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The impact of smoke point and aroma profile of sweet red pepper seed oil on culinary application and consumer acceptance

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ABSTRACT

The category of edible plant oils with additional health and sustainable benefits is growing steadily. However, this category still represents a relatively small market segment known as 'niche oils'. Oils derived from byproducts, especially seeds, are considered as functional foods due to their properties. However, to increase their usage, it is necessary to examine their sensory acceptability among consumers. The results of this research demonstrate that cold-pressed sweet pepper seed oil (*Capsicum annuum* L.), from the Podravka and Slavonka cultivars, is acceptable to consumers as an ingredient in meal preparation and in various processed food products, due to its favorable organoleptic and physicochemical characteristics. The quality of oil is highly dependent on the quick manipulation of pepper seeds. Pepper seeds, that have been dried for a shorter time, yield oil that has a higher smoke point (230 °C), which makes it suitable even for frying food. Aroma profile analysis revealed that cold-pressed sweet pepper seed oil is rich in terpene trans-β-ocimene (40%), as dominant component. Trans-β-ocimene plays a crucial role in the plant's protective mechanisms their during growth and development. Consequently, sweet pepper seed oil represents a potential natural resource for isolating this terpene to be used as a biopesticide. Notably, this innovative oil is entirely produced from byproducts (seeds) and thus it provides an additional benefit for consumers who seek to contribute to the sustainability of our planet through their dietary choices. Therefore, this oil holds significant potential for closing the loop in the circular bioeconomy.

KEYWORDS
sweet pepper seed oil; smoke point; consumers; culinary application; niche oils

KEY CONTRIBUTION

Sweet pepper seed oil is produced from a byproduct and is of great importance for sustainable development.
Sweet pepper seed oil has good properties for the use in industrial processing and gastronomy.

Preparation and processing of sweet pepper seeds are key factors for achieving the best sensorial, physicochemical and nutritional properties of sweet pepper seed oil.
Due to the presence of terpenes, especially trans-β-ocimene, as the dominant ingredient in the aroma of sweet pepper seed oil, the seeds or oil represent a potential source for their isolation and the use in plant protection (biopesticides).

Introduction

The edible oils market is experiencing continuous growth. Considering the production volumes of palm oil, soybean oil, sunflower oil, rapeseed oil, and olive oil in 2022, the global market value reached USD 212.6 billion. By 2027, it is projected to grow at a compound annual growth rate (CAGR) of 4.8%, reaching a value of USD 268.9 billion (MarketsandMarkets, 2023). The increase in oilseed production plays a significant role. Over the last three decades, the area under oilseed cultivation has expanded by 82%, resulting in increased production (Rahman, de Jiménez, 2016). The consumption of vegetable oils is estimated to reach 249 million metric tons globally, with the food sector accounting for the major share (MarketsandMarkets, 2023). Notably, the use of edible oils per capita, in low and middle-income countries in the Asia Pacific, has contributed to rising demand. However, the production of edible plant oils is associated with the environmental challenges, particularly due to increased greenhouse gas emissions. The cultivation phase has the most significant impact, while processing has a lesser effect (Schmidt, 2010; Schmidt 2015; Khatri and Jain, 2017; Mouron et al., 2016). Prado and colleagues highlight the potential utilization of agricultural byproducts in mitigating climate change. They specifically examine cottonseed oil (a byproduct of cotton processing commonly used in textiles) through life cycle analysis (Prado et al., 2021). Substituting palm or soybean oil with refined cottonseed oil in frying processes, especially in large restaurants like McDonald’s, can contribute to achieving greenhouse gas reduction goal.

In Croatia, consumer attitudes toward oil consumption were studied in 2023 (Brandpuls, 2023). Among a nationally representative sample (n=1836) aged 16-64, 95% of respondents use oil, with 34.7% using it once or more than once daily. Sunflower oil (80.4%), olive oil (70.9%), and pumpkin seed oil (29.4%) are mostly used. Interestingly, those who use oil daily (34.7%) perceive olive oil as healthier than regular oil. Such an attitude shows that consumers in Croatia are well-informed about the effects of olive oil on health. Olive oil is rich in polyphenols, which have proven anti-inflammatory, antiallergic, antiatherogenic, antithrombotic, and antimutagenic properties, which can prevent the onset of cardiovascular, neurodegenerative diseases, and cancer (Gorzynik-Debricka et al., 2018). In addition, olive oil is a part of the Mediterranean diet, which is also known to have a favourable effect on human health (Owen et al., 2004). Recently, ‘niche oils’ have appeared on the shelves of European stores. In a study of a representative sample of Polish consumers (n=1000) from 2022, more than 70% define ‘niche oils’ as oils from small producers, obtained from plants not intended for large industrial production, and for 50.7% of respondents, these are oils without GMOs and harmful chemicals, whose production is in line with sustainable development (46.0%), and of high nutritional value (45.5%) (Czwartkowski et al., 2022). For 83.2% of respondents, these oils are perceived more as food supplements than for direct consumption (65%), and the vast majority believe that such oils should not be subjected to thermal processing, because they lose their important properties (82.1%). Polish consumers of ‘niche oils’ (4.3% regular consumers) are individuals younger than 31 and older than 50 (53-60 years), and they would like to try flaxseed oil, castor oil, and grapeseed oil the most. Out of the 23 ‘niche oils’ mentioned in the study, 9 oils are produced from seeds (black seed oil, cotton seed oil, flaxseed oil, grape seed oil, plum seed oil, pumpkin seed oil, raspberry seed oil, tomato seed oil). Although for Polish respondents the physical, chemical, and technological properties of 'niche oils' are more important factor than sensory properties, the authors conclude that future research should, nevertheless, deal with the organoleptic evaluation of such products available on the market.

