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THE INFLUENCE OF FERTILISATION ON THE YIELD AND ANTIOXIDANT CAPACITY OF COMMON AND TARTARY BUCKWHEAT

SUMMARY

Buckwheat is an annual plant in the Polygonaceae family that is classified as a pseudocereal. It is mainly used as a source of antioxidants and gluten-free foods. Buckwheat yield and quality depend on genetic properties, environmental conditions, and cultural practices. Therefore, this study aimed to determine the effects of organomineral fertiliser on buckwheat yield and antioxidant activity in the environmental conditions of Bosnia and Herzegovina. The treatments used in this research consisted of a combination of fertilisers (fertilised and non-fertilised) and two buckwheat species (common and tartary buckwheat). During 2019, two field experiments were conducted in Butmir and Kakanj (B&H). The tested properties were plant height, a mass of 1000 kernels, yield, total phenolic, and antioxidant activity of leaves, flowers, and kernels. Yield depended on the treatment, ranging from 946.9 kg ha^{-1} to 1438.6 kg ha^{-1}. The total phenol contents were affected by fertiliser treatment, buckwheat species, and plant organs. The kernel had the lowest total phenol content (30.55 mg GAE g^{-1}), whereas the flowers had the highest content (158.03 mg GAE g^{-1}).

Keywords: tartary buckwheat, common buckwheat, organomineral, fertiliser, antioxidant capacity, yield

INTRODUCTION

Buckwheat is an annual plant in the Polygonaceae family that is classified as a pseudocereal. Although there are 23 different species of buckwheat in the world, only common (*Fagopyrum esculentum* Moench) and tartary buckwheat (*Fagopyrum tataricum* Gaertn) are cultivate (Gavrić *et al.,* 2018). Buckwheat is mainly grown on all continents. On the other hand, tartary buckwheat is grown at higher altitudes, including in China, Bhutan, India, Nepal, Slovenia, and

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Luxembourg (Luthar *et al.,* 2020). Although both species of buckwheat have a similar morphology and growing practise, there are some differences. For example, tartary buckwheat, compared to common buckwheat has various advantageous traits, such as cold tolerance, self-pollination ability, and better kernel yield (Tsuji *et al.,* 2000). Buckwheat is commonly referred to as a pseudocereal. It is an excellent food source of nutrients for humans. The flour made from buckwheat is gluten free (Siqueira *et al.*, 2020) and contains a balanced amino acid composition, with arginine and lysine particularly abundant (Gavrić *et al.,* 2018; Nicolic *et al.,* 2019). Additionally, buckwheat flour has a higher fiber content than other cereals (Shruti *et al.*, 2015).

Because of buckwheat's positive impact on human health, buckwheat has recently grown in popularity in human nutrition. Several studies have demonstrated that buckwheat intake affects the treatment and prevention of numerous illnesses, including diabetes (Qiu *et al*., 2016), cardiovascular disorders, arterial hypertension (Llanaj *et al.,* 2022), and cancer (Dziedzic *et al.*, 2018; Noreen *et al.,* 2021). The therapeutic properties of buckwheat are the result of its high antioxidant potential. Buckwheat's antioxidant potential is due to its high phenolic content (Guo *et al.,* 2011). Total phenols are found mainly in all plant organs (leaves, flowers, kernel, stem, root). Their content depends primarily on the species of buckwheat. Also, many environmental factors, including aridity, salinity, ultraviolet radiation, altitude, weather, etc., significantly affect the production of these components (Sharma *et al*., 2019; Valle *et al*., 2020). On the other hand, cultural practices directly alter the environment, affecting plant quality and productivity (Gadžo *et al.,* 2016). For example, one of the more frequent cultural practices is the application of fertilisers, which significantly affects the growth, development, yield, and quality of plants.

