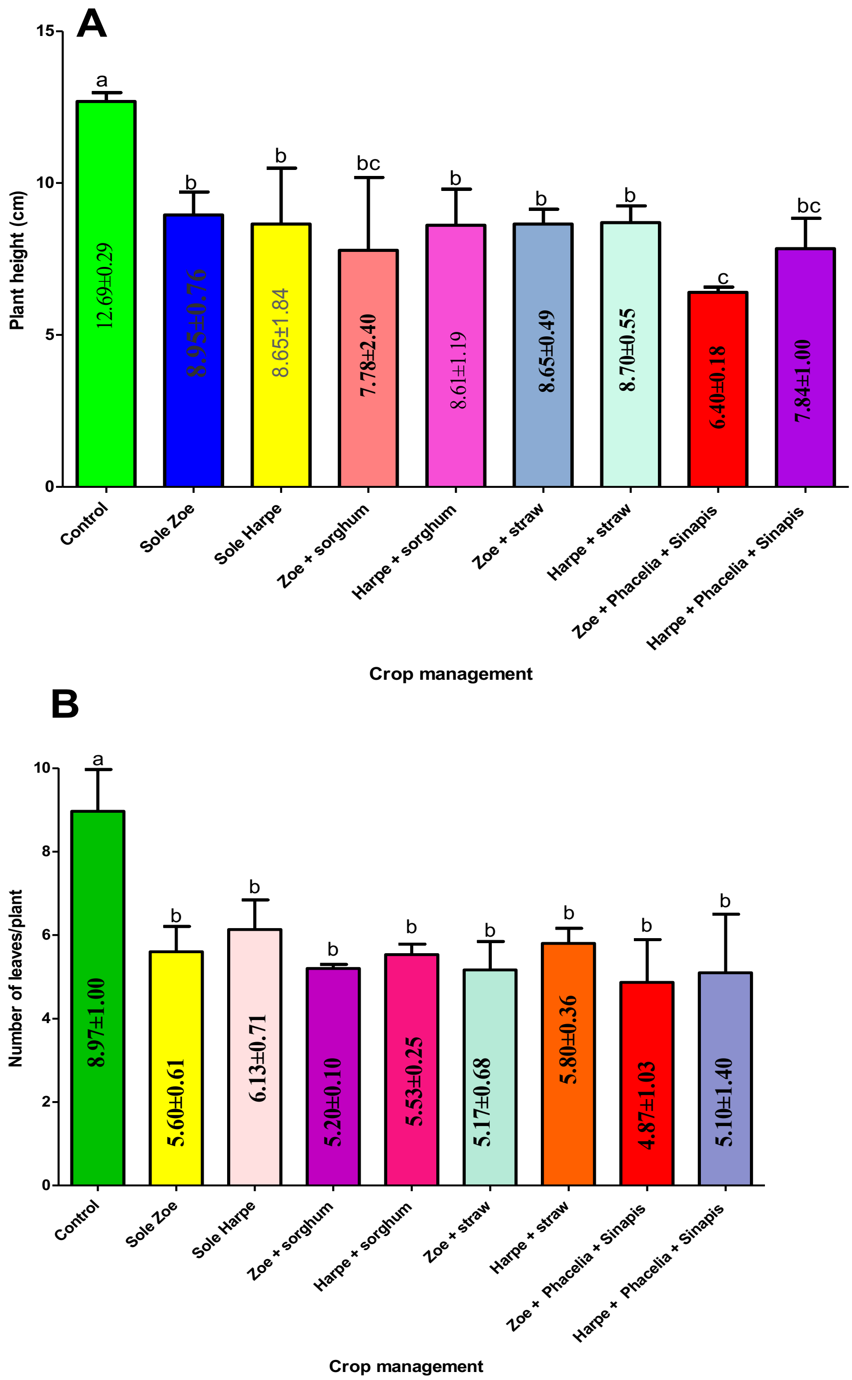


Fig. 2. Effect of buckwheat on the (A) plant height (cm) and (B) number of leaves/plant of white mustard. Error bars denote the standard deviation. Bars with same letter(s) in **A** and **B** are not significantly different using DMRT at 5% level of probability.

