Volatile Compounds in Pulses

Subjects: Agriculture, Dairy & Animal Science

Contributor: Adeline KAROLKOWSKI

The worldwide demand for pulse-based products is increasing in the face of climate change, but their acceptability is limited due to the presence of off-flavours. Off-notes contribute to negative perceptions of pulses (beany notes). Volatile compounds belong to a large variety of chemical classes. They are mainly produced from the oxidation of unsaturated free fatty acids and the degradation of amino acids during seed development, storage, and transformation (dehulling, milling, and starch or protein production).

pulses volatile compounds off-flavour odour-active compounds

1. Introduction

Pulses (*Fabaceae*) are an interesting alternative to animal proteins. They are rich in proteins, unsaturated fatty acids, and bioactive compounds and thus present nutritional and environmental benefits [1][2][3][4][5]. Moreover, they offer functional properties for food applications [2][3]. Many forms are available, such as whole seed, flour, starch, and protein concentrate/isolate [3]. Despite all of the interest in pulses, the presence of off-flavours is in some cases a barrier to their consumption by humans and limits their expansion [4][5][6].

Off-flavours or unpleasant flavours are related to negative organoleptic perceptions. They originate from different volatile molecules responsible for off-notes (unpleasant odours) and from sapid compounds [6]. These tasting compounds activate bitter taste receptors (TAS2Rs) located on the tongue and in the oral cavity. Astringent molecules can precipitate salivary proteins and lead to a loss of lubrification in the mouth [7]. Some saponins, phenolic compounds, alkaloids, peptides, and free amino acids contribute to pulse bitterness whereas phenolic compounds also seem to be involved in astringent sensations [6].

Many volatile compounds have been identified in pulses, and they are mostly responsible for unpleasant odours [6]. These compounds mainly originate from free fatty acids present in the grains and are oxidized into smaller molecules. This phenomenon naturally occurs in the grains but is intensified under stress conditions (water stress or mechanical or herbivore/insect attacks). The production of these compounds contributes to a defence mechanism for these plants and can continue after harvesting [8]. Small compounds, such as aromatic hydrocarbons, aldehydes, alkanes, alkenes, alcohols, ketones, acids, esters, pyrazines, terpenes, furans, and lactones, have been identified in pulses [6]. Even though each of these molecules has a specific odour, the perception of an aroma is often due to a mixture of different notes from several molecules [9]. Off-notes in pulses are described as beany, green, pea-like, earthy, hay-like, fatty, pungent, and metallic [6].

2. Origins of Volatile Compounds in Pulses

2.1. Oxidation of Unsaturated Free Fatty Acids

Different classes of volatiles, such as aromatic hydrocarbons, aldehydes, alcohols, alkanes, ketones (furans) and esters, are mostly derived from enzymatic or nonenzymatic oxidation (autoxidation) of free fatty acids. Although pulses have a low fat content (0.8–7% of seed weight), this mechanism is dominant and strongly contributes to unpleasant odours, such as herbal, green, pea, beany, mould, and rancid notes [10]. The synthesis of these compounds follows three phases.

2.2. Degradation of Free Amino Acids

The degradation of amino acids has been shown to be the second source of volatile compound production in pulses. Several origins exist, such as biodegradation in seeds, degradation by microorganisms, and Maillard reactions.

2.3. Degradation of Carotenoids

Terpenes can be derived from the degradation of carotenoids. Carotenoids are oxidized by LOX 2 at neutral pH and produce these volatile compounds [11]. This origin is highly disputed. Indeed, due to the low concentrations found in plants, these molecules would be absorbed by plant roots at the soil level during their cultivation and then accumulate in the seeds [12].

3. Extraction, Separation, Identification, and Semi-Quantification Methods

The characteristics of the studied pulses (cultivar and year and location of cultivation), conditions of storage, transformation, and volatile compound analysis are described in **Table 1** [13][14][15][16][17][18][19][20]. Different classical methods are used to extract volatile compounds, which are briefly described here. By using HS-SPME (HeadSpace Solid-Phase MicroExtraction), the volatile compounds in the vapour phase are first adsorbed on a fibre and desorbed in the GC (Gas Chromatography) injector to be separated and identified. This method is robust, rapid, simple to use, and solvent-free but allows only semi-quantification due to competition between analytes on the fibre [21][22][23]. SAFE (Solvent-Assisted Flavour Evaporation) combines vacuum distillation and solvent extraction [24]. This method allows quantification by a standard but requires a long extraction time and requires the use of organic solvents to extract volatiles [23]. The differences highlighted in these two methods could also explain some differences between pulse volatile compounds.

Table 1. Characteristics of pulses: extraction and identification methods of volatile compounds.

Code	Pulses	Cultivar	Year	Location	Storage	Seed Transformation	Extraction	Separation and Identification	References
Black bean	Black bean (Phaseolus vulgaris L.)	AC Harblack	2005	Morden, Canada	Dry room (23 °C, 15–20% RH) (whole).	Ground in flour (coffee mill) (whole).	HS-SPME: 10 g in a 125-mL Erlenmeyer flask capped, DVB/CAR/PDMS Stable Flex SPME fibre at 50 °C for 1 h.	GC-MS: desorption at 250 °C for 2 min, Supelcowax 10 polar column, started at 40/1/70 °C, then 70/5/200 °C and 200/50/250 °C.	[25]
		CDC Rio							
		Onyx							
Pinto bean	Pinto bean (Phaseolus vulgaris L.)	AC Pintoba							
		Maverick							
Dark red kidney bean	Dark red kidney bean (Phaseolus vulgaris L.)	ROG 802							
		Redhawk							
Whole pea	Pea (Pisum sativum L.)	Eclipse (Yellow field pea)	2005	Near Saskatoon, Canada	4 °C (whole).	Ground in flour (whole).	HS-SPME: 3 g, CAR/PDMS SPME Fibre at 50 °C for 30 min.	GC-MS: desorption at 300 °C for 3 min, VF-5MS capillary column, started at 35/6/80 °C and 80/20/280 °C.	[26]
			2006						
			2007						
Dehulled pea		-	Before 2013	-	In a glass bottle, −18 °C.	Ground in flour (dehulled).	SAFE: 20 g in 100 mL of water, 2 h at 30 °C and 10–2 mbar. Liquid-liquid separation with 3 × 10 mL of CH2Cl2. Concentration using Kuderna Danish apparatus, 70 °C.	GC-MS: ZB1.MS non-polar column, injection of 2 µL, started at 50/4/160 °C, then 160/15/320 °C.	[27]
Pea protein						Protein isolate, Nutralys® (dehulled, wet process).			
		-	Before 2020	-	-	Protein concentrate (dehulled, dry process).	HS-SPME: 1.5 g was dissolved into saturated NaCl solution for	GC-MS: desorption at 250 °C for 3 min, DB-	[28]

