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Review

Fagopyrum esculentum Moench: A crop with many purposes in agriculture and human nutrition

Flávio Marcel Ferreira Gonçalves[1]*, Rafael Rostirolla Debiage[1], Regildo Márcio Gonçalves da Silva[2], Petrônio Pinheiro Porto[1], Eidi Yoshihara[3] and Erika Cosendey Toledo de Mello Peixoto[1]

[1]Universidade Estadual do Norte do Paraná (UENP/Bandeirantes), BR-369, km 54, Vila Maria, Caixa Postal 261, CEP 86360-000, Bandeirantes, Paraná, Brasil.
[2]Faculdade de Ciências e Letras de Assis, Universidade Estadual Paulista Júlio de Mesquita Filho,Laboratório de Fisiologia Vegetal e Fitoterápicos, Avenida Dom Antônio, 2100, CEP 19806-900, Assis, São Paulo, Brasil.
[3]Agência Paulista de Tecnologia dos Agronegócios, Polo Alta Sorocabana, SP 270, km 561, Caixa Postal 298, CEP 19015-970, Presidente Prudente, São Paulo, Brasil.

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Buckwheat is a dicotyledonous crop that quickly grow at high altitudes. It presents high tolerance to acidity and ability to grow in poor soil. This study aimed to identify different buckwheat forms of use and benefits in agriculture and human nutrition. It can be used as green manure, being an option as soil cover plant and recycling of nutrients, as well as an alternative grain and forage. At the plant flowering, it can provide a food source to the predators of common insects' pests, increasing their populations. In livestock, it can feed cattle, sheep, pigs, goats and poultry because it features similar quality to millet forage, but with higher concentration of protein. Buckwheat could act as a functional forage to manipulate ruminal fermentation. The presence of tannins in plants can positively influence the health of small ruminants because these represent a promising alternative control of gastrointestinal nematodes. For human nutrition, the buckwheat is an important food that contain a well-balanced amino acid profile with a high quantity of lysine, limiting amino acid in grasses such wheat, relatively high fibre content, zinc (Zn), copper (Cu), manganese (Mn) and selenium (Se). Furthermore, this flour is gluten-free and it can be used as a supplement for patients with celiac disease. Therefore, it is a culture that should be best explored in different regions of the world.

Key words: Buckwheat, celiac sprue, green manuring, high protein, tanniferous plants, recycling of soil nutrients.

INTRODUCTION

Buckwheat (*Fagopyrum esculentum* Moench) is a dicotyledonous crop belonging to Polygonaceae family taxonomically unrelated to wheat (Heffler et al., 2014). It is popular in the mountainous regions of China and in

*Corresponding author. E-mail: flavio.mfg@gmail.com. Tel: 55-43 3542-8040.

Table 1. World's largest countries producers of buckwheat in 2013 (FAOSTAT, 2013).

Countries	Production (tonnes)	Area (ha)	Yeld (t ha^{-1})
RussianFederation	833936	905911	0,921
China	733000*	705000*	1,040
Kazakhstan	276840	202008	1,370
Ukraine	179020	168400	1,063
France	154800	44500	3,479
Poland	90874	70384	1,291
USA	81000†	77500†	1,045
Brazil	62000†	48000†	1,292
Japan	33400	61400	0,544
Belarus	30353	31403	0,967
World Total	2547014	2386212	1,067

* Aggregate, may include official, semi-official or estimated data. †FAO estimate.

other countries at the northern hemisphere. It can be grown at high altitudes and has a short growing span (Zhou et al., 2012).Buckwheat has been a culture of secondary importance, however it is produced in almost all countries where cereals are grown (Campbell, 1997).

The crop is not a cereal, but the seeds (achenes) are usually classified among the cereals grains because of its similar usage. The grain is generally used as human food and as animal feed. The dehulled groats can be cooked as porridge and the flour can be used in the preparation of pancakes, biscuits, noodles, cereals, among others (Campbell, 1997). Buckwheat contains proteins with high biological value and balanced amino acid composition, presenting relatively high content of fibre, Zn, Cu, Mn and Se (Ahmed et al., 2014).

Currently, China, Russian Federation, Kazakhstan and Ukraine are the leading producers of buckwheat, with production in other countries of different continents, according to Table 1, which shows the current leading producers of buckwheat, area harvested and yield in 2013. The leading continents producers are Europe and Asia (FAOSTAT, 2013). So, the aim of this study was to identify different buckwheat forms of use and benefits in agriculture and human nutrition.