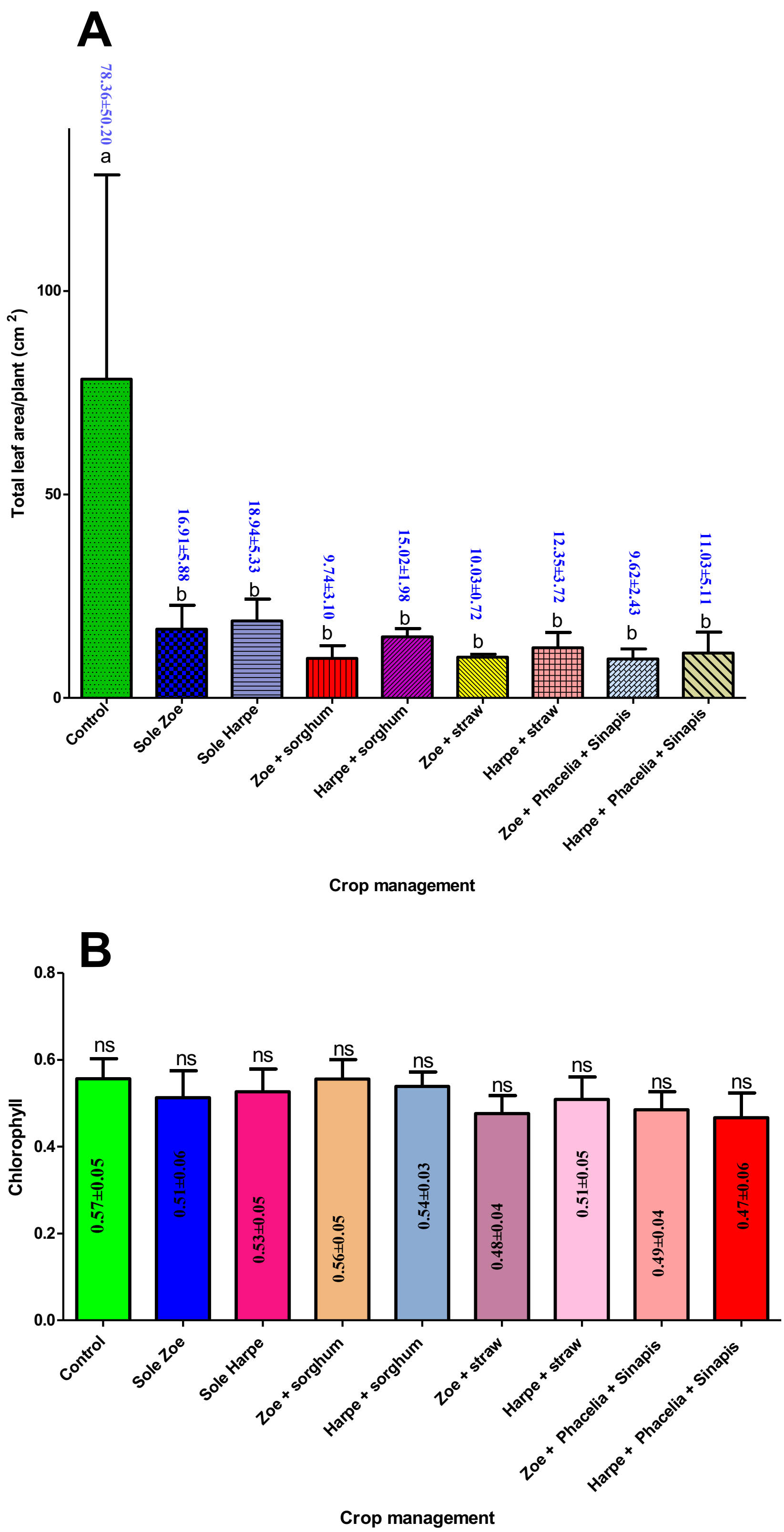


Fig. 3. Effect of buckwheat on (A) total leaf area/plant (cm^2) and (B) chlorophyll of white mustard. Error bars denote the standard deviation. Bars with same letter(s) in are not significantly different using DMRT at 5% level of probability; ns: not significant.

Chlorophyll (Greenness)

The effect of buckwheat on the chlorophyll of white mustard was not significantly different among treatments (Figure 3). The value ranged from 0.48 - 0.56. The control and Zoe intercropped with sorghum jointly had the highest greenness values of 0.56 while Zoe + straw and Harpe + *Phacelia* + *Sinapis* mixture had the least (0.48). The non-significant effect observed indicate that chlorophyll remained stable despite other growth reduction.

Stem girth (cm)

The stem girth of white mustard varied from 0.12-0.33cm (Figure 4). The highest stem girth (0.33cm) was obtained from white mustard without buckwheat exudates while Zoe + sorghum and both varieties mulched with straw had the least (0.12cm). In all, the Zoe + Sorghum treatment significantly reduced the girth of white mustard with 64% than the control.

Root length (cm)

The results in Figure 4 showed that buckwheat root exudates had a significantly suppressed the root length of white mustard. The mean root length varied from 2.13-5.09cm. The control had the highest root length (5.09cm) while Zoe + *Phacelia* + *Sinapis* gave the least (2.13cm). The buckwheat root exudates had a strong root length inhibition which ranged from 37 % to 58% over the control.

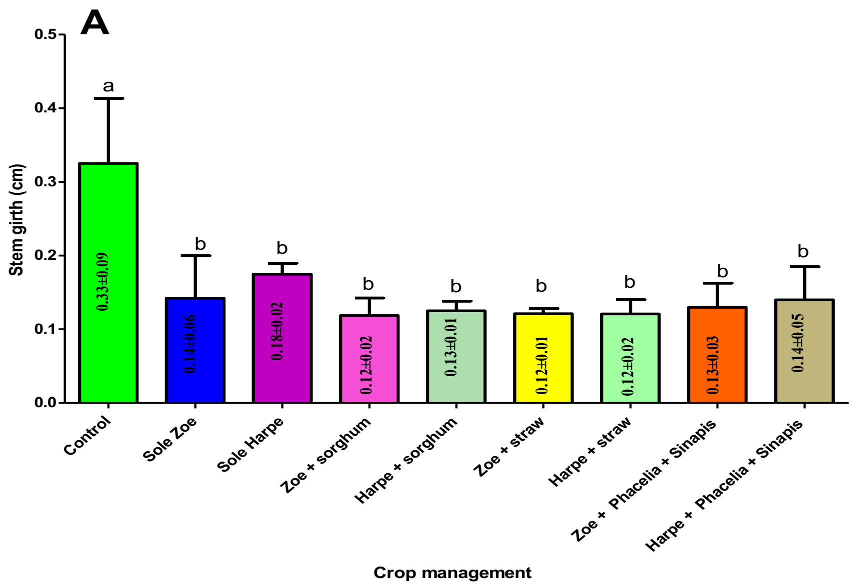
3.3 Yield

Fresh biomass yield

The fresh plant weight of white mustard as influenced by buckwheat soil exudates are shown in Figure 5. Forage weight was highest in the control (273.5 kg/ha) and least (56kg/ha) in Zoe + *Phacelia* + *Sinapis* mixture. The highest reduction (80%) of fresh weight over the control was obtained in Zoe + *Phacelia* + *Sinapis*.

Dry matter yield

Dry matter weight of white mustard followed similar trend with fresh weight with the highest dry matter weight obtained in the control and least in Zoe + *Phacelia* + *Sinapis* mixture (Figure 5). The dry matter yield was reduced among treatments and highest (39.4%) reduction obtained at Zoe + *Phacelia* + *Sinapis*.