Code	Pulses	Cultivar	Year	Location	Storage	Seed Transformation	Extraction	Separation and Identification	References
							1 h at 20 °C, then transferred into a bottle and incubated at 50 °C in an ultrasonic bath, insertion of the DVB/CAR/PDMS Stable Flex SPME fibre at 50 °C for 20 min.	5MS column, started at 40/5/70 °C, then 70/10/200 °C and 200/50/250 °C.	
Chickpea	Chickpea (Cicer arietinum)	Kabuli (Benying-1)	2018	Urumqi, China	−18 °C for a maximum of 3 weeks (whole). −20 °C for a maximum of 1 week (powder).	Dried using sunlight before storage (whole). Ground to a fine powder (80 mesh, mill).	HS-SPME: 1.5 g was dispersed in water and 5 mL was placed in a 20-mL headspace sampling vial and capped, PDMS/DVB fibre at 60 °C for 60 min.	GC-MS: desorption at 250 °C for 5 min, PEG 20 M column, started at 35/5/130 °C and 130/9/200 °C.	[29]
		Desi (YZ-364)							
Faba bean Tannin	Faba bean (Vicia faba L. minor)	High tannin	2016	Alberta, Canada	In freezer bags (polypropylene), 22 °C and 18% RH in a dark and solvent-free room (flour).	Ground in flour (impact mill) (whole).	HS-SPME: 2 g was pre-incubated at 50 °C for 5 min, DVB/CAR/PDMS Stable Flex SPME fibre at 50 °C for 1 h.	GC-MS: desorption at 250 °C for 60 s, DB-17 mod polarity column, 40/5/200 °C.	[30]
		Low tannin							
Faba bean Location		Low tannin (13 cultivars)	2009	Barrhead, Canada	-	Ground in flour (coffee mill) (whole).	HS-SPME: 10 g in a 125-mL Erlenmeyer flask capped, DVB/CAR/PDMS Stable Flex SPME fibre at 50 °C for 1 h.	GC-MS: desorption at 250 °C for 2 min, Supelcowax 10 polar column, started at 40/1/70 °C, then 70/5/200 °C and 200/50/250 °C.	[31]
				Namao, Canada					

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nd **Table 13**, each describes a chemical class of volatile compounds: aromatic hydrocarbons, aldehydes, alkanes/alkenes, alcohols, ketones, acids, esters (without lactones), pyrazines, terpenes, furans, lactones, and other volatile compounds. For each pulse, one column corresponds to the minimum and the maximum (min–max) of a set of different cultivars, harvest years, locations and conditions of storage, or seed transformations (dehulling and production of protein concentrates or isolates) (see **Table 2** for more details).

Table 2. Aromatic hydrocarbons in pulses (expressed as percentages).

Aromatic Hydrocarbons	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea		Chickpea	Faba Bean		
						Whole	Dehulled		Tannin	Location	Storage
Toluene	108-88-3	FFA [1,2]	0.00–0.86	0.96–1.86	0.00–0.73	1.20–2.40	Coelution		0.26–0.37	0.88–0.96	0.41–3.12

Aromatic Hydrocarbons	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea		Chickpea	Faba Bean		
						Whole	Dehulled		Tannin	Location	Storage
m-Ethyltoluene	620-14-4								0.09–0.11		0.00–0.28
Benzene	71-43-2	FFA [4]				0.00–0.50			0.09–0.11		
Ethylbenzene	100-41-4	FFA [1,2]	0.00–0.45	0.00–0.44		0.30–0.80			0.12–0.17	1.19–1.28	0.19–0.73
1,2,3-Trimethylbenzene	526-73-8	FFA [2]	0.00–0.54	0.54–1.03					0.12–0.13		0.00–0.21
1,3,5-Trimethylbenzene	108-67-8	FFA [2]	0.00–0.77	0.81–1.84							0.00–0.19
Propylbenzene	103-65-1		0.00–0.35	0.00–0.40							0.00–0.19
Cumene	98-82-8	FFA [2]	0.70–1.13	0.84–0.86	1.11–1.69	0.30–0.60				0.42–0.46	
p-Xylene	106-42-3	FFA [1]	1.15–1.50	0.00–1.20	0.00–1.17	0.40–1.00				0.27–0.38	0.00–0.70
o-Xylene	95-47-6	FFA [1,2,4]	0.95–1.16	1.14–1.73	1.13–1.45		Coelution				
m-Xylene	108-38-3	FFA [1]					1.25				
4-Ethyl-m-xylene	874-41-9								0.05–0.07		0.00–0.64
p-Cymene	99-87-6						Trace		0.32–0.33		
Styrene	100-42-5	FFA [1,2,3], N [2,3]	32.55–45.47	30.88–31.76	38.75–47.57	0.70–2.20		0.00–0.60		11.36–13.79	0.00–1.90
α-Methylstyrene	98-83-9		0.00–0.43	0.00–0.38	0.00–0.49						
Total			38.51–49.28	38.24–38.51	43.41–50.72	3.50–6.70	1.25	0.00–0.60	1.07–1.27	14.15–16.89	0.68–7.75

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1 [26]; 2 [25]; 3 [31]; 4 [33][34]. FFA: free fatty acids; Naturally present (not considered as a contaminant). The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond to 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], and "Dehulled" corresponds to dehulled pea flour [27]. "Chickpea" refers to 2 cultivars [29]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], "Location" corresponds to different low-tannin cultivars that were harvested at 2 different locations in Canada [31], and "Storage" corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) for 60 days and a control (sample stored for 0 days) [32]. No aromatic hydrocarbon was detected in pea proteins (concentrate and isolate) (see **Table 1** for more details).

Table 3. Aldehydes in pulses (expressed as percentages).

