Characterization of volatile compounds in Swedish yellow and gray peas: Implications for new legume-based ingredients

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Abstract
There is a growing demand for alternative protein-source ingredients from domestically cultivated pulses in Europe, including Sweden. However, the use of legumes as a food ingredient is limited by the presence of a distinct beany flavor. Mapping the volatile compounds composition in a standardized approach will aid in comparing different legume varieties and processing treatments. The composition of volatile compounds in flour from yellow and gray peas (raw and boiled) was investigated and compared. Volatile compounds were isolated by headspace solid-phase microextraction (HS-SPME) and analyzed using gas chromatography-mass spectrophotometry (GC-MS). A total of 43 volatiles were identified, consisting mostly of aldehydes, followed by alkanes, alcohols, ketones, alkenes, furans, terpenes, aromatics, and sulfur-containing compounds. Boiling led to a marked reduction in alcohols and an increase in aldehydes. Several markers of beany flavor, such as 1-octen-3-ol, 2-pentylfuran, and 3,5-octadien-2-one, were significantly decreased after boiling. The composition of volatiles collected from yellow and gray peas was comparable, but boiled yellow pea had a higher abundance of beany flavor as compared to gray pea. Gray pea is an interesting variety to be explored further as a potential alternative to the well-known yellow pea.

KEYWORDS
boiling, gray pea, yellow pea, volatile compounds, HS-SPME-GC-MS

1 | INTRODUCTION

The Western diet is typically composed of a high proportion of meat, which can result in adverse effects on human health and the environment (Wolk, 2017). However, the increasing shift towards vegetarian and flexitarian diets is driving demand for plant-based products (European Commission, 2018). In particular, pea (Pisum sativum) is gaining global interest as a sustainable alternative protein source (European Commission, 2018). Pea also contains abundant amounts of dietary fiber, minerals, and vitamins and is considered as a healthy food choice (Sánchez-Chino, Jiménez-Martínez, Dávila-Ortiz, Álvarez-González, & Madrigal-Bujaidar, 2015).

In Sweden, peas are traditionally consumed in the form of soup from dried yellow pea. However, to stimulate utilization of peas in different food applications, it is necessary to process peas further into, for instance, pea flour (Ferawati, Hefni, & Witthöft, 2019; Ma, Boye, Azarnia, & Simpson, 2016; Szczygiel, Harte, Strasburg, & Cho, 2017). Pea flour is versatile and can be used in products such as gluten-free bakery goods, meat analog products, or beverages (Ferawati et al., 2019). Moreover, there is an increasing interest among food companies in Sweden in using ingredients from domestically grown pulses, such as yellow and gray peas, to reduce dependency on imported soybean (Olsson, 2017). Yellow pea (Pisum sativum) is one of the main pulses cultivated in Sweden, with total production of 48,900...
tions in 2018 (Swedish Board of Agriculture, 2019). Gray pea (Pisum sativum var. arvense) is an ancient and underutilized local pea variety in Sweden that is currently cultivated on a small scale (Hushållningssällskapet, 2013; Swedish Board of Agriculture, 2015). A previous study reported that flour from gray pea has similar functional properties as compared with flour from yellow pea (Ferawati et al., 2019). Additionally, gray pea had a higher amount of resistant starch and folate content (Ferawati et al., 2019). Cultivation of yellow and gray peas could potentially be expanded, as demand for pea-based foods is projected to rise in future (European Commission, 2018; Röös et al., 2018).

One of the main challenges using pea as a functional food ingredient is the presence of a strong, beany flavor (Murat, Bard, Dhalléine, & Cayot, 2013). There is no consensus in the literature on the compounds responsible for the beany flavor in pulses, especially in peas (Azarnia, Boye, Warkentin, & Malcolmson, 2011; Jiang et al., 2016; Khrisanapant, Kebede, Leong, & Oey, 2019; Ma et al., 2016; Mishra, Tripathi, Gupta, & Vairiy, 2017; Murat et al., 2013; Oomah & Liang, 2007; Oomah, Razafindrainibe, & Drover, 2014; Szczygiel et al., 2017). However, hexanal, 1-octen-3-ol, and 2-pentylfuran are frequently mentioned as potential markers of beany flavor with a low threshold value (Mishra et al., 2017; Oomah et al., 2014; Oomah & Liang, 2007; Xu, Jin, Lan, Rao, & Chen, 2019). The compounds 1-octen-3-ol and 2-pentylfuran have been reported as the main beany flavoring compound in commercial soybean products and green pea (Oomah et al., 2014; Rodríguez-Bernaldo De Quiros, López-Hernández, González-Castro, De La Cruz-García, & Simal-Lozano, 2000), and 3,5-octadien-2-one has been suggested to contribute to beany flavor in dry beans (Oomah & Liang, 2007; Szczygiel et al., 2017).

These beany flavor compounds mainly originate from lipid degradation due to chemical and enzymatic reactions that occur during harvesting, storage, and processing (Ma et al., 2016).