Buckwheat can be grown with small doses of organic and mineral fertilisers. Organic fertiliser positively impacts soil structure and contains all macro and micronutrients. However, the main disadvantages of organic fertilisers are their lack of nutrients and the slow decomposition of organic materials (Hirzel *et al.,* 2018; Yürürdurmaz, 2022). On the other hand, mineral fertilisers are available to plants and contain significant concentrations of macronutrients, allowing for excellent yields. However, applying these fertilisers, especially in high quantities, negatively affects the environment, including reduced soil microbial biodiversity and surface and subsurface water contamination (Timsina, 2018). Thus, both organic and mineral fertilisers have certain benefits and drawbacks. Recently, organomineral fertilisers are also used in plant cultivation. Organomineral fertilisers combine the advantages of organic and mineral fertilisers (Ojo, Olowoake and Obembe, 2014).

Additionally, a few authors' research (Corrêa *et al*., 2016; Da Rosa *et al*., 2022; Gavrić *et al.*, 2021) has shown that adding organomineral fertilisers to certain crops improves their growth. However, although the use has expanded considerably in some parts of the world, little has been studied in the environmental conditions of Bosnia and Herzegovina (B&H). In this context, hypothesis of this study is that the applied organomineral fertiliser will increase buckwheat yield and antioxidant activity. Therefore, this work aims to influence of organomineral fertilisers on buckwheat yield and antioxidant activity in the environmental conditions of B&H.

MATERIAL AND METHODS

Experiment location

Two field experiments (Kakanj and Butmir, B&H) (Figure 1) were conducted in 2019. The first field experiment was carried out in Kakanj, B&H (44°07'30.1 "N, 18°07'42.3"E; 400 m a.s.l.) at a private farm called Gavrić. The second field experiment was performed in Sarajevo, B&H, at the Faculty of Agriculture and Food Science (43°49'34.42" N, 18°19'18.48" E; 505 m a.s.l.).

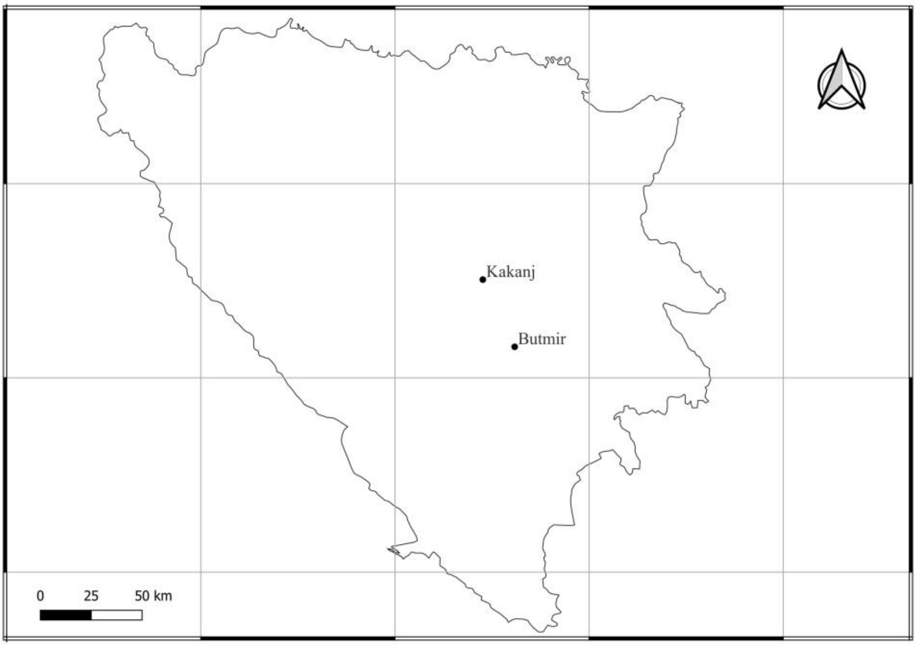

Figure 1. The locations of field experiments

Meteorological data sources

This research used data from two regional meteorological stations (Zenica and Butmir) of the Federal Hydrometeorological Institute, B&H (FHMZ, 2022). The study used data for the average monthly air temperature and precipitation amount. Figure 1 presents the climate data collected from regional meteorological stations. Mean monthly temperatures differed between the two study locations and the reference period (1961–1990). For example, the average temperature in Zenica (location Kakanj) during the growing season of 2019 (June–August) was 3.5°C warmer than it was reference period (1961–1990) (Figure 2). At the same study location, there was 58.7 mm more precipitation than in the reference period

(1961-1990). Similar weather were recorded at another location. The results demonstrate that Sarajevo (location Butmir) experienced above-average temperatures during the growing season. The average temperature ranged from 21.0 in July to 21.9 in August. During the same period (June to August), 234.6 mm of rain fell, about the same as the reference period.