Aldehydes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Benzaldehyde	100-52-7	FFA [2]; AA [5,7,11]	2.36–3.64	2.58–2.60	3.46–4.04			0.00–2.11	0.00–2.19	0.36–0.45	2.09–2.10	0.46–0.85
4-Ethylbenzaldehyde	53951-50-1							0.00–0.54				
Phenylacetaldehyde	122-78-1	AA [3,5,7,11]						0.00–0.67		0.14–0.17		0.21–0.39
Vanillin	121-33-5						0.16	0.00–0.08				
2-Methylpropanal	78-84-2	AA [11]								0.49–0.51		
3-Methylthiopropanal	3268-49-3	AA [3,11]						0.00–0.03				
2-Methylbutanal	96-17-3	AA [5,8,11]						0.03–0.49		0.31–0.48		0.00–0.13
3-Methylbutanal	590-86-3	AA [5,7,11]				0.00–1.00		0.00–0.10		1.04–1.17		0.36–0.59
Pentanal	110-62-3	FFA [2,9,10]	0.00–0.59	0.60–0.79	1.03–1.11			0.00–0.73			0.96–1.21	
Furfural	98-01-1							0.00–0.05				

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Aldehydes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Hexanal	66-25-1	FFA [1,2,3,4,6,7,8,9,10]	12.76–16.71	9.77–11.27	15.88–18.6	1.50–6.10	0.93	27.22–54.12		10.28–13.85	40.78–40.88	1.29–25.07
2-Ethylhexanal	123-05-7											0.00–0.16
(E)-2-Hexenal	6728-26-3	FFA [1,2,4,8,9,10]	0.00–1.60	0.00–1.67	0.00–1.75			0.00–0.19				
Heptanal	111-71-7	FFA [2,3,7,8,9,10]	0.00–0.75	0.00–0.82	0.00–0.95			1.13–5.31		1.04–1.14	1.10–1.14	0.00–1.91
(E)-2-Heptenal	18829-55-5	FFA [1,2,4,8,9,10]	1.52–1.75	1.54–2.01	1.52–1.88	0.00–2.60		0.00–0.58			1.79–1.97	
(E,E)-2,4-Heptadienal	4313-03-5	FFA [2,8,9,10]	0.57–0.66	0.57–0.59	0.00–0.71		Trace	0.00−Coelution				
Octanal	124-13-0	FFA [2,7,8,9,10]	0.00–0.62		0.00–0.68			0.00–0.58	1.35–1.76	2.07–2.40	1.15–1.29	0.08–2.22
(E)-2-Octenal	2548-87-0	FFA [1,3,7,8,9,10]				3.00–13.10		0.00–0.10	2.13–2.16	0.23–0.23	0.48–0.51	0.19–0.45
Nonanal	124-19-6	FFA [2,4,6,7,8,9,10]	2.11–3.08	2.42–2.80	2.13–3.60		1.30	3.12–5.24	3.70–4.60	9.8–12.31	7.99–10.54	3.54–36.29
(E)-2-Nonenal	18829-56-6	FFA [2,7,9,10]	0.00–0.67	0.00–0.58						0.20–0.26		0.14–2.52
4-Oxononanal	74327-29-0								0.72–0.91			
(E,E)-2,4-Nonadienal	5910-87-2	FFA [7,9,10]							0.00–0.44			
Decanal	112-31-2	FFA [2,7,10]	0.81–1.59	0.00–1.06	0.72–0.99		Coelution	Coelution−1.33	1.28–1.33	2.86–3.26	1.15–1.41	0.37–6.16
(Z)-2-Decenal	2497-25-8	FFA [7,10]							0.79–1.15			
(E,E)-2,4-Decadienal	25152-84-5	FFA [3,7,9,10]					Trace					
Undecanal	112-44-7									0.22–0.26		0.00–1.61

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Aldehydes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Dodecanal	112-54-9											0.00–0.89
Tetradecanal	124-25-4						0.63		0.26–0.55			0.00–0.39
Total			24.42–28.01	18.19–23.57	25.77–33.33	10.70–17.70	3.02	40.21–63.66	12.41–12.91	29.14–36.39	58.05–60.58	9.19–79.03

1 [26]; 2 [25]; 3 [27]; 4 [28]; 5 [30]; 6 [31]; 7 [32]; 8 [35]; 9 [12]; 10 [33][34]; 11 [36]. FFA, free fatty acids; AA, amino acids. The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond to 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. "Chickpea" refers to 2 cultivars [29]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], "Location" corresponds to different low-tannin cultivars that were harvested at 2 different locations in Canada [31], and "Storage" corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) for 60 days and a control sample stored for 0 days [32] (see **Table 1** for more details).

Table 4. Alkanes/alkenes in pulses (expressed as percentages).

Alkanes/Alkenes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Trichloromethane	67-66-3	N [1]				0.00–0.50						
Octylcyclopropane	1472-09-9		0.00–0.96	0.00–1.28	0.00–2.04							
Pentane	109-66-0	FFA [4]								0.10–0.10		
Hexane	110-54-3	FFA [4]	0.74–1.54	1.14–1.72	0.83–0.86							
3-Methylhexane	589-34-4					0.00–2.50						
Butylcyclohexane	1678-93-9		0.00–0.49	0.00–0.51								

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Alkanes/Alkenes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Heptane	142-82-5	FFA [3]	0.54–1.15	0.94–1.07	0.57–0.76						0.55–0.56	
Octane	111-65-9	FFA [4]	1.74–2.66	0.00–1.74	1.89–3.64						1.79–1.96	
2,6-Dimethyloctane	2051-30-1		0.00–0.48	0.46–0.83								
Nonane	111-84-2	FFA [4]	0.75–0.95	1.00–1.37	0.77–1.17					0.16–0.17	0.34–0.36	
3-Methylnonane	5911-04-6		0.00–0.52	0.56–0.80								
4-Methylnonane	17301-94-9		0.00–0.94	0.95–1.64								
3,7-Dimethylnonane	17302-32-8									0.18–0.19		
Decane	124-18-5	FFA [2,4]	2.66–4.27	4.78–6.55	1.60–1.86					0.67–0.70		0.95–3.88
4-Methyldecane	2847-72-5		0.00–0.75	0.64–1.34								
2,4-Dimethyldecane	2801-84-5											0.00–0.32
3,7-Dimethyl-decane	17312-54-8								0.00–0.31			
Undecane	1120-21-4	FFA [1,4]	0.00–0.87	1.06–1.51		1.80–2.60				0.15–0.15	1.36–1.52	
Dodecane	112-40-3		0.00–1.12	1.22–1.27		0.80–3.60				0.57–0.62		0.80–3.22
2,4-Dimethyldodecane	6117–99–3	FFA [1]								0.09–0.09		0.00–0.33
5,8-Diethyldodecane	24251-86-3									0.04–0.06		
2,6,10-Trimethyldodecane	3891-98-3		0.00–0.79	0.64–1.27								