Pulses, including peas, must be processed before consumption to diminish the content of anti-nutrients (Sánchez-Chino et al., 2015). Processing techniques, such as soaking, boiling, and drying, are reported to reduce the activity of protease inhibitors and lectins and reduce the content of flatulence causing components, that is, α-galactosides, in pulses (Sánchez-Chino et al., 2015). Processing could also alter the volatile compound composition in pulses. A decrease in total area counts of volatiles and a loss of alcohols have been reported in response to boiling peas, but results for other compound groups are inconsistent (Azarnia, Boye, Warkentin, & Malcolmson, 2011; Ma et al., 2016). Published studies have examined cooked mashed peas which might not be a practical choice for industrial food production. Cooked mashed peas require more resources, such as larger storage space and man power for handling, as compared with pea flour. Moreover, the water content in cooked mashed pea might be highly varied depending on the raw pea seeds; thus, it will add a challenge to adjust the product formulation. Hence, it motivates additional studies to investigate the factors affecting volatile profiles in raw pea flour as well as boiled peas that have been dried and milled, to obtain flours suitable for food applications.

Headspace solid-phase microextraction (HS-SPME), in combination with gas chromatography (GC) and mass spectrophotometry (MS), is commonly used for profiling volatile compounds in various matrices (Vas & Vékey, 2004). HS-SPME is a simple, sensitive, and fast sampling technique for collecting volatile compounds from samples without using any solvents (Vas & Vékey, 2004). The method only requires a small amount of sample and is cost-effective (Vas & Vékey, 2004). A number of researchers have analyzed the composition of volatile compounds and studied the effect of processing on the volatile profile in beans using HS-SPME-GC-MS (Jiang et al., 2016; Mishra et al., 2017; Oomah et al., 2014; Oomah & Liang, 2007; Szczygiel et al., 2017). However, only a few studies have focused on peas (Azarnia, Boye, Warkentin, & Malcolmson, 2011; Ma et al., 2016; Murat et al., 2013; Xu et al., 2019). Furthermore, there are no studies on the volatile compound profile of yellow and gray peas cultivated in Sweden.

Therefore, the objectives of the present study were (i) to identify and compare volatile compounds in flours from raw Swedish yellow and gray peas and (ii) to investigate the effects of processing (i.e., a combination of soaking, boiling, and drying) on the volatile compound profile of pea flours. Data on the volatile compound profiles of yellow and gray peas flours can provide the basis for development of food products with little or no beany flavor, which is of particular interest to manufacturers of products such as beverages, bakery goods, snacks, or meat analog products.

2 | MATERIALS AND METHODS

2.1 | Materials

Dried yellow pea (Pisum sativum, Clara variety) and gray pea (Pisum sativum, unknown Latvian variety), grown in Öland, Sweden, were obtained from Kalmar-Ölands Trädgårdsproduktor (KÖTP), Kalmar, Sweden. All materials were harvested in 2017. The pulses were stored packed in a cardboard box at room temperature (~20°C) for approximately 22 months until processing.

The reference compounds benzaldehyde, butanal-3-methyl, 3-carene, furan-2-pentyl, heptanal, 1-heptanol, 5-hepten-2-one-6-methyl, 2-hexenal, 1-pentanol, toluene, and α-pinene were obtained from Sigma-Aldrich (Darmstadt, Germany). Other references used were 1-octen-3-ol and octanal obtained from Lancaster Synthesis (Morecambe, England), 2-heptanal obtained from ICI (Belgium), and 5-hepten-2-ol-6-methyl was from a personal collection in the organic chemistry laboratory at Linnaeus University (Kalmar, Sweden).

2.2 | Methods

2.2.1 | Preparation of pea flours

Flour from raw pea: Whole dried yellow and gray peas were ground using a laboratory-scale mill (Cyclotec 1093, Tecator, Sweden). Flour
from boiled pea: Dried peas were soaked in tap water (1:3 w/v) at room temperature for 14 h then boiled in water (1:5 w/v) until they get soft (50 min for yellow pea and 35 min for gray pea; Ferawati et al., 2019). The boiled peas were dried in a convection oven at 50°C for 16 h. The dried boiled peas were ground (500 μm particle size) using the laboratory-scale mill referred to above.

2.2.2 | Headspace solid-phase microextraction

Volatile compounds extraction from the pea flours was performed with a modification of published extraction conditions (Oomah & Liang, 2007), using freshly milled raw or dried boiled pea seeds. The ground samples (approximately 50 g) were analyzed within 4 h after milling. For this, pea flour was transferred directly after milling to three 100-ml Erlenmeyer flasks (10 g each), which were tightly covered with aluminum foil and kept in room temperature until analysis. One sample at a time was equilibrated at 50°C for 30 min in a water bath. After that, the volatile compounds were extracted by exposing a 1-cm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) SPME fiber (Supelco, Bellefonte, PA, USA) to the headspace of the sample for 30 min. The DVB/CAR/PDMS fiber is recommended for studies of volatile compounds in food and beverages due to its broad binding capacity for a variety of volatiles (Murat, Gourrat, Jerosch, & Cayot, 2012; Oomah & Liang, 2007; Vas & Vékey, 2004; Xu et al., 2019). The extraction was done in pace with the chromatography analysis. Extracted volatile compounds were desorbed by injecting and exposing the fiber at the injection port of the GC at 250°C for 10 min. All samples were analyzed within 24 h. The SPME fiber was conditioned before use at 270°C for 1 h, as recommended by the supplier. A blank extraction was also performed daily to detect contamination. The same fiber was used for all analyses.

