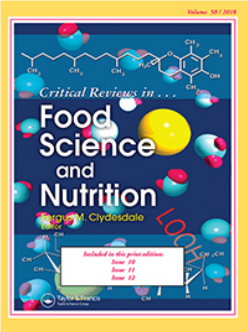

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Sensory analysis and aroma compounds of buckwheat containing products—a review

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ABSTRACT

Buckwheat is a rich source of starch, proteins, minerals and antioxidants, and as such has become a popular functional ingredient incorporated in diverse recipes/products with particular use in the gluten free market. Due to the absence of gluten, application of buckwheat or buckwheat derived ingredients in this particular food sector has increased significantly over recent years with many buckwheat-based products appearing globally.

Sensory analysis is an integral part of the development of products that fulfill consumer expectations. Therefore, investigations on the incorporation of health promoting functional ingredients such as buckwheat into traditional recipes are often complemented by the evaluation of appearance, aroma, taste and texture as well as overall quality through standardized procedures involving trained judges or consumer panels. Aroma is of particular importance in driving consumer preference and its sensory assessment is often complemented with analytical workflows aiming to isolate and determine the concentration of volatile compounds in food and understand the effect of food components on the overall aroma intensity and/or perception of the final product.

The present manuscript provides a review of recent advances and knowledge on the sensory characteristics, consumer preference and volatile compound analysis of buckwheat and buckwheat based products.

KEYWORDS

Common buckwheat; tartary buckwheat; sensory analysis; volatile determination; aroma compounds

1. Introduction

Studies related to buckwheat have mostly focused on common (*Fagopyrum esculentum* Moench) and tartary (*Fagopyrum tataricum* Gaertn) buckwheat and their various morphological parts as a source of bioactive compounds (Zhang et al., 2012; Zielińska & Zieliński, 2009). The role of bioactive compounds from buckwheat as antioxidant scavengers was carefully determined using available analytical methods (Oomah and Mazza, 1996) while human, animal and *in vitro* studies suggest significant hypocholesterolemic effects and anticancer activity related to buckwheat consumption (Giménez- Bastida and Zieliński, 2015). *Inter alia* buckwheat honey is known for its health benefits due to the presence of *p*-hydroxybenzoic, *p*-coumaric, benzoic, abscisic acids and flavonoids and elevated antioxidant features (Gheldof, Wang and Engeseth, 2003; Pasini et al., 2013). It was also claimed that buckwheat honey can be a good marker of environment contamination with perfluoroalkyl compounds (Surma et al., 2016). Due to the potential health benefits, buckwheat has been receiving increasing attention as a potential functional food and various buckwheat-based products for example bread, cakes, noodles, honey, tea, tarhana, alcoholic beverages (beer, shochu), vinegar, sprouts have been developed and are available in the food market (Giménez-Bastida et al., 2015a). Absence of gliadin and glutenin composite (gluten) in buckwheat groats is another important reason for the significant increase in the use of the pseudocereal in developing gluten-free products (Giménez- Bastida et al., 2015b).

Sensory evaluation plays an important role in product development ensuring the attractiveness and consumer acceptability of new products and recipes as producers, using the suggestions and indications of consumers, are able to make changes in product features through recipe and/or process parameter modifications (Baryłko-Pikielna and Matuszewska, 2014). This workflow is particularly important during the development of recipes incorporating functional ingredients associated with health benefits such as phenolic compound rich plant extracts or flours, which occasionally negatively affect the sensory qualities of the product. Therefore, sensory evaluation is a critical part of investigations on the development of functional foods. However, Deana et al. (2007) showed that personal relevance and expectations about the benefits of functional foods influences people's perceptions, thus sensory evaluation becomes less straightforward to interpret. Imm et al. (2011) confirmed that there are gender and country differences in people's perceptions of benefits related to functional cereal products, and that consumers' perceptions could change according to the raw materials used or the type of process modifications and the health benefits associated with the products.

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Linking analytical and sensory methods is a powerful tool that allows food manufacturers to improve their products, however, Chambers IV and Koppel (2013) suggested that the knowledge of sensory and chemical analysis is insufficient to make a link between individual volatile chemicals and attributes noting the need to improve in this research area. This review, is aimed to both researchers and manufacturers of products containing buckwheat derived ingredients as it provides current information on the sensory evaluation and aroma compounds of buckwheat and its products. The products are divided into two groups, those manufactured using common buckwheat (*Fagopyrum esculentum* Moench) and those using tartary buckwheat groats (*Fagopyrum tataricum* Gaertn). Recent studies on sensory and aroma compound analysis of buckwheat-based products like tea, honey, a large variety of bakery products, alcoholic and non-alcoholic beverages such as Shochu and mead are also summarized while extraction techniques, methods and aroma compounds of buckwheat and its products are highlighted.

2. Sensory evaluation of buckwheat containing products

2.1. Bakery products from buckwheat flours

There is a growing interest in the formulation of functional cereal products (Kowalska et al., 2012) while overall good taste, health and dietary benefits are the main aspects determining consumers' preference for functional products. Sensory analysis studies on buckwheat-based products are briefly summarized in Table 1. Sensory evaluation of wheat based biscuits made with 30% (Filipčev et al., 2011a) and with 40% buckwheat flour incorporation (Filipčev et al., 2011b) successfully demonstrated the development of buckwheat-based products with high sensorial acceptability. Chlopicka et al. (2012) also demonstrated that introduction of buckwheat flour (30%) to a wheat bread recipe, is highly acceptable improving both antioxidant and sensory properties of bread. Moreover, research conducted by Wronkowska et al. (2008) and Wronkowska et al. (2012), using more sophisticated Quantitative Descriptive Analysis (QDA) and semi-consumer tests proved that 30% of buckwheat incorporation to gluten-free bread gave the best sensory results. Studies on Turkish bread indicated that the best sensorial score was achieved for bazlan than for yufka breads, both supplemented with 10% of buckwheat flour. The authors suggested that the fermentation process used during preparation of yufka breads (Levent & Bilgiçli, 2012) influenced negatively the sensory properties of this type of bread, indicating possible interactions between buckwheat flour incorporation and the fermentation process. Selimović et al. (2014) used wholegrain buckwheat flour to substitute wheat bread suggesting 40% as the optimum level of substitution to increase antioxidant properties without a significant decrease in sensory quality. Furthermore, 50% of buckwheat flour addition to wheat bread was highly accepted by about 77% of a consumer panel (n = 80) (Stokić et al., 2015).