Alkanes/Alkenes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Tridecane	629-50-5					0.90–4.30				0.06–0.08		0.00–0.15
2-Methyltridecane	1560-96-9	FFA [1]								0.05–0.05		0.00–0.14
3-Methyltridecane	6418-41-3	FFA [1]								0.12–0.15		0.00–0.42
2,2-Dimethyltridecane	61869-04-3									0.13–0.15		
Tetradecane	629-59-4					0.00–1.10	Trace	0.00–1.10		1.30–1.90		0.48–1.34
Pentadecane	629-62-9							0.00–1.57		0.19–0.21		0.00–0.64
3-Methylpentadecane	2882-96-4									0.15–0.26		0.00–0.08
Hexadecane	544-76-3							0.00–2.75		0.24–0.26		0.00–0.35
Heptadecane	629-78-7						1.27			0.07–0.10		
Nonadecane	629-92-5									0.02–0.06		0.46–0.99
Tetracosane	646-31-1								0.00–0.57			
Total alkanes			7.84–15.66	16.43–20.00	7.95–8.09	7.30–14.30	1.27	0.00–5.44	0.31–0.57	4.37–5.22	4.06–4.41	4.61–9.22
(E)-5-(Pentyloxy)-2-pentene	34061-80-8							0.00–0.69				
(Z)-1-Methoxy-3-hexene	70220-06-3								0.00–1.91			
3-Ethyl-2-methyl-1,3-hexadiene	61142-36-7							0.00–0.05			0.37–0.42	
1-Tetradecene	1120-						5.74	0.00−Coelution		0.07–		

Alkanes/Alkenes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
	36-1									0.08		
Total alkenes							5.74	0.05–0.69	0.00–1.91	0.07–0.08	0.37–0.42	

1 [26]; 2 [25]; 3 [31]; 4 [33][34]. N, naturally present (not considered as a contaminant); FFA, free fatty acids. The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond to 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. "Chickpea" refers to 2 cultivars [29]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], "Location" corresponds to different low-tannin cultivars that were harvested at 2 different locations in Canada [31], and "Storage" corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) for 60 days and a control (sample stored for 0 days) [32] (see **Table 1** for more details).

Table 5. Alcohols in pulses (expressed as percentages).

Alcohols	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Ethanol	64-17-5	AA [5] FFA [9,10,11]								0.48–1.29		0.00–0.42
2-Phenylethanol	60-12-8	AA [5,7,11]								0.27–0.34		0.00–0.83
2-Butoxyethanol	111-76-2						0.95	0.00–0.88				
2-Phenoxyethanol	122-99-6						Coelution	0.00−Coelution				0.00–0.30
Propanol	71-23-8	AA [1] FFA [9,10]				0.60–1.30				0.48–0.53		0.00–0.64
2-Propanol	67-63-0									0.48–0.57		0.00–0.15
1,2-Propanediol	57-55-6							0.00–0.04				

Alcohols	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
2-Methylpropanol	78-83-1	AA [9,11]				0.00–0.50						
1-Methoxy-2-Propanol	107-98-2								0.00–0.28			
2-Phenyl-2-propanol	617-94-7										0.38–0.41	
1-[1-Methyl-2-(2-propenyloxy)ethoxy]-2-propanol	55956-25-7							0.00–0.09				
Butanol	71-36-3	FFA [9,10]							4.32–4.72			
2-Butanol	78-92-2									1.29–1.38		0.00–1.90
2-Methylbutanol	137-32-6	AA [5,8,9,11]						0.06–0.34		3.52–4.80		0.38–5.48
3-Methylbutanol	123-51-3	AA [5,7,8,9,11]	0.00–0.80	0.58–0.86			0.42	0.06–0.22		1.97–2.43		0.12–3.23
3-Phenyl-2-butanol	52089-32-4								0.00–1.23			
2,3-Butanediol	513-85-9									0.39–0.40		0.00–1.72
Pentanol	71-41-0	FFA [2,3,4,7,8,9,10]	0.00–1.61	0.00–0.62			1.52	1.17–3.89	4.90–4.98	1.28–1.36	1.85–2.29	0.74–1.57
2-Pentanol	6032-29-7	FFA [9]					0.23			0.18–0.27		0.00–0.46
3-Methyl-3-pentanol	77-74-7						5.34	0.00–0.60				
1-Penten-3-ol	616-25-1	FFA [2,3,4,8,9,10]	0.99–1.86	1.34–1.88	2.30–2.64		6.87	0.44–5.58				
2-Penten-1-ol	20273-24-9							0.00–3.84				
5-[3-(4-Methoxyphenyl)-2-	-								0.33–0.90			

Alcohols	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
oxaziridinyl]-1-pentanol												
Phenol	108–95–2		0.00–0.47	0.31–0.34				0.00−Coelution	0.54–0.70			
Benzyl alcohol	100-51-6	AA [5,11]	0.00–0.24	0.26–1.11				0.00−Coelution		0.54–0.54		0.58–1.46
Hexanol	111-27-3	FFA [2,3,4,6,7,8,9,10]	1.58–1.86	1.39–1.60	1.24–1.25		4.54	0.88–9.53		10.64–11.32	3.87–4.29	0.33–31.41
2-Ethylhexanol	104-76-7		0.29–0.45	0.29–0.66	0.00–0.4			0.00–1.39				0.00–9.38
4-Ethylcyclohexanol	4534-74-1									0.15–0.17		
2,3-Dimethylcyclohexanol	1502-24-5											0.00–0.20
1-Hexen-3-ol	4798-44-1						0.29	0.00–0.14				
(Z)-3-Hexen-1-ol	928-96-1	FFA [8,9]					4.23	0.00–0.29				
(Z)-4-Hexen-1-ol	928-91-6							0.00–0.33				
Heptanol	111-70-6	FFA [8,9,10]				0.00–1.20	Coelution	Coelution−0.66		0.32–0.36	0.50–0.54	0.00–0.26
2-Heptanol	543-49-7	FFA [9]				0.00–0.40						
2-Methyl-3-heptanol	18720-62-2						0.72					
3-Methyl-2-heptanol	31367-46-1					0.00–2.40						
2-Hepten-4-ol	4798-59-8								0.00–0.78			
Octanol	111-87-5	FFA [3,7,8,9,10]	0.00–0.33	0.29–0.61	0.00–0.29	3.7–10.7	1.16	0.82–1.29		0.24–0.28	1.18–1.48	0.35–0.83

