VYTAUTAS MAGNUS UNIVERSITY
LITHUANIAN RESEARCH CENTRE FOR AGRICULTURE AND FORESTRY

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PHYTOCHEMICAL AND ANTIOXIDANT ACTIVITY ASSESSMENT OF RASPBERRY (*RUBUS IDAEUS*) FOR SUSTAINABLE WASTE-FREE PRODUCTION

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LIST OF PAPERS

The doctoral thesis is based on the research contained in the following papers. **Papers in journals indexed in database *Clarivate Analytics Web of Science***

1. **Ispiryan, A**.; Viškelis, J.; Viškelis, P. Red Raspberry (*Rubus idaeus* L.) Seed Oil: A Review. Plants 2021, 10, 944. IF – 4,8 Q1 https://doi.org/10.3390/plants10050944

2. **Ispiryan, A**.; Viškelis, J.; Viškelis, P.; Urbonavičienė, D.; Raudonė, L. Biochemical and Antioxidant Profiling of Raspberry Plant Parts for Sustainable Processing. Plants 2023, 12, 2424. IF – 4,8 Q1 https://doi.org/10.3390/plants12132424

3. **Ispiryan, A**.; Bobinaite, R.; Urbonaviciene, D.; Sermuksnyte-Alesiuniene, K.; Viskelis, P.; Miceikiene, A.; Viskelis, J. Physico-Chemical Properties, Fatty Acids Profile, and Economic Properties of Raspberry (*Rubus idaeus* L.) Seed Oil, Extracted in Various Ways. Plants 2023, 12, 2706. IF – 4,5 Q1 https://doi.org/10.3390/plants12142706

4. **Ispiryan, A**.; A.; Giedraitis, A.; Sermuksnyte-Alesiuniene, K.; Butu, M.; Atkociuniene, V.; Butu, A.; Viskelis, J.; Miceikiene, A. Sustainable Development Solutions: Growing and Processing Raspberries on Lithuanian Farms. Foods 2023, 12, 3930. IF – 5,2 Q1 https://doi.org/10.3390/ foods12213930

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Conferences

1. **Ispiryan A**., Viškelis J., Bobinaitė R. Raspberry waste applications in food, cosmetics, pharmaceuticals and other industries. Third Symposium on Fruit and Vegetable Processing. November 24 and 25, 2020, Avignon, France, e-conference.
2. **Ispiryan A.**, Giedraitis, A. Integration of Information and communication Technologies (ICT) in berry and fruit farms cooperation in Lithuania. 13th International Scientific Methodical – Practical Conference Sustainable Regional Development: Economical, Management, Law and Technology Possibilities. October 24, 2019, Klaipėda, Lithuania.
3. **Ispiryan, A**., Montvydaitė, D., Greblikaitė, J. Comparative analysis of berry farming in European countries. 9th International scientific conference „Rural Development 2019: Research and Innovation for Bioeconomy". September 28, 2019, Kaunas, Lithuania
4. **Ispiryan A**. Valorization of berry pomace in the context of sustainable food systems. International scientific conference "Sustainable development of bioeconomy 2020: From global thinking towards local action". June 25, 2020, Kaunas, Lithuania.

5. **Ispiryan A**., Viskelis J., Bobinaite R. Physicochemical properties of raspberries (*Rubus Idaeus*) seeds oil from different varieties. CYSENI 2021 - 17th International Conference of Young Scientists on Energy and Natural Sciences Issues, May 24-28, 2021, e-conference.

6. **Ispiryan A**., Urbonaviciene D., Viskelis P., Viskelis J. Biochemical composition of different morphological parts of the raspberry. CYSENI 2022 - 18th International Conference of Young Scientists on Energy and Natural Sciences Issues, May 24-27, 2022, Vilnius, Lithuania.

7. **Ispiryan A**., Viskelis J., Raudone L. Biochemical profiling of raspberry plant parts. CYSENI 2023 - 19th International Conference of Young Scientists on Energy and Natural Sciences Issues, May 23-26, 2023, Kaunas, Lithuania.

INTRODUCTION

The world is faced with the challenges of an ever-increasing population and their need for food, depletion of natural resources, increasing environmental impact, and climate change. The Europe 2050 long-term strategy [1], European Green Deal [2] calls for a growth model capable of addressing Europe's future societal, economic, and environmental challenges. Such growth must be sustainable, based on a resource-efficient, greener, and more competitive economy, and high employment social and territorial cohesion [3].

Not only political strategies, but also consumers around the world are becoming more aware, more educated, and more demanding to recognize and purchase quality, health-promoting food [4]. Food, cosmetic, pharmaceutical, and other industry regulatory agencies are looking for innovative technologies to ensure safe and stable products for their customers [5]. The global intensive change of environmental factors enables us to look for various new ways to improve agricultural business, to create products with high added value on an international scale, to develop the product by discovering new possibilities of use, and to develop waste-free processing technologies [6-9].