Sweet pepper seed oil (*Capsicum annuum* L.) is not significantly present in the European market (except in Hungary), while chili pepper seed oil is prevalent in the global market, particularly in Asia (where Asian producers account for 70% of the market for dried chilies and peppers). Cold-pressed sweet pepper seed oil (*Capsicum annuum* L.*,* cultivars Podravka and Slavonka) has been investigated for its physicochemical, sensory, and nutritional attributes, as well as its production process (Cvetković et al., 2020; Cvetković et al., 2022). The taste and aroma of the product are influenced by various components such as alcohols, aldehydes, ketones, and terpenes. Recently, the interest in terpenes has been increased due to their potential application as natural protectors in plant cultivation. Among terpenes, β-ocimene has been extensively researched in scientific literature (Kang et al., 2018; Ding et al., 2020). β-ocimene is a monoterpenoid ($C_{10}H_{16}$) that exists in two forms (stereoisomers): cis or (Z)-β-ocimene and trans or (E)-β-ocimene. The trans isomer is much more abundant in nature (94-97%) than the cis isomer (2-4%) and has a stronger floral scent (Farré-Armengol et al., 2017). β-ocimene is synthesized in plant chloroplasts from geranyl diphosphate by the action of the enzyme (E)-β-ocimene synthase. Due to its floral fragrance, it attracts pollinators (bees, butterflies) to the plant while also providing protection against pests. It stimulates plant defense by promoting the production of salicylic acid, jasmonic acid and ethylene, which collectively act as hormonal shields in defending the plant against insects (Kang et al., 2018). Researchers, including Kang and colleagues, have demonstrated that treating Chinese cabbage with β-ocimene can activate protection against green peach aphids (*Myzus persicae*), making it an interesting approach for natural pest control in agriculture. Since the cloning of the first gene (E)-β-ocimene synthase (AtTPS03) from Arabidopsis (a plant from the Brassicaceae family), more genes responsible for the synthesis of (E)-ocimene and their insect-repellent functions have been characterized in various plants, such as tomatoes, Chinese cabbage, and lima beans, soyabean and tobacco (Kang et al., 2018; Han et al., 2023).

For culinary use of oils, several factors are essential, including the content of free fatty acids, water, peroxide value, saponification value, iodine number, fatty acid composition, and other components. Cold-pressed sweet pepper seed oil (*Capsicum annuum* L.*,* Podravka and Slavonka cultivars) is rich in linoleic acid (omega-6 or 18:2) at 74.30% - 77.69%, palmitic acid at 11.07% - 11.20%, oleic acid at 9.18% - 10.32%, and stearic acid at 2.62% - 2.91% (Cvetković et al., 2020). The free fatty acid (FFA) content in oil indicates the hydrolytic deterioration process, which depends on the health of the fruit and seeds, as well as subsequent processing, storage, heating, or frying, and the water content in the oil (Mahesar et al., 2014). Not all oils are suitable for frying in gastronomy. During deep-frying, temperatures can exceed 205 °C, so the USDA recommends oils with high smoke points (210 °C-232 °C), such as peanut oil, soybean oil, safflower oil, grape seed oil, sunflower oil, sesame oil and olive oil (USDA, 2013). The smoke point is the specific temperature at which smoke first appears from the oil, and the FFA content significantly influences this point (Bockisch, 1998; Guillaume et al., 2018). Palm oil has smoke point at 223 °C, FFA 0.06%, rapeseed oil's smoke point at 218 °C, FFA 0.08%, soybean oil's smoke point at 213 °C, FFA 0.04%, sunflower oil's smoke point at 209 °C, FFA 0.1%, peanut oil's smoke point at 207 °C, FFA 0.09%, extra virgin olive oil's smoke point at 207 °C, FFA 0.075% and coconut oil's smoke point at 194 °C, FFA 0.2% (Bockisch, 1998; Guillaume et al., 2018). Cottonseed oil dominated the global oil market before World War II due to its lower costs, compared to other edible oils, and widespread availability (O'Brien, 2002). Recently, it has regained attention because it is produced from cottonseed processing byproducts, positively impacting climate change. Its interesting physicochemical and nutritional composition makes it valuable for gastronomic use.