Sensory analyses of wheat-buckwheat (80:20, w/w) round rolls (Mikulajová, et al., 2015) indicated that most of the evaluated sensory characteristics were positively affected by wheat bran and buckwheat flour supplementation. These results are in agreement with Bajleet, et al. (2010) and Yildiz and Bilgiçli (2012), who successfully incorporated 10% to 40% buckwheat flour to a range of regional bakery product formulations. Hromádková et al. (2007) used hemicellulose from buckwheat groats to achieve better physical characteristics while keeping high overall acceptability of wheat-buckwheat bread. They reported that wheat bread with 0.5% addition of buckwheat hemicellulose received the highest sensory score. Despite the dark color of crumbs, breads with buckwheat hemicellulose were highly accepted by panelists. Lin et al. (2009b) also demonstrated that color of breads with buckwheat incorporation increased their attractiveness. Moreover, Lee (2010) innovatively prepared bread with modest amounts of buckwheat flour using steaming. The highest overall acceptance of wheat bread was estimated to be at 3% buckwheat flour addition.

However, there are some examples where buckwheat flour could lead to a decreased overall acceptability especially at high percentages of incorporation. The decreased liking of buckwheat bread aroma, in comparison to typical bread types, can be linked to the presence of undesirable odor notes like moldy, pealike and vomit-like, which have been detected by Hager et al. (2012) in gluten-free products from commercial flours. Chopra et al. (2014) ascribed the reduction of flavor score of wheat cookies with 75% buckwheat addition to high flavonoids concentration, that are probably responsible for creating the bitter taste of buckwheat flour. Recently, Przygodzka et al. (2015) indicated that using selected spices especially vanilla and cinnamon at 2%, in recipes of rye-buckwheat ginger cakes significantly increased the overall acceptability and successfully masked the specific, pungent aroma and taste of roasted buckwheat groat flour (30% addition). Vujić et al. (2015), demonstrated that the specific aroma of buckwheat in tea biscuits was successfully masked at 30% buckwheat supplementation level, however, the biscuits received low scores related to the acceptability of texture.

Although formulation of sensorially acceptable wheat or rye based products with added buckwheat ingredients has been successfully demonstrated, formulation of gluten-free products in the absence of gluten containing flours is more problematic. Mancebo et al. (2015) observed that consumers' rating of gluten-free cookies prepared from buckwheat did not reach a high score mainly due to the unpleasant and pungent taste of buckwheat. Loredana et al. (2015) analyzing gluten-free products' sensory profiles suggested that the optimum buckwheat flour addition is different in cake, cookies and muffins. The optimum amount of buckwheat flour in gluten-free cakes was established at 30%, 10% for gluten-free cookies and 20% for muffins. According to Torbica et al. (2010) combination of rice and buckwheat flour (husked and unhusked) results in high sensorial acceptability, satisfying textural properties of gluten-free bread while addition of unhusked buckwheat flour at 20% was accepted for further rice-buckwheat breads development (Torbica et al. 2012). Similarly, 20% and 30% buckwheat flour incorporation to gluten-free cookies (rice-buckwheat flour mix) achieved the best overall quality score (Sakač et al., 2015),

Table 1. Summary list of sensory analysis evaluated in buckwheat and its products.

Product	Product formulation	Best overall quality (score/ product)	No of panelists	Sensory scale	Main attributes	References
Biscuits/ cookies/ crackers	Wheat durum semolina (100, 90, 80, 70%) Buckwheat (*Fagopyrum esculentum*) (0, 10, 20, 30%)	7.67 (30% of buckwheat)	8	1–9	appearance, taste, aftertaste, structure shape, appearance of upper surface, appearance of lower surface, fracture, structure, chewiness and flavor	Filipčev, Šimurina, Bodroža-Solarov and Vujakovič (2011a)
	Wheat flour (100, 70, 60, 50%) Buckwheat (*Fagopyrum esculentum*) (0, 30, 40, 50%)	18 (30% of buckwheat)	7	1–5* (different factors of significance)		Filipčev et al. (2011b)
	Wheat flour (90, 80, 70, 60%) Buckwheat flour (10, 20, 30, 40%)	6.71 and 6.20 (20 and 30% buckwheat addition respectively)	10	1–9	color, appearance, flavor, texture, taste, overall acceptability	Bajleet, Ritika and Roshan (2010)
	Wheat flour (0, 25, 50%) Buckwheat flour (100, 75, 50%)	5.71 (75% of buckwheat)	—	1–9	texture, appearance, flavor	Chopra, Dhillon and Puri (2014)
	Rye flour (70%) Buckwheat flour (*Fagopyrum esculentum*) (30%) Selected spice (2%)	7.78 (with cinnamon)	6	0–10	color, odor, taste, aftertaste, hardness, crispness	Przygodzka, Zieliński, Ciesarová, Kukurová and Lamparski (2015)
	Wholemeal and white wheat flour (60 and 10%) Barley/ buckwheat/ oat/ amaranth/ soy (30%)	4.49 (with amaranth) 3.80 (taste of buckwheat biscuits)	8	1–5	appearance, flavor, structure, taste, overall acceptability	Vujić, Čepo and Dragojević (2015)
	Buckwheat flour (43% on dough basis)	4.8	63	1–9	appearance, odor, taste, texture	Mancebo, Picon and Gomez (2015)
	Rice flour (0, 10, 20, 30%) Buckwheat flour (100, 90, 80, 70%)	5.7 (cake with 30%), 3.6–3.8 (cookies with 10%), 3–3.7 (muffins with 20%)	—	1–9	shape, crust aspect, volume, consistence and comparison to mastication, crumb aspect, smell, taste, the product volume, crumb porosity and elasticity	Loredana, Petru, Daniela, Ioan and Monica (2015)
	Rice flour (80%) Buckwheat flour (20%)	Different for each attribute	8	0–6	color, odour, flavor, uncharacteristic odour and flavor, hardness, fracturability, crumbliness, fattiness	Sakač et al. (2016)
	Rice flour (90, 80, 70%) Buckwheat flour (10, 20, 30%)	3.9 for taste, 3.7 for odour, 3.5 for taste (20% of buckwheat addition)	8	0–6	color, odour, hardness, fracturability, sharpness, crumbliness, fattiness, adhesiveness, particle size/ shape, taste	Sakač et al. (2015)
	Wheat flour (60%) Wholegrain buckwheat flour (40%) Gum acacia, guar gum, gum tragacanth or xanthan gum addition	6.96 (buckwheat flour and xanthan gum)	10	1–9	color, appearance, flavor, texture, taste	Kaur, Singh Sandhu, Arora and Sharma (2015)
	Refined buckwheat flour (70%) Cornmeal (30%) Wholegrain buckwheat flour (70%) Cornmeal (30%)	4.57 4.20	10	1–5 (different factors of significance)	appearance, structure, break, firmness, chewiness, odor and taste.	Sedej et al. (2011)
	Chickpea flour (0, 20, 40, 60, 80, 100%) Buckwheat flour (100, 80, 60, 40, 20, 0%)	4.67 (60% of buckwheat)	25	0–10	color, taste, texture, overall acceptance	Yamsaengsung et al. (2012)
	Wholemeal wheaten flour (19.5%) Buckwheat hulls (6%) Green/ yellow tea leaves (5.5%)	7.63 (without teal leaves and similar for yellow tea addtion)	30	1–10	aroma, taste, color, crispness and overall acceptance	Gramza-Michałowska et al. (2016)
Snacks	Buckwheat flour (10, 20, 30, 40, 50%) Corn grits (90, 80, 70, 60, 50%)	4.06 (10% of buckwheat addition)	15	1–9	taste, shape, color, flavor, crispness and overall quality	Wójtowicz, Kolasa and Mościcki (2013)
Bread	Wheat flour (70, 85%) Buckwheat flour (30, 15%)	7–8 (30% buckwheat addition)	31	0–10	color, odor, consistency	Chlopicka, Pasko, Gorinstein, Jedryas and Zagrodzki (2012)
	Commercial gluten-free mix (90, 80, 70, 60, 50%) Buckwheat flour (10, 20, 30, 40, 50%)	5.8 (30% of buckwheat)	8	0–10	appearance, odor, taste, texture, mouth feel	Wronkowska et al. (2008)
	Commercial gluten-free mix (90, 80, 70, 60, 50%) Buckwheat flour (10, 20, 30, 40%)	7.1 (40% of buckwheat)	30	0–10	appearance, odor, taste, texture, mouth feel	Wronkowska, Zielińska, Szawara-Nowak, Troszyńska and Soral-Śmietana (2012)