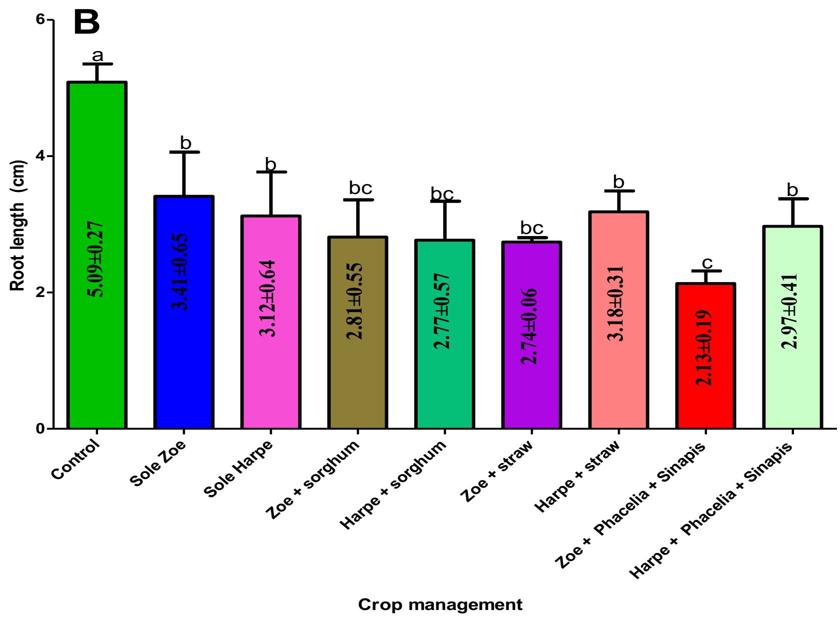


Fig. 4. Effect of buckwheat on the (A) stem girth (cm) and (B) root length (cm) of white mustard. Error bars denote the standard deviation. Bars with the same letters in **A** and **B** are not significantly different using DMRT at 5% level of probability.

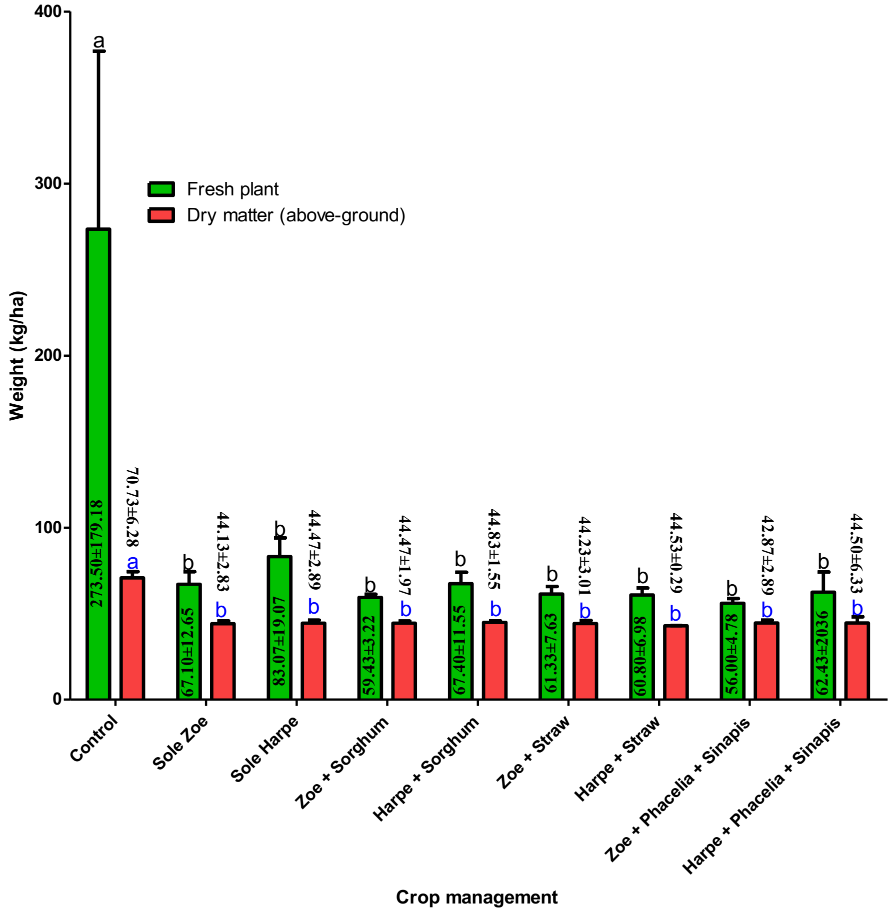


Fig. 5. Effect of buckwheat on the fresh and dry weight of plants (kg/ha) of white mustard. Error bars denote the standard deviation. a. Bars in green colour with same letter(s) are not significantly different. b. Bars in red colour with the same letter are not significantly different using DMRT at 5% level of probability.

Fresh root yield

The results in Figure 6 showed that the buckwheat soil exudates significantly reduced the fresh weight of roots of white mustard across treatments compared to the control. The fresh root weight ranged from 8.23-23.44 kg/ha. Control had the highest fresh root weight (23.44 kg/ha) while Harpe + sorghum had the least (8.23 kg/ha). The least values obtained in Harpe + sorghum treatment showed 65% reduction compared to the control.

Dry root yield

The highest and least dry yield of root obtained from the buckwheat treatments followed similar trends with fresh root weight (Figure 6). The buckwheat treatment showed a great significant suppression on the dry root weight of white mustard which varied from 42.7 % in Harpe + sorghum to 60.9% in Zoe + sorghum.