2.2.3 | Gas chromatography-mass spectrometry (GC-MS) analysis

The volatile compounds from the samples were analyzed using GC-MS (Agilent 6890/5973, Agilent Technologies Wilmington, DE, USA) and separated on a nonpolar DB-5 MS column (30 m × 0.25 mm, 0.25 μm film thickness). The operating conditions of GC-MS were a modification of an established method (Mishra et al., 2017). The injection port was maintained at 250°C in splitless mode and fitted with a straight, narrow bore liner (0.75 mm LD). The split vent was set at 80 ml/min at 1 min, and gas oven temperature was 20 ml/min after 2 min. Helium was used as the carrier gas in constant flow mode at 1 ml/min. The GC oven temperature was programmed as follows: an initial temperature of 35°C was held for 5 min, then increased to 200°C at 4°C/min, followed by a 10°C/min increase to 280°C, which was held for 1 min. Reference compounds and alkane series were analyzed by injecting 1 μl sample using an autosampler (Agilent 7683). The concentration of each compound was approximately 50 ng/ml in dichloromethane. All GC conditions were identical, except for the liner that was changed to a standard liner (4 mm I.D). The fiber used for the analysis of pea flour headspace was never in contact with the reference compounds in order to avoid contamination. The mass spectrometer (MS) was operated in electron ionization mode at 70 eV. The ionization source temperature was set at 230°C and quadrupole at 150°C. The mass spectrometer scanned masses from m/z 35 to 500 and data collection started at 2.5 min after injection.

The volatile compounds were identified by comparison with a mass spectra library (Wiley 275/NIST 05; ≥80% match quality), reference compounds, and retention index (RI) based on a series of C7-C18 n-alkanes using the equation of Van Den Dool and Kratz (1963). Peaks with a total peak area ≥0.25 × 10^6 counts and a signal to noise ratio (S/N) ≥ 20 were selected. The level of each volatile compound was reported as the average of total area counts from three analyses.

2.2.4 | Statistical analysis

The total peak area was expressed as the mean of area counts ± standard deviation (n = 3). Significant differences in the content of each volatile compound identified in flours from raw versus boiled yellow pea, raw versus boiled gray pea, and boiled yellow versus gray pea were determined using Student’s t test. The level of significance was set to 0.05. All statistical analyses were performed using GraphPad Prism 7.