(*Continued on next page*)

Table 1. (*Continued*)

Product	Product formulation	Best overall quality (score/ product)	No of panelists	Sensory scale	Main attributes	References
	Wheat flour (70%) Buckwheat flour (30%)	6.7 (bazlana) 6.2 (yufka)	12	1–9	appearance, shape and symmetry, texture, mouth feel, taste and odor, elasticity	Levent and Bilgiçli (2012)
	Wheat flour (85, 70, 60%) Wholegrain buckwheat flour (15, 30, 40%)	4.42–4.71	5	1–5	external appearance, appearance of crumb, flavor of crust and crumb, taste of crust and crumb	Selimović et al. (2014)
	Wheat flour (50%) Buckwheat flour (50%)	7.5–8.5	80	1–9	appearance, texture, aroma, taste, after and pleasureness of taste, crust chewiness, fineness of crumb pores and overall acceptance	Stokić et al. (2015)
	Wheat flour (80, 70, 60%) Whole buckwheat flour (20, 30, 40%)	4.7 (20% of buckwheat)	10	1–5	color of crust, elasticity, chewiness, taste-odor, overall acceptance	Yildiz and Bilgiçli (2012)
	Wheat flour Buckwheat hull hemicellulose (*Fagopyrum esculentum)* (0, 0.3, 0.5, 0.7%)	37 (0.5%)	6	0–4*	crumb: adhesiveness, hardness, color, porosity, elasticity; crust and crumb: flavor, aroma; crust: hardness, color	Hromádková, Stavová, Ebringerová and Hirsch (2007)
	Wheat flour (85%) Husked and unhusked buckwheat flour (15%)	5.78 (with husked buckwheat)	48	1–7	appearance, color, flavor, mouth feel, overall acceptance	Lin et al. (2009b)
	Wheat flour Buckwheat flour (0, 3, 6, 9%)	5.8 (3% of buckwheat)	47	1–9	color, texture, flavor, taste, uniformity, chewiness, elasticity	Lee (2010)
	Buckwheat flour (Fagopyrum esculentum) (100%)	3	22	1–9	odor	Hager et al. (2012)
	Rice flour (90, 80, 70%) Husked buckwheat flour (10, 20, 30%) Rice flour (90, 80, 70%) unhusked buckwheat flour (10, 20, 30%)	>6	10	1–9	appearance, taste, softness and flavor	Torbica, Hadnađev and Dapčević (2010)
	Rice flour (90, 80, 70%) Husked buckwheat flour (10, 20, 30%)	4.11 (20% buckwheat flour incorporation)	10	1–9	shape, upper and bottom surface appearance, rupture, cross-section structure, chewiness and flavor	Torbica, Hadnađev and Hadnađev (2012)
	Rice (51%) and maize flour (34%), buckwheat sourdough (15%) Rice (45%) and maize flour (30%), buckwheat sourdough (15%), teff flour (10%)	-	15	1–4	appearance, taste, texture, ortho- and retronasal aroma	Campo et al. (2015)
	Common buckwheat flour (63%) Banana/ passion fruit/ apple flour (37%)	6.28 (with banana flour) 6.20 (with apple)	36	1–9	acceptance, texture, color, flavor and appearance	Möller et al. (2013)
	Wheat flour (96, 92, 88%) Tartary buckwheat flour (4, 8, 12%) Wheat flour (96, 92, 88%) Tartary buckwheat sprouts (4, 8, and 12%)	4% of flour addition and 8% of sprouts were most acceptable	7	0–100	appearance, color, structure, elasticity, viscosity, adhesiveness, flavor,	Xu, Gao, Ma, Guo and Wang (2014)
Roll	White wheat flour T 512 (80%) Whole common buckwheat flour (20%),	89	11	0–100	shape, crust and crumb color, elasticity and porosity, adhesiveness, odor, taste.	Mikulajová, Kohajdová, Németh and Hybenová (2015)
Spaghetti	Wheat durum semolina (100, 90, 80, 70%) Common buckwheat (0, 10, 20, 30%),	7.4 (30% of buckwheat)	10	1–9	adhesiveness, bulkiness, firmness, shiny appearance, color, aroma, flavor	Chillo, Laverse, Falcone, Protopapa and Del Nobile (2008)
Noodles	Common buckwheat Tartary buckwheat	5.57- 6.71 (common buckwheat) 4.57–4.71 (tartary buckwheat)	7	1–9	color, taste, odor, hardness, slipperiness, chewiness	Ma, Guo, Liu, Xu and Wang (2013)
Pancakes	Pea flour (80, 60, 40, 20%) Common buckwheat flour (20, 40, 60, 80%)	40 and 60% of buckwheat addition	8	0–10	aroma, taste, color, hardness, structure	Beitane et al. (2014)
Beer	Buckwheat malt (100%) Unhulled buckwheat malt	3.36–3.57 3.83	- 8	DLG scale[1] (0–5) 1–5	aroma, purity of taste, mouth feel, tingling, bitterness odor, purity of taste, palate-fullness, sparkling, quality of bitterness	Nic Phiaris et al. (2010) Deželak et al. (2014)
Honey	Buckwheat, monofloral	Different for each attribute	13	0–10	aroma: floral, burnt sugar, fruity/estery, malty, buttery, vanilla)	Zhou, Wintersteen and Cadwallader (2002)
Sprouts	Common buckwheat	8.5	15	1–9	appearance, color	Chun and Song (2013)