As the cold-pressed sweet red pepper seed oil of the Podravka and Slavonka varieties is an innovative product, for use in culinary and food products, it is necessary to examine the wider features of the oil important for this purpose. Therefore, the objectives of this paper are to determine a) the smoking point of pepper seed oil during the two-year harvesting season, b) the aroma profile of the oil and c) the use of pepper seed oil as an ingredient in gastronomy and food valued by consumers.

Materials and methods

Material and cold-pressed oil preparation

Seeds of horn oblong sweet pepper (*Capsicum annuum* L.), cultivars Podravka and Slavonka, were obtained during two consecutive pepper harvest seasons, but were differently separated and prepared. Seeds from the 2020 season were manually extracted from pepper fruits and dried in two phases: first at room temperature (25 °C) for 12-24 hours, followed by sterilization (toasting) at 130 °C for 20 minutes in a kitchen oven until the moisture content was below 10% (measured with halogen moisture analyzer, Mettler Toledo HR73) (Cvetković, 2020; Cvetković, 2023). Seeds from the 2021 harvest season were separated using a specially designed mechanical laboratory device and immediately dried using warm air at two temperature levels (80 °C/50-60 minutes; 130 °C/20 minutes), also until the moisture content was below 10%. Separation of pepper seeds, drying and packaging of seeds was done in the Corporate Product Development Laboratory, Podravka Inc. Within 7 days of drying, pepper seeds from both seasons (2020, 2021) were cold pressed using a laboratory screw press (KOMET, screw oil expeller Ca 59 G) to obtain the oil. After allowing the oil to settle for 10 days, it was decanted, filtered, and packaged in dark bottles with 500 ml caps, then stored in a refrigerator at 4 °C (Cvetković, 2023). Pressing and packaging of pepper seed oil was dine in the Laboratory of the Department of Technological Design and Pharmaceutical Engineering at the Faculty of Food Technology Osijek.

Smoke point and aromatic profile analysis

The smoke point of the pepper seed oil was visually assessed in three repetitions during the 2020 and 2021 pepper harvest seasons in the Corporate Product Development Laboratory, Podravka Inc. (Cvetković, 2023). The analysis of the aromatic profile of sweet pepper seed oil (*Capsicum annuum L.),* cultivars Podravka and Slavonka, was conducted using the headspace solid-phase microextraction (HS-SPME) technique coupled with gas chromatography-mass spectrometry (GC-MS) on oil obtained from the 2021 pepper harvest season (Kušević, 2022). An Agilent Technologies 7890 B gas chromatograph with an Agilent Technologies 5977 A mass-selective detector, connected to a computer, was used for the analysis. Component separation was performed on H5-5MS capillary columns (30 m length, 0.25 mm diameter, 0.25 µm stationary phase thickness, J&W, USA). The column temperature program ranged from 70 °C/2 min to 200 °C, with an ionization energy of 70 eV, an ion source temperature of 230 °C, and a mass scanning interval of 45-450 mass units (Kušević, 2022). Determination of fatty acid composition, tocopherol and other parameters were described earlier in literature (Cvetković et al., 2022). Aromatic profile analysis was carried out in the Laboratory of the Department of Technological Design and Pharmaceutical Engineering at the Faculty of Food Technology Osijek.

Application of oil and sensory evaluation

For all sensory analyses in this study, cold-pressed sweet pepper seed oil from the 2021 harvest season was used. The oil's application in gastronomy (both hot and cold) and the development of new food products were investigated through two types of sensory analyses: quantitative descriptive analysis (QDA) on a unipolar scale (0-150 mm) and a hedonic scale (1-9 scale and 1-5 scale). For hot gastronomic applications, products such as French fries and vegetable sauce (a newly developed laboratory prototype food product) were used, while for cold applications, hummus and legume salad were considered. The descriptive analysis of French fries during deep frying was conducted from February 3rd to February 10th, 2022, with the participation of a trained descriptive panel consisting of five sensory assessors (women, average age 45 years). Expert panel used for the analysis had extensive experience in descriptive analysis of food products and was previously trained for sensory analysis of extra virgin olive oil. For this sensory analysis, panel was trained using commercial vegetable oils and seed pepper oil. Panel was consistently trained during six months, two sessions per week, one hour each in the morning hours of the day. The panel was trained under supervision of a sensory expert. The same trained sensory panel (n=5) was also used for the descriptive analysis of vegetable sauce (from March to May 2022), and in the hedonic acceptability evaluation during June 2022, 60 consumers participated (85% women, 58.4% aged over 50).

