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Yield and protein composition in seeds of four buckwheat (*Fagopyrum* sp.) cultivars cropped in Sweden

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Buckwheat (*Fagopyrum* sp.) is increasingly favoured for its nutritional composition and overall health benefits in Sweden. However, buckwheat cultivation in Sweden is low. This project evaluated the cultivation of four cultivars of common buckwheat in Scandinavian cropping conditions over two years, employing standard sowing methods and harvesting techniques. The results showed that a seeding rate of 200 seeds per m² was sufficient to achieve a yield comparable with other studies. There were no significant differences in germination rate and number of plants per m² between buckwheat cultivars, while significant differences were observed in maturation time and yield. The average yield of buckwheat (common or Tartary) varied from 724 kg ha^{-1} ("Darja") to 3 276 kg ha^{-1} ("Panda") in 2021, and from 2 587 kg ha^{-1} ("Kora") to 3 133 kg ha^{-1} ("Tartary buckwheat") in 2022. All buckwheat cultivars had a protein content in the seeds of approximately 110 g kg^{-1} of dry matter and were composed of a well-balanced amino acid profile. Our results indicate that the Swedish geographic latitude and meteorological conditions were suitable for achieving high buckwheat yields for some cultivars.

Key words: *Fagopyrum esculentum, Fagopyrum tataricum,* Nordic environment, amino acid content

Introduction

Climate changes and increasing global population pose major concerns for land and water resources in ensuring adequate food production. In Europe, changes in cropping and farming systems due to climate change have already been well described (Chloupek et al. 2004, Olesen et al. 2011). Intensive agricultural practices and the use of monocultures have led to the loss of biodiversity (Schröder et al. 2007). It has become evident that changes in agricultural routines are needed to address the global challenges of climate change and biodiversity loss while considering sustainable production and consumption. To tackle these multiple challenges, there is a need for more climate-resilient crops. Ideally, these crops should be suitable for multifunctional farming, including organic-, low-input-, and mixed farming. Buckwheat (*Fagopyrum* sp.), being able to be cultivated in a broad range of climatic conditions and improving soil structure and fertility due to deep rooting and fast leaf development, is a potential candidate (Jha et al. 2024, Vieites-Alvarez et al. 2024, Zamaratskaia et al. 2024). While buckwheat is highly valued in Eastern Europe and Asia, its cultivation in Nordic countries is limited. The acreage of buckwheat in Sweden is below the threshold for statistical registration. We estimate that less than 300 hectares are used for buckwheat production.

Buckwheat is gluten-free and can be safely consumed by individuals with celiac disease or gluten sensitivity. Nowadays, 1.4% of the world's population suffers from celiac disease and avoids consumption of gluten-containing products from wheat, rye and barley (Singh et al. 2018). Avoiding gluten is also recommended for individuals with non-celiac gluten sensitivity. Additionally, gluten-free diets have become popular among non-celiac consumers due to the widespread belief in the unhealthy consequences of high gluten intake (Kaminski et al. 2020). Thus, the global market for gluten-free foods is growing creating a higher demand for gluten-free raw materials. This can be met with increased production of buckwheat and development of innovative buckwheat-based products. Furthermore, buckwheat has gained great interest due to its nutritional quality and attractive sensory properties (Zamaratskaia et al. 2024). While the protein content of buckwheat (8–14%) is comparable to that of wheat (12–14%), buckwheat stands out by containing all essential amino acids and being a good source of dietary fibre and bioactive compounds. In numerous countries, buckwheat is consumed in various forms, such as cooked grains or as a foundation for bread, pasta, noodles, and cookie making (Breslauer et al. 2023, Utarova et al. 2024, Zamaratskaia et al. 2024).

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Swedish agriculture is based on a limited number of crops, with cereals, mainly winter wheat, holding a dominant position. Increased farm size and grain dominated crop rotations have resulted in a decline in crop diversity both spatially and temporally, along with an increased reliance on pesticides for pest control. Without breaking crops, there is a risk of further escalating pesticide use, potentially exerting a negative impact on biodiversity in agricultural landscapes over the long term (Riggi et al. 2024).