[1]DLG Deutsche Landwirtschaftsgesellschaft –German Agriculture Society
*for each attribute

while Sakač et al. (2016), drew attention to the consistent sensory acceptability of rice- light buckwheat cookies after a 9-month storage period.

A main problem in the gluten-free bakery market is producing products with high sensory acceptability and maintaining good textural properties. To improve textural properties of a gluten-free product, a biscuit recipe using wholegrain buckwheat flour was modified with the addition of hydrocolloids (Kaur et al. 2015). The authors indicated that the addition of xanthan gum was beneficial, leading to high scores for color, appearance and flavor attributes while guar gum improved the taste better than others gums. The panelists marked the best overall acceptability score for biscuits with added xanthan gum, followed by biscuits with guar gum. Campo et al. (2015) prepared gluten-free breads from teff flour and buckwheat sourdough to improve the nutritional and physical properties of such breads. Although the products didn't receive a high sensory score due to the bitter taste of buckwheat sourdough, some of the participants liked the "bitter" notes of such breads as they related it to products baked in a traditional way. More detailed sensory profiling with quantitative descriptive analysis (QDA) demonstrated that using 30% of either refined or wholegrain buckwheat flour is optimal to create an innovative gluten-free cracker with very good acceptability (Sedej et al., 2011). Yamsaengsung et al. (2012), proposed improving acceptability of buckwheat cookies by adding 60% to 80% chickpea flour. It was suggested that chickpea flour increased positively the texture and taste attributes of this gluten free product. Moreover, addition of 6% buckwheat hulls in cookies was satisfactorily masked by tea-like flavors and received a high sensory panel acceptance (Gramza- Michałowska et al., 2016). To increase attractiveness of bakery products based on buckwheat Möller et al. (2013) proposed addition of apple, banana and passion fruit flours to bread formulas based on common buckwheat flour (ratio 1:1.6 w/w) achieving high acceptability for color, taste, texture and appearance. Moreover, extruded corn snacks with 10% to 50% of flour from buckwheat dehulled seeds were proposed by Wójtowicz et al. (2013) as a good appetizer with higher sensory scores (including texture) achieved for corn-buckwheat snacks with up to 30% buckwheat addition. Generally, addition of buckwheat led to snacks with darker color, lower scores for mouthfeel and decreased hardness.

2.2. Other products from buckwheat flours

The sensory properties of other products based on buckwheat flour such as spaghetti pasta, noodles and pancakes have been investigated (Table 1). Chillo et al. (2008) demonstrated that introduction of buckwheat flour to a durum semolina spaghetti led to products with increased bulkiness, firmness and adhesiveness, while influencing some sensory attributes such as aroma, flavor, shiny appearance and color. However, spaghetti with added buckwheat flour and durum wheat bran presented an overall quality score statistically equal to that of the spaghetti made only of durum semolina. Incorporation of common buckwheat flour (20%) to a recipe of instant noodles led to the highest quality of instant noodles, due to texture and color (Choy et al. 2013). Furthermore, Ma et al. (2013) showed that, according to panelists, common buckwheat is a better material than tartary buckwheat for gluten-free noodle production. Noodles made of common buckwheat received higher scores in all sensorial descriptors including color, taste, aroma and mouthfeel. Bitter taste was more intense in samples made of tartary buckwheat, although more recent reports indicate that noodles, made of flour from a special Tartary buckwheat variety- *Manten-Kirari*, characterized by high rutin concentration had no bitter taste (Suzuki et al., 2015). Such developments are promising for both manufacturers and consumers, who value the nutritional properties of buckwheat but might prefer less bitter taste. Moreover, Beitane et al. (2014) described that sensory properties in gluten free pancakes, made of pea and buckwheat flour mix, changed in relation with the increasing amount of buckwheat flour. The pancakes texture became softer and thicker, the color-darker and buckwheat-like taste and aroma were predominant.

2.3. Buckwheat beer

European Union's legislation states that gluten-free labeled products could contain up to 20 ppm of gluten (www.codexalimentarius.net) while if the gluten content in traditionally gluten containing products is reduced to 20 to 100 ppm, the manufacturers could not make such a statement (the method of marketing defined at national level). In the case of beer based on traditional malts, gluten content may fall in the latter category, although further reductions are possible through enzymatic hydrolysis and improvements of the brewery process. Gluten-free beers with high sensorial acceptability are difficult to achieve and usually involve increases in production costs (Podeszwa 2013). Maccagnan et al. (2004) described a procedure for manufacturing gluten-free beer, based on 40% to 60% of buckwheat and 20% to 60% gluten-free starch syrup. The sensory scores of this buckwheat beer were equal to barley beer. In further studies, Nic Phiaris et al. (2010) published the results of optimization of malting and mashing processes to produce gluten-free beer from 100% buckwheat malt (Table 1). Sensory analysis according to the German Agricultural Society (DLG) indicated that fresh and aged buckwheat beer was highly acceptable for organoleptic features like odor, purity of taste, mouthfeel, tingling and bitterness. The panelists described the taste of such beer as bitter which was not only related to buckwheat malt, but also to the dried yeast and extensive mashing regime. The variable biochemical properties of buckwheat groats were recognized to have a large impact on the quality of buckwheat malt and beer (Nic Phiaris et al., 2010). Moreover, high sensory acceptability was obtained in studies of gluten-free beer from buckwheat malt (Deželak et al. 2014). The buckwheat beer achieved better scores in sparkling and purity of taste in comparison to quinoa beer. According to this study the high content of polyphenols or some amino acids may negatively impact the taste of buckwheat beverages increasing the perception of bitterness in this kind of beer. These studies show that optimization of malting, grist milling, boiling of wort and fermentation could lead to acceptable new products dedicated to consumers with celiac disease.