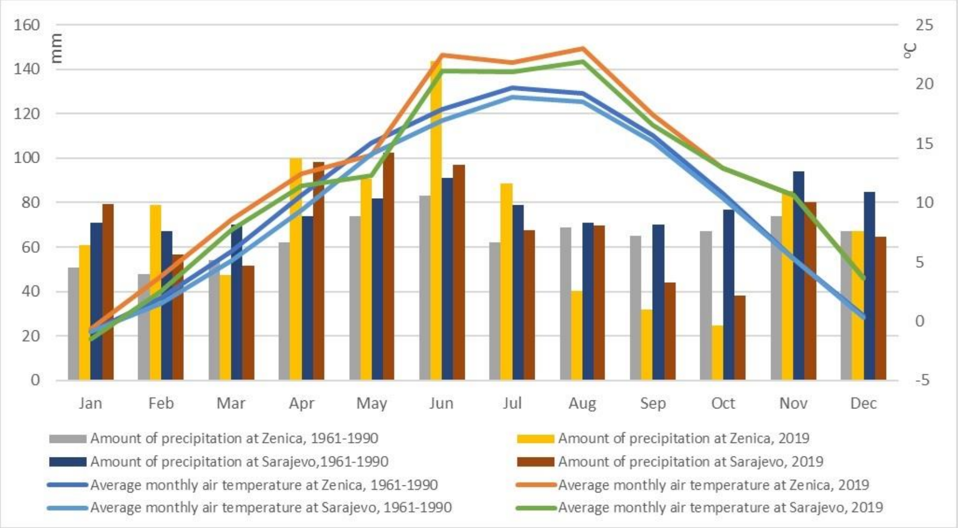

Figure 2. Average monthly temperatures and amount of rainfall

Treatments and experiment design

The treatments used in this research consisted of a combination of fertilisers (fertilised and non-fertilised) and two buckwheat species (common and tartary buckwheat). Common buckwheat (*Fagopyrum esculentum* Moench, cv. Darja) from Slovenia and tartary buckwheat (*Fagopyrum tataricum* Gaertn) from Luxembourg were used for sowing. Organomineral fertiliser (Humus 20 Goldfert) was applied at a rate of 250 kg ha^{-1}. The fertiliser contained organic matter (20%), N (10%), P_2O_5 (10%), K_2O (10%), and SO_3 (15%). The basic plot size was 4.8 m^2. The experimental plots were organised in a random block design with four replications. At both locations, the buckwheat was manually sown with 300 kernels per square metre on May 22, 2019. During the growing season, weeds were eliminated by hand. Buckwheat was harvested at the stage of technological maturity at both locations (September 10, 2019).

Soil analysis

Before the experiment set, soil samples were taken. The soil's pH was measured after the sample preparation using a digital pH metre (ISO 10390, 1994). It was used the dichromate method determines the humus content (ISO 14235, 1998). The Al method evaluated available P and K (Egnér, Riehm and Domingo, 1960). The experimental plots contained the following chemical properties, according to soil analysis: pH 7.5, 5.50% organic matter, P_2O_5=20.10 mg 100 g^{-1} and K_2O=31.40 mg 100 g^{-1} (Location Kakanj), and pH 6.40, 2.32%

organic matter, P_2O_5=6.04 mg 100 g^{-1} and K_2O=18.30 mg 100 g^{-1} (Location Butmir).

Plant height, yield and mass of 1000 kernels

All data were recorded during the harvesting period. The height (cm) of ten randomly chosen plants per plot was measured from the soil surface. The yield per hectare was calculated based on the yield per 1 m^2. The mass of 1000 kernels were determined by kernel weighing after harvesting.