From a climatic and agricultural point of view, buckwheat has significant potential for expansion in Sweden. Minimal pesticides are required to cultivate buckwheat, which is beneficial for biodiversity in agricultural landscapes and buckwheat is considered to have allelopathic effects on weeds (Szwed et al. 2019). Furthermore, the cover crop mixture of buckwheat and oilseed radish showed a potential to reduce soil mineral N and concentrations of N in drainage water (Norberg and Aronsson 2020) and the crop flowers provide food for pollinating insects.

However, as there are only a handful of Swedish buckwheat farmers, no domestic seed suppliers, and limited information on suitable cultivars, yield expectations and protein outcomes, farmers are reluctant to invest in a buckwheat cultivation. Thus, our study aimed to evaluate four European buckwheat cultivars and compare them with the cultivar today commonly used in Sweden, regarding kernel and protein yield, harvest time and protein composition, in order to provide a basis for increased cropping in Sweden.

Materials and methods

Field trials and field demonstrations were conducted over a two-year period (2021 to 2022) in fields managed by the Rural Economy and Agricultural Society of Östergötland, Sweden (Hushållningssällskapet Östergötland), situated at 58° 21′ 44.604′′ N, 15° 39′ 23.22′′ E. The climate in this region is a warm humid continental climate (Dfb) according to the Köppen-Geiger climate classification. During field season (May to October) in 2021, the average temperature and precipitation were 13.9 °C and 324 mm, respectively. In the following year, 2022, the average temperature recorded was 14.9 °C, with a total precipitation of 257 mm (May to September). The site is located 51–56 m above sea level.

In 2021, four cultivars of common buckwheat were included, and in 2022, three cultivars. The trials were conducted using a randomized complete block design with four replicates, each consisting of plots measuring 3 × 12 m. Harvesting was performed on a net plot of 2 × 9 m.

Although buckwheat is depended on pollinators to ensure seed setting, there was no possibility to use bee hives to promote pollination. The soil in the 2021 trial was classified as a moraine clay with pH 7.4 to 7.6. In the 2022 trial another field with similar soil type was used, but with a lower pH of 6.4–7.0. The seeds for the study were obtained from commercial seed suppliers in Europe "Semenarna Ljubljana d.o.o", Slovenia, and "Małopolska Hodowla Roślin", Krakow, Poland. Tartary buckwheat from the Swedish company "Wermlands bovete AB" (www.wermlands-bovete.se) served as a control because it is already successfully cultivated in Sweden. The studied cultivars and their characteristics are presented in Table 1.

Table 1. List and characteristics of tested cultivars of common buckwheat and Tartary buckwheat

Name	Characteristics
Tartary buckwheat	Russian (Siberian) species, medium-early buckwheat with a good resistance to spring frosts, the length of the growing season 80–95 days, grows 100–120 cm high, and can be grown on acidic soils.
Kora	Polish cultivar, medium-early buckwheat with good resistance to spring frosts and drought under vegetation, grows up to 100–120 cm, the length of the growing season 85–95 days, has low water requirements, tolerant to weaker soils, even sandy, recommended seed rate 80–100 kg ha^{-1}, 25–30 g per 1000 seeds.
Panda	Polish cultivar, medium-early buckwheat with good resistance to spring frosts and drought under vegetation, grows 110–115 cm high, the length of the growing season 90–115 days, can be grown on heavier soils, recommended seed rate 80–100 kg ha^{-1}, 25–32 g per 1000 seeds.
Smuga	Polish cultivar, registered in 2019, medium-early buckwheat with good resistance to spring frosts, grows 95–115 cm high, the length of the growing season 85–90 days, high yield.
Darja	Slovenian cultivars, medium early, the length of the growing season 80–120 days. In this project, it was included only in 2021.