In terms of planted area, red raspberries are the fourth most important berry crop in the world. Based on a comparison of 44 countries in 2021, Russia ranked the highest in raspberry production with 197,700 tonnes followed by Mexico and Serbia. Total raspberry production reached 886,539 tonnes in 2021 in the world, according to FAOSTAT (Food and Agriculture Organization of the United States). This is 32.4% more than 10 years ago [10]. Most of them are used for processing. Fresh and processed raspberries are a good source of biologically valuable substances [11-15]. Their demand is increasing all over the world, the cultivation and processing of various berries are being successfully developed, and the perception of value is moving from the simplest processing products, such as juice, and jam, to high-value products from the waste generated in the production process [16, 17].

With the advent of digital technologies and the development of innovative facilities, recycling technologies are also developing at a rapid pace, creating sustainable conditions for the creation of bioactive materials products with high added value from the waste obtained in the cultivation or production process. However, in the cultivation and processing of raspberries, research is focused on the berries themselves and their pomace, leaving aside other parts of the plant: leaves, stems, roots, flowers, and other by-products.

As large amounts of residual raw material and unused by-products are obtained during the cultivation and processing of berries, and as scientists present more and more research results [18-21] emphasizing the benefits of bioactive compounds obtained from natural sources and their ability to function properly for the vital functions of the human body, the interest in natural products from berries is completely understandable, the tendency to search for new functional ingredients, create high-value products from bio residual material. The food and beverage manufacturing sector needs to manage it more sustainably. This is emphasized not only by the above mentioned latest scientific research but also by such programs as the United Nations Environment Program [22] and, European Commission Work Program 2018-2020 [23]. To realize the goals, it is necessary to carry out detailed calculations and qualitative research, doing so requires good planning of raspberry production's environmental, social, and economic performance.

Economic entities, industry, and researchers lack research on biologically active substances in raspberries for the development of new products, information on how to improve waste management for the benefit of society, a coherent system of waste-free recycling technologies, recommendations for the creation and development of high-value products from raspberries using the entire raspberry plant potential for achieving the objectives set by agriculture, the essence of which is to help ensure maximum financial benefits [24-26], i.e. to earn maximum profit with minimal costs, to optimize production processes - to valorize all waste and to create products with the highest possible value and which could be linked to consumer, public preferences and farming and processing practices.

The overall intensive change of environmental factors become serious arguments to look for ways to optimize raspberry processing, rational use of resources, detailed knowledge of raspberries, not only the berries but also individual parts of the plant, to determine the correct waste-free technologies, which would create the prerequisites for creating and introducing new sustainable products on the market, to meet consumer needs with high quality, to get more economic benefits and achieve a better overall result. The development of waste-free technologies in the modern context would allow berry growers to think more analytically about raspberry harvest, processing, and its environment, would show various operational possibilities and perspectives, and would protect them from threats posed by the external environment.

In general, despite the increasing number of studies on berry by-products, the knowledge concerning the composition and biological activity of raspberry plant parts and their sustainable production is still unsatisfactory. Assessing the phytochemical composition of raspberries and evaluating biological activity are important in determining the quality of local plant raw materials and in the rational use of plant resources. Given the high importance of raspberry processing by-products, health promotion, and sustainability, research aspiring to this knowledge gap is very significant.

Hypothesis

It is presumed, that the determination of the composition and antioxidant activity of raspberry (*Rubus Idaeus*) phytochemical compounds can be the basis for the development of sustainable waste-free production and high added value products.

Research objective

To determine the phytochemical compounds composition and antioxidant activity of morphological parts of the raspberry plant, and to present directions for sustainable production without waste.

Research tasks

1. To evaluate the phytochemical compound composition of morphological parts of the raspberry plant and antioxidant activity for added value.
2. To investigate the physical and chemical properties of raspberry seed oil with the influence of different processing methods on its quantity, quality, and economic profit.
3. To analyze sustainable development directions for efficient raspberry production (growing and processing) without waste.

Statements to be defended

1. The amounts and composition of phytochemical compounds and antioxidant activity of morphological parts of the raspberry plant differ significantly, therefore, differentiation of plant parts in the processing is essential for the optimization of the quality of production and for creating innovations.
2. Raspberry varieties and extraction methods essentially determine oil production quantity, and economic profit but not fatty acids profile.
3. Sustainability measurement creates the prerequisites for developing raspberry production (cultivation and processing) without waste.

The scientific novelty of the research

Biochemical composition and nutritious value of morphological parts of raspberry plant (raspberry plant parts) grown under the same conditions have been established for the first time. As well, the comparison of antioxidant properties of raspberries by-products from primary production was performed and compared. These results are an important step toward the creation of a database in raspberry production. The obtained research results also provide new knowledge and valuable information about the physical fatty acid composition of different varieties of raspberry seed oil, and the influence of oil extraction technologies on quantity and quality. The possibilities of secondary use and reasonable methods of valorization of raspberry waste from a technological point of view were evaluated and product prototypes were created. A qualitative study revealed raspberry production sustainability factors in Lithuania on a Likert scale from very unsustainable to very sustainable in the economic, environmental, and social dimensions. Presented sustainable operational solutions for waste-free raspberry production and created a digital model for sustainability that can be used for evaluation of efficiency and establishing development directions.