Alcohols	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
3-Octanol	589-98-0	FFA [1]				0.00–1.3						0.00–0.42
1-Octen-3-ol	3391-86-4	FFA [2,3,4,6,7,8,9,10]	1.18–1.43	1.23–1.60	0.00–3.51		2.61	1.23–1.38		0.35–0.41	3.93–4.00	0.29–1.64
(E)-2-Octen-1-ol	18409-17-1	FFA [10]						0.00–0.96			0.37–0.41	
(E,E)-3,5-Octadien-2-ol	69668-82-2									0.10–0.14		
Nonanol	143-08-8	FFA [7]	0.42–1.30	0.92–1.10	0.00–0.43		1.27	0.00–2.69		0.92–1.14	0.28–0.41	0.85–1.74
Decanol	112-30-1									0.22–0.29		
Undecanol	112-42-5						6.18					0.00–0.09
2-Pentadecyn-1-ol	2834-00-6								0.00–0.55			
Total			6.13–7.72	8.05–9.04	4.67–7.41	7.40–12.70	36.33	8.22–30.70	11.22–13.01	24.21–27.63	13.00–13.27	4.34–53.01

1 [26]. 2 [25]. 3 [27]. 4 [28]. 5 [30]. 6 [31]. 7 [32]. 8 [35]. 9 [12]. 10 [33][34]. 11 [36]. AA, amino acids; FFA, free fatty acids. The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond to 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. "Chickpea" refers to 2 cultivars [29]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], "Location" corresponds to different low-tannin cultivars that were harvested at 2 different locations in Canada [31], and "Storage" corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) for 60 days and a control (sample stored for 0 days) [32] (see **Table 1** for more details).

Table 6. Ketones in pulses (expressed as percentages).

Ketones	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
Acetophenone	98-86-2	AA [5]; FFA [6]	0.63–0.98	0.53–0.77	0.00–0.82					0.33–0.36		0.00–0.50
p-Isopropylacetophenone	645-13–6							0.00–0.73				0.15–0.57
p-Acetylacetophenone	1009-61-6											0.19–0.29
Acetone	67-64-1	FFA [5]	0.66–1.47	0.85–1.12	1.16–1.75					1.99–2.46	1.00–1.02	0.41–0.92
Butanone	78-93-3	FFA [1,2,6]	0.00–0.41	0.00–0.38		0.00–0.50		0.00–0.97		3.20–3.43	0.58–0.67	0.79–4.82
3-Hydroxy-3-methyl-2-butanone	115-22-0							0.00−Coelution				
Pentanone	107-87-9	FFA [1,6]				0.00–1.20						
3-Pentanone	96-22-0						0.87					
2,3-Pentanedione	600-14-6	FFA [6]					0.42	0.00–1.05				
Hexanone	591-78-6	FFA [6]								0.03–0.04		
Cyclohexanone	108-94-1							0.00–0.15				
5-Hexen-2-one	109-49-9						3.29	0.00–1.75				
6-Methyl-5-hepten-2-one	110-93-0	FFA [2]; CAR [4]	1.97–2.45	0.94–1.76	1.27–2.44				0.82–0.87	1.08–1.50	1.06–1.09	0.00–1.27
Heptanone	110-43-0	FFA [3,6]					0.17	0.25–1.03		0.27–0.32	0.46–0.48	0.24–0.35
2-Methyl-3-heptanone	13019-						6.85	0.00–6.50				

Ketones	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean		
						Whole	Dehulled	Proteins		Tannin	Location	Storage
	20-0											
Isobutyl-2-heptenone	-							0.00–0.17				
Octanone	111-13-7	FFA [6]					0.41					
3-Octanone	106-68-3	FFA [4,6]					Trace					
3-Octen-2-one	1669-44-9	FFA [5]						0.28–0.83			0.69–0.86	
2,3-Octanedione	585-25-1						Trace	0.00–1.34	1.71–2.00		0.52–0.53	
(E,E)-3,5-Octadien-2-one	30086-02-3	FFA [2,5]	1.14–1.98	1.31–2.41	1.42–1.46			0.00–8.00		0.20–0.28		0.16–0.20
Nonanone	821-55-6									0.26		
Decanone	693-54-9							0.00–0.35				
1,6-Dioxacyclododecane-7,12-dione	777-95-7								0.00–0.72			
Undecanone	112-12-9						Trace	0.00–0.18				
2-Butyl-1,3,2-dioxaborinan-4-one	33823-94-8								0.00–0.37			
Total			4.95–6.90	4.74–5.38	4.73–5.62	0.50–1.20	12.01	1.69–21.96	3.24–3.25	7.59–8.42	4.48–4.53	3.72–7.46

1 [26]. 2 [31]. 3 [32]. 4 [35]. 5 [12]. 6 [33][34]. AA, amino acids; FFA, free fatty acids; CAR, carotenoids. The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond to 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. "Chickpea" refers to 2 cultivars [29]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], "Location" corresponds to different low-tannin cultivars that were harvested at 2 different locations in Canada [31], and "Storage" corresponds to high-tannin

cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) for 60 days and a control (sample stored for 0 days) [32] (see **Table 1** for more details).

Table 7. Acids in pulses (expressed as percentages).

Acids	CAS	Origin (s)	Pea		Chickpea	Faba Bean	
			Dehulled	Proteins		Tannin	Storage
Acetic acid	64-19-7	AA [2,3,4]			3.10–3.90	1.84–2.35	0.49–1.94
2-Methylbutanoic acid	116-53-0	N [1]; AA [1,2,4]		0.00–0.22		0.13	0.00–0.26
3-Methylbutanoic acid	503-74-2	AA [2,3,4]	0.42	0.00–0.41		8.79–12.37	2.55–10.36
Pentanoic acid	109-52-4		0.48				
Hexanoic acid	142-62-1	FFA [1]	0.73	0.00−Coelution	1.06–1.98	0.57–1.54	
2-Ethyl hexanoic acid	149-57-5		0.51	0.00–0.43			
Heptanoic acid	111-14-8		1.46				
Octanoic acid	124-07-2	N [1]; FFA [3]	1.54	0.00−Coelution			0.00–0.24
Nonanoic acid	112-05-0	FFA [3]	1.92	0.00–1.40			0.00–0.58
Decanoic acid	334-48-5				0.00–0.89		
Palmitic acid	57-10-3				12.00–15.00		
Oleic acid	112-80-1				11.00–24.00		
Total			7.07	0.63–1.84	32.77–40.16	11.33–16.39	3.24–13.15

Table 8. Esters in pulses (expressed as percentages).