3 | RESULTS AND DISCUSSION

3.1 | Sample analysis

A typical HS-SPME-GC-MS chromatogram contains a few large peaks and a high number of peaks that are close to the detection limit of the instrument. The present study aimed to identify as many peaks as possible in order to create a “volatile signature” of the different pea flours. Several small peaks below the limit of detection (total peak area 0.25 × 10^6 counts and S/N 20) were not identified. Compounds with a low boiling point (less than approximately 80°C) were not retained by the column and excluded by starting the detection at 2.5 min. Because of these reasons, it is unlikely that all odor active volatile compounds were captured. In a recent HS-SPME-GC-MS/offactory study of germinated pulses by Xu et al. (2019), 16 compounds were identified by olfactory means but not detected by GC-MS. As it is impossible to detect all odor active compounds, we focused on a few marker compounds in combination with the total area of different groups of volatiles. Hexanal, 1-octen-3-ol, 2-pentylfuran, and 3,5-octadien-2-one were selected as markers for a beany flavor based on previous studies (Murat et al., 2013; Oomah & Liang, 2007; Rodríguez-Bernaldo De Quiros et al., 2000; Vara-Ubol, Chambers, & Chambers, 2004; Xu et al., 2019). The presence of these
| Compound name                  | RI calculated | Yellow pea | Gray pea | Identification† |
|--------------------------------|---------------|------------|----------|-----------------|
|                                |               | Raw       | Boiled   | Raw             | Boiled   |                      |
|                                |               |           |          |                 |          |                      |
| **Aldehydes**                  |               |           |          |                 |          |                      |
| Butanal, 3-methyl              | 655           | 0.7 ± 0.06a | 0.3 ± 0.02bA | 0.4 ± 0.14a | 0.5 ± 0.15bA | MS, RI, STD          |
| Butanal, 2-methyl              | 659           | 0.6 ± 0.02a | 0.2 ± 0.01bA | 0.5 ± 0.05a  | 0.5 ± 0.20bA | MS                   |
| Hexanal                        | 802           | 31.5 ± 4.33b | 73.0 ± 4.33bA | 37.3 ± 1.46a | 44.8 ± 5.74bA | MS, RI               |
| 2-Hexenal, (E)                 | 853           | 0.3 ± 0.08b | 1.5 ± 0.06aA | 0.3 ± 0.04b  | 0.8 ± 0.20bA | MS, RI, STD          |
| Heptanal                       | 901           | 1.9 ± 0.32a | 2.7 ± 0.88bA | 2.2 ± 0.12a  | 1.5 ± 0.11bA | MS, RI, STD          |
| 2-Heptenal, (E)                | 956           | 1.6 ± 0.03a | 0.3 ± 0.02bA | 1.6 ± 0.03a  | 0.4 ± 0.05bA | MS, RI, STD          |
| Benzaldehyde                   | 959           | 1.9 ± 0.23a | 0.3 ± 0.02bA | 1.9 ± 0.04a  | 0.8 ± 0.24bA | MS, RI, STD          |
| Octanal                        | 1,003         | 1.9 ± 0.36a | 0.8 ± 0.11bA | 1.9 ± 0.07a  | 1.1 ± 0.05bA | MS, RI, STD          |
| **Subtotal**                   |               | 63.6 ± 10.38b | 135.5 ± 10.01bA | 68.9 ± 0.53b | 92.6 ± 11.17bA |                      |
| **Alkanes**                    |               |           |          |                 |          |                      |
| Heptane                        | 700           | 1.8 ± 0.15a | 0.6 ± 0.03bA | 1.8 ± 0.18a  | 0.4 ± 0.02bA | MS, STD              |
| Octane                         | 800           | 14.1 ± 1.59b | 26.9 ± 1.60bA | 15.7 ± 0.39a | 16.6 ± 2.00bA | MS, STD              |
| Nonane                         | 900           | 2.4 ± 0.14a | 0.7 ± 0.03bA | 1.0 ± 0.02a  | 1.0 ± 0.03bA | MS, STD              |
| Decane                         | 1,000         | 0.5 ± 0.23a | 0.1 ± 0.01bA | 0.3 ± 0.13a  | 0.2 ± 0.01bA | MS, STD              |
| Undecane                       | 1,100         | 0.2 ± 0.02a | 0.1 ± 0.01bA | 0.4 ± 0.07a  | 0.2 ± 0.01bA | MS, STD              |
| Dodecane                       | 1,200         | 0.2 ± 0.02a | 0.1 ± 0.01bA | 0.2 ± 0.04a  | 0.1 ± 0.01bA | MS, STD              |
| Tridecane                      | 1,300         | 0.3 ± 0.05a | nd        | 0.2 ± 0.03a  | nd        | MS, STD              |
| Tetradecane                    | 1,400         | 0.5 ± 0.08a | 0.2 ± 0.01bA | nd          | nd        | MS, STD              |
| **Subtotal**                   |               | 20.0 ± 1.93b | 28.8 ± 1.61bA | 19.7 ± 0.47a | 18.6 ± 1.97bA |                      |
| **Alcohols**                   |               |           |          |                 |          |                      |
| 1-Pentanol                     | 765           | 1.1 ± 0.07a | 0.6 ± 0.06bA | 1.4 ± 0.28a  | 0.3 ± 0.05bA | MS, RI, STD          |
| 1-Hexanol                      | 870           | 4.0 ± 0.36a | nd        | 2.5 ± 0.44a  | nd        | MS, RI, STD          |
| 1-Heptanol                     | 972           | 0.5 ± 0.13a | nd        | 0.3 ± 0.07a  | nd        | MS, RI, STD          |
| 1-Octen-3-ol                   | 981           | 4.8 ± 0.28a | 2.8 ± 0.19bA | 5.4 ± 0.37a  | 2.0 ± 0.19bA | MS, RI, STD          |
| 5-Hepten-2-ol, 6-methyl         | 993           | 0.9 ± 0.09a | nd        | nd          | nd        | MS, RI               |
| 1-Octanol                      | 1,074         | 2.3 ± 0.36a | 0.7 ± 0.06bA | 2.0 ± 0.16a  | 0.5 ± 0.04bA | MS, RI               |
| 1-Nonanol                      | 1,178         | 0.3 ± 0.05a | nd        | 0.5 ± 0.10a  | nd        | MS, RI               |
| **Subtotal**                   |               | 13.8 ± 0.59a | 4.2 ± 0.28bA | 12.1 ± 1.08a | 2.8 ± 0.19bA |                      |
| **Furans**                     |               |           |          |                 |          |                      |
| Furan, 2-ethyl                 | 675           | 5.6 ± 0.22a | 0.9 ± 0.03bA | 3.4 ± 0.13a  | 1.0 ± 0.0bA | MS, RI               |
| Furan, 2-pentyl                | 989           | 6.7 ± 0.47a | 2.4 ± 0.05bA | 7.0 ± 0.03a  | 4.2 ± 0.03bA | MS, RI, STD          |
| 2(3H)-Furanone, 5-ethylidihydro | 1,054        | 0.5 ± 0.06a | nd        | nd          | nd        | MS, RI               |
| **Subtotal**                   |               | 12.8 ± 0.57a | 3.3 ± 0.08bA | 10.4 ± 0.46a | 5.2 ± 0.08bA |                      |
| **Ketones**                    |               |           |          |                 |          |                      |
| 2-Heptanone                    | 889           | 0.7 ± 0.03a | 0.1 ± 0.01bA | 0.7 ± 0.11a  | 0.1 ± 0.01bA | MS, RI               |
| 5-Hepten-2-one, 6-methyl        | 985           | 1.3 ± 0.04a | 1.4 ± 0.17bA | 1.1 ± 0.06a  | 0.8 ± 0.16bA | MS, RI, STD          |
| 2,5-Octanedione                | 986           | 1.0 ± 0.13a | 0.4 ± 0.04bA | 0.8 ± 0.02a  | 0.6 ± 0.03bA | MS, RI               |
| 3-octen-2-one                  | 1,044         | 0.6 ± 0.06a | 0.2 ± 0.01bA | 0.6 ± 0.06a  | 0.2 ± 0.04bA | MS, RI               |
| 3,5-Octadien-2-one             | 1,072         | 0.7 ± 0.09a | nd        | 0.5 ± 0.08a  | nd        | MS, RI               |
| **Subtotal**                   |               | 4.3 ± 0.33a | 2.2 ± 0.16bA | 3.7 ± 0.14a  | 1.8 ± 0.22bA |                      |
compounds indicates that reactions connected with lipid degradation have occurred, which might produce other odor active compounds.