2.4. Buckwheat honey

Sensory profile evaluation of buckwheat honey is limited in the literature. QDA sensory evaluation (scale from 0 to 10) (Zhou et al. 2002) revealed that the predominant aroma notes in buckwheat honey samples as described by panelists were: malty, burnt sugar, vanilla, buttery, floral and fruity-estery. The sensory experience was compared to chemical profiling through volatile analysis with malty flavor linked to 3-methylbutanal, sweet aroma to maltol and furaneol, vanilla to vanillin, fruity to various esters and floral to 2-phenylethanol, β-damascenone and phenylacetaldehyde. Sensory analysis of buckwheat honey could be facilitated by a lexicon developed for floral honeys containing the main sensory descriptors of odor, texture and flavor (Galan-Soldevilla et al. 2005).

2.5. Buckwheat sprouts

Buckwheat sprouts is another product of current interest with pro-healthy attributes. *In vivo* studies confirmed that intake of fermented buckwheat sprouts can decrease blood pressure (Nakamura et al. 2013), while pro-healthy attributes of buckwheat sprouts are linked to high content of flavonoids, i.e., rutin (2.57 mg/g), isoorientin (1.27 mg/g), vitexin (0.11 mg/g), isovitexin (0.04 mg/g), and also anthocyanins, i.e., cyanidin 3-O-glucoside (0.16–0.20 mg/g) and cyanidin 3-O-rutinoside (5.55–6.57 mg/g) (Liu et al. 2007; Kim et al., 2007). Generally, as sprouts need to be cleaned from microbial contamination some methods can influence both the chemical composition and sensory attributes. Chun and Song (2013) found that using a combination of chlorine dioxide, fumaric acid and ultraviolet-C to reduce microbial contamination of buckwheat sprouts was effective, while the sensory acceptability was retained with minimal sensory changes. There is very little information on incorporating buckwheat sprouts in food formulations. In one of the few studies, Xu et al. (2014) incorporated tartary buckwheat sprouts to steamed bread formulation instead of buckwheat flour, however the strong bitterness and astringency of sprouts restricted their addition to relatively low levels (8%), as increased amounts led to significant negative effects on consumer acceptance.

3. Volatile compounds of buckwheat and its products

3.1. Current methods of aroma compounds determination

Few studies deal with the evaluation of aroma compounds of buckwheat and buckwheat related products. Methodologies, pertinent to flavor compound evaluation using instrumental analysis have been recently reviewed with Jeleń et al. (2012) suggesting that microextraction techniques such as solid phase microextraction (SPME) and stir bar sorptive extraction (SBSE) have a great potential to evaluate food odor. Dynamic headspace (DHS), solid phase microextraction (SPME), headspace sorptive extraction (HSSE), solvent extraction (SE) and simultaneous distillation-extraction (SDE) coupled with gas chromatography mass spectrometry (GC-MS) were proposed by Prosen et al. (2010) as the most suitable extraction methods for buckwheat volatile compounds. The analysis of aroma compounds is presented in two sections according to products obtained from two main buckwheat species: tartary and common buckwheat. The methodology used for aroma compound determination is presented in Table 2 while identified compounds and their determined odor properties in selected buckwheat-based product is presented in Table 3.

3.2. Aroma compounds of tartary buckwheat and its products

Aroma profiling investigations revealed that tartary buckwheat kernels have a strong aroma that characteristically differs from the aroma of common buckwheat (Janeš et al. 2012). From 48 volatiles, 26 odor-active compounds were found to contribute to the overall tartary buckwheat aroma including high odor activity aldehydes: hexanal, nonanal, decanal, (E)-2-nonenal, (E, E)-2,4-nonadienal, (E, E)-2,4-decadienal, as well as phenylethyl alcohol. The most important difference of the aroma of tartary buckwheat is the absence of salicylaldehyde and presence of naphthalene indicating the potential to use salicylaldehyde as a marker to detect contamination/adulteration of tartary buckwheat with common buckwheat or *vice versa*.

Tartary buckwheat tea is an important and popular healthy drink with distinct malty aroma in Asia, Europe and America and a rich source of flavonoids, polyphenols, micronutrients and amino acids (Zhao, 2010). Qin et al. (2011) were first to identify and quantify the aroma compounds characteristic for this type of tea. Using GC-MS and GC-O, 2,5-dimethyl-4-hydroxy-3-(2H)-furanone, maltol, nonanal, benzeneacetaldehyde, 2,3-diethyl-5-methylpyrazine, 2,5-dimethylpyrazine, 2-ethyl-5-methylpyrazine, and trimethylpyrazine were identified as compounds with a high odor activity contributing to the tartary buckwheat tea aroma. Additionally, the authors also determined some bioactive compounds in buckwheat tea, e.g. furaneol, linoleic acid, niacin, vanillic acid, 7-hydroxycoumarin, and butylated hydroxytoluene.

Studies describing aroma components in Shanxi aged vinegar made from tartary buckwheat were performed to evaluate the optimum conditions of the fermentation process (Wang et al. 2012a). Most of the 39 identified compounds have been already identified, but dimethyl trisulfide, 2-methyl-2-butenal, benzene acetaldehyde, ethyl myristate, 1-pentanol, butanoic acid, 2-butanone, 2,3- and 2,6-dimethylpyrazine, 2-ethyl-5-methylpyrazine and benzothiazole were identified for the first time in this type of vinegar. The characteristic aroma of tartary buckwheat vinegar was mostly assigned to pyrazines and furfurals formed during the Maillard reaction. The authors suggested that decreasing the time of vinegar heating (at 85 °C) from 6 to 3 days may contribute to counteract the oxidation, thermal degradation or volatilization processes and increase the attractiveness of the product. Moreover, another study dedicated to tartary buckwheat vinegar (Wang et al. 2012b) demonstrated that some volatile and nonvolatile components of this vinegar are highly correlated to antioxidant capacity measured by DPPH and differential pulse voltammogram assays. Thus, Maillard reaction products formed during high temperature treatment contribute both to the characteristic aroma of tartary buckwheat vinegar and to its antioxidant capacity overall.

Table 2. Volatile flavor compounds identified in buckwheat and its products.