DESCRIPTION OF BUCKWHEAT

Fagopyrum esculentum Moench is common buckwheat, widely cultivated over the Northern and to some extent the Southern hemisphere. There are many cultivars or landraces in this species and their achene forms can vary, some of them being winged on the angles. It is an annual crop, branched, glabrous, and reaching up to 1 m tall (Campbell, 1997).

The leaves are petiolate, blades are ovate-triangular to triangular, 2 to 8 cm long, with acuminate tips, bases are cordate or approximately hastate; upper leaves are smaller, sessile. The inflorescences are terminal and auxiliary, branch in dense corymbose or paniculate cyme. Flowers are white or pink, 6 mm in diameter; pedicel is 2 to 3 mm long, articulate; perianths are 3 mm long; 8 nectaries are yellow, alternating with stamens; being heterostyly, capitate stigma (Campbell, 1997). The achenes are triquetrous, acute angle, longer than 5 mm, more than twice the persistent perianths lenght, brown or black-brown, lucid (Campbell, 1997). Details of buckwheat are presented in Figure 1.

USES IN AGRICULTURE

Buckwheat can be used as a cover crop (green manure) by having high tolerance to acidity and good ability to grow in poor soils. It can reach 30 Mg ha^{-1} of green mass and dry mass up to 7 Mg ha^{-1} with a height up to 1.30 m at 72 days after sowing (DAS). Klein et al. (2010) found higher concentration of potassium and nitrogen and micronutrients zinc, manganese and iron, showing good ability to recycle nutrients from the soil (Table 2). In alfafa (*Medicago sativa*), green manure crops (like buckwheat) may provide benefits in production systems by increasing pathogen antagonists (Samac et al., 2013). Other benefits of using green manures include reduction on the dependence on mineral fertilizers, maintenance of organic matter in the soil providing nutrients for plant growth (Yadav et al., 2000) and increase of size and activity of soil microbial communities (Kautz et al., 2004; Manici et al., 2004; Tejada et al., 2008). However, the positive effects of green manure are affected by the crops chosen for this purpose (Mancinelli et al., 2013).

The crop is known to increase beneficial insects which are predators of common insects pests and can help to reduce their populations. The increase in population is due to the food source provided to the insect in the plant flowering. As examples, can be mentioned hover flies, predatory wasps, minute pirate bugs, insidious flower bugs, tachinid flies, and lady beetles (Valenzuela and

(a) (b) (c)

Figure 1. Details of buckwheat: (a) Structures (Thomé, 1903); (b) Buckwheat specimen (Smith, 2007); (c) Seeds (Hurst, 2015).

Table 2. Dry mass production and mass nutrients recycled per hectare and the carbon/nitrogen ratio of plants of an early and a late cultivar (Klein et al., 2010).

Sample	Drymass	N	P	K	C/N ratio
	kg ha^{-1}				
Late	5633	113.22	17.46	208.99	20.17
Early	6870	111.30	18.55	220.53	23.97

Smith, 2002).

Buckwheat should not be grown in fields with presence of root lesion nematodes (*Pratylenchus penetrans*) and root-knot nematodes, because the crop is suscetible to these nematodes (Valenzuela and Smith, 2002). In a previous trial work, buckwheat showed promising as a nematode suppressant, significantly reducing *Pratylenchuszeae* numbers in comparison to sugarcane (Berry and Rhodes, 2006). In addition, may have ability to increase the population of beneficial soil nematodes to crops, like *Helicotylenchus* (Rhodes et al., 2014). The use of buckwheat can be an option to reduce the use of chemical control, because in general, nematode control has traditionally relied to this kind of control (e.g. aldicarb in South African sugar industry) (Berry and Ramouthar, 2012).

Though producing low amounts of biomass, buckwheat grows and flowers in a short time period. For sugarcane growers, it can be ideal due to pressing circumstances, may need to include only a short fallow in their sugarcane cycle (Rhodes et al., 2014).

USES IN LIVESTOCK

Grains, hay or silage buckwheat can be fed to cattle, sheep, pigs, goats and poultry (Goepfert, 1968). It features similar quality to millet forage (Gorgen, 2013), but with a higher concentration of protein.

Buckwheat could act as a functional forage to manipulate ruminal fermentation (Amelchanka et al., 2010; Leiber et al., 2012) and, subsequently, milk quality and specially milk fatty acids profile (Kälber et al., 2011) for producing high levels of various secondary compounds (Wijngaard and Arendt, 2006). Additionally, can happen a certain mitigation of methane emission without a concomitant severe decline of rumen microbial productivity (Leiber et al., 2012). The main phenolic constituent in buckwheat which occur in substancial amounts is the flavonoid rutin and also hyperoside and chlorogenic acid (Hinneburg and Neubert, 2005; Kalinova et al., 2006). An important property of rutin appears to be the partial protection of dietary proteins from ruminal degradation (Leiber et al., 2012).