The risk of contamination from the environment, for example, from packaging materials, is an essential aspect to consider in HS-SPME-GC-MS studies. Plastic materials were found to contribute to contaminating peaks (data not shown), which is in agreement with others who found several volatile compounds from plastic packaging in the plastic-wrapped cheese (Panseri, Chiesa, Zecconi, Soncini, & De Noni, 2014). Thus, all plastics were excluded in the analytical procedure. Glassware was heat-treated at 105°C, and blank extractions from empty flasks were performed every day to exclude the possibility of contamination. Ground samples (10-g pea flour) were incubated at 50°C for 30 min to ensure that volatiles in the samples were released to the headspace, and then the SPME fiber was inserted for 30 min. Previous studies have shown that an extraction time of 30 min is enough to reach equilibrium (Azarnia, Boye, Warkentin, & Malcolmson, 2011; Mishra et al., 2017). The same SPME fiber was used throughout the study to avoid differences due to manufacturing variations of the fiber.

It is important to note that the abundance of volatile compounds in the headspace is expressed in peak area counts in this paper, as reported by the MS detector. The percentage of a compound group or an individual compound refers to its relative abundance. Care was taken to perform the collection of volatiles identically for every sample. It is crucial because an internal standard (IS) is difficult to use without adding a solvent to the pea flour that would have an impact on the collected compounds. The use of IS is otherwise a common practice in most chromatography applications to adjust the variances between samples that arise from sample workup, injection volume, or detector response. Volatile compounds were manually identified with a combination of identification from reference samples, mass spectral libraries, and retention index (RI). The set-up enabled replicate analysis with high repeatability in both retention time and area counts (%CV on average 0.04% for retention time and 12% for area counts, n = 3) despite the lack of IS. The high repeatability simplified the cross-identification of volatile compounds in different samples.

### 3.2 Volatile compound composition in flour from raw yellow and gray peas

In the present study, 40 volatile compounds were identified in flour from raw gray pea. All of these volatile compounds were also found in flour from raw yellow pea, along with three additional compounds: tetradecane, 5-hepten-3-ol-6-methyl, and 5-ethylidihydro-2(3H)-furanone (Table 1). Moreover, the similarity between raw yellow pea and gray pea was also apparent when comparing the total counts of all compound groups (Figure 1, Table 1). Aldehydes were the dominant group, comprising 56% of the total peak area, followed by alkanes (17%), alcohols (11%), furans (10%), ketones (3%), and others (4%) (alkenes, terpenes, aromatics, and sulfur-containing compounds).

| Compound name                  | RI calculated | Yellow pea | Gray pea | Identification‡ |
|--------------------------------|---------------|------------|----------|-----------------|
|                                |               | Raw       | Boiled   | Raw             | Boiled         |
| **Alkenes**                    |               |            |          |                 |                |
| 1-Octene                       | 791           | 0.7 ± 0.20^b | 1.4 ± 0.15^aA | 0.6 ± 0.16^a | 0.6 ± 0.07^bA | MS, RI          |
| 1-Nonene                       | 891           | 0.8 ± 0.03^a | nd       | 0.3 ± 0.03^a   | nd             | MS, RI          |
| 1-Tridecene                    | 1,292         | 0.2 ± 0.05^a | nd       | nd             | nd             | MS, RI          |
| 1-Tetradecene, (E)             | 1,392         | 0.4 ± 0.08^a | nd       | 0.1 ± 0.01^a   | nd             | MS, RI          |
| **Subtotal**                   |               | 2.2 ± 0.32^a | 1.4 ± 0.15^aA | 1.1 ± 0.25^a  | 0.6 ± 0.07^bA |               |
| **Aromatic compound**          |               |            |          |                 |                |
| Toluene                        | 759           | 1.2 ± 0.03^a | 0.3 ± 0.01^bA | 1.2 ± 0.03^a  | 0.4 ± 0.08^bA | MS, RI, STD     |
| **Subtotal**                   |               | 1.2 ± 0.03^a | 0.3 ± 0.01^bA | 1.2 ± 0.03^a  | 0.4 ± 0.08^bA |               |
| **Terpenes**                   |               |            |          |                 |                |
| 1R-alpha-Pinene                | 930           | 0.4 ± 0.04^a | 0.4 ± 0.01^bA | 0.6 ± 0.13^a  | 0.5 ± 0.09^bA | MS, RI, STD     |
| 3-Carene                       | 1,015         | 0.8 ± 0.07^a | 0.4 ± 0.01^bA | 1.2 ± 0.03^a  | 0.5 ± 0.03^bA | MS, RI, STD     |
| **Subtotal**                   |               | 1.1 ± 0.12^a | 0.9 ± 0.02^bA | 1.9 ± 0.10^a  | 1.0 ± 0.11^bA |               |
| **Sulfuric compound**          |               |            |          |                 |                |
| Disulfide, dimethyl            | 735           | 0.7 ± 0.07^a | 0.3 ± 0.03^bA | 0.5 ± 0.11^a  | 0.2 ± 0.02^bA | MS, RI          |
| **Subtotal**                   |               | 0.7 ± 0.07^a | 0.3 ± 0.03^bA | 0.5 ± 0.11^a  | 0.2 ± 0.02^bA |               |