The hedonic acceptability of pepper seed oil in cold applications was tested on cold dishes: hummus and bean salad with 25 consumers (90% women, 56% over 50 years old), during the period from August 31 to September 23, 2022. For the hot application of oil on the product (commercial french fries), the deep-frying process at a temperature of 175 °C/9 min, in cycles of three consecutive repetitions, was chosen. Two pasteurized vegetable sauces were developed, one with the addition of commercial sunflower oil, and the other with pepper seed oil at a concentration of 6.8%, while all other sauce ingredients were: red pepper fillet (over 50%), other vegetables, fruit, salt and spices, in the same proportions. Two pasteurized vegetable sauces were developed in the Corporate Product Development Laboratory, Podravka Inc. For the cold application of oil, two cold dishes were prepared: hummus spread (30 ml of added pepper seed oil) and bean salad (60 ml of added pepper seed oil) (Cvetković, 2023). All sensory tests were conducted in the Laboratory for Sensory and Nutrition, Podravka Inc.

Results and discussion

Smoke point of cold-pressed sweet pepper seed oil: comparison over two seasons

The smoke point of cold-pressed pepper oil from the 2021 harvest season (230.2 °C) was significantly higher than the oil from the 2020 pepper harvest, which was 217.3 °C ($P < 0.05$) (Table 1). In comparison with the smoke points of edible commercial vegetable oils range from 194 °C (coconut oil) to 230 °C (cottonseed oil), pepper seed oil has the similar or slightly higher smoke point relating to the upper limit of commercial oils used for frying (Bockisch, 1998; Guillaume et al., 2018; O'Brien, 2002). Even though the seeds from both seasons (2020, 2021) had the same moisture at the end of the drying (less than 10%) and pressing process, the smoke point was different. The only difference was that the seeds from the 2021 season were dried in the first phase at 80 °C/1h, and seeds from the 2020 season at a lower temperature and longer 25 °C/12-24h. Regardless of this difference, the amount of free fatty acids (FFA) in the oils remained the same for both seasons (about 0.2%). Such a proportion of FFA is found in coconut oil (0.2%), but it has a significantly lower smoke point of 194 °C (Bhatnagar et al., 2009). On the other hand, pepper seed oil from the 2021 season has almost the identical smoke point as cottonseed oil (230 °C), but it has almost 20 times less FFA (0.01%) than pepper seed oil (O'Brien, 2002).

Interestingly, there are some other similarities with cottonseed oil: saponification number (189-200 mg KOH/g), stearic fatty acid (2.1-3.3%), arachidic fatty acid (0.2-0.5%) (Regulation no 117/21). These results and a comparison with the characteristics of other vegetable oils indicate what earlier studies have revealed, that there is no single factor that affects the smoke point, but that it is the result of several factors, such as the proportion of monounsaturated fatty acids, phenols and antioxidants that prevent degradation and oxidation of fatty acids during heat treatment (Lozano-Castellón, 2022). The content of monounsaturated fatty acid (oleic acid) in cold-pressed sweet pepper seed oil from the 2021 harvest season was 10.3 g/100 g, significantly higher than in the oil from the 2020 season, which was 9.2 g/100 g ($p < 0.05$) (Table 1). Oils from both seasons were rich in linoleic acid and ϒ – tocopherol. The amount of linoleic in the oil from the 2020 season was slightly higher than in 2021 (75.0 vs 74.3%; $p<0.05$), whether the opposite, ϒ – tocopherol, was higher in oil from season 2021 compared to season 2020 (57.4 vs 53.5 mg/100g; $p<0.05$). The high content of γ-tocopherol, combined with oleic acid, polyphenols, and sterols, contributes to a higher smoke point, making pepper seed oil suitable for baking and frying according to the recommendations of the United States Department of Agriculture (USDA, 2013).

Table 1. Smoke point and other physical-chemical properties of cold pressed sweet pepper seed oil cultivars Podravka and Slavonka, during harvest seasons 2020 and 2021 (Cvetković, 2023.)