The presence of tannins in plants can positively influence the health of small ruminants because they represent a promising alternative control of gastro-intestinal nematodes of these animals. However, their effects depend on the type and concentration of these metabolites (Oliveira et al., 2011). Karamac´ (2010) found that the total phenolic content of the tannin fraction from buckwheat seeds was higher than that from buckwheat

Table 3. Total phenolic content, 1,1-diphenyl-2-picrylhydrazyl radical (DPPH) scavenging activity and Trolox equivalent antioxidant capacity (TEAC) of buckwheat tannin fractions (Karamac´, 2010).

Buckwheat tannin fraction	Total phenolics (mg catechinequivg^{-1})*	DPPH scavenging activity EC_{50} (mg)	TEAC (nmolTroloxequivg^{-1})*
Seeds	477 ± 11^{a}	0.019	4.06 ± 0.14^{a}
Groats	371 ± 10^{b}	0.021	3.55 ± 0.09^{b}

Data expressed as means ± standard deviations (n = 3). In the same column, means with different letter (a, b) differ significantly (P<0.05).* Results are expressed as equivalents (equiv) of standard per g of tannin fraction.

Table 4. Comparison of buckwheat flour composition with wheatflour (m g^{-1} DW*).

Nutrient	Buckwheat flour	Wheat flour	References
Carbohydrates	737	835	
Crudeash	22	12	
Crudefat	28	26	Quin et al., 2010; Lin et al., 2009
Crudefibre	23	20	
Crudeprotein	103	106	
Protein	110	115	
Ash	26	17	
Lipid	34	10	Bonafaccia and Fabjan, 2003
Solublefibre	12	10	
Insolublefibre	53	15	
Total fibre	65	24	

*DW, dry weight.

groats. Constituents of tannin fractions, which reacted with Folin-Ciocalteu's reagent (FCR) expressed as catechin equivalents amounted to 477 and 371 mg g^{-1} of fraction (Table 3). The comparison of antioxidant activity of tannin fractions from buckwheat with the literature data concerning the antioxidant activity of fractions isolated from other plants, leads to the conclusion that buckwheat fractions are strong antioxidants.

With regard of nutritional value for animals, crude protein is particularly concentrated in leaves, followed by flowers, whereas stems are characteristically high in fiber. Leiber et al. (2012) found 620 g of non-NDF carbohydrates/kg DM in buckwheat grains, and leaves also were rich in non-NDF carbohydrates. In comparison with ryegrass (*Lolium multiflorum*), the entire aerial part of the buckwheat herb contained less crude protein, ether extract and fibre, but more non-fibre carbohydrates (e.g. starch, oligosaccharides and sugars) and almost six times more total extractable phenols (Leiber et al., 2012).

USE IN HUMAN NUTRITION

Buckwheat is an important ingredient of traditional dishes of Asia (e.g. Japanese and Korean noodles and jellies), Russia (e.g. pancakes or a sort of porridge called "kasha"), and Europa (e.g. French pancakes, Dutch "poffertjes" and Northern Italian hot porridge and pasta). Hulls are also used to fill pillows. It is used to obtain dark gluten-free flour which can be used as supplement for patients with celiac (or coeliac) disease (also known as celiac sprue and gluten-sensitive enteropathy), one of the most common food intolerances in the world (Heffler et al., 2014). Therefore, buckwheat has the potential to be used as natural means of fortification and enrichment in gluten-free, allergen-free foods and to benefit these individuals (Omary et al., 2014).

The composition of buckwheat is similar to other cereals and pseudo-cereals consumed around the world. The comparison of buckwheat and wheat flour is shown in Table 4. The bran contains fagopyritols and rutin, compounds which may be useful medicinally. However, it also contains large amounts of phytic acid, a major anti-nutritional factor in common wheat (*Triticum aestivum*) (Steadman et al., 2001).

Buckwheat grains hulls have some components with biological activity, e.g. flavonoids and flavones, phenolic acids, condensed tannins, phytosterols, fagopyrins, RS, dietary fibre, lignans, plant sterols, vitamins and minerals (Ahmed et al., 2014).

Table 5. Essential amino acid composition (mg g^{-1} protein) of buckwheat and wheat and comparison of mineral composition (mg 100 g^{-1} flour) of its flours.