The practical significance of the research

This study revealed biochemical composition, and antioxidant activity differences between raspberry parts. Consider this, products can be enriched with desired value in production to meet consumer needs by creating higher-value products. These results are significant not only for raspberries but also for other berry or fruit processors, as they reveal the potential of the whole plant. Using the results in farms or production would contribute to global strategic plans, the goals of which are for businesses to implement waste-free technologies and work on the principles of a circular economy.

The obtained results also can be used to highlight information to the consumers in the product labeling. Analyzed amounts of micro and macro elements, phenolic content, fatty acid, carotenoids and tocopherols content, antibacterial and antioxidant activity, economical profit, and sustainability analysis revealed very important knowledge and shows promising results, which can shed new light on raspberry quality standards methodologies in the food, pharmacy, cosmetic, packaging industries. The data provided by the study creates an opportunity to increase properly the production of raspberries by exploiting all parts of the plant according to its biochemical and bioactivity compounds, to strengthen waste-free raspberry production in economic, environmental, and social dimensions for sustainable development. The research results were presented to the members of the Association of Lithuanian Berry Growers, Processors, and Traders and LAMMC recommendation was published. The knowledge is applied in carrying out investment activities, optimizing resources, improving operations, creating innovative products, and providing information to consumers.

Approval of the research

This doctoral dissertation is prepared based on four scientific papers which are reproduced with the permission of the publisher. The papers are published in journals indexed in the database Clarivate Analytics Web of Science. Audronė Ispiryan is the first author of all papers. Results obtained during this research were presented at 7 scientific conferences.

The structure and volume of the doctoral dissertation

This doctoral dissertation is written in English (49 pages) with a summary in Lithuanian (14 pages), including 1 table and 14 figures. It contains following chapters: List of papers, Introduction, Literature review, Materials and methods, Results and discussion, Conclusions, References (191 reference sources), About the author, Acknowledgement, Summary and Appendix with a copy of 4 papers.

1. LITERATURE REVIEW

1.1. Research problem

In early Christian artwork, raspberries were used to symbolize kindness. Raspberry's red juice invoked the energy of the blood, which runs from the heart and carries love, nutrition, and kindness through the body [27]. In our days red raspberries (*Rubus idaeus* L.) are highly valued and increasingly popular foods in contemporary diets due to their freshness, nutritional value, and health claims [28-32]. They have a high content of vitamins (C, A, E, B1, B2, B3, B6, and K), organic acids (citric, malic), phenolic acids (derivatives of cinnamic and benzoic acids), polyphenols, cyanidin, aromatic compounds, pectins, minerals, sugars, and dietary fiber [33-38]. It has been revealed that Rubus berries are an increasingly important source of bioactive substances due to their antioxidant [39-47], anti-inflammatory [48-49], chemopreventative, and antibacterial [50-52] properties, their positive effects on blood lipids and above-mentioned atherosclerosis, as well as their advantageous composition. Nevertheless, there are no studies that reveal the biochemical results of all parts of the raspberry plant grown under the same conditions.

Different morphological parts of the raspberry plant have different profiles of bioactive compounds and possible target extraction [53-59]. For these reasons, they can be differentiated in the food, beverage, and cosmetic industries. Vegetative organs serve to maintain the life of the individual and are differentiated into roots, stems, and leaves. Fructifying organs or reproductive organs (fruits, flowers, and seeds) enable the survival of the species. However, of all these mentioned parts, mostly only the berries and leaves are commercialized, the other parts are thrown away as waste. Food losses and waste can occur in the food supply chain, starting from harvest up to retail and consumption levels [60-65]. Only very recently, other parts have started to be used, and in the scientific literature, products created from such parts are called by-products, which means a product produced in addition to the principal product, may be produced during processing and include leaves, stems, seeds, etc. Therefore, rather than considering waste, these can be utilized for the recovery of valuable compounds, thereby leading to the zero-waste concept [66-68].

Waste valorization, which has been defined as the process of converting waste into more useful products [69-71] is one of the EU's field-to-fork sustainability targets for fruit and berries cover key processes. To organize and carry out these processes sustainably, it is important to consider environmental, economic, and social factors. All these sustainability elements must be integrated into all levels of production, from cultivation to secondary, thirty processing, to achieve the goals of the green course, the circular economy. Moreover, the processes must lead, if possible, to low quantities of waste, the generation of this waste being able to be reduced by the reduction of the sources of waste or by the re-use of the products. In this context, it is important to investigate all raspberry plant parts, their by-product potential, and the influence of processing methods on its quantity and quality, to understand what and how sustainability factors impact raspberry production.