	Unit	**Method**	**2020**	**2021**
Smoke point*	°C	Visually	217.3 ±0.5	230.2 ± 0.6
Moisture	g/100g	Gravimetrically	0.1±0.0	0.1±0.0
Free fatty acids	%	Titration	0.2±0.1	0.2± 0.9
Nonsaponifying substances*	g/100 g	Extraction (hexane)	1.0±0.0	1.1±0.0
Saponification number*	mg KOH/g	Titration	199.7±0.9	188.8±0.9
Peroxide number	mmol O_2/kg	Titration	2.2±0.1	2.2±0.1
Iodine number	g I_2/100 g	Titration	133.1±4.5	137.9±1.9
Insoluble impurities	%	Gravimetrically	0.0	0.0
Monounsatur. fatty acids*	g/100g	GC-FID	9.2±0.0	10.4±0.0
Polyunsat. fatty acids*	g/100g	GC-FID	72.0±0.1	71.3±0.0
Saturated fatty acids*	g/100g	GC-FID	14.5±0.0	14.0±0.0
Myristic fatty acids (C14:0)	%	GC-FID	0.1±0.0	0.1±0.0
Palmitic fatty acids (C16:0)	%	GC-FID	11.2±0.0	11.1±0.1
Stearic fatty acids*(C18:0)	%	GC-FID	2.9±0.0	2.6±0.0
Arachidic acid*(C20:0)	%	GC-FID	0.3±0.0	0.3±0.0
Palmitoleic fatty acids (C16:1)	%	GC-FID	0.3±0.0	0.4±0.0
Oleic acids*(C18:1)	%	GC-FID	9.2±0.0	10.3±0.1
Linoleic acid*(C18:2)	%	GC-FID	75.0±0.1	74.3±0.2
Linolenic acid (C18:3)	%	GC-FID	0.3±0.0	0.3±0.0
Vitamin E (tocoph. Equi.)*	mg/100g	HPLC	5.4±0.0	5.7±0.0
ϒ – tocopherol*	mg/100g	HPLC	53.5±0.4	57.4±0.4

*± standard deviation (two repetitions); smoking point=average smoking point calculated through three repetitions; *significant level at p<0.05*

Aroma profile of cold-pressed sweet pepper seed oil

Luning and colleagues analyzed the volatile components of Dutch commercial peppers *(Capsicum annuum* L.) at various ripening stages (Luning et al., 1994). Using gas chromatography-mass spectrometry (GC-MS), pepper samples were ground and sliced. The measurement results revealed 64 different volatile components in peppers (alcohols, aldehydes, ketones, terpenes), with the highest levels found in green peppers (unripe fruits). During ripening, most volatile components decreased or even disappeared. Only (E)-2-hexanal and (E)-2-hexanol remained at approximately the same concentration, contributing almond-like, fruity, and sweet aromas. These compounds were more abundant in the ground pepper sample than in the sliced one. In the analysis of aromatic components in cold-pressed sweet pepper seed oil from Croatian cultivars Podravka and Slavonka (*Capsicum annum* L.), using headspace solid-phase microextraction coupled with gas chromatography-mass spectrometry (HS-SPME/GC-MS), 19 volatile components were identified. Among these, the most prominent was (E)-β-ocimene (or trans-β-ocimene) at 40.0% (Table 2).

Table 2. Volatile compounds of cold-pressed sweet pepper seed oil cultivars Podravka and Slavonka (HS-SPME/GC-MS) (Kušević, 2022)

No.	Compound	Rt (min)[1]	%
1	Ethanol	1.6	7.9
2	Ethanethiol	1.6	4.7
3	Acetic acid	1.7	8.5
4	3-methylbutanal	1.9	2.9
5	2-methylbutanal	2.0	6.2
6	Heptane	2.1	4.4
7	Acetoine	2.2	0.0
8	Pentane-1-ol	2.3	1.8
9	Butane-2,3-diol	2.7	3.2
10	Butane-1,3-diol	2.7	2.2
11	Hexanal	2.9	2.8
12	2-Methylbutanoic acid	3.3	1.2
13	Dimethyl sulfide	3.5	0.9
14	Hexan-1-ol	3.8	1.2
15	Benzaldehyde	5.8	0.2
16	(Z)-β-ocimene	7.9	0.6
17	Phenylacetaldehyde	8.2	0.5
18	(E)-β-ocimene	8.3	40.0
19	(E,E)-2,6-Dimethyl-1,3,5,7-octatetraene	11.3	0.9

[1] *Retention time*

Other significant compounds included acetic acid (8.5%), ethanol (7.9%), and 2-methylbutanal (6.2%), while the remaining compounds were present in much smaller amounts. Luning and colleagues also identified (E)-β-ocimene in a very high proportion in green, sliced peppers (62.34%, GC peak area 379.63), which decreased during ripening, reaching 22.99% in red, sliced peppers (GC peak area 28.44).

The aroma of β-ocimene has been described in the literature as floral, herbal, "mushroom-like," sweet, and woody (Luning et al., 1994; Farré-Armengol et al., 2017; Kušević, 2022). Although Luning and authors did not specifically comment on whether they removed the seeds during grinding or slicing of the peppers in their study, this investigation of pepper seed products (oil) confirms a high content of trans and cis β-ocimene, total 40.6% (Table 2). Previous research on pepper seeds of the Podravka and Slavonka cultivars found dietary fiber content (41.2-42.1%), protein (16.5-16.7%), carbohydrates (3.2-3.4%), oil (26.7-27.2%), and total phenols ranging from 149 to 158 mg/100g (Cvetković et al., 2022). Although did not specifically examine the quantity of β-ocimene terpene in pepper seeds to comment on how processing methods (drying, pressing) affect its concentration, it is evident that pepper seeds serve as a natural "storehouse" for this terpene, even in their oil form. It is well-known that seeds contain everything necessary for the new life development, and the results of this research underscore the significance of byproducts as novel raw materials and the importance of investing in processes for extracting, isolating, or applying their beneficial components. Due to its protective function in plants, pepper byproducts (seeds, pepper seed oil) represent a potential source of this terpene to be used as a biopesticide, as indicated by published studies (Kang et al., 2018; Han et al., 2023). Biopesticides are gaining significant attention globally due to their potential to replace synthetic pesticides that harm the environment (Nuruzzaman et al., 2019; Meshram et al., 2022; Koul, 2023).