Product	Buckwheat origin	Method	Identification	No of compounds (markers)*	Publication
Buckwheat flour	unknown	continuous distillation-extraction, GC-MS	MS	45	Aoki, Koizumi, Ogawa & Yoshzaki (1981)
	Fagopyrum esculentum M.	HS-SPME, GC-MS VOCOL column (60 m × 0.25 mm × 1.5 μm)	MS	14 (2)	Janeš, Kantar, Kreft & Prosen (2009)
	Fagopyrum tataricum Gaertn.	GC-MS VOCOL column (60 m × 0.25 mm × 1.5 μm)	MS, STD	48	Janeš, Prosen & Kreft (2012)
	Fagopyrum esculentum M.	GC-MS Supelcowax 10 capillary column (60 m × 0.25 mm × 0.25 μm)	MS	25	Mazza et al. (1999)
Bread	*Fagopyrum esculentum M.*	GC-MS Simultaneous distillation-extraction (SDE) DB-Wax (60 m × 0.25 mm × 0.25 μm)	MS, STD	37	Lin et al. (2009a)
Tea	*Fagopyrum tataricum Gaertn.*	HS-SPME GC-MS PDMS/DVB HP-5 MS (30 m × 0.25 mm × 0.25 μm) GC-O	MS, LRI, STD	77 (35)	Qin et al. (2011)
Honey	unknown	HS-SPME GC/MS CAR/PDMS/DVB fiber Rtx-Wax column (30 m × 0.25 mm × 0.25 μm)	MS, LRI	86 (14)	Panseri et al. (2013)
		HS-SPME GC/MS CAR/PDMS/DVB fiber Stabilwax-DA column (30 m × 0.32 mm × 0.5 μm)	MS, LRI	(16)	Plutowska et al. (2011)
Vinegar	*Fagopyrum tataricum Gaertn.*	Dynamic Headspace Sampling GC-O/MS DB-Wax (30 m × 0.32 mm × 0.25 μm) DB-5MS capillary column (30 m × 0.32 mm × 0.25 μm)	MS, LRI	45	Wang et al. (2012b)
Fermented milk with buckwheat	*Fagopyrum esculentum M.*	HP-5MS column (30 m × 0.25 mm × 0.25 μm) GC-HS-SPME DVB/CAR/PDMS	MS	11	Lee & Park (2013)
Alcoholic beverages Shochu	*Fagopyrum esculentum M.*	GC-MS, GS-O AEDA aroma extract dilution analysis	MS, LRI	21	Sakaida et al. (2003)
Mead	*Fagopyrum esculentum M.*	HS-SPME GC/MS DVB/CAR/PDMS fiber DB-FFAP column (30 m × 0.25 mm × 0.25 μm)	MS, LRI	10	Wintersteen, Andrae & Engeseth (2005)
Beer	*Fagopyrum esculentum M.*	GC-FID	Kovats indexes	25	Nic Phiaris et al. (2010)
	Fagopyrum esculentum M.	GC-FID, GC-MS	MS, STD	8	Deželak et a. (2014)
Sprouts	*Fagopyrum esculentum M. Fagopyrum tataricum Gaertn.*	Solvent-free solid injector (SFSI) extraction HP-5 MS (30 m × 0.25 mm × 0.25 μm) GC-MS	MS, LRI	35	Kim et al. (2014)

Identification methods: MS- identification by comparison with mass spectra, RI- identification by comparison with published GC retention index, STD- identification supported by authentic standard compounds.
*Authors declared that markers are characteristic compounds for investigated product

3.3. Aroma compounds of common buckwheat and its products

Salicylaldehyde was identified by gas chromatography coupled with mass spectrometry as a predominant compound of common buckwheat (Janeš and Kreft, 2008) but absent in tartary buckwheat flours Janeš et al. (2010). In further studies, Janeš et al. (2009) calculated the odor activity values for each identified compound and demonstrated that other important aroma-active compounds in common buckwheat include (E, E)- 2,4-decadienal, (E)-2-nonenal, 2,5-dimethyl-4-hydroxy-3(2H)-furanone, 2-methoxy-4-vinylphenol and 2-phenylacetaldehyde. Sweet, fruity, strawberry, hot sugar, caramel or burnt pineapple odor was characteristic of furanone whereas grassy, sweet and orange aroma of decadienal; both contributing to buckwheat aroma.

The first available research on buckwheat flour was published by Aoki et al. (1981) who suggested that buckwheat flour flavor depends on separate milling fractions, the effect of n-alcohols and salicylaldehyde amount. Yajima et al. (1983) identified two hundred and nine compounds in boiled buckwheat flour extracted using a Likens-Nickerson apparatus and fractionated into acidic, weak acidic, basic and neutral fractions. The significance of these compounds for the aroma of buckwheat and buckwheat products such as noodles is not known, since research on the odor evaluation of buckwheat volatile compounds is limited. Aoki and Koizumi (1986) indicated that nonanal, octanal, and hexanal are important aroma compounds of buckwheat because of their low odor threshold values in water. Przybylski et al. (1995) found that the content of total volatile compounds, analyzed in buckwheat groats using a purge and trap system, decreased with storage in air, and that the concentration of saturated and nonsaturated aldehydes increased during storage. Further, Mazza et al. (1999) studied the composition of volatile components in buckwheat flour freshly milled and stored for 1 year under controlled conditions (97% of nitrogen, 1.5% of oxygen, and 1.5% of carbon dioxide). Twenty-five volatile compounds were identified from this flour using a dynamic headspace technique coupled to gas

Table 3. Individual or groups of main volatile compounds and their odor properties in selected buckwheat-based products.