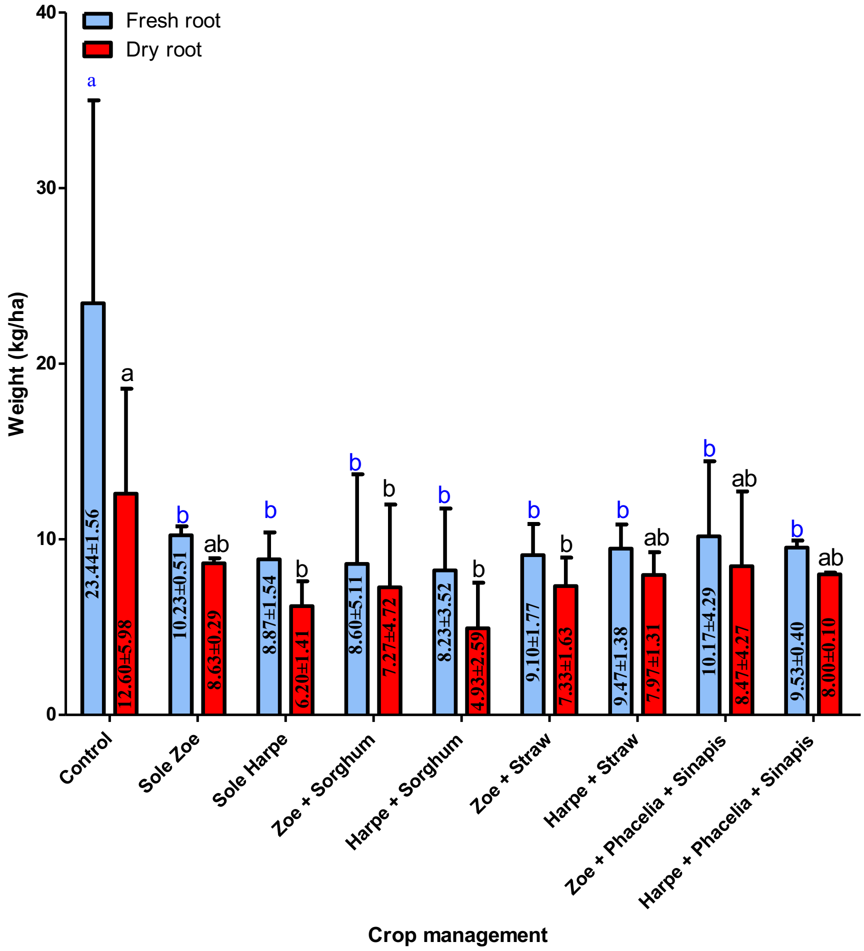


Fig. 6. Effect of buckwheat on the fresh and dry weight of roots (kg/ha) of white mustard. Error bars denote the standard deviation. a. Bars in blue colour with the same letters are not significantly different. b. Bars in red colour with the same letter(s) are not significantly different using DMRT at 5% level of probability.

3.4 Inhibition rates

Relative root length (%)

The effect of buckwheat on the relative root length was significant among treatments (Figure 7). Generally, the treatments significantly reduced the root length of white mustard compared to the control. However, Zoe + *Phacelia* + *Sinapis* mixture had the least relative root length of 42.01% which showed 58% reduction. In all, relative root length from other treatments showed 37% and 47% reduction, compared to the control.

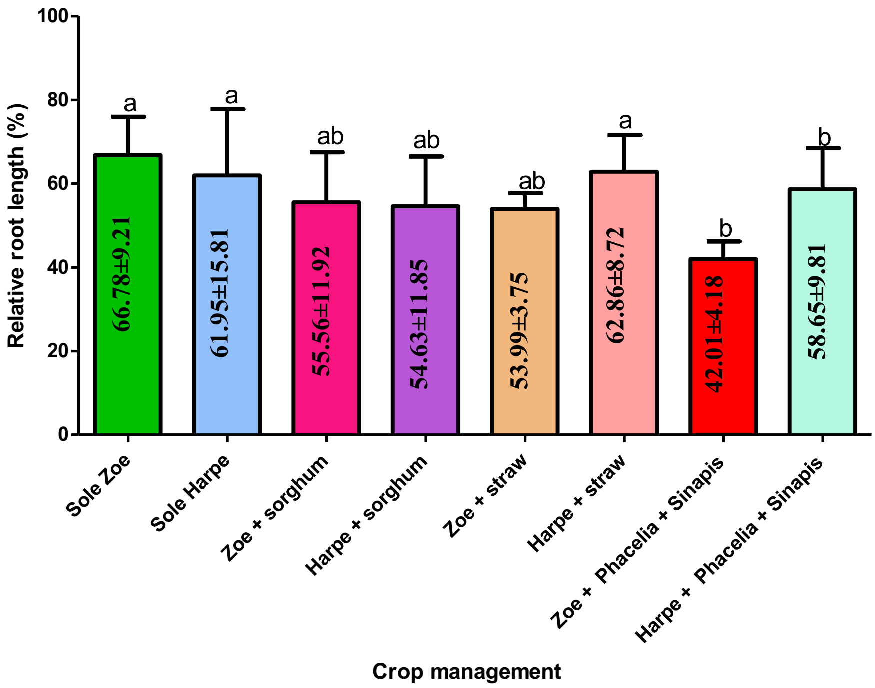


Fig. 7. Effect of buckwheat on the relative root length (%) of white mustard. Error bars denote the standard deviation. Bars with the same letter are not significantly different using DMRT at 5% level of probability.

Germination inhibition rate (%)

The germination inhibition rate of white mustard is shown in Figure 8. The value varied from 23.33 – 40.00%. Zoe mulched with straw had highest value of 40% germination inhibition rate while Zoe + Sorghum had the least (23.33%). Although the Zoe mulched with straw inhibited white mustard germination by 40%, the value was not significantly different from other treatments.

Root inhibition rate (%)

Buckwheat significantly affected the root inhibition rate of white mustard (Figure 8). The value ranged from 33-58%. The highest and least root inhibition rates were obtained from Zoe + *Phacelia* + *Sinapis* and sole Zoe treatments with the values 58% and 33%, respectively. A higher root inhibition was observed in sole Zoe (33%) than other treatments.