1 [27]; 2 [30]; 3 [32]; 4 [36]. AA, amino acids; N, naturally present (not considered as a contaminant); FFA, free fatty acids. The value “min–max” corresponds to the minimum and maximum percentages for each volatile compound identified. For peas, “Dehulled” corresponds to dehulled pea flour [27], and “Protein” refers to protein concentrate

Esters	CAS	Origin (s)	Black bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean	
						Whole	Dehulled	Proteins		Tannin	Storage
Ethyl ethanoate	141-78-6	FFA [3]				0.00–1.20					
2-Ethylhexyl ethanoate	103-09-3										0.00–0.79
Butyl ethanoate	123-86-4										0.00–0.25
Hexyl ethanoate	142-92-7	FFA [2]									0.00–2.96
Ethyl cyanoacetate	105-56-6								0.00–0.39		
Decyl bromoacetate	5436-93-1		0.00–0.36	0.00–0.32	0.00–0.34						
1,2-Dihydro-2-naphtalenylacetate	-								0.80–1.06		
Ethyl propanoate	105-37-3						Coelution	0.00–17.19			
Octyl pivalate	-										0.00–0.76
Hexyl 2-methylbutanoate	10032-15-2										0.00–3.54
Ethyl butanoate	105-54-4						0.93	0.00–0.05			0.00–3.66
2-Ethylhexyl butanoate	25415-84-3										0.00–0.92
Methyl isovalerate	556-24-1	AA [1]									0.00–2.11
Isoamyl isovalerate	659-70-1										0.00–0.51
Butyl hexanoate	626-82-4										0.00–7.48
2-Propenyl hexanoate	123-68-2						0.82				

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Esters	CAS	Origin (s)	Black bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean	
						Whole	Dehulled	Proteins		Tannin	Storage
Hexyl hexanoate	6378-65-0										0.00–3.33
Octyl hexanoate	4887-30-3							0.00–1.75			
Methyl salicylate	119-36-8									0.04–0.05	0.00–0.50
5-Isobutylnonane	62185-53-9								0.00–3.10		
4-Dodecanoyloxybutyl dodecanoate	624-07-7								0.00–0.77		
Isopropyl myristate	110-27-0								0.44–0.53		
3-Hydroxy-ethyl mandelate	-		0.28–0.42	0.34–0.45	0.00–0.42						
Total			0.42–0.66	0.45–0.66	0.00–0.77	0.00–1.20	1.75	1.75–17.25	1.50–5.59	0.04–0.05	0.00–24.15

1 [32]; 2 [35]; 3 [34]. FFA, free fatty acids; AA, amino acids. The value “min–max” corresponds to the minimum and maximum percentages for each volatile compound identified. “Black bean” refers to the 3 cultivars studied, and “Pinto bean” and “Dark red kidney bean” correspond to 2 cultivars for each [25]. For peas, “Whole” corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], “Dehulled” corresponds dehulled pea flour [27], and “Protein” refers to protein concentrate (dry process) [28] and to protein isolate (wet process) [27]. “Chickpea” refers to 2 cultivars [29]. For faba beans, “Tannin” corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], and “Storage” corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) during 60 days and a control (sample stored for 0 days) [32]. No ester was detected in “location” faba beans (see **Table 1** for more details).

Table 9. Pyrazines in pulses (expressed as percentages).

Pyrazines	CAS	Origin (s)	Pea		
			Whole	Dehulled	Protein
2,3-Diethyl-5-methylpyrazine	18138-04-0		0.00–1.30		
2-Methyoxy-3-isopropyl(5or6)-methylpyrazine	32021-41-3	AA [1]		2.62	0.00–0.13

Pyrazines	CAS	Origin (s)	Pea		
			Whole	Dehulled	Protein
2-Methoxy-3-isobutylpyrazine	24683-00-9	AA [2]		Trace	
Total			0.00–1.30	2.62	0.00–0.13

[1] [27]; [2] [37]. AA, amino acids. The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. No pyrazine was detected in black beans, pinto beans, dark red kidney beans, chickpeas, and faba beans ("tannin", "location", and "storage") (see **Table 1** for more details.).

Table 10. Terpenes in pulses (expressed as percentages).

Terpenes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Faba Bean	
						Whole	Dehulled	Proteins	Tannin	Storage
α-Pinene	80-56-8	CAR [1,2]	1.37–2.29	2.11–3.92	0.75–1.07					
Δ3-Carene	13466-78-9	CAR [1,2]	0.00–0.50	0.00–0.48		0.30–0.70				
Limonene	138-86-3	CAR [1,2]	0.00–1.36	1.31–2.96			0.66	0.00–0.11	0.96	0.00–10.81
γ-Terpinene	99-85-4									0.00–0.79
Terpinolene	586-62-9									0.00–0.12
Thujospsene-I3	-									0.00–0.09
(E)-β-Ionone	79-77-6	CAR [3]							0.11–0.12	
β-Myrcene	123-35-3	CAR [2]								0.00–0.60
Geranylacetone	689-67-8		0.00–0.69		0.00–0.30					
Elemol	639-99-6						2.71			

Terpenes	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Faba Bean	
						Whole	Dehulled	Proteins	Tannin	Storage
α-Muurolol	19435-97-3						2.94			
t-Muurolol	19912-62-0						7.45			
α-Cadinol	481-34-5						Coelution			
β-Eudesmol	473-15-4						Trace			
β-Linalool	78-70-6									0.11–0.79
Menthol	1490-04-6								0.28–0.45	0.00–0.60
p-Menth-1,5-dien-8-ol	1686-20-0						Coelution			
Total			2.06–4.77	3.91–6.89	1.06–1.07	0.30–0.70	13.77	0.00–0.11	1.35–1.63	0.11–12.73

1 [26]; 2 [35]; 3 [12]. CAR, carotenoids. The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond to 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], and "Storage" corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) during 60 days and a control (sample stored for 0 days) [32]. No terpene was detected in chickpeas and "location" faba beans (see **Table 1** for more details).

Table 11. Furans in pulses (expressed as percentages).