Buckwheat product	Individual/group of main volatile compounds	Odour property	References
Flour	2,5-dimethyl-4-hydroxy-3-(2H)-furanone	sweet, fruity, strawberry, hot sugar, caramel, burnt pineapple-like	Janeš, Kantar, Kreft and Prosen (2009)
	(E,E)-2,4-decadienal	green to sweet, orange-like	Mazza et al. (1999)
	toluene	paint	
	ethyl benzene	gasoline-like	
	p-, m-xylene	plastic	
	o-xylene	geranium	
	4-ethyltoluene trimethyl benzene isomer	oily	
	ethyl acetate	pineapple	
	butyl acetate	fruit-like, apple, banana	
	5-ethyl-indole-2-carboxylic acid ethyl ester	waxy	
	ethanol	sweet	
	1-butanol	medicine, fruity	
	1-penten-3-ol	green, fruity	
	2-metyhl-1-butanol	malt-like	
	1-pentanol	fruity	
	1-hexanol	flowery, fruit	
	cumic acid	green	
	hexanal	grassy	
	nonanal	fat, citrus, green-like	
	2-heptanone	soapy	
	6-methyl-5-hepten-2-one, limonene	citrus-like	
Boiled flour	phenol, guaiacol, 4-vinylphenol, salicylaldehyde	smoky, phenolic-like	Yajima et al. (1983)
	2-(1′-ethoxyethyl)- and 2-(1′-ethoxyethyl)-5-methyl-pyrazine	nutty-like	
	1-octen-3-ol	musty-like	
	thiazoles	cereal-like	
	alkanals	green-like	
Bread	furfuryl alcohol	burnt	Lin, Hsieh, Liu, Lee and Mau (2009a)
	2,4-decadienal	seaweed	
	furfural	almond-like	
	phenylethanal	honey-like	
	ethyl acetate	pineapple	
	acetoin	buttery	
	6-dodecalactone	sweet, fruit	
Sprouts	alcohols	fruity and grassy	Kim et al. (2014)
Honey	methylpropanal, 3-methylbutanal	malty	Zhou et al. (2002)[1]
	ethyl 2-methylpropanoate	fruity	
	ethyl 2-methylbutanoate	estery, fruity	
	dimethyl trisulfide	sulfurous	
	methional	cooked potato-like	
	phenylacetaldehyde	floral, rosy	
	β-damascenone	cooked apple/ grape-like	
	2-phenylethanol	rosy, floral	
	p-anisaldehyde	sweet, fragrance, floral	
	coumarin	wild flower, herbaceous	
	furfural	almond-like	Plutowska, Chmiel, Dymerski and Wardencki, (2011)
	methylbutyraldehydes	pungent, sweet, malty, burnt cocoa-like	
	butanoic acid	pungent-like	Panseri, Manzo, Chiesa and Giorgi (2013)
	pentanoic acid	sour aroma and acid taste	
Mead	ethyl butanoate	fruity, bubble gum-like	Wintersteen, Andrae and Engeseth (2005)
	ethyl 2-methylbutanoate	fruity, berry-like	
	ethyl 3-methylbutanoate	fruity, blueberry-like	
	isoamyl acetate	fruity, banana-like	
	ethyl hexanoate	fruity, apple-like	
	ethyl octanoate	fruity	
	ethyl decanoate	sweet, nut-like	
	isoamyl alcohol	malty, sour	
	2-phenylethanol	rosy	
	4-methylphenol	phenolic	
Shochu	ethyl isobutyrate	fruity	Sakaida et al. (2003)
	isoamyl acetate	banana-like	
	isoamyl alcohol	oily	
	ethyl caprylate	adzuki bean-like	
	isovaleric acid	buttery, nutty	
	methional	sulfurous	
	β-phenethyl acetate, phenethyl alcohol, ethyl cinnamate	floral	

(Continued on next page)

Table 3. (*Continued*)

Buckwheat product	Individual/group of main volatile compounds	Odour property	References
Beer	1-hexanol	resin, flower, green	Nic Phiaris et al. (2010)
	1-heptanol	mushroom	
	1-octanol	orange-like	
	1-decanal	floral	
	2-phenylethanol	floral	
	isobutyl acetate, hexyl acetate, heptyl acetate, octyl acetate, furfuryl acetate	fruity/ floral	
	phenyl acetic acid-ethyl-ester,	fruity, banana-like	
	ethyl butyrate, ethyl caproate, ethyl caprate, ethyl caprinate	fruity/ floral	
	caproic acid, caprylic acid, pelargonic	coconut-like	
	acid, capric acid	acidic	
	lauric acid		
	α-terpineol	fatty	
	linalool	oil, anise, mint	
	nerol	floral, lavender	
	γ-nonalactone	sweet	
		coconut, peach	
	acetaldehyde	ethereal	Deželak et al. (2014)
	ethyl acetate	sweet	
	methanol	alcoholic	
	1-propanol	alcoholic	
	isoamyl acetate	banana-like	
	2- and 3-methylbutanol	malty, solvent-like	
	2-phenylethyl acetate	floral, honey-like	
	2-phenylethanol	floral	
Tea[2]	2-methylpyrazine	nutty, cocoa, roasty	Qin et al. (2011)
	2,5-dimethylpyrazine and 2-ethyl-5-methylpyrazine	nutty, roasty	
	ethylpyrazine	nutty, buttery	
	2,3-dimethylpyrazine	nutty, cocoa	
	2-ethyl-3-methylpyrazine and 3-ethyl-2,5-dimethylpyrazine	roasty	
	2-isobutyl-3-methylpyrazine	earthy	
	benzaldehyde	sweet, almond, nutty	
	benzenacetaldehyde	sweet, floral	
	5-methyl-2-furancarboxyaldehyde	sweet, spicy	
	nonanal	wax, green grass	
	decanal	sweet, waxy	

[1]Results presented only for neutral fraction
[2]Volatiles extracted by SPME technique

chromatography of which 18 were odor-active but none of them were characteristic of the typical buckwheat flour aroma. A lower concentration of the key buckwheat aroma compounds was noticed during flour storage with low oxygen and high carbon dioxide levels while a 4-fold increase of hexyl acetate and hexanol content was observed in flour stored for 14 months. Kawamaki et al. (2008) investigated the effects of storage temperature on flavor of flour milled from buckwheat groats. Storage at temperatures above 10 °C resulted in low sensory scores due to an increase of bitterness and a decrease of aroma. In contrast, samples of buckwheat flour stored at 5 °C showed low scores in bitterness and hardness. These findings indicated that storage conditions in low temperatures are suitable for preserving buckwheat flour aroma. A following study (Kawamaki et al. 2009) demonstrated that longer storage time of buckwheat flour negatively influenced the sensory attributes resulting in higher bitterness and astringency. The low sensory scores were confirmed using instrumental analysis by GC-MS revealing that the total amount of aroma compounds decreased during longer storage time.

The aroma of popular Japanese buckwheat noodles was investigated by Suzuki et al. (2010). They demonstrated that in boiled buckwheat noodles, flavor formation was strictly linked with enzyme activity such as lipases and peroxidases as indicated by correlation analysis between hexanal, butanal, 2- and 3-methylbutanal concentrations and enzyme activity. Ohinata et al. (2001) investigated the differences on flavor generation between buckwheat flour milled by various methods. Aroma analysis revealed that ethylbenzene and xylene concentrations were significantly higher in comparison to others just after buckwheat groats milling, however decreased after few days. Moreover, the authors suggested that the pungent taste of buckwheat flour is correlated with oxidation conditions during groats milling.