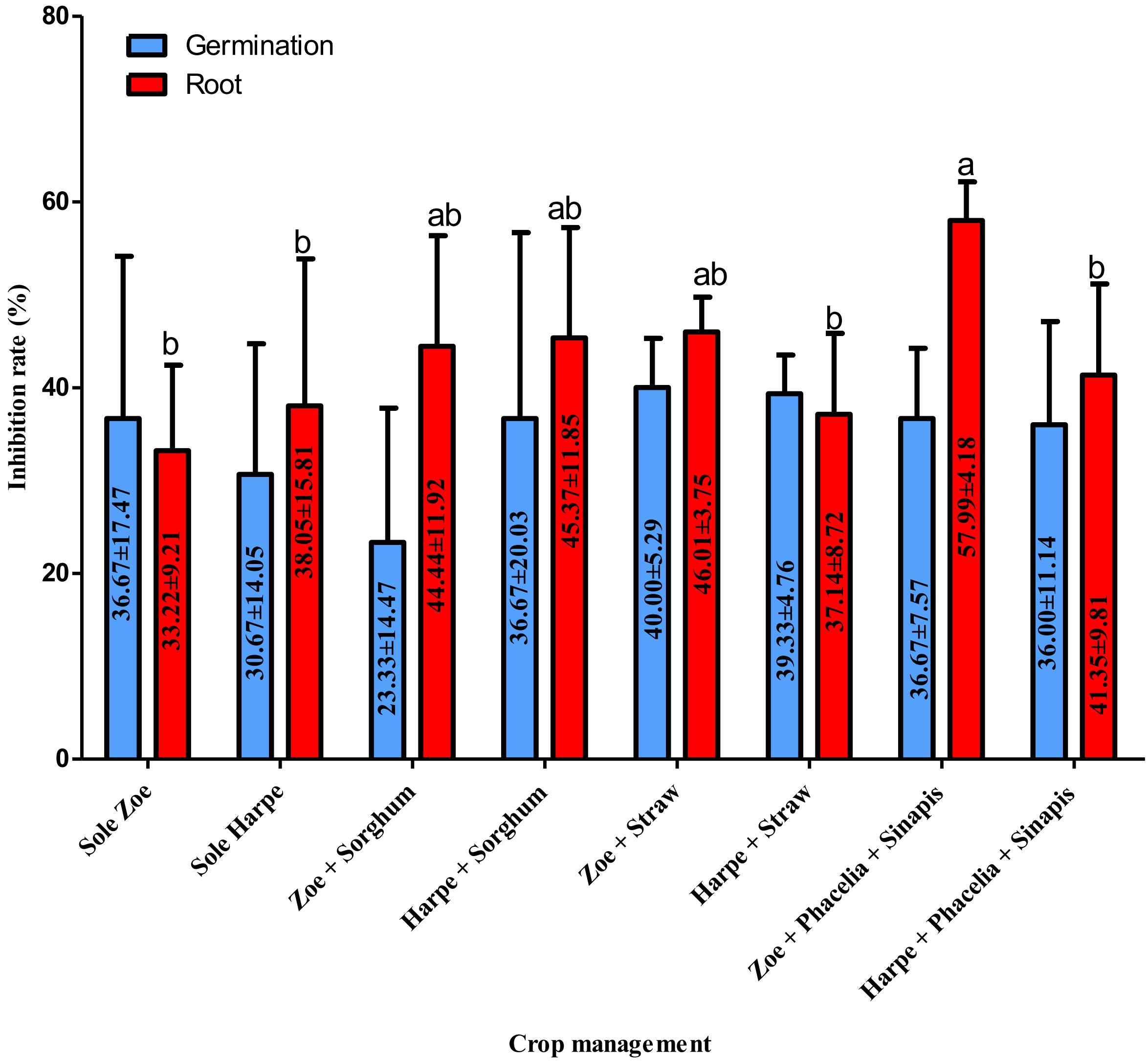


Fig. 8. Effect of buckwheat on the germination and root inhibition (%) of white mustard. Error bars denote the standard deviation. a. Red bars with the different letter(s) are significantly different using DMRT at 5% level of probability; b. Blue bars without letters are not significantly different.

4. DISCUSSION

Effect of buckwheat on the germination of white mustard

Germination is the development of seeds into seedling when conditions are favorable. As observed from the present study, buckwheat soil exudates resulted in reduced germination rates compared to the control (Figures 1). Buckwheat had great inhibitory effects on the germination of white mustard. The findings suggest that chemical compounds released by the buckwheat during growing seasons interfere with seed metabolic processes, likely by disrupting water uptake or enzyme activity (Rys et al. 2022). This finding aligns with the previous studies by Bicksler & Masiunas (2009), Gfeller et al. (2018) who reported that buckwheat release allelochemicals that suppress seed germination.

Effect of buckwheat on the plant height of white mustard

Plant height is an important characteristic in the assessment of growth and development of crops. The height of white mustard was significantly reduced by the buckwheat and most pronounced in Zoe + *Phacelia* + *Sinapis* treatment (50%) compared to the control (Figure 2). This may be due to the fact that buckwheat allelochemicals can limit cell elongation and division in young seedling leading the reduced growth. This reduction in plant height is consistent with previous findings by Kato-Noguchi et al. (2007), Rys et al. (2022) where buckwheat residues negatively impacted the growth of various plant species.

Effect of buckwheat on the number of leaves/plant of white mustard

The significant reduction was determined in the number of leaves/plant of white mustard (Figure 2). May be due to buckwheat exudates which may have interfered with the photosynthetic activity and cell division processes needed for the formation of leaves. Kato-Noguchi et al. (2007), Rys et al. (2022) stated that allelochemicals produced by buckwheat may inhibit meristematic activity which reduces the initiation and development of young leaves. Iqbal et al. (2002), Kato-Noguchi et al. (2007), Kato-Noguchi (2022) reported that allelopathic compounds such as phenolic acids and flavonoids have been shown to inhibit meristematic activity, which reduces the initiation and development of new leaves. This finding is in line with the results of the present study.

Effect of buckwheat on the total leaf area of white mustard

Leaf area performs a physiological duty such as photosynthesis efficiency, dry matter accumulation, transpiration, nutrient absorption and competition (Rys et al., 2022). Allelochemicals released by plants can suppress leaf area by inhibiting growth. Reduction in total leaf area can impact on the ability of plants to produce assimilates and lower dry matter accumulation and reduced yield. The significant reduction observed in the total leaf area per plant of white mustard is an indication that the buckwheat exudates may have inhibited cell division and leaf tissue expansion leading to lower leaf growth compared to the control (Figure 3). This corresponds with the earlier report by Wiczkowski et al. (2016), Szwed et al. (2019) that plant exudates significantly reduced the leaf area of weed species, there by altering the endogenous hormone level resulting in restricted leaf expansion and canopy formation.

Effect of buckwheat on the chlorophyll content of white mustard

The intensity of green color in leaves, often measured as Dark Green Color Index (DGCI) or chlorophyll content, is an indicator of plant health, nitrogen status, and overall photosynthetic efficiency. Buckwheat significantly affected the growth of white mustard, but their impact on chlorophyll content was insignificant (Figure 3). This may be that the allelochemicals may have targeted the root and shoot elongation rather than chlorophyll biosynthesis. The relatively stable chlorophyll levels observed in white mustard suggest that the crop could slightly compensate for growth suppression by maintaining steady photosynthesis in their existing leaves. This finding agreed with Bączek and Halarewicz (2022), Vieites-Álvarez et al. (2024) who found that long term exposure of white mustard to allelochemical affected chlorophyll synthesis, leading to reduced photosynthetic efficiency and overall plant growth.