Application of oil at temperature 175 °C and beyond: Sensory analysis of deep-fried French fries

In Table 3, the results of the descriptive analysis by a trained sensory panel for French fries deep-fried in pepper seed oil and palm oil are presented. French fries (FF) deep-fried in pepper seed oil exhibited significantly darker color (36.6±12.9; $p<0.05$) and a stronger pepper aftertaste (29.4±24.9; $p<0.05$) compared to FF fried in palm oil ($p<0.05$), while all other FF characteristics were similar. The odour of baked food was slightly more pronounced in FF deep-fried in palm oil (29.2±21.5), while the baked flavour was slightly higher in FF deep-fried in pepper seed oil (22.2±22.0).

Table 3. Descriptive analysis of French fries (FF) deep-fried in sweet pepper seed oil cultivars Podravka and Slavonka and Plam oil by trained sensory panelist (QDA) (Cvetković, 2023)

No.	Feature	FF in Pepper seed oil	FF in Palm oil
1	Colour*	36.6±12.9	19.9±12.8
2	Pepper odour	38.8±24.0	35.0±23.6
3	Baked odour	27.4±22.1	29.2±21.5
4	Smoky/burnt odour	4.0±5.4	1.7±2.4
5	Rancid odour	13.1±23.5	0.2±0.2
6	Flavour of Pepper	26.9±24.7	24.6±22.2
7	Bitterness	1.8±3.3	0.8±1.5
8	Baked flavour	22.2±22.0	19.0±18.4
9	Smoky/burnt flavour	6.0±12.0	0.7±1.2
10	Rancidity	10.5±19.1	0.6±1.5
11	Texture	40.7±16.5	36.2±19.0
12	Aftertaste*	29.4±24.9	14.6±22.1

*n=5; unipolar scale rating (0-150 mm the highest intensity); ± standard deviation (three deep-frying cycles); *significant level at p<0.05*

Application of oil at temperature below 100 °C: Sensory analysis of pasteurized vegetable sauce

The sensory analysis of two laboratory prototypes of pasteurized vegetable sauces with added pepper seed oil and sunflower oil (6.8%) showed a statistically significant difference in two of the eighteen analyzed characteristics by a trained sensory panel (Table 4).

Table 4. Descriptive analysis of vegetable sauces (VS) with sunflower oil and sweet pepper seed oil cultivars Podravka and Slavonka by trained sensory panelist (QDA) (Cvetković, 2023)

No.	Feature	VS with Sunflower oil	VS with Pepper seed oil
1	Colour	45.4±26.5	39.5±13.0
2	Visual consistency	36.3±17.4	41.4±23.1
3	Surface appearance	42.9±24.5	38.8±19.4
4	Odour of vinegar*	56.0±18.0	37.9±15.8
5	Pepper odour	54.5±16.6	49.8±21.4
6	Sharpeness of odour	56.5±33.0	50.4±35.5
7	Sandiness	46.9±31.9	51.5±38.5
8	Consistency in the mouth	37.7±18.8	33.4±18.2
9	Fullness in the mouth	60.8±39.2	66.2±37.1
10	Saltiness	66.2±21.6	65.3±24.3
11	Acidity	64.0±18.7	58.0±24.5
12	Bitterness	29.3±14.3	33.4±24.4
13	Astringency	25.7±11.1	35.5±24.1
14	Spiciness	30.3±19.3	29.3±18.3
15	Flavour of Pepper	56.7±19.7	51.3±17.5
16	Flavour of spices	40.6±25.9	49.8±27.0
17	Sweetness	29.8±11.5	34.3±11.8
18	Aftertaste*	34.7±35.4	63.6±31.8

*n=5; unipolar scale rating (0-150 mm the highest intensity); ± standard deviation (two repetition); *significant level at p<0.05*