1.2. Biochemical composition and antioxidant activity

Raspberry fruits are the most studied by scientists. Studies have been carried out with fruits of different varieties, in different countries or in comparison with other berries [72-91], under different growing conditions, with different vegetation periods, storage, or other in/external conditions [92-101]; under different processing conditions [102-110]; effects on health [111-121]. The authors point out that anthocyanins and ellagitannins are polyphenolic compounds and the major antioxidant phytochemicals present in raspberries.

Another, not less, interest of scientists was attracted by raspberry leaf biochemical profiling [122-124]. Leaves, as an alternative source of bioactive natural products of nutritional and medicinal value were investigated for their biochemical antioxidant and antibacterial properties [125-143]. Regardless of the increasing number of studies on red raspberry leaves, industrial production and commercialization of such products remain insufficient.

Scientific literature analysis also revealed only a few researchers about the biochemical antioxidant activity of other raspberry plant parts: buds [144], stems [145], roots [146, 147], and some more seeds [148]. However, the research conducted is with different raspberry varieties, grown in different conditions, and the analysis methods and reagents used by the researchers are also different, which can influence the results therefore it is difficult for practitioners to organize production and make decisions. Also, for the same reasons, it is not possible to determine which morphological part of the plant contains a more biologically active substance or chemical element. Lithuanian scientists also made a significant contribution to scientific research on parts of the raspberry plant: R. Bobinaitė et al., P. Viškelis, L. Buskienė, L. Labanauskas, L. Ivanauskas [149-152]. They investigated different raspberry varieties and, influence of processing technologies.

The existing literature shows data on the biochemical, and antioxidant activity in the fruits and leaves of raspberries (*Rubus idaeus* L.), but there are only a few studies about stems, inflorescence, and roots and no studies of all the parts grown under the same conditions. Also, comparing the results of other researchers' studies who used different analytical methods, different plant growing conditions, or plant varieties can be a very difficult task.

1.3. Physical and chemical properties of raspberry seed oil

An extended literature review of raspberry seed oil and its application and national and international regulations is discussed in the review article (Article 1). Scientists who did recent research with raspberry seed oil emphasize that seeds from berry fruits are a waste product that can be reused to fortify the final product or to obtain high-quality oil in food or other industries. Applied methods of thermal properties studies are appropriate to determine the stability and quality of seeds and oils extracted from seeds. Further research is needed on the properties of oils obtained from berries by-products to determine their possible applications and changes during technological processing or storage [153].

1.4. Sustainability measurement in agriculture

The exploitation of raspberry waste during fruit processing as a source of functional compounds and their application in food is a promising field that requires interdisciplinary research [154]. Practitioners of sustainable agriculture seek to integrate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. Every person involved in the food system-growers, food processors, distributors, retailers, consumers, and waste managers-can play a role in ensuring a sustainable agricultural system. Consumers and retailers concerned with sustainability can look for “values-based” foods that are grown using methods promoting farmworker wellbeing, that are environmentally friendly, or that strengthen the local economy [155].

A growing number of innovative farmers and scientists are taking a different path, moving toward a farming system that is more sustainable-environmentally, economically, and socially. Such a system uses state-of-the-art, science-based practices that maximize productivity and profit while minimizing environmental damage. Scientists emphasize that agriculture must achieve sustainability by creating a balance [156-158]. There is still no consensus on the standardization of agricultural sustainability assessment as part of a unified concept of sustainable development. In the reviewed studies [159-161], stakeholder participation has proved crucial in the determination of the level of sustainability.

In addition, very little information is available on the assessment of berries by-products from bio-waste in terms of their economic, environmental, and social performance for sustainable business. Meanwhile, for the commercialization and development of berries waste, the measures with the expected results need to be more thorough. The use of inexpensive berry biomass by-products in the production of a value-added product is a new step toward sustainability.

Summarizing the literature review, we can state that there is not enough data in the literature about the amounts of biologically active compounds in the morphological parts of the raspberry plant. The scientific literature does not provide detailed data on the phytochemical composition and antioxidant activity of other raspberry products (flowers, stems, roots, leaves, seeds), or the optimization of processes for sustainable waste valorization during cultivation and processing.

A comprehensive understanding of raspberry cultivation and processing is important and necessary to find new opportunities in terms of sustainability. The conducted research would supplement and clarify the available knowledge about the quantities and quality of raspberry products growing and processing. Among the many factors, the impact of berries waste has been identified as a major problem. The use of raspberries and all plant parts in the production can lay a foundation to improve the implementation of by-products in a sustainable system.

This work aimed to answer what is the phytochemical profile, and antioxidant activity of individual parts of the raspberry plant, what are the physical and chemical properties of raspberry seed oil, the influence of different processing methods on its quantity, quality, and economic profit, and what is the sustainability of raspberry waste valorization, which are the best directions for the development of waste-free production, how to reduce raspberry waste during cultivation and production, what are the possibilities of their use. Waste prevention, and waste ecological design could help berry farms to be environmentally friendly and sustainable.