Furans	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Faba Bean		
						Whole	Dehulled	Proteins	Tannin	Location	Storage
2-Methylfuran	534-22-5	FFA 3				0.00–1.80					

Furans	CAS	Origin (s)	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Faba Bean		
						Whole	Dehulled	Proteins	Tannin	Location	Storage
2-Ethylfuran	3208-16-0	FFA [1,5]	0.00–0.64	0.62–0.74	0.00–0.58	0.00–3.90				0.29–0.29	
2-Acetylfuran	1192-62-7						Coelution	0.00–Trace			
2-Propylfuran	4229-91-8		0.53–0.71	0.49–0.61	0.75–0.85						
2-Propionylfuran	3194-15-8		0.44–0.66	0.00–0.78	0.53–0.69						
2-Pentylfuran	3777-69-3	FFA [2,3,4,5]						0.00–0.91	0.60–0.78	1.72–1.91	0.61–1.43
Total			1.37–1.64	1.23–2.02	1.43–1.97	0.00–5.70		0.00–0.91	0.60–0.78	2.02–2.21	0.61–1.43

1 [31]; 2 [28]; 3 [32]; 4 [35]; 5 [33]. FFA, free fatty acids. The value “min–max” corresponds to the minimum and maximum percentages for each volatile compound identified. “Black bean” refers to the 3 cultivars studied, and “Pinto bean” and “Dark red kidney bean” correspond to 2 cultivars for each [25]. For peas, “Whole” corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], “Dehulled” corresponds to dehulled pea flour [27], and “Protein” refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. For faba beans, “Tannin” corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], “Location” corresponds to different low-tannin cultivars that were harvested at 2 different locations in Canada [31], and “Storage” corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) for 60 days and a control (sample stored for 0 days) [32]. No furan was detected in chickpeas (see **Table 1** for more details).

Table 12. Lactones in pulses (expressed as percentages).

Lactones	CAS	Origin (s)	Pea		Chickpea	Faba Bean	
			Dehulled	Proteins		Tannin	Storage
γ-Butyrolactone	96-48-0				0.00–0.85	0.32–0.63	0.22–1.08
3-Methylbutyrolactone	1676-49-8		0.45				
4-Methyl-4-vinylbutyrolactone	1073-11-6					0.08–0.09	

Lactones	CAS	Origin (s)	Pea		Chickpea	Faba Bean	
			Dehulled	Proteins		Tannin	Storage
Pentolactone	599-04-2				2.20–2.30		
γ-Pentalactone	108-29-2		1.01				
δ-Caprolactone	823-22-3	N [2]				0.24–0.26	0.00–0.82
γ-Caprolactone	695-06-7	N [2]	10.11	0.00–Coelution		0.34–0.36	0.00–1.07
γ-Methyl-γ-caprolactone	2865-82-9		1.16	0.00–1.63			
4-Hydroxy-2-hexenoic acid lactone	2407-43-4			0.00–0.17			
γ-Octalactone	104-50-7	FFA [1]	Trace	0.00-Trace			
γ-Nonalactone	104-61-0	FFA [1]	1.31	0.00–0.33			
4-Hydroxy-2-noneic acid lactone	21963-26-8	FFA [1]	0.72	0.00–1.04			
δ-Undecalactone	710-04-3	N [2]			0.00–0.47	0.19–0.20	
Total			14.76	0.00–3.18	2.30–3.52	1.21–1.50	0.22–2.47

[1] [27]; [2] [30]. FFA, free fatty acids; N, naturally present (not considered as a contaminant). The value “min–max” corresponds to the minimum and maximum percentages for each volatile compound identified. For peas, “Dehulled” corresponds to dehulled pea flour [27], and “Protein” refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. “Chickpea” refers to 2 cultivars [29]. For faba beans, “Tannin” corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], and “Storage” corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) during 60 days and a control (sample stored for 0 days) [32]. No lactone was detected in black beans, pinto beans, dark red kidney beans, whole peas, and “location” faba beans (see **Table 1** for more details).

Table 13. Other volatiles in pulses (expressed as percentages).

Other Volatiles	CAS	Black Bean	Pinto Bean	Dark Red Kidney Bean	Pea			Chickpea	Faba Bean	
					Whole	Dehulled	Proteins		Tannin	Storage
Estragole	140-67-0									0.00–0.16
Benzothiazole	95-16-9					0.42	0.00–1.50	0.00–0.30		
4,5-Dimethylimidazole	2302-39-8							0.00–1.22		
Dimethyl sulphide	75-18-3				0.86–3.30					
Dimethyl disulphide	624-92-0				0.00–0.80					
3-Phenylindole	1504-16-1	0.00–0.84	0.49–1.18	0.72–0.73						
Methoxy-phenyl-oxime	-	0.43–0.88	0.00–0.62	0.00–0.72					3.39–3.60	
2,4-Dimethylbenzenamine	95-68-1	0.00–0.26	0.00–0.25	0.00–0.35						
2-(Trimethylsilylethynyl)pyridine	86521-05-3							0.00–0.40		
Total		0.72–1.72	1.18–1.37	0.72–1.80	1.26–3.40	0.42	0.00–1.50	0.00–1.92	3.39–3.60	0.00–0.16

The value "min–max" corresponds to the minimum and maximum percentages for each volatile compound identified. "Black bean" refers to the 3 cultivars studied, and "Pinto bean" and "Dark red kidney bean" correspond 2 cultivars for each [25]. For peas, "Whole" corresponds to 3 different harvest years of the cultivar Eclipse (2005, 2006, and 2007) [26], "Dehulled" corresponds to dehulled pea flour [27], and "Protein" refers to protein concentrate (dry process) [28] and protein isolate (wet process) [27]. "Chickpea" refers to 2 cultivars [29]. For faba beans, "Tannin" corresponds to a group of low-tannin cultivars and a group of high-tannin cultivars [30], and "Storage" corresponds to high-tannin cultivars that were stored under 3 different conditions (ambient, positive, and negative temperatures) during 60 days and a control (sample stored for 0 days) [32]. No other volatile was detected in "location" faba beans (see **Table 1** for more details).

5. Odour-Active Compounds in Pulses

An odour-active compound is a volatile compound whose concentration is greater than or equal to its odour detection threshold. It contributes to the product's aroma. These compounds can be detected by GC-O.

In dehulled peas, 15 odour-active compounds are present compared to 16 in pea protein isolates, and they are related to different types of odour descriptors, such as mushroom/earth, vegetable/green/pea, empyreumatic (peanut-grilled), animal, floral/fruity, and sweet [27]. For lupin, 19 odour-active compounds (including an unknown volatile) were identified in whole grains and 26 in dehulled grains. These volatiles are described as sweet, beany/pea/green/cardboard, floral, mushroom, fruity/floral, and animal [38][39]. Odour-active compounds are distributed into aldehydes, alcohols, ketones, acids, lactones, and pyrazines; however, aromatic hydrocarbons, alkanes, alkenes, esters, terpenes, and furans are not involved in the aroma of these pulses. The origin of these compounds is free fatty acid oxidation, except for acids and pyrazines, which are derived primarily from amino acid degradation.