The field trials and the field demonstrations were carried out on fields used for organic farming and therefore neither mineral fertilizers nor herbicides were used. In both trial years, seeding took place in spring-early summer 4 June 2021 respectively 13 May 2022, and had a seed rate intended to reach at least 170 plants m^{-2}. Using the average weight of thousand kernels (TKW) of buckwheat seeds (27 g/1000 seeds) and estimated germination capacity of 80%, the seed rate was 200 seeds m^{-2}, which corresponds to 54 kg ha^{-1}. In 2022, the seed rate was 210 seeds m^{-2} corresponding to approximately 56 kg ha^{-1}. Row spacing was set to 12.5 cm in both years, which is a typical row distance for grain cropping in Sweden. Sowing depth was 1.5 cm in 2021, increased to 2 cm in 2022.

As buckwheat is characterized by indeterminate flowering and blooms throughout the growing season, the harvest must take place when the majority of the seeds are ripe, taking weather and soil conditions into consideration. Buckwheat was harvested during the period 5 September to 1 November, when weather and soil conditions allowed for combine harvest and about 80% of the seeds were assessed as mature. Each plot was harvested using a plot combine, seeds were dried and weight by staff at the Rural Economy and Agricultural Society of Östergötland and cleansed by the authors. Suitability of the cultivars for Swedish cultivation was evaluated according to the following parameters: germination, number of plants per m^2, maturation time, TKW (only 2022), yield, moisture content of seeds, amino acid composition, and crude protein. Amino acid composition (ISO 13903:2005) and crude protein analyses (ISO 16634) were performed by Eurofins (Lidköping, Sweden).

Statistical analyses

ARM 2022.5 (Agriculture Research Management) software was used for the statistical analysis. One-way ANOVA was used to estimate the differences between the cultivars of common buckwheat and Tartary buckwheat. Multiple comparisons of the means were conducted using Newman–Keuls test when ANOVA has given a statistically significant result. P-values below 0.05 were considered statistically significant.

Results

The results showed that the selected seeding rate of 200 seeds m^{-2} was sufficient to achieve a yield in line with average European yields. There were no significant differences in germination rate and number of plants m^{-2} between buckwheat cultivars neither in 2021 nor in 2022 (Table 2). However, significant differences were observed in maturation time and yield (p< 0.05). The "Darja" cultivar reached maturity later than all other cultivars and had the highest moisture content at harvest time, although fully matured. The yield of buckwheat varied from 724 kg ha^{-1} ("Darja") to 3 276 kg ha^{-1} ("Panda") in 2021 and from 2 587 kg ha^{-1} ("Kora") to 3 133 kg ha^{-1} ("Tartary buckwheat") in 2022. The "Darja" was not included in the trial in 2022 due to low yield and late maturation in 2021. In 2021, the "Smuga" and "Panda" cultivars had the highest yields, while in 2022, "Tartary buckwheat" and "Panda" had the highest yields.

Table 2. Cultivations parameters of four cultivars of common buckwheat and Tartary buckwheat in 2021–2022

Parameter	Year	Tartary	Buckwheat				LSD**
			Smuga	Panda	Kora	Darja*	
Germination, %	2021	97.5	98.8	97.5	97.5	96.3	6.3
	2022	93.8	100	100	100		2.0
Plants m^{-2}	2021	192.8	187.5	186.8	188.5	192.8	10.6
	2022	192.8	206.5	208.5	203.8		14.2
Days from sowing to seed maturity	2021	110^{b}	104^{d}	108^{c}	93^{e}	151^{a}	1.33
	2022	133^{a}	129^{c}	131^{b}	127^{d}		1.0
Moisture, %	2021	30.2^{a}	28.6^{a}	29.6^{a}	29.4^{a}	42.1^{b}	2.0
	2022	32.7^{a}	31.4^{ab}	32.8^{a}	30.1^{b}		1.56
TKW, g	2021						
	2022	26.2^{b}	26.0^{a}	26.9^{b}	30.5^{a}		1.3
Yield, kg ha^{-1}	2021	2450^{c}	3046^{a}	3276^{a}	2709^{b}	724^{d}	243.2
	2022	3133^{a}	2829^{b}	3101^{a}	2587^{c}		149.1

Data are presented as means and standard deviations of four replicates. *The cultivar Darja was not included in the trial 2022 due to late ripening and low yield in 2021. **LSD = least significant difference. Means followed by different letters significantly differ (p= 0.05, Newman-Keuls test).