2. METHODS AND MATERIALS

2.1. Material and its preparation

The study was conducted in 2019-2022 Lithuanian Research Centre for Agriculture and Forestry, Institute of Horticulture, Laboratory of Biochemistry and Technology. Raspberry (*Rubus idaeus*) plant parts were collected at Audrone's Ispiryan raspberry farm and Lithuanian Research Centre for Agriculture and Forestry.

In the first stage, the primocane fruiting red raspberry cultivar 'Polka' was acquired from the raspberry farm, located in North Lithuania (55°47055.000 N 22°44057.400 E 55.798603, 22.749268). The study variants consisted of: ripe raspberries, unripe raspberries, flowers, leaves, stems, seeds and roots. The agrochemical properties of the soil are described in Table 1.

Table 1. Soil properties in the raspberry growing area

1 lentelė. *Dirvožemio savybės aviečių auginimo vietoje*

Soil properties	Description
Soil location	55°47'42.2"N 22°44'59.0"E
Granulometric composition	Loam
pH 1 mol/l KCl in suspension	5,6 ±0,2
Concentration of mobile phosphorus (P_2O_2), mg/kg	136 ±14
Concentration of mobile potassium (K_2O), mg/kg	167 ±11
Nitrogen (sum of nitrate plus nitrite), mg/kg	109,05 ±7,90
Concentration of nitrogen (ammonia), mg/kg	5,67 ± 1,04
Concentration of mineral nitrogen, mg/kg	114,72 ±4,66
Organic carbon concentration %	3,89 ±0,43
Humus concentration	6,71 ± 0,74

Note: data are expressed as average value ± standard deviation of three replicates and indicate significant differences ($p < 0.05$).

Pastaba: duomenys išreiškiami kaip vidutinė vertė ± standartinis trijų pakartojimų nuokrypis ir nurodo reikšmingus skirtumus ($p < 0,05$).

The average air temperature in Lithuania in August was 16.1 °C. Randomly selected raspberry parts were harvested in August 2020 and 2021 at physiological maturity (phenological phase 8 (fruit maturity) in the BBCH system) in the morning and transported to the laboratory of the Institute of Horticulture of the Lithuanian Research Centre for Agriculture and Forestry. Raspberry plant parts (leaves, stems, roots, buds, inflorescence, and fruits) were collected separately and randomly in an area of approximately 50 m^2. All parts of the raspberry plant in the fields were grouped and immediately taken to the laboratory of the Lithuanian Institute of Agronomy and Forestry, where they were frozen and lyophilized. Raspberry seeds were obtained by separating them using a "Voran" destoning and pulping machine. The seeds were dried at approximately 40 °C. In the second stage, all parts were grounded in a rotary hammer mill SR 300, 200-240 V, 50/60 Hz Retch (Germany) using a 0.5 mm sieve and stored in glass jars until analyses.

Material preparation for the second stage (oil analyses) was divided into two parts:

First part. Raspberry of the 16 varieties from Lithuanian Research Centre for Agriculture and Forestry: 'Polka', 'Austrijas Remontanta', 'Bristol', 'Volnica', 'Willamette', 'Malling Seedling', 'Ariadne', 'Novokitajevskaja', 'Meeker', 'Helkal', 'Zorinka', 'Toma', 'Peresvet', 'Sputnica', 'Nagrada', and 'Canby' were collected from the Lithuanian Research Centre for Agriculture and Forestry, the Institute of Horticulture. After harvesting, berries were immediately frozen and stored at -30 °C until needed. Prior to the analysis, the berries were defrosted at room temperature. After pressing the berries, the seeds were collected and dried in a convection dryer (thickness of approx. 0.5 cm) at a temperature (40 °C) for 24 h, with occasional stirring. Raspberry seeds were ground in an ultra-centrifugal rotor mill ZM200 (Retsch, Haan, Germany) using a 0.2 mm particle size sieve, but the process was stopped for 15 s at 15-30 s intervals to avoid heating the sample. Oil was extracted from raspberry seeds solvent (hexane) extraction.

Second part. The Polish primocane raspberry variety 'Polka' from Audrones Ispiryan farm was selected for more detailed research. The influence of supercritical CO_2, supercritical CO_2, cold pressing and hexane extractions on the quantity and chemical composition of raspberry oil was determined. This variety has been chosen as currently the most popular and one of the main cultivated raspberry varieties grown in the world, with excellent quality dessert berries and a rich harvest. This variety has also attracted a great deal of interest from scientists. Raspberries were collected at Audrone Ispiryan farm and immediately deboned by using a de-stoning machine EP500 (VORAN Maschinen GmbH, Pichl, Austria). The seeds were dried naturally at approximately 25-28 °C and grounded in a rotary beater mill SR 300 (Retsch, Germany) using a 1 mm sieve (with an average particle size of 1 mm) and stored in hermetically closed glass jars in a dark, dry room until the oil was extracted. To determine the effect of raspberry seed grounding on oil yield, seeds were grounded using 1 mm, 0.75 mm, and 0.5 mm sieves (with an average particle size of 1 mm, 0.75 mm, and 0.5 mm). Oil was extracted using four different methods: cold extraction/pressing, extraction with subcritical CO_2, and extraction with supercritical CO_2 and solvent (hexane) extraction.