Amino acid (mg g^{-1}protein)	Buckwheat	Wheat	References
Lysine	51	25	Ahmed et al., 2014
Methionine	19	18	
Cystine	22	18	
Threonine	35	28	
Valine	47	45	
Isoleucine	35	34	
Leucine	61	68	
Phenylalanine	42	44	
Histidine	22	23	
Tryptophan	16	10	
Mineral composition (mg 100 g^{-1})	**Buckwheat Flour**	**Wheat Flour**	
Ca	12.4	14.8	Ikeda et al., 2006
Cu	0.52	0.16	
Fe	2.86	0.79	
K	450	96	
Mg	375	35	
Mn	1.61	0.43	
P	394	124	
Zn	2.51	0.80	

Ca, calcium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Mn, manganese; P, phosphorus; Zn, zinc.

Table 6. Vitamin composition of buckwheat (Wijngaard and Arendt, 2006).

Vitamins	Level (mg g^{-1})
A (carotenoids)	2.1
B1 (thiamine)	4.6
B2 (riboflavin)	1.4
B3 (niacin)	18.0
B5 (pantothenicacid)	10.5
B6 (pyridoxine)	7.3
C (ascorbicacid)	50.0
E (tocopherols)	54.6

The protein content in buckwheat is significantly higher than important grasses such rice, wheat, sorghum, millet and maize, being the second highest after oat flour. Buckwheat has a well-balanced amino acid profile with a high quality of lysine, limiting amino acid in grasses such wheat (Table 5). The crop have one of the highest amino acid scores among plant sources (Ikeda et al., 2002). The buckwheat flour is a good source of many essential minerals, contains higher levels of Zn, Cu and Mn (Ikeda et al., 1999; Steadman et al., 2001) (Table 6). The content of these essential minerals is higher in comparison with other cereal flours (Ikeda et al., 2006). Buckwheat grains contain higher levels of vitamin B1 (thiamine), B2 (riboflavin), E (tocopherol) and B3 (niacin and niacinamide) compared with most cereals. The vitamin content of buckwheat are presented in Table 6 (Wijngaard and Arendt, 2006).

In breads supplemented with 40% seed mixture of buckwheat and quinoa, it was shown potential to improve nutritional characteristics with 2.5% higher protein, 2% higher fat as well as two-fold higher fiber content and higher Ca and P contents. The sensory characteristics of evaluated breads were excellent even at the level of 40% supplementation level and the addition of quinoa and buckwheat seeds also influenced the rheological characteristics of dough. The inclusion of such high levels of seed in bread was possible by modification in technological procedure of seed preparation, and it could enable the development of a range of new baking products with enhanced nutritive value (Demin et al., 2013).

Buckwheat allergy

Buckwheat allergy is already seen in Asia, Europe and USA. In Europe, since the crop was introduced in popular food sectors. Failure to recognize buckwheat allergy can expose people to a risk to health. Allergy to buckwheat is

typically IgE mediated and it is often associated to severe anaphylaxis (Wieslander and Norbäck, 2001). Although various buckwheat allergens have been identified, the proteins 24 kDa (Fag e 1), 26 kDa and 67-70 kDa have been suggested as important (Tohgi et al., 2011). In all patients with allergies to buckwheat, the protein Fag e 1, which is homologous to 11S or 12S globulin, has reacted with all of the serum IgE. The protein 16 KDa is resistant to digestion and has been identified as a major buckwheat allergen in Japanese and Korean patients with allergy (Park et al., 2000).

Over the past decades, many studies on buckwheat allergy has been published (Smith, 1909; Wieslander and Norbäck, 2001; Heffler et al., 2014). The first study was published in 1909, a case about patients who suffered from dyspnoea, acute rhinitis, urticaria and mucosal angioedema after the ingestion of buckwheat flour (Smith, 1909). Failure to recognize buckwheat allergy can expose people to a risk to health. It is recommended to clinician's suspect and test allergy to buckwheat in patients with symptoms of food allergy, when have the consumption of food produced with this plant in the composition (Heffler et al., 2014).

CONCLUSION

Buckwheat is a crop with potential in agriculture, livestock and human nutrition. In agriculture, it can be used as green manure, to increase predators of common insects pests helping reduce their populations etc. In livestock, it can be used to feed cattle, sheep, pigs, goats and poultry. The plant could act as a functional forage to manipulate ruminal fermentation and the presence of tannins can positively influence the health of small ruminants. In human nutrition, buckwheat is an important food, which contains balanced amino acid composition, relatively high fiber content, high contents of available Zn, Cu and Mn and dietary Se. Therefore, it is a culture that should be further explored, as it promotes many benefits and is easily adaptable to various areas, which can be grown in different regions of the world.

Conflict of Interests

The authors have not declared any conflict of interests.

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