Table 3. Protein content and amino acid profile in seeds of four cultivars of common buckwheat and Tartary buckwheat in 2021–2022.

	Tartary	Buckwheat				
		Smuga	Panda	Kora	Darja*	LSD**
Protein content, g kg^{-1} DM***	10.8 ± 0.89	11.1 ± 0.35	10.8 ± 0.35	11.0 ± 0.57	11.4	1.72
Amino acids, g/100 g						
Alanine	0.5 ± 0.06	0.4 ± 0.03	0.4 ± 0.06	0.4 ± 0.03	0.5	0.18
Arginine	1.1 ± 0.12	1.0 ± 0.1	0.9 ± 0.07	1.0 ± 0.06	1.1	0.31
Aspartic acid	1.0 ± 0.13	0.9 ± 0.03	0.9 ± 0.07	1.0 ± 0.05	1.0	0.27
Glutamic acid	1.9± 0.20	1.8 ± 0.13	1.6 ± 0.13	1.7 ± 0.06	1.9	0.51
Glycine	0.7 ± 0.05	0.6 ± 0.02	0.6 ± 0.04	0.6 ± 0.02	0.7	0.15
Histidine	0.3 ± 0.04	0.3 ± 0.03	0.2 ± 0.02	0.3 ± 0.02	0.3	0.11
Hydroxiproline	<0.2	<0.2	<0.2	<0.2	<0.2	
Isoleucine	0.4 ± 0.04	0.4 ± 0.03	0.3 ± 0.02	0.3 ± 0.02	0.4	0.10
Leucine	0.7 ± 0.08	0.7 ± 0.04	0.6 ± 0.07	0.7 ± 0.04	0.7	0.21
Lysine	0.7 ± 0.11	0.6 ± 0.05	0.6 ± 0.07	0.6 ± 0.05	0.8	0.32
Ornithine	<0.05	<0.05	<0.05	<0.05	<0.05	
Phenylalanine	0.5 ± 0.07	0.5 ± 0.02	0.5 ± 0.03	0.5 ± 0.01	0.5	0.15
Proline	0.4 ± 0.01	0.3 ± 0.03	0.3 ± 0.05	0.3 ± 0.01	0.2	0.19
Serine	0.6 ± 0.06	0.5 ± 0.01	0.5 ± 0.01	0.5 ± 0.03	0.6	0.13
Threonine	0.4 ± 0.05	0.4 ± 0.01	0.4 ± 0.03	0.4 ± 0.02	0.4	0.10
Tyrosine	0.3 ± 0.06	0.3 ± 0.04	0.3 ± 0.03	0.3 ± 0.03	0.4	0.17
Valine	0.6 ± 0.07	0.5 ± 0.04	0.5 ± 0.04	0.5 ± 0.04	0.6	0.18
Cisteine+Cistine	0.3 ± 0.01	0.3 ± 0.01	0.3 ± 0.01	0.2 ± 0.01	0.3	0.08
Methionine	0.2 ± 0.03	0.2 ± 0.03	0.2 ± 0.02	0.2 ± 0.01	0.18	0.05

Data are presented as arithmetical means and standard deviations of two years measurements made at least in duplicates. *The cultivar Darja was not included in the trial 2022 due to late ripening and low yield in 2021. Thus, no standard deviation. **LSD = least significant difference. Means followed by different letters significantly differ (p= 0.05, Newman-Keuls test). *** DM = dry matter. The essential amino acids are highlighted in bold.