All values are mean of area counts ± SD (n = 3). For each type of pulse, means within rows with different letters are significantly different (t test, p < 0.05). Different capital letters indicate a significant difference for each volatile compound between flour from boiled yellow and gray peas (t test, p < 0.05). Identification of the compound was done by comparison with a mass spectra (MS) library (Wiley 275/NIST 05; ≥80% match quality), reference compounds (STD) and retention index (RI) based on alkane series (C7-C18) using the equation of Van Den Dool and Kratz.
The results agree with a previous HS-SPME-GC-MS study on volatiles from raw peas stored at room temperature in which aldehydes were identified as the most abundant group, followed by hydrocarbons and alcohols (Azarnia, Boye, Warkentin, & Malcolmson, 2011). These authors also reported that the storage at 4°C decreases the total peak area of volatile compounds and changes the composition in the headspace. As a result, alcohols and ketones were found to be the main compounds instead of aldehydes, which were explained by a lower lipid oxidation (Azarnia, Boye, Warkentin, Malcolmson, Sabik, et al., 2011). Others (Ma et al., 2016; Murat et al., 2012) have also reported that alcohols were the most abundant group of volatile compounds in raw yellow pea, but the storage time or temperature was not specified in these studies.

Hexanal, nonanal, octane, 1-octen-3-ol, and 2-pentylfuran were the most abundant volatile compounds in the present study (Table 1). These five compounds accounted for 66%-72% of the total peak area in the raw flour samples. Three out of five main volatile compounds found in the present study (hexanal, 1-octen-3-ol, and 2-pentylfuran) were among the markers for a beany flavor. Additionally, 3,5-octadien-2-one was observed in low abundance in raw yellow and gray peas. The aroma of odor active compounds such as 1-octen-3-ol is described as earthy, green, oily, and fungal, whereas furan-2-pentyl is described as having a green, earthy, beany, and vegetable aroma (Acree & Arn, 2004; The Good Scent Company, 2018). The aroma of 3,5-octadien-2-one is described as fatty, mushroom-like, and fruity (The Good Scent Company, 2018). Hexanal as an individual compound is reported to lack beany characteristics (Vara-Ubol et al., 2004) but may cause beany flavor in combination with other compounds (Szczygiel et al., 2017; Vara-Ubol et al., 2004).

### 3.3 Effects of processing on the volatile compound composition of pea flours

Flour from boiled yellow pea had a significantly higher peak area of aldehydes than flour from raw yellow pea ($p = 0.006$; Table 1). Others have reported a similar increase in aldehydes after cooking of green bean and faba bean (Jiang et al., 2016; Rodriguez-Bernaldo De Quiros et al., 2000), due to the enzymatic and nonenzymatic oxidation processes promoted by heating (Jiang et al., 2016). The total peak area of volatiles in boiled yellow pea was higher than seen in flours from raw pea or boiled gray pea. The seemingly higher abundance of volatiles in boiled yellow pea might be related to the longer boiling time of yellow peas (50 min) as compared with gray pea (35 min). Moreover, there was an apparent decrease in the number of volatile compounds detected in flour from boiled yellow pea compared with raw pea flour. Only 33 volatile compounds were identified after processing due to a significant loss of alcohols (Table 1; Figure 1). Aldehydes accounted for 77% of total peak area obtained for yellow pea after boiling, followed by alkanes (16%), furans (4%), alcohols (2%), ketones (1%), and others (2%).

As found for yellow pea, there was a notable increase in the peak area of aldehydes and a lower abundance of alcohols in flour from boiled gray pea (Table 1). Moreover, only 32 volatile compounds were detected in flour from boiled gray pea. Volatile compounds in flour from boiled gray pea consisted of aldehydes (75% of total peak area), alkanes (15%), furans (4%), alcohols (2%), ketones (1%), and others (2%).

Hexanal was the main compound found in flours from boiled yellow and gray peas (Table 1) and was detected at significantly higher levels ($p = 0.0003$) in boiled peas than in raw pea flours.
(Figure 2). A higher peak area of hexanal in flours from boiled peas might not necessarily be associated with a stronger beany flavor because hexanal lacks beany character by itself, but it is an indicator of heat treatment. We also observed a significant reduction in the peak area of 1-octen-3-ol and furan-2-pentyl in flours from boiled peas compared with raw flours (Figure 2) and did not detect any 3,5-octadien-2-one in flours from boiled peas (Figure 2). A reduction in the 1-octen-3-ol, furan-2-pentyl, and 3,5-octadien-2-one levels after processing is in agreement with previous findings (Mishra et al., 2017). Lower abundance of these compounds in flours from boiled peas suggests lower beany flavor concentration compared with raw pea flours.