Dehulled peas and pea isolates share the following odourant compounds: vanillin, hexanal, (E,E)-2,4-decadienal, 1-octen-3-ol, 2,3-octanedione, undecanone, γ-octalactone, 4-hydroxy-2-noneic acid lactone, 5- or 6-methyl, and benzothiazole. Some compounds are not detected in whole peas but are active compounds in pea protein isolates, such as 4-ethybenzaldehyde, phenylacetaldehyde, 3-methylthiopropanal, heptanal, (E)-2-octenal, (E,E)-3,5-octadien-2-one, heptanoic acid, and dimethyl trisulfide; they mainly come from free fatty acids and amino acids. However, nonanal, pentanol, octanol, nonanol, 3-methylbutanoic acid, and γ-nonalactone are only active in dehulled peas; they mainly come from free fatty acid oxidation. Curiously, nonanal, pentanol, and octanal are more concentrated in volatile extracts of pea protein isolates than dehulled peas but are only perceived as odour-active in dehulled samples.

Whole and dehulled lupins have only a few odour-active compounds in common: (E)-2-nonenal, (E,Z)-2,6-nonadienal, 1-octen-3-one, 3-isobutyl-2-methoxypyrazine, and 3-isopropyl-2-methoxypyrazine. Many compounds from amino acids are only present in dehulled lupin, such as 2-acetyl-1-pyrroline, maltol, sotolone, and some acids. They are probably due to contamination by microorganisms in these grains.

Vanillin and gama-octalactone are odour-active compounds in peas and dehulled lupins. Gama-octalactone is described as floral/anise/mint in peas and coconut/sweet in lupins. Hexanal is not an odourant only in dehulled peas. Pea protein isolates and whole lupins have two odourant compounds in common: (E)-2-octenal and dimethyl trisulfide; this last compound is described as faeces/meat broth/sewer in peas and meaty/metallic/sulphur in lupins. 3-Methylbutanoic acid and -nonalactone are odour-active compounds of whole peas and dehulled lupins; 3-methylbutanoic acid is perceived as animal in peas but sweaty/fruity/cheesy in lupins. These differences are not necessarily due to the variety of pulses; the descriptors depend on the panellists, the possible presence of coelution, or large differences in the volatile concentrations.

Odour-active compounds present in peas and lupins are derived mainly from free fatty acids and amino acids. The large variety of these perceived volatiles depends on the type of pulses, the cultivar, the storage conditions, and the transformation steps. Finally, descriptors for the same molecule could be very different and depend on the studied matrix.

6. Conclusions and Perspectives

A qualitative comparison of volatile compounds between pulses is presented. Indeed, the main drawback to making quantitative comparisons of volatiles is that the data are often expressed as peak areas or relative percentages, without using a standard compound allowing real quantification of each volatile compound. However, it was possible to suggest some hypotheses on the origins of the off-notes present in pulses with the aim of increasing the acceptability of pulses in food for humans.

The diversity of unsaturated free fatty acid contents and the characteristics of endogenous lipoxygenases in pulses mainly explain the large variety of volatile compounds identified. All of the classes of volatiles are present in pulses, but ketones, pyrazines, furans, and lactones are minority classes. Aromatic hydrocarbons represent more than 38% of the volatiles detected in common beans (black beans, pinto beans, and dark red kidney beans), whereas aldehydes and alcohols are more specific to dehulled peas, pea proteins (concentrate and isolate), and faba beans (location and storage). Seed transformations or uncontrolled parameters of storage promote the generation of volatile compounds from the degradation of free fatty acids and amino acids. For whole peas, the 2006 harvest-year seeds present higher percentages of aromatic hydrocarbons, aldehydes, alkanes, ketones, and furans than those of the 2005 and 2007 seeds [13]. If the storage conditions are supposed to be equivalent for these three harvest years, bad culture conditions could be suggested during 2006, such as water stress and/or mechanical or insect attacks, compared to years 2005 and 2007 and could explain these differences in terms of volatiles. Finally, all of these parameters could account for such heterogeneity in volatile compounds, yet they are not always taken into consideration in explaining the variability in aromatic composition.

Although the number of volatile compounds identified in pulses is high, only a small part contributes to the aroma. These odour-active compounds present different descriptors and threshold detection. However, identifying odour-active compounds in pulses is rarely done, and only two studies report on their olfactory impact, namely in lupins and peas. Only aldehydes, alcohols, ketones, acids, lactones, and pyrazines are involved in the aroma. The origin of these compounds is free fatty acid oxidation, except for acids and pyrazines, which originate primarily from amino acid degradation by unwanted microorganisms. Off-notes are described as vegetable, green, hay, potato, bean, metallic, mushroom, animal, dust, solvent, cardboard, etc., and refer to “beany” notes, but other volatiles present a pleasant smell, such as floral, fruity, grilled, sweet, and vanilla odours.

Precise identification of the odour-active compounds in pulses could allow the determination of their main origins and the proposal of strategies to reduce their perception. Some strategic axes have been identified to improve pulses’ aroma: to limit the production of volatile compounds, to remove the off-notes, and to decrease the perception of off-notes [40][41]. One approach consists of generating lipoxygenase-free legume seeds to limit off-note production, and this experiment was carried out on soybeans[42]. However, volatiles provided by the LOX pathway are also fully involved in a mechanism of defence for plants[43]. Therefore, a potential lower resistance of mutated plants should be considered. Moreover, due to climate change, water stress, or other stressors increase in future years, these new cultivars could be less adapted and produce lower yields. Moreover, heat treatments, such as blanching, microwave, radiofrequency, and conventional heating of mature seeds, allow the decrease or inhibition of lipoxygenase activity [44][45]. However, high temperatures favour the autoxidation of unsaturated free fatty acids. A compromise must be considered to limit these two phenomena. Finally, for the past 20 years, fermentation has modified the aroma profile of pulses by reducing or masking off-notes. Some molecules are still detected, such as pentanal, hexanal and heptanal in fermented lupin proteins or 2,3-butanedione, hexanal, 1-penten-3-one,2-heptanone, and 3-methylbutanol in fermented pea proteins [46][47]. A perspective that must be studied is the use of microorganism coculture to improve the aroma of pulses [48]. Another approach could consist of using perceptual interactions to mask off-notes or modify the aroma product to a pleasant product, in particular using odour-mixture, odour-taste, and/or odour-texture interactions [49][50].

Furthermore, non-volatile compounds also contribute to the off-flavours of pulses, particularly for bitterness and astringency (off-tastes). Saponins, alkaloids, and phenolic compounds have been identified in pulses, but their role in sensorial perception has rarely been studied. The elimination of these molecules could increase the acceptability of plantbased products.