Effect of buckwheat on the stem girth of white mustard

Stem girth refers to the thickness of plant stem which play an important role in water transport and resistance or susceptibility to lodging conditions. The significant reduction in stem girth (up to 63.6%) indicates that buckwheat may have allelochemicals capable of suppressing secondary growth, nutrient transport, and hormonal balance in white mustard (Figure 4). There was 50-64% girth size reduction from the treatments which shows that buckwheat soil exudates had weakened the stem development. The findings suggest that buckwheat residues can suppress vascular tissue development and structural integrity, making plants more susceptible to environmental stress. Similarly, Ahmad Nazarudin et al. (2007) found a significant reduction (48.6%) in xylem thickness of *Syzygium myrtifolium* after application of pesticide paclobutrazol and this substance can also inhibit stem girth by affecting vascular tissue development.

Zoe in mixture with *Phacelia* and *Sinapis* treatment impacted higher inhibitory effects than the Harpe variety at other treatments. Kalinova (2008) reported significant varietal differences in the allelopathic potential of common buckwheat, suggesting that certain buckwheat varieties may have stronger inhibitory effects on the growth of other plants.

Effect of buckwheat on the root length of white mustard

Root length refers to the total extension of a plant's root system, which assist the plant in the absorption of water, nutrient and anchorage. Longer roots provide a greater soil exploration capacity, leading to improved nutrient and water uptake, especially in competitive or stressful environments. Buckwheat negatively affected the root length of white mustard (Figure 4). This may be due to the fact that the buckwheat can reduced root meristem activity other plants resulting in the inhibition of water and nutrient absorption, thereby restricting root development. Similar findings have been reported by Falquet et al. (2015), Gfeller et al. (2018) who observed that allelopathic compounds from buckwheat reduced root length in plant species, limiting their establishment and growth.

Effect of buckwheat on the forage and dry matter yield of white mustard

The strong inhibition and suppression of the biomass yield *of* white mustard (Figure 5) under buckwheat soil exudates could be linked to the reduced growth characteristics. The highest values of 80% decrease in fresh biomass yield and a 39.4% decrease in dry biomass yield were observed in the treatment Zoe + *Phacelia* + *Sinapis.* The low biomass yield of white mustard observed was due the inhibited growth characteristics by buckwheat exudates. Iqbal et al. (2003) found that buckwheat variety Hashikami-wase suppressed the growth of plants, potentially affecting fresh and dry matter yields in weed species. Kumar-Tiwari and Dongre (2022) found shoot biomass of mustard to be significantly reduced by the applied extracts of weed species. This agreed with results of the present study.

Effect of buckwheat on the fresh and dry root of white mustard

The significant decline in both fresh and dry root weights of white mustard suggests that allelochemicals present in buckwheat soil exudates may have affect root development in of the crop (Figure 6). The buckwheat may have interfered with the hormonal regulation, leading to suppressed root expansion, nutrient uptake efficiency and biomass accumulation. Similar finding was reported by Kumar-Tiwari and Dongre (2022), and they attributed the suppression to allelochemicals in weed extracts.

Effect of buckwheat on the relative root length of white mustard

Relative root length is a measure of root growth in treated plants compared to the control, expressed as a percentage. It indicates the extent to which root elongation is inhibited or promoted under specific environmental conditions, such as exposure to allelopathic compounds. The significant reduction in RRL, particularly, in Zoe + *Phacelia* + *Sinapis* mixture may be due to the allelopathic compounds in the buckwheat (Figure 7). Tsuzuki & Dong (2003), Szwed et al. (2019) in a similar study found that buckwheat reduced the root growth of crops due to the released allelochemicals.

Effect of buckwheat on the germination and root Inhibition rates of white mustard

Inhibition refers to the percentage or extent to which a particular process or growth is suppressed or hindered by an external factor(Bączek & Halarewicz 2022). In plants, the inhibition rate often refers to the reduction in growth such as germination or root length caused by substances like allelopathic compounds or other environmental factors. Generally, germination inhibition rate takes in to account the germination of seeds when exposed to substances that prevent seeds from sprouting. Root inhibition on the other hand indicate reduction in root growth due to the presence of inhibitory substances like soil exudates from other plants. The mixture of Zoe + *Phacelia* + *Sinapis* had stronger root inhibition (58%) due to the presence of buckwheat exudates (Figure 8). The presence of buckwheat in mixture with weeds and mulched with straws gave a stronger root inhibition than the intercrop with sorghum which produce a moderate effect. The highest germination inhibition rate (40%) observed in Zoe + straw may be due to the plant exudates in the soil. Similar findings were reported by Kato-Noguchi et al. (2007), Kato-Noguchi (2022) that germination and root growth of weeds were suppressed due to sensitivity of the buckwheat exudates.

5. CONCLUSION

The buckwheat soil exudates had significant effects on the germination and seedling growth of *white mustard*. There was significant reduction in germination, plant height, leaf development, root length, and biomass accumulation which indicates the inhibitory potential of buckwheat. The strongest inhibitory effects were observed in the treatment after growing of mixture common buckwheat + Lacy phacelia + white mustard as well as in the treatment common buckwheat + wheat straw, compared to other treatments. Unfortunately, we did not observe any statistically significant effect of co-cultivation of buckwheat with sorghum or with wheat straw on the accumulation of inhibitory substances in the soil and subsequently on the growth of the test plant white mustard. We determined only statistically significant effect of co-cultivation of buckwheat with *Phacelia* + *Sinapis* on height, root length, and root dry matter of white mustard. Further studies on the allelopathic effect of buckwheat should be conducted with a major focus to identify the specific compounds responsible for these effects and exploring the appropriate strategies when considering weed management in agricultural system.

REFERENCES

Ahmad Nazarudin, MR, Mohd Fauzi, R & Tsan, FY 2007, 'Effects of paclobutrazol on the growth and anatomy of stems and leaves of *Syzygium campanulatum*', *Journal of Tropical Forest Scienc*e, vol. 19, no.2, pp. 86-91.