Discussion

Agricultural intensification and the use of monocultures are among the main factors leading to the decline in biodiversity. Moreover, global food security requires an increase in food production in the coming decades. In our trials we used a standard cultivation technique commonly used for grain cropping as this probably would increase interest in buckwheat cropping as standard sowing machines can be used. The typical grain row spacing of 12.5 cm is often used for buckwheat in Europe. We found that a sowing depth of about 2 cm was suitable, but generally a sowing depth of 3–6 cm is recommended depending on soil type and climatic conditions. Our results were similar to the studies by Gerhards and Schappert (2020), which proposed seeding depths of 2–3 cm, and partly to those by Xiang et al. (2014), which recommended a sowing depth of 4 cm, as this improves seedling number and emergence compared to depths of 2 and 6 cm, respectively. Seeding time varied between years due to weather and soil conditions, available machines and staff. A main concern was to seed as soon as possible after last frost nights as buckwheat is sensitive to low temperatures at early development stages. Sowing time influences seed germination, flowering time, length of vegetation and grain yield of buckwheat (Babu et al. 2018). The range for seed germination varies from 5 to 42 °C, but the optimum temperature is around 24–26 °C (Dražić et al. 2016). As Sweden has a cool climate, seeding cannot take place too late as this would shorten the vegetation period. Thus, soil temperatures of 10–15 °C (late May to early June) will be typical at seeding. The selection of cultivars for the study was associated with available seed and early maturation. The growing length is limited by late frost in the spring and early frost in the autumn. This phenomenon was observed in the first experimental year, when the cultivar "Darja" did not reach full maturity. The cultivars "Panda", "Smuga" and "Kora" required about 100 days from seeding to maturity making it possible to delay seeding to early June (1–15 June) and still reach maturity before autumn frost, while Darja with its longer maturity time requires a warmer climate than the Swedish to guarantee yield.

The average yield of buckwheat is lower compared to national average yield (SJV 2024) of winter wheat (7 000 kg ha^{-1}) and rye (6 485 kg ha^{-1}). In the present study, the yield of buckwheat varied from 724 kg ha^{-1} to 3 276 kg depending on cultivar and year. Similar results were obtained in Belgium where buckwheat yield varied from 2 037 kg ha^{-1} to 3 667 kg depending on the type of buckwheat (Tatary or common buckwheat) and variety (Aubert et al. 2021, Aubert and Quinet 2022). Yields of all tested cultivars were within the range obtained in Belgium, except for "Darja". The cultivar "Darja" had a significantly lower yield in 2021, compared to that of other cultivars, which motivated us to exclude it from the further investigations. Sowing time is an important determiner of the yields (Siracusa et al. 2017). Depending on sowing time, the cultivar "Darja" can have a yield from 370 to 1680 kg ha^{-1}, with earlier sowing producing higher yield (Brunori et a. 2018). In contrast, "Darja" yielded 2370 kg ha^{-1} under Belgium conditions (Aubert et al. 2021) and 1290 kg ha^{-1} in Italy (Brunori et al. 2005). In Slovenia, where "Darja" is commonly cultivated, a typical yield is about 2000 kg ha^{-1} when grown as a full-season crop, which is higher than landraces (Bavec et al. 2002). Today "Darja" is one of the most cultivated buckwheat cultivars in South-eastern Europe (Grahic et al. 2022).

Sowing rate depends mainly on sowing method, cultivars, soil type and soil cultivation methods. The most recommended sowing rate is 200–500 seeds m^{-2} (Kumskova 2004, Berdin et al. 2018), although recommendations of 90–160 seeds m^{-2} are also found (Vieites-Alvarez et al. 2024). We used 200 seeds m^{-2}, which corresponds to approx. 54 kg ha^{-1} in 2021, and 210 seeds m^{-2} corresponding to approx. 56 kg ha^{-1} in 2022. These seed rates resulted in 186–208 plants m^{-2}. Visual assessment during cropping period showed a dense, even stand with well-developed plants indicating that the chosen seed rate was suitable for East-Swedish conditions. Several studies have focused on the relationship between buckwheat yield and plant density. The yield of Tartary buckwheat increased with increase in plant density from 800 000 plants ha^{-1} to 1 400 000 plants, while the grain number per plant, total grain weight per plant, and TKW decreased (Zhou et al. 2023). Wan et al. (2023) compared the grain yields of common buckwheat in a non-fertilised trial, the "Xinong 9976" variety, with plant densities of 600 000 plants ha^{-1}, 900 000 plants and 1 200 000 plants respectively, and showed that the lowest yield was obtained at the planting density of 1 200 000 plants ha^{-1}. Similarly, a combination of plant density of 900 000 plants ha^{-1} and application of N fertilizer was recommended to increase the yield of common buckwheat by Fang et al. (2018). In contrast, the yield of common buckwheat in China ("Xinong D4103" variety) was significantly increased by increasing the plant density from 900 000 plants ha^{-1} to 1 350 000 plants including fertilization with N: 180, P_2O_5: 115.2 and K_2O: 84.6 kg ha^{-1} (Lei et al. 2024). It should be noted that the lodging rate and lodging index also rose with increased plant density (Lei et al. 2024).