In the third part of the study, assessing sustainability, qualitative research methods of social sciences were chosen, i.e. content and descriptive analysis. This study analyzed the sustainability aspects of zero-waste production. Using content analysis, we explored scientific literature and documents and looked for directions for establishing sustainability criteria. Using the coding textual data, which was then categorized, we constructed a questionnaire survey of interviews. The study used a semi-structured personal interview in which respondents were asked to rate the sustainability of raspberry cultivation and processing on a Likert scale based on their competence and experience. Each item was evaluated on a five-point Likert scale, according to which the participant had to choose the priority level of the indicator: 1 - very unsustainable, 2 - unsustainable, 3 - medium, 4 - sustainable, 5 - very sustainable. After collecting all the interviewees' responses, a mean was derived, which was used in the descriptive analysis and presented in the results of this study. The data was processed and systematized according to three areas of sustainability: economics, environment and sociology at work.

2.2. Determination of biochemical composition (Article 2)

Determination of titratable acidity, sugars, dry matter, ascorbic acid (Vitamin C) content, amount of macro and microelements, colors, nutritional values, and total content of phenolic compounds are described in Article 2.

2.3. Antioxidant activity (Article 2)

Antioxidant activity assessed by ABTS, DPPH, and FRAP methods is described in Article 2.

2.4. Extraction methods

Cold pressing method. Cold-pressed oil is obtained by pressing the seeds with an oil press Machine PR-H100/1 (1Head) (Oil press GmbH & Co. KG, Reut, Germany) at a speed of 10 Hz (8 RPM), capacity of 2.38 kg/h. The oil was centrifuged (3000 x g; 15 min, 10 °C), poured into dark (brown) glass bottles (100 ml), and stored at -40 °C in the dark.

Solvent extraction. A total of 1 kg of the ground raspberry seeds were placed in a 3 L glass vessel and filled with hexane. The extraction is carried out for 24 h at a temperature of 25 ± 2 °C in dark with stirring. The solvent was removed by vacuum filtration, and the sample was extracted twice. After the last filtration, the extract was pooled, hexane was removed with a vacuum rotary evaporator Rotavapor R-205 (BÜCHI Labortechnik AG, Flawil, Switzerland) at 35 ± 2 °C and 170 mbar pressure, purged with nitrogen, and stored at −18 °C until analysis

Extraction with subcritical and supercritical carbon dioxide. The dried raspberry seeds were ground with an ultra centrifugal mill ZM200 (Retsch, Germany) using a 0.2 mm sieve and extracted with subcritical SBK-CO2 and supercritical (SPK-CO2) carbon dioxide. Carbon dioxide is in its supercritical fluid state when both the temperature and pressure equal or exceed the critical point of 31°C and 73 atm. The scheme and diagram of the supercritical CO_2 extractor is presented in Figure 1.

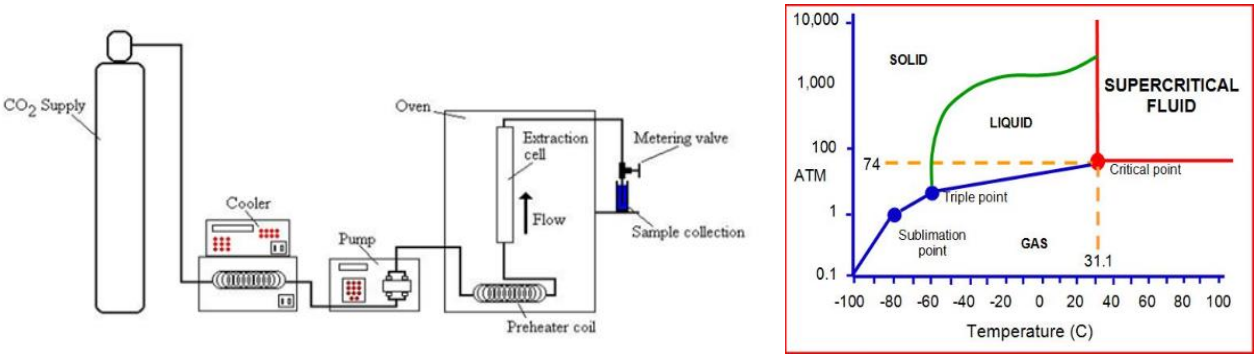


Figure 1. Supercritical CO_2 extraction scheme and diagram of supercritical fluid

1 paveikslas. *Superkritinio CO_2 ekstrahavimo schema ir superkritinio skysčio diagrama*

2.5. Determination of physio-chemical oil composition (Article 3)

Material preparation for oil analyses is described in detail in article No. 3.