The vinegar odour was significantly more expressed in the sample with sunflower oil, and the aftertaste of pepper in the sample with pepper seed oil (63.6±31.8, $p<0.05$). In FF deep-fried in pepper seed oil, a stronger aftertaste of pepper was also recorded (Table 3), and interestingly, the trained panelists felt it twice as intensly in the sauce with pepper seed oil, compared to FF (Table 4). It is possible that the intensity of the aftertaste in the sauce was synergistically negatively influenced by other sauce ingredients such as salt, spices and apple vinegar (4.5%). Indeed, the intensities of saltiness, sourness, and fullness of flavour were the most pronounced characteristics in both sauce samples (Table 4). In the examination of the most important sensory attributes of the sauce by average consumers, colour was the best-rated sensory attribute in both sauces, but statistically, significantly more acceptable in the sauce with sunflower oil compared to the sauce with pepper seed oil (4.3±0.7 vs 3.9±0.8, $p<0.05$) (Table 5). The sauce with sunflower oil also had a slightly better smell and taste. Both samples were rated very positively in terms of overall acceptability, but a slightly higher number of respondents preferred the sauce with sunflower oil (83.3% vs 75.0% responses 9,8,7) (Figure 1). For 21.7% of respondents, the sauce with pepper seed oil was extremely likable (response 9).

Table 5. Sensory evaluation of vegetable sauces (VS) with sunflower oil and sweet pepper seed oil cultivars Podravka and Slavonka by consumers (5-point scale) (Cvetković, 2023)

No.	Feature	VS with Sunflower oil (average score)	VS with Pepper seed oil (average score)
1	Colour*	4.3±0.7	3.9±0.8
2	Odour	4.0±0.7	3.8±0.6
3	Taste	4.0±0.8	3.7±0.9
4	Consistency	3.9±0.8	3.9±0.9
5	Aftertaste	3.9±0.8	3.7±0.8

*n=60; 5-point scale (5- strongly like, 1 – strongly dislike); ± standard deviation (two repetition); *significant level at p<0.05*

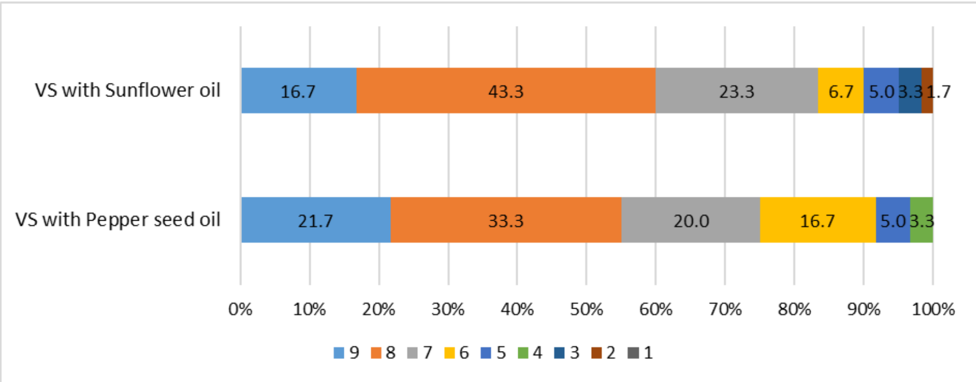

Figure 1. Hedonic ranking of vegetable sauce (VS) with sunflower oil and sweet pepper seed oil cultivars Podravka and Slavonka varieties by consumers (%) (9-point hedonic scale 9- strongly like, 1 – strongly dislike) (Cvetković, 2023); n=60

Application of oil 'on cold': Sensory analysis of cold dishes

The bean salad (with 60 ml of added pepper seed oil) was more accepted (92% responses on the scale of 9, 8, 7) compared to hummus (with 30 ml of added pepper seed oil) (76% responses on the scale of 9, 8, 7) (Figure 2).

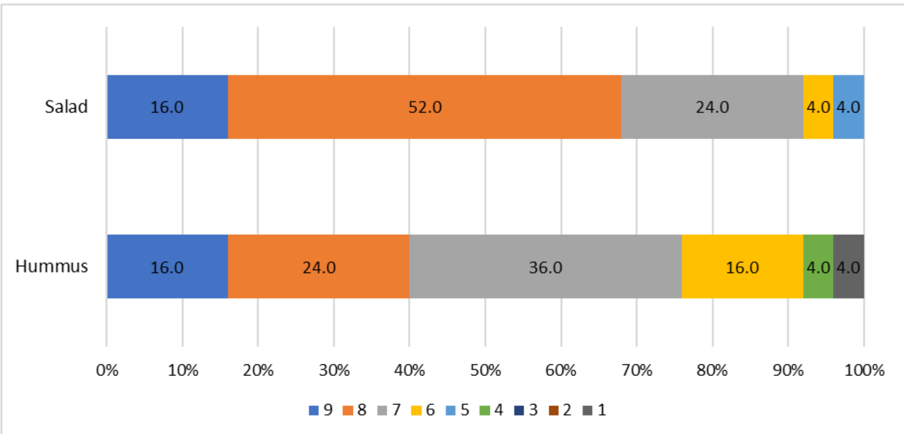

Figure 2. Sensory evaluation of cold dishes (salad and hummus) with sweet pepper seed oil cultivars Podravka and Slavonka by consumers acceptance (%); n=25; 9-point hedonic scale (9- strongly like, 1 – strongly dislike) (Cvetković, 2023)

Even in terms of the average basic organoleptic properties, the bean salad received a higher average score than hummus (4.2±0.8 vs 3.9±1.0). Overall, the most likeable characteristic was the colour in salad (4.5±0.6) and odour of hummus (4.1±0.8) (Table 6).