The levels, in terms of peak area counts, of the three out of four beany marker compounds (i.e., hexanal, 1-octen-3-ol, and 3,5-octadien-2-one) were higher in flour from boiled yellow pea than in flour from boiled grey pea. The exception was 2-pentylfuran, which showed significantly ($p < 0.0001$) higher abundance in grey pea than in yellow pea after processing (Figure 2). Overall, the results indicated that flour from boiled yellow pea has higher abundance in beany flavor causing compounds than flour from boiled grey pea. Therefore, the two types of flours from yellow and grey peas could be used in different food applications, depending on the desired characteristics of the final products. Moreover, a previous study has shown that grey pea had a higher content of resistant starch and folate than yellow pea (Ferawati et al., 2019). Thus, grey pea is an attractive commodity for further exploration due to a higher content of nutrients and a lower level of beany flavor compounds than the well-known yellow pea.

We believe that data from this study will contribute to the general knowledge on volatile profiles of different raw and processed legumes. Our study confirms that raw peas stored at room temperature have a volatile profile dominated by aldehydes. Also, the information on the length of storage of the pea seeds will be useful to compare findings from different studies. The abundance of aldehydes increased after heat treatment, but all other beany flavor compounds decreased. The data on the presence of beany flavor compounds (i.e., hexanal, 1-octen-3-ol, 2-pentylfuran, and 3,5-octadien-2-one) might be useful in, for example, comparing the quality of different harvests, varieties, and effects of storage and treatments. Information on the volatile compound profile of flours from different varieties of pea will be interesting to food industries seeking to increase the utilization of pea in food products. Based on our findings, HS-SPME-GCMS is a

**FIGURE 2** Effect of boiling yellow and grey peas on potential beany flavor compounds: (a) hexanal, (b) 2-pentylfuran, (c) 1-octen-3-ol, and (d) 3,5-octadien-2-one. Bars represent the mean of area counts ± SD ($n = 3$). Asterisks indicate significant differences between samples (t-test, * $= p < 0.01$; ** $= p < 0.001$).
useful screening procedure before planning more technically advanced and labor-intensive investigations. Further research using quantitative descriptive analysis and gas chromatography/olfactory analysis could provide useful complementary information to the obtained data.

4 | CONCLUSIONS

A total of 43 volatiles were identified in the headspace of pea flours using the HS-SPME-GC-MS technique applied. The volatile profiles of raw yellow and gray peas were almost identical with aldehydes as the dominating group. Heat treatment had an apparent effect on the abundance and profile of volatile compounds with a loss of alcohols and an increase in aldehydes. There was a significant decrease in beany flavor compounds (1-octen-3-ol, 2-pentylfuran, and 3,5-octadien-2-one) after processing, suggesting a diminishing abundance of beany flavor in flours from boiled peas. Data on the volatile composition of flours from different varieties of peas could provide input to product developers to overcome the off-flavor challenges and increase the utilization of pulses in formulation of new ingredients or food products.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

F. F. designed the study, performed the experiments, analyzed and interpreted the data, and wrote the original manuscript draft. C. W. supervised the concept and reviewed and edited the manuscript. M. B. designed the study, analyzed and interpreted the data, and reviewed and edited the manuscript.

ETHICAL STATEMENT

This study does not involve any human or animal testing.

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are included in this published article.