2.6. Sustainability analysis (Article 3, 4 and unpublished data)

A cost-benefit analysis method was used to assess the economic sustainability of the technology’s impact on raspberry seed oil production (Article 3). Content and descriptive sustainability analysis were applied to analyze the sustainability of raspberry production (Article 4).

2.7. Statistical analysis

The results were evaluated statistically using GraphPad Prism 8 software (GraphPad, USA). All the results were presented as means, and standard deviation (SD). In addition, one-way ANOVA followed by Tukey's HSD test was calculated to compare the means and demonstrated significant variation ($p < 0.05$). In general, all analytical replicants were performed at least three times.

3. RESULTS AND DISCUSSION

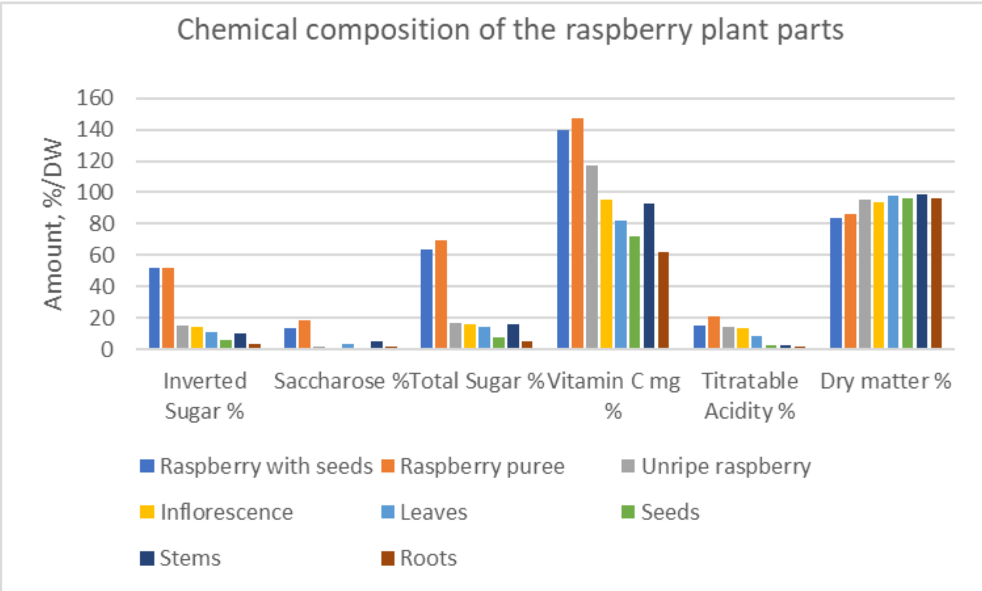
3.1. Biochemical composition of raspberry morphological parts (Article 2 and unpublished data)

3.1.1. Biochemical composition

The main aim of the first part was to identify the amounts and composition of biologically active compounds of individual parts of the autumn-fruiting cultivars raspberry plant (variety 'Polka') which is the most grown variety in Lithuania and Poland.

The biochemical composition of berries (ripe and unripe), leaves, stems, leaves, inflorescence, seeds, and roots total and individual phenolic compounds, ascorbic acid (vitamin C), titratable acid, dry matter, and micronutrients were determined. Detailed information is provided in Article 2.

The inverted sugar, saccharose, total sugar, ascorbic acid (Vitamin C), titratable acidity, and dry matter were investigated as the most important and primary indices in the processing. Also, these product characteristics such as sweetness, acidity, and juiciness are important for consumers. In this study, the contents of inverted sugar, saccharose, and total sugar varied from 51.8 ± 2.46%, 18.9 ± 0.31%, and 69.7 ± 4.36% in raspberry puree to 5.9 ± 0,23%, 1.51 ± 0.03%, 7.39 ± 0.33% in the seeds, respectively. The results are shown in Figure 2 below.



Note. Values were expressed as means with standard deviation error bars.

Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis

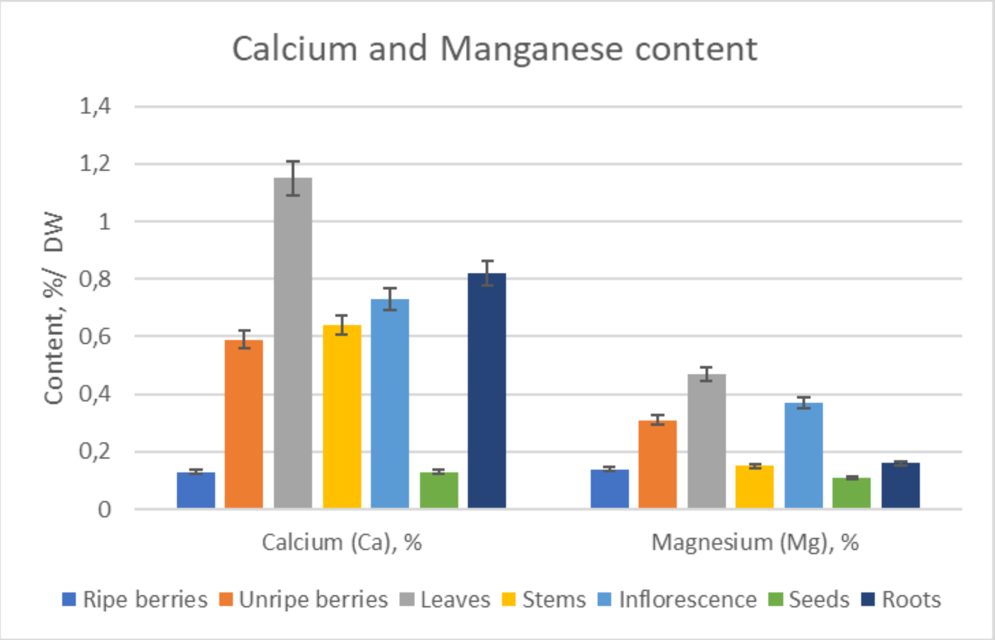
Figure 2. Chemical composition of different morphological raspberry parts