Materials for analysis

The total phenol content and antioxidant activity of leaves, flowers, and kernels is determined. Leaves and flower samples were collected at the full flowering stage (July 19, 2019). Kernel samples are collected at the stage of ripeness. The samples were dried for 30 days at ambient temperature in a dim environment. After drying, the samples were ground to a size of 1 mm.

Preparation of extracts

The extract was made in the following way: In a 100 mL volumetric flask, 1 g of each dried and milled sample was added. After that, the volume of the flask was filled with 60% ethano and mixed. Following extraction, the entire volume was filtered through Blue Ribbon filter paper and analysed.

Determination of total phenol content

A modified Folin-Ciocalteu method was used to determine the total phenol concentration of the extracts (Gavrić *et al.*, 2023). Briefly, 5 mL volumetric flask was filled with 0.5 mL of extract, blank, or standard. After that, 0.25 mL of Folin-Ciocalteu reagent was added to the volumetric flask, and the reaction proceeded. Than, 0.75 ml of 20% Na_2CO_3 was added, and the volume of the flask was filled to the mark with water. The absorbance at 765 nm was measured using a UV-VIS spectrophotometer (Ultrospec 2100 pro). Gallic acid equivalents were used to express the total phenol content (mg GAE 100 g^{-1}).

Determination of antioxidant activity

The total antioxidant capacity of buckwheat extract was determined using the FRAP (ferric reducing antioxidant power) method (Benzie *et al.*, 1996). In summary, 240 μL of H_2O, 80 μL of ethanol extract, blank or standard, and 2.080 L of FRAP reagent (0.3 M acetate buffer: 20 mM $FeCl_3.6H_2O$:10 mM TPTZ=10:1:1) were mixed in an Erlenmeyer flask. After 5 min of 37°C incubation, the absorbance at 595 nm was measured. The total antioxidant capacity was determined using a calibration curve that was created using an aqueous solution of $FeSO_4.7H_2O$ as the standard.

Statistical methods

The research findings were statistically analysed using the SPSS 22 software. The average values of the determined data were evaluated using the Test Support at a significance level of p=0.05.

RESULTS AND DISCUSSION

The influence of fertiliser on plant height, the mass of 1000 kernels, and yield is presented in tables 1 and 2 and explained in detail below. The findings of the study indicated that the plant height, a mass of 1000 kernels, and yield of buckwheat in the control treatment were significantly lower (102.8 cm, 18.8 g, and 1092.6 kg ha^{-1}, respectively) than in the fertiliser treatment (110.2 cm, 19.6 g, and 1192.8 kg ha^{-1}, respectively). The application of organomineral fertilisers had a positive effect on the growth and productivity of buckwheat. This result was expected because the plant received additional nutrients for growth from the used fertiliser. Many authors (Katar *et al.*, 2022; Sazhina *et al.*, 2020) have found a similar influence of fertilisers on the development of buckwheat. However, some authors also found that fertilisation can reduce yield. For example, Fang et al. (2018) recorded that increasing nitrogen fertiliser application from 0 to 45 kg ha^{-1} increased grain yield, but a further increase in the fertiliser dose decreased the grain yield. Yield reduction is associated with crop lodging (Gavrić *et al.*, 2018). Namely, buckwheat is known for its relatively high biomass productivity in different environmental conditions (Leto *et al.*, 2022), contributing to crop lodging (Gavrić *et al.*, 2018). Gavrić and Gadžo (2011) believe that buckwheat is an unpredictable crop in terms of fertilisers, and that poor soils and slow-degrading fertilisers should be preferred in the cultivation of this plant.