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REFERENCES

Acree, T., & Am, H. (2004). Flavornet and human odor space. Retrieved November 7, 2019, from http://flavornet.org/flavornet.html
Azarnia, S., Boye, J., Warkentin, T., & Malcolmson, L. (2011). Changes in volatile flavour compounds in field pea cultivars as affected by storage conditions. International Journal of Food Science and Technology, 46(11), 2,408–2,419. https://doi.org/10.1111/j.1365-2621.2011.02764.x
Azarnia, S., Boye, J., Warkentin, T., Malcolmson, L., Sabik, H., & Bellido, A. S. (2011). Volatile flavour profile changes in selected field pea cultivars as affected by crop year and processing. Food Chemistry, 124, 326–335. https://doi.org/10.1016/j.10942912.2015.1121494
European Commission. (2018). Market developments and policy evaluation aspects of the plant protein sector in the EU. Brussels: European Commission. https://doi.org/10.2762/022741
Ferawati, F., Hefni, M., & Witthöft, C. (2019). Flours from Swedish pulses: Effects of treatment on functional properties and nutrient content. Food Science and Nutrition, 1-11. https://doi.org/10.1002/fsn3.1280
Hushällningssällskapet. (2013). Alternativa livsmedelsgrödor odling. Uppsala: Hushällningssällskapet. Retrieved from. http://hushallningssallskapet.se/wp-content/uploads/2014/09/alternativa-livsmedelsgrodor-for-hemsidan.pdf
Jiang, Z. Q., Pulkkinen, M., Wang, Y. J., Lampi, A. M., Stoddard, F. L., Salovaara, H., ... Sontag-Strohm, T. (2016). Faba bean flavour and technological property improvement by thermal pre-treatments. LWT - Food Science and Technology, 68, 295–305. https://doi.org/10.1016/j.lwt.2015.12.015
Khrisanapant, P., Kebede, B., Leong, S. Y., & Oey, I. (2019). A comprehensive characterisation of volatile and fatty acid profiles of legume seeds. Foods, 8(651), 1–21.
Ma, Z., Boye, J. I., Azarnia, S., & Simpson, B. K. (2016). Volatile flavor profile of Saskatchewan grown pulses as affected by different thermal processing treatments. International Journal of Food Properties, 19(10), 2,251–2,271. https://doi.org/10.1080/10942912.2015.1121494
Mishra, P. K., Tripathi, J., Gupta, S., & Varyar, P. S. (2017). Effect of cooking on aroma profile of red kidney beans (Phaseolus vulgaris) and correlation with sensory quality. Food Chemistry, 215, 401–409. https://doi.org/10.1016/j.foodchem.2016.07.149
Murat, C., Bard, M. H., Dhalleine, C., & Cayot, N. (2013). Characterisation of odour active compounds along extraction process from pea flour to pea protein extract. Food Research International, 53(1), 31–41. https://doi.org/10.1016/j.foodres.2013.03.049
Murat, C., Gourrat, K., Jerosch, H., & Cayot, N. (2012). Analytical comparison and sensory representativity of SAFE, SPME, and Purge and Trap extracts of volatile compounds from pea flour. Food Chemistry, 135(3), 913–920. https://doi.org/10.1016/j.foodchem.2012.06.015
Olsson, C. (2017). Expanding the grain legume food production in southern Sweden industry. Alnarp: Swedish University of Agricultural Sciences.
Oomah, B. D., & Liang, L. S. Y. (2007). Volatile compounds of dry beans (Phaseolus vulgaris L.). Plant Foods for Human Nutrition, 57(3), 177–183. https://doi.org/10.1007/s11130-007-0059-3
Oomah, B. D., Razafindrainibe, M., & Drover, J. C. G. (2014). Headspace volatile components of Canadian grown low-tannin faba bean (Vicia faba L) genotypes. J Sci Food Agric, 473–481. https://doi.org/10.1002/jsfa.6272
Panseri, S., Chiesa, L. M., Zeconci, A., Soncini, G., & De Noni, I. (2014). Determination of volatile organic compounds (VOCs) from wrapping films and wrapped PDO Italian cheeses by using HS-SPME and GC/MS. Molecules, 19(7), 8,707–8,724. https://doi.org/10.3390/molecules19078707
Rodriguez-Bernaldo De Quiros, A. I., López-Hernández, J., González-Castro, M. J., De La Cruz-García, C., & Simal-Lozano, J. (2000). Comparison of volatile components in raw and cooked green beans by GC-MS using dynamic headspace sampling and microwave desorption. European Food Research and Technology, 210(3), 226–230. https://doi.org/10.1007/PL00005517
Röös, E., Carlsson, G., Ferawati, F., Hefni, M., Stephan, A., Tidåker, P., & Witthöft, C. (2018). Less meat, more legumes: Prospects and challenges in the transition toward sustainable diets in Sweden. Renewable Agriculture and Food Systems, 35(2010), 192–205. https://doi.org/10.1017/S1742170518000443

Sánchez-Chino, X., Jiménez-Martínez, C., Dávila-Ortiz, G., Álvarez-González, I., & Madrigal-Bujaidar, E. (2015). Nutrient and nonnutrient components of legumes, and its chemopreventive activity: A review. Nutrition and Cancer, 67(3), 401–410. https://doi.org/10.1080/01635581.2015.1004729

Swedish Board of Agriculture. (2015). Ärter—Smaka Sverige. Retrieved May 10, 2018, from http://smakasverige.jordbruksverket.se/ravaror/ravarorarkiv/arter.221.html

Swedish Board of Agriculture. (2019). Production of cereals, dried pulses, oilseed crops, potatoes and temporary grasses in 2018. Retrieved from http://www.jordbruksverket.se/webdav/files/SJV/Amnesomraden/Statistik/fakta/Vegetabilieproduktion/JO16/JO16SM1901/JO16SM1901_inEnglish.htm.

Szczygiel, E. J., Harte, J. B., Strasburg, G. M., & Cho, S. (2017). Consumer acceptance and aroma characterization of navy bean (Phaseolus vulgaris) powders prepared by extrusion and conventional processing methods. Journal of the Science of Food and Agriculture, 97, 4,142–4,150. https://doi.org/10.1002/jsfa.8284

The Good Scent Company. (2018). The good scent company information system. Retrieved November 7, 2019, from http://www.thegoodscentcompany.com/

Van Den Dool, H., & Kratz, P. (1963). A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. Journal of Chromatography, 11, 463–471.

Vara-Ubo!, S., Chambers, E. IV, & Chambers, D. H. (2004). Sensory characteristics of chemical compounds potentially associated with beany aroma in foods. Journal of Sensory Studies, 19, 15–26. https://doi.org/10.3390/molecules23081867

Vas, G., & Vékey, K. (2004). Solid-phase microextraction: A powerful sample preparation tool prior to mass spectrometric analysis. Journal of Mass Spectrometry, 39(3), 233–254. https://doi.org/10.1002/jms.606

Wolk, A. (2017). Potential health hazards of eating red meat. Journal of Internal Medicine, 281, 106–122. https://doi.org/10.1111/jim.12543

Xu, M., Jin, Z., Lan, Y., Rao, J., & Chen, B. (2019). HS-SPME-GC-MS-/olfactometry combined with chemometrics to assess the impact of germination on flavor attributes of chickpea, lentil, and yellow pea flours. Food Chemistry, 280, 83–95. https://doi.org/10.1016/j.foodchem.2018.12.048

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