Further studies determined the volatile fraction in common buckwheat sprouts (Kim et al., 2014) with 35 volatile compounds detected in 10 varieties. Alcohols and ester derivatives represented the largest chemical groups among the different volatile components giving rise to fruity and grassy aromas.

The organoleptic properties of buckwheat honey are characterized by the sharp sweet smell of buckwheat flowers and have a specific sharp, sweet and lightly biting taste. The product's volatiles profile is influenced frequently by plant variety and/or geographical and environmental conditions and as such comparison between different studies is relatively difficult.

Manyi-Loh et al. (2011) generally grouped the main honey volatiles into groups as aldehydes, ketones, acids, alcohols, hydrocarbons, norisoprenoids, terpenes and benzene compounds and their derivatives, furan and pyran derivatives. More inquisitive investigation was conducted by Zhou et al. (2002), who presented the characteristic aroma components of buckwheat honey by combining sensory and instrumental techniques. Relative aroma intensity of individual volatile components was evaluated using GC-olfactometry. Results indicated that 3-methylbutanal, furaneol, and β-damascenone were the most potent odorants in buckwheat honey. Whereas 3-methylbutanal was mainly responsible for the distinct malty aroma, other important aroma-active compounds included methylpropanal, 2,3-butanedione, phenylacetaldehyde, 3-methylbutyric acid, maltol, vanillin, methional, coumarin, and *p*-cresol. Wolski et al. (2006) were first to employ GC-MS with solid phase microextration as a method to determine the aroma of buckwheat honey. Pentanal, furfural and 2-ethylhexanol were identified in buckwheat honey employing GC-MS and olfactometry with SPME (Wardencki et al. 2009). In further studies, they observed that as well as furfural, 2- and 3-methylbutyraldyhyde were the main compounds in the volatile fraction of Polish buckwheat honey (Plutowska et al. 2011). The researchers declared that furfural with odor of sweet almonds and methylbutyraldehydes with pungent, sweet, malty and burnt cocoa smell can be specific markers of buckwheat honey. However, their study also illustrated that fatty acids like 2- and 3-methylbutanoic as well as butanoic acid can be also potential markers of organoleptic properties of buckwheat honey. Panseri et al. (2013) reported that butanoic acid is responsible for the characteristic pungent smell of buckwheat honey while pentanoic acid induced a sour smell and an acid taste. In addition, Pasini et al. (2013) stated that 5-methylfurfural and other furans are also important odorants in buckwheat honey.

Key aroma compounds of buckwheat-based alcohol beverages were investigated in various studies. Samples of Japanese Schochu were analyzed using gas chromatography-olfactometry and GC-MS (Sakaida et al., 2003) coupled with aroma extract dilution analysis (AEDA) to estimate the relative odor potency of each key aroma compound and calculation of the dilution factor (FD). Twenty-two potent odorants were identified in buckwheat Schochu, (higher FD factors compared to rice or barley Schochu) with ethyl cinnamate being the most intense aroma active component. The volatile profile of buckwheat mead was also investigated (Wintersteen et al., 2005) with noticeable differences observed in aroma profile between low and high-heated mead. Moreover, GC analysis was used to determine/describe aroma compounds in buckwheat-malted beer (Nic Phiaris et al., 2010; Deželak et al., 2014). 2-phenylethanol was found to be a representative aroma compound in buckwheat-based alcoholic beverages like mead (Wintersteen et al., 2005) and beer (Nic Phiaris et al., 2010; Deželak et al., 2014) while a wide range of esters were also identified. Isoamyl acetate, giving rise to banana-like aroma, had high aroma thresholds in buckwheat mead, Schochu and beer (Wintersteen et al., 2005; Sakaida et al., 2003; Deželak et al., 2014) while Nic Phiaris et al. (2010) observed high amounts of ethyl caprinate with characteristic coconut flavor.

Another study was focused on buckwheat introduction to dairy products. Lee and Park (2013) aimed to improve the quality of plain yogurt by varying concentrations of a buckwheat saccharification solution (BSS) which was added to the milk, followed by fermentation with commercially available mixed strains of lactic acid bacteria. Volatile compounds were analyzed using gas chromatography-headspace-solid phase microextraction (GC-HS-SPME). Eleven volatile compounds were identified by GC-MS, of which, diacetyl, butanoic acid, and 2-heptanone proportionally increased as the levels of BSS increased. Undesirable compounds such as acetic acid and 2-butanone, decreased as BSS concentration increased. Fermentation properties were significantly altered with the addition of BSS indicating that the flavor quality of plain yogurt can be improved by adding BSS for fermentation, with the additional health benefits from buckwheat.

4. Conclusions

The use of buckwheat flour or buckwheat related ingredients as functional raw materials has increased significantly over the recent years as a result of consumer awareness of the potential health benefits of buckwheat and increased commercial activity in the gluten free market. Incorporation of buckwheat in several types of products such as biscuits, snacks and breads has been successful, leading to products with acceptable sensory characteristics. The highest sensory acceptance is typically achieved for products with 20–30% of buckwheat flour. However, there are instances where further technological and recipe modifications are necessary to improve overall product satisfaction.

This review also aimed to summarize recent activities in relation to sensory analysis and volatile profiling using instrumental methods of buckwheat-based products and the importance and necessity of complementary approaches. In general, volatile compound profile of buckwheat is dominated by alcohols, aldehydes, ketones, benzene derivatives, terpenoids, alkanes, and furanoids. Tartary and common buckwheat kernels have similar volatile compounds but there are qualitative differences in the various kernel fractions (Lasekan and Lasekan, 2012).

Most common instrumental analysis techniques have already been employed on several buckwheat based products. However, potential future work could include the use of advanced techniques of aroma measurement such as proton transfer reaction mass spectrometry, PTR-MS, to better understand the relationships between precursors and products (Czepa and Muenz, 2015) while complementary technologies such as electronic nose and electronic tongue could provide useful insights in product quality and sensory panel monitoring (Dymerski et al., 2014). Moreover, new methods to dynamically monitor aroma release during food consumption such as Atmospheric Pressure Chemical Ionization coupled with mass spectrometry (APCI-MS) (Gan et al., 2016) could also be applied to allow monitoring of aroma in real time.

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