Table 1. Effect of fertiliser and buckwheat species on plant height, the mass of 1000 kernels, and yield

Organo-mineral fertiliser	**Species of buckwheat**	**Plant height**	**Mass of 1000 kernels**	**Yield**
		-cm-	-g-	-kg ha^{-1}-
Applied	Common buckwheat	129.3	23.7	1438.6
	Tartary buckwheat	91.1	15.5	946.9
	Average	**110.2a**	**19.6a**	**1192.8a**
Non-applied	Common buckwheat	119.9	22.9	1193.3
	Tartary buckwheat	85.6	14.7	991.8
	Average	**102.8b**	**18.8b**	**1092.6b**
Average	Common buckwheat	124.6a	23.3a	1315.9a
	Tartary buckwheat	88.3b	15.1b	969.1b
	Average	**106.5**	**19.2**	**1142.6**

Significant differences at the 0.05 level are indicated by different letters; ns indicate nonsignificant differences.

In our research, buckwheat species significantly impacted plant height, the mass of 1000 kernels, and yield. It was recorded that common buckwheat has higher values of research traits (124.6 cm, 23.3 g, and 1315.9 kg ha^{-1}, respectively) than tartary buckwheat (88.3 cm, 15.1 g, and 969.1 kg ha^{-1}, respectively) (Table 1). Therefore, our research recorded that a smaller mass of

1000 kernels caused a lower yield. Many studies (Da Rosa *et al.* 2022) have also shown that the mass of 1000 kernels is one of the main yield components strongly influencing buckwheat yield.

Table 2. Effect of location of research on plant height, the mass of 1000 kernels, and yield

Location of research	**Plant height**	**Mass of 1000 kernels**	**Yield**
	-cm-	-g-	-kg ha^{-1}-
Kakanj	117.4a	18.6b	1148.6ns
Butmir	95.5b	19.8a	1136.5ns
Average	106.5	19.2	1142.6

Significant differences at the 0.05 level are indicated by different letters; ns indicate nonsignificant differences.

The research location also significantly influenced the plant height and the weight of 1000 kernels (Table 2). Buckwheat cultivated at the Kakanj location had an 18.6% taller plant and a 6% lower mass of 1000 kernels than the Butmir location. The resulting differences are most likely the result of different weather conditions, that is, the distribution of precipitation between research locations. Namely, as seen in Figure 2, Kakanj location had more rainfall at the beginning of the growing season than the Butmir location. This rainfall positively affected plant growth. In contrast, the amount of precipitation at the period of kernel filling stage positively influences the mass of 1000 kernels. In our research, in the second part of the vegetation, i.e., the period of kernel filling stage, less precipitation was recorded at the Kakanj than at the Butmir (Figure 1). Several authors have also reported similar observations of weather effects on buckwheat plant height (Gavrić *et al.,* 2018; Ikanović *et al*., 2013; Popović *et al*., 2013). For example, Gavrić *et al.* (2018) found that plants were 11.5% lower in somewhat unfavourable weather conditions (lack of rain) than in favourable weather conditions.

The content of total phenols depended on all studied treatments. Thus, this component recorded significant differences in the leaves depending on fertilisation. (Table 3). The treatment without fertilisation had significantly higher phenol content (80.63 mg GAE g^{-1}) than the treatment with fertilisation (72.02 mg GAE g^{-1}). The use of fertilisation did not significantly affect the content of phenol in the flowers and kernels and the antioxidant activity in the leaves and flowers. These results follow Christensen *et al.* (2010), which found that different fertiliser rates have no significant effect on the level of phenolic compounds in all plant parts. In our research, the buckwheat species also significantly influenced the content of total phenols and antioxidant value (Table 3). It was found that tartary buckwheat has higher total phenols content and antioxidant capacity values.

Table 3. Effect of fertiliser and buckwheat species on total phenolic, flavonoid, and antioxidant capacity in leaves, flowers, and kernels

Organo-mineral fertiliser	**Species of buckwheat**	**Total phenolics**			**Antioxidant capacity**		
		Leaves	**Flowers**	**Kernels**	**Leaves**	**Flowers**	**Kernels**
			mg GAE g^{-1}			μM Fe^{2+} g^{-1}	
Applied	Common buckwheat	64.81	154.50	25.24	39.73	123.63	2.18
	Tartary buckwheat	79.23	164.38	34.77	53.89	118.55	23.92
	Average	**72.02b**	**159.44ns**	**30.01ns**	**46.81ns**	**121.09ns**	**13.05a**
Non-applied	Common buckwheat	78.08	144.08	25.60	45.40	117.18	3.05
	Tartary buckwheat	83.17	169.18	36.57	55.30	130.18	18.06
	Average	**80.63a**	**156.63ns**	**31.08ns**	**50.35ns**	**123.68ns**	**10.55b**
Average	Common buckwheat	71.45	149.29b	25.42b	42.57b	120.40ns	2.62b
	Tartary buckwheat	81.20a	166.78a	35.67a	54.59a	124.37ns	20.99a
	Average	**76.32b**	**158.03**	**30.55**	**48.58**	**122.38ns**	**11.80**