Protein content (10.8–11.4%) did not statistically differ among cultivars, but was somewhat lower compared to previous findings of 13%–15% (Bonafaccia et al. 2003, Mota et al. 2016). Domingos and Bilsborrow (2021) have reported a protein content of 12% protein which is similar to our Swedish results.

Generally, the digestibility of buckwheat protein is lower compared to other pseudocereals, 80% for buckwheat vs 92% for quinoa and 90% for amaranth (Mota et al. 2016). The digestibility of buckwheat proteins can be improved by various processing techniques, such as extrusion (Zhang et al. 2024). It should be emphasised that the majority of the studies on protein digestibility were done *in vitro,* and the results are greatly affected by the choice of digestion model.

Buckwheat proteins are composed of a well-balanced amino acid profile and are rich in arginine (0.9–1.1 g 100 g^{-1}) and lysine (0.6–0.7 g 100 g^{-1}), which are limiting in cereal proteins. It implies that combining buckwheat with cereals might provide a complete protein. Arginine and lysine concentrations in wheat usually vary from 0.1 to 0.6 (arginine) and from 0.2 to 0.4 g 100 g^{-1} dry matter (lysine) (Anjum et al. 2005). In rice, lysine concentrations were even lower, 0.1 mg 100 g^{-1} (Mota et al. 2016). The concentrations of leucine and isoleucine in our study were similar to those found by Bonafaccia et al. (2003), 7.1 g 100 g^{-1} of protein for Tartary buckwheat, and 6.9 g 100 g^{-1} of protein for common buckwheat. In the Bonafaccia et al. (2003) study, the protein content in buckwheat flour was 10.3%. However, Bhinder et al. (2020) reported that isoleucine couldn't be detected in some cultivars.

The essential amino acid tryptophan was not measured in our work, but other studies reported the presence of tryptophan in quantities up to 0.76 g 100 g^{-1} (Bhinder et al. 2020), which is higher than the tryptophan content in wheat (0.2 g 100 g^{-1}) (Malalgoda et al. 2020, Rakszegi et al. 2023). We found that glutamic acid was the most abundant nonessential amino acid in all buckwheat cultivars tested. Similar results have been shown for wheat (Urošević et al. 2023) and for rice (Mota et al. 2016).

Conclusions

We conclude that the European cultivars of the common buckwheat (*Fagopyrum esculentum*) generally can be cropped in Sweden and that the yields of these cultivars are similar to those of central Europe. The yields of these cultivars are also similar to Tartary buckwheat (*Fagopyrum tataricum*), which is cold-resistant and currently cropped in Sweden. Cultivars "Panda" and "Smuga" were consistent in high yields similar to Tartary buckwheat (*Fagopyrum tataricum*) whereas "Darja" was less suitable for Swedish conditions.

These results are promising from both a biodiversity conservation perspective and a nutritional point of view. Buckwheat's high nutritional value, gluten-free properties, extensive geographical prevalence, and versatile applications make it an economically important crop world-wide. However, further studies are needed to investigate the Swedish consumers' acceptance of buckwheat-based products and the development of new tasty, sustainable foods. Further studies on cropping systems, such as direct seeding, fertilization and de-hulling of kernels are also recommended.

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