Table 6. Sensory evaluation of Cold dishes with sweet pepper seed oil cultivars Podravka and Slavonka s by consumers (5-point scale) (Cvetković, 2023)

No.	Feature	Hummus (average score)	Salad (average score)
1	Colour	4.0±0.8	4.5±0.6
2	Odour	4.1±0.8	4.2±0.7
3	Taste	3.7±1.1	4.2±0.9
5	Aftertaste	3.8±1.0	4.1±0.9
	Average Total	3.9±1.0	4.2±0.8

n=25; 5-point scale (5- strongly like, 1 – strongly dislike); ± standard deviation

The colour (reddish-orange) and aroma of these dishes were highly acceptable attributes. It is well-known that colour influences food purchasing decisions. Red colour attracts attention and is associated with good, appealing taste, while green, for example, is associated with healthy food (Luo et al., 2019). The aftertaste of pepper in the bean salad was weaker (4.1±0.9), which is consistent with the findings in the applications of oil in hot dishes (Table 3, Table 4). The aftertaste of pepper is an inherent characteristic of sweet red pepper oil made from *Capsicum annuum L.* cultivars Podravka and Slavonka, rather than an undesirable trait that would indicate hydrolytic spoilage. A mild bitter taste was noticed by consumers in the pepper seed oil product during this research (Table 4). In the past, a bitter taste was a signal of food spoilage and a health risk for humans (Ruxton and Kennedy, 2006). Recent studies show that bitterness is associated with an abundance of phytonutrients in certain vegetables and fruits, and although they have a positive impact on health, they do not always have equal taste acceptability among all individuals. According to sensitivity to 6-n-propylthiouracil (PROP), which involves measuring the suprathreshold of the bitter component, an investigation of cruciferous vegetable Savoy cabbage (*Brassica oleracea* var. sabauda) showed that out of 261 adult respondents, the majority were moderately sensitive to bitter taste (41.4%), followed by insensitive (35.2%) and very sensitive (23.4%) individuals (Gajari et al., 2022).

Salt and salt substitutes can successfully “mask” the bitter taste in cruciferous vegetable dishes, depending on people’s preferences for salty flavours and their sensitivity threshold to bitterness. Interestingly, Tewksbury and Nabhan note that pepper is not acceptable to most mammals (Tewksbury and Nabhan, 2001). The use of chili peppers or chili oil is widespread mostly in China, Mexico, South, and Central America. Chili peppers contain capsaicin, which causes spiciness and activates thermoreceptors, leading to sweating upon consumption. However, they also provide taste satisfaction, and their use is closely tied to dietary habits and culture (Abdel-Salam, 2016). Since pepper seed oil obtained from non-capsaicin peppers imparts a specific mild taste and aroma reminiscent of pepper, the results indicate its overall acceptability in culinary applications, creating a new sensory experience for foodies worldwide.

Conclusions

To achieve the best organoleptic properties of sweet pepper seed oil from cultivars Podravka and Slavonka, it is crucial to dry and press the pepper seeds as soon as possible after harvest and pack and store the oil in dark bottles to prevent fat oxidation and preserve its phytonutrient composition. As a result, the oil obtained from seeds that underwent a shorter drying and pressing process had a higher smoke point (230 °C), which is particularly interesting in hot culinary applications (frying). However, according to consumer test results, it is more recommended for cold use. The analysis of the aromatic profile of cold-pressed sweet pepper seed oil in this study revealed 19 aroma components, with the highest terpene content being trans-β-ocimene (40.0%) and cis β-ocimene (less than 1%). In nature, β-ocimenes, predominantly trans-β-ocimene, play a vital role in the protective mechanisms of plant growth and development, and the results confirm that they are largely preserved in the oil. This suggests that pepper seeds, as byproducts, could potentially serve as a source of β-ocimene for its application as a biopesticide, which is already supported by preliminary evidence in the literature. Nutritionally, this oil is of high quality, comparable to olive oil, and would, very likely, attract new health-conscious consumers. In addition to desirable sensory attributes, pepper seed oil also has the added characteristic of sustainability, as it is produced from pepper seeds, which are a byproduct of pepper processing. Sustainability increases on the list of consumer priorities, especially among younger individuals, when choosing food. Overall, this is a new oil in the ‘niche oils’ category. Besides gastronomy, pepper seeds and pepper seed oil are potentially interesting sources of terpenes as natural chemicals in plant protection, which should be proven in future research.

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