Significant differences at the 0.05 level are indicated by different letters; ns indicate nonsignificant differences. GAE-gallic acid equivalents.

The growing location also influenced the total phenolic content and antioxidant capacity. For example, buckwheat at location Kakanj had higher phenols content and antioxidant capacity than those at the Butmir location. These findings agree with previous research, which found that the total phenols were determined by the interaction of genetic factors and environmental conditions (Huda *et al.,* 2021; Ncube *et al*., 2012). Al-Huqail *et al.* (2020) believe that exposure of plants to stressful environmental conditions causes the synthesis of phenolics. Phenolics generally protect plants from unfavorable environmental conditions like UV radiation, drought, and extreme temperatures (Kumar *et al.*, 2014; Martínez-Silvestre *et al*., 2022). Therefore, their increased concentration is an indicator of stressful conditions (Stagnari *et al*., 2017). Stressful conditions were recorded in Kakanj location. Namely, as seen in Figure 1, the second part of the vegetation, i.e., during the collection period of samples, less precipitation was recorded at the Kakanj location than at the Butmir location.

The content of total phenols and antioxidant capacity were different in plant organs (Table 3 and 4). For example, in flowers, total phenol concentrations (158.03 mg GAE g^{-1}) were average, 5.17 times greater than in kernels (30.55 mg GAE g^{-1}). These findings are consistent with other researchers (Bystrická *et al.*, 2011), who also reported that phenols concentration is different between the anatomical parts of buckwheat. However, data on the precise amount of total phenols in various plant organs varied greatly. These differences were likely due to differences in buckwheat species, cultivation techniques, climatic conditions, and extraction and measurement methods for total phenols. Nevertheless, the research results show that both buckwheat species are good sources of phenols and antioxidants.

Table 4. Effect of location of research on total phenolic, flavonoid, and antioxidant capacity in leaves, flowers, and kernels

Location of research	**Total phenolics**			**Antioxidant capacity**		
	Leaves	**Flowers**	**Kernels**	**Leaves**	**Flowers**	**Kernels**
		mg GAE g^{-1}			μM Fe^{2+} g^{-1}	
Kakanj	81.86a	184.31a	19.35b	53.29a	124.48ns	11.62ns
Butmir	70.79b	131.75b	41.74a	43.88b	120.29ns	11.98ns
Average	76.32	158.03	30.55	48.58	122.38	11.80

Significant differences at the 0.05 level are indicated by different letters; ns indicate nonsignificant differences. GAE-gallic acid equivalents.

Although our research has offered a glimpse into the impact of organomineral fertilisers in different environmental conditions on buckwheat productivity and antioxidant activity, they have certain limitations. There is not enough information about how organomineral fertiliser doses affect buckwheat's productive properties, crop lodging, and antioxidant properties. As a result, future studies should examine the potential impact of this fertiliser on these properties.

CONCLUSIONS

The experiment results showed that using organomineral fertiliser has increased buckwheat yield and antioxidant capacity. Therefore, using these fertilisers could be agrotechnical measure for the improvement buckwheat's mentioned characteristics. In addition, our research has shown that the leaves, flowers, and kernels of booth buckwheat species have a high level of total phenols and antioxidant activity, which is especially important if the plant is used as a medicinal plant.

Our study showed certain benefits that could be applied in practice. Specifically, organomineral positively impacted the yield of buckwheat. Therefore, the more intense application of these and similar fertilisers in practice could indirectly affect the increase in the yield and quality of buckwheat.

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