Ali, KA 2013, 'Allelopathic potential of some crop plant species on bread wheat (*Triticum aestivum*) using equal compartment agar method', *Journal of Agriculture and Veterinary Science,* vol. 2, pp. 52–55.

Babineau, M, Mathiassen, SK, Kristensen, M & Kudsk, P 2017, 'Fitness of ALS-Inhibitors Herbicide Resistant Population of Loose Silky Bentgrass (*Apera spica-venti*)', *Frontiers in Plant Science*, vol. 8, pp. 1660-1673, https://doi.org/10.3389/fpls.2017.01660

Bączek, P & Halarewicz, A 2022, 'Allelopathic effect of black cherry (*Prunus serotina* Ehrh.) on early growth of white mustard (*Sinapis alba* L.) and common buckwheat (*Fagopyrum esculentum* Moench): Is the invader a threat to restoration of fallow lands?' *Agronomy*, vol. 12, no. 9, pp. 2103-2113. https://doi.org/10.3390/agronomy12092103

Bicksler, AJ & Masiunas, JB 2009, 'Canada thistle (*Cirsium arvense*) suppression with buckwheat or sudangrass cover crops and mowing', *Weed Technology*, vol. 23, no. 4, pp. 556–563, https://doi.org/10.1614/WT-09-050.1

Björkman, T & Shail, JW 2013, 'Using a buckwheat cover crop for maximum weed suppression after early vegetables', *Horticultural Technology,* vol. 23, no. 5, pp. 575–580, https://doi.org/10.21273/HORTTECH.23.5.575

Björkman, T, Lowry, C, Shail, JW, Brainard, DC, Anderson, DS & Masiunas, JB 2015, 'Mustard cover crops for biomass production and weed suppression in the Great Lakes Region', *Agronomy Journal*, vol. 107, no. 4, pp. 1235–1249, https://doi.org/10.2134/agronj14.0461

Breskinaa., GM & Chuyana, NA 2021, 'The Role of Biological Products and Nitrogen Fertilizers in the Formation of Buckwheat Productivity under Conditions of the Kursk Region' *Russian Agricultural Sciences*, Vol. 47, No. 3, pp. 256–260.

Falquet, B, Gfeller, A, Pourcelot, M, Tschuy, F & Wirth, J 2015, 'Weed suppression by common buckwheat: A Review', *Environment Control in Biology*, vol. 53, no. 1, pp. 1–6. https://doi.org/10.2525/ecb.53.1

GenStat 2009, GenStat for windows (12th ed.), VSN International. Retrieved from https://www.vsni.co.uk

Gfeller, A, Glauser, G, Etter, C, Signarbieux, C & Wirth, J 2018, '*Fagopyrum esculentum* alters its root exudation after *Amaranthus retroflexus* recognition and suppresses weed growth', *Frontiers in Plant Science*, vol. 9, pp. 50-63, https://doi.org/10.3389/fpls.2018.00050

Golisz, A, Gawronska, H & Gawronski, SW 2007, 'Influence of buckwheat allelochemicals on crops and weeds', *Allelopathy Journal,* vol. 19, no. 2, pp. 337–349.

Iqbal, Z, Hiradate, S, Noda, A, Isojima, S & Fujii, Y 2002, 'Allelopathy of buckwheat: Assessment of allelopathic potential of extract of aerial parts of buckwheat and identification of fagomine and other related alkaloids as allelochemicals', *Weed Biology and Management*, vol. 2, no. 2, pp. 110–115, https://doi.org/10.1046/j.1445-6664.2002.00055.x

Iqbal, Z, Hiradate, S, Noda, A, Isojima, S & Fujii, Y 2003, 'Allelopathic activity of buckwheat: Isolation and characterization of phenolics', *Weed Science*, vol. 51, no. 5, pp. 657–662, https://doi.org/10.1614/0043-1745(2003)051[0657:AAOBIA]2.0.CO;2

Jop, B, Wawrzyńczak, K, Polaszek, K & Synowiec, A 2021, 'Analysis of the Sensitivity of Spring Wheat and White Mustard Seedlings to the Essential Oil of Parsley Seeds, The 1st International Electronic Conference on Agronomy', *Biology and Life Sciences Forum*, vol. 3, no. 12, pp. 1-5, https://doi.org/10.3390/IECAG2021-09710

Kalinova, J, Triska, J & Vrchotova, N 2005, 'Biological activity of phenolic compound present in buckwheat plants', *Allelopathy Journal*, vol. 16, pp. 123–129.

Kalinova, J, Vrchotova, N & Triska, J 2007, 'Exudation of Allelopathic Substances in Buckwheat (*Fagopyrum esculentum* Moench)', *Journal of Agricultural and Food Chemistry*, vol. 55, no. 16, pp. 6453–6459, https://doi.org/10.1021/jf070795u

Kalinova, J 2008, 'Varietal differences in allelopathic potential of common buckwheat (*Fagopyrum esculentum* Moench)', *Cereal Research Communications,* vol. 36, no. 3, pp. 397–408, https://doi.org/10.1556/CRC.36.2008.3.4

Kalinova, J & Vrchotova, N 2009, 'Level of catechin, myricetin, quercetin and isoquercitrin in buckwheat (*Fagopyrum esculentum* Moench), Changes of their levels during vegetation and their Effect on the growth of selected weeds', *Journal of Agricultural and Food Chemistry*, vol. 57, no. 7, pp. 2719–2725, https://doi.org/10.1021/jf803633f

Kato-Noguchi, H, Sugimoto, H & Yamada, M 2007, 'Buckwheat seedlings may inhibit other plant growth by allelopathic substances', *Environment Control in Biology*, vol. 45, no. 1, pp. 27–32. https://doi.org/10.2525/ecb.45.27

Kato-Noguchi, H 2022, 'Allelopathy and Allelochemicals of *Imperata cylindrica* as an invasive plant species', *Plants*, vol. 11, no. 9, pp. 2551-2556, https://doi.org/10.3390/plants11192551

Kumar, V, Brainard, DC & Bellinder, RR 2008, 'Suppression of powell amaranth (*Amaranthus Powellii*), Shepherd's-purse (*Capsella Bursa-pastoris*), and corn chamomile (*Anthemis arvensis*) by buckwheat residues: Role of nitrogen and fungal pathogens', *Weed Science,* vol. 56, no. 2, pp. 271–280, https://doi.org/10.1614/WS-07-106.1

Kumar-Tiwari, H & Dongre, PN 2022, 'Allelopathic Interference of weeds on brown mustard in pot culture', *Ecology, Environment and Conservation*, vol. 28, pp. 11–15, https://doi.org/10.53550/EEC.2022.v28i07s.003

Mendes Da Silva, L & Andrade –Vieira, LF 2025, 'Ecotoxicological bioassays with terrestrial plants: A holistic view of standards, guidelines, and protocols', *Journal of Toxicology and Environmental Health, Part B*, vol. 28, no. 3, pp. 183–221, https://doi.org/10.1080/10937404.2024.2440876.

Mioduszewska H, Klocek, J, Horbowicz, M & Wolska, K 2013, 'Effect of water extracts from tissues of common buckwheat on seed germination and seedlings growth of winter wheat and lettuce', *Acta Scientiarum Polonorum, Agricultura,* vol. 12, pp. 45–54.

Nwajei, SE, Omoregie, AU Ogedegbe, F.O. (2019). Effects of planting dates on the growth and grain yield of two indigenous varieties of pearl millet (*Pennisetum glaucum* (L.) R.Br.) in a forest-savanna transition zone of Edo State, Nigeria, *Acta Agriculturae Slovenica*, vol. 114, no. 2, pp. 69–181, doi:10.14720/aas.2019.114.2.3

Omoregie, AU & Nwajei, SE 2015, 'Evaluation of some varieties of pearl millet (*Pennisetum typhoides*) in a forest-savanna transition zone of Edo State, Nigeria'. In: Omeje, SI, Emosairue, CC, Chukwuji, CC, Bratte, L, Isikwenu, JO, Iaiorhovoja, RA, Agbogidi, MO (eds.), Agriculture: The Nigerian economy beyond oil, *Proceedings of the 49th Annual Conference of the Agricultural Society of Nigeria held at Delta State University, Asaba Campus,* Agricultural Society of Nigeria, Asaba, Nigeria, pp. 1346-1349.

Oueslati, O, Yahyaoui, M, Hamdi, R & Ben-Hammouda, M 2023, 'Allelopathy and weed control ability of three cover crops residues, in conservation of agriculture', *Bangladesh Journal of Botany*, vol. 52, no. 3, pp. 845–852, https://doi.org/10.3329/bjb.v52i3.68933

Rys, M, Saja-Garbarz, D & Skoczowski, A 2022, 'Phytotoxic effects of selected herbal extracts on the germination, growth and metabolism of mustard and oilseed rape', *Agronomy*, vol. 12, no. 1, pp. 110, https://doi.org/10.3390/agronomy12010110

Saifullah, AJ, Fazalmunsf, MA, Hamayoon, K, Kawsar, A, Muhammad, W & Abid, A 2011, 'Performance of millet varieties under different irrigation levels', *Sarhad Journal of Agriculture* vol. 27, pp. 1-6.

Szwed, M, Sławianowska, J, Koczkodaj, D, Mitrus, J, Sytykiewicz, H & Horbowicz, M 2014, 'Allelopathic properties of extracts and some metabolites present in the tissues of common buckwheat (*Fagopyrum esculentum* Moench) seedlings', *Acta Scientiarum Polonorum, Agricultura* vol.13, pp. 139–151.

Szwed, M, Wiczkowski, W, Szawara-Nowak, D, Obendorf, RL & Horbowicz, M 2019, 'Allelopathic influence of common buckwheat root residues on selected weed species', *Acta Physiologiae Plantarum*, vol. 41, no. 6, 92-101, https://doi.org/10.1007/s11738-019-2885-y

Tawaha, AM & Turk, MA 2003, 'Allelopathic effects of black mustard (*Brassica nigra*) on germination and growth of wild barley (*Hordeum spontaneum*)', *Journal of Agronomy and Crop Science*, vol. 189, no. 5, pp. 298–303, https://doi.org/10.1046/j.1439-037X.2003.00047.x

Tominaga T & Uezu, T 1995, 'Weed suppression by buckwheat. In: T. Matano, A. Ujihasa (Eds.). Current advances in buckwheat research', *Proceedings of the 6th international symposium of buckwheat, Nagano, Japan*, vol. 2, pp. 693–697.

Tsuzuki, E & Dong, YJ 2003, 'Buckwheat Allelopathy use in weed management', *Allelopathy Journal* vol. 12, pp. 1-12.

Uddin, MN, Robinson, RW & Caridi, D 2014, 'Phytotoxicity induced by *Phragmites australis*: An assessment of phenotypic and physiological parameters involved in germination process and growth of receptor plant', *Journal of Plant Interactions*, vol. 9, no.1, pp. 338–353. https://doi.org/10.1080/17429145.2013.835879

Verma, SK, Prasad, SK, Kumar, S, Singh, SB, Singh, RP & Singh, YV 2017, 'Effect of mulching and herbicides on weeds, yield and economics of greengram (*Vigna radiata* L.) grown under eight-year old agri-horti system', *Research on Crops,* vol. 18, no. 3, pp. 438-443. https://doi.org/10.5958/2348-7542.2017.00076.6

Vieites-Álvarez, Y, Reigosa, MJ & Sánchez-Moreiras, AM 2024, 'A decade of advances in the study of buckwheat for organic farming and agroecology (2013-2023)', *Frontiers in Plant Science*, vol. 15, pp. 1-20, https://doi.org/10.3389/fpls.2024.1354672.

Wiczkowski, W, Szawara-Nowak, D, Sawicki, T, Mitrus, J, Kasprzykowski, Z & Horbowicz, M 2016, 'Profile of phenolic acids and antioxidant capacity in organs of common buckwheat sprout', *Acta Alimentaria*, vol. 45 no. 2, pp. 250–257, https://doi.org/10.1556/066.2016.45.2.12

Xuan, TD & Tsuzuki, E 2004, ‘Allelopathic plants: buckwheat (*Fagopyrum spp.*)’, *Allelopathy Journal,* vol. 13, pp. 137–148.