2 paveikslas. *Aviečių augalo morfologinių dalių cheminė sudėtis*

All raspberry plant parts are rich in Vitamin C. Significantly lower levels of Vitamin C were found in the studied leaves and higher in the fruits than reported by others [162]. It should be noted that the preparation of scientists' material and research methodologies differ. Differences may occur due to different sample preparation procedures, and the material preparation: in this study, the samples were lyophilized, while others studied fresh or dried by simple convection. Therefore, in the future, it would be relevant to study in detail the influence of processing methods on production quality. Research results show that raspberry stems, leaves, inflorescence can be also a source of vitamin C in such products as tea, and dried and molded spices.

Another analyzed parameter, one of the oldest quality parameters of fruit is dry matter content. Using this parameter has made berries more sustainable to transport and store. This study has shown that Raspberries 'Polka' fruits are good for transportation and storage. However, only raspberry fruit is distinguished by its sugar content. Other parts of the plant are low in sugar (Article 2).

This study also aimed to analyze and compare raspberry plant parts for the contents of selected minerals (calcium, magnesium, boron, zinc, copper, iron, manganese) as nutrition is an influential determinant of the risk of present-day metabolic diseases. From the data presented in Figure 3 below, it can be seen that the mineral content between raspberry plant parts is fundamentally different. The highest statistically significant calcium and magnesium content was found in raspberry leaves, roots, and inflorescence, while the lowest was in raspberry seeds and fruits.



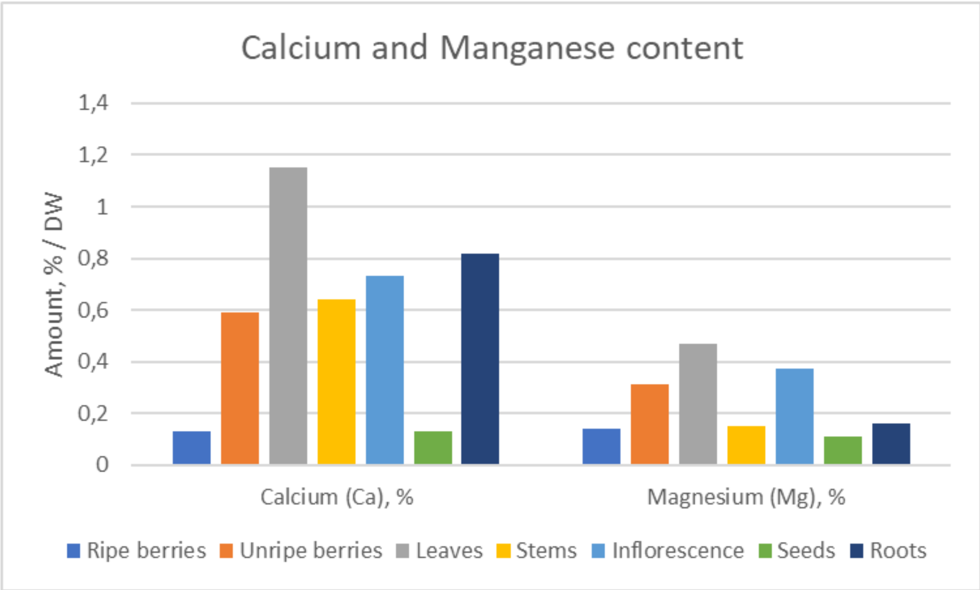
Note. Values were expressed as means with standard deviation error bars.

Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis.

Figure 3. Calcium and Manganese content in raspberry plant parts

3 paveikslas. *Kalcio ir mangano kiekis aviečių augalo morfologinėse dalyse*

From the given figure, we can see that the highest concentration of Ca was found in the leaves and is significantly different from other parts of the plant. Meanwhile, fruits and seeds have the least amount of calcium among other tested elements. Magnesium content is significantly lower than calcium in the parts of the raspberry plant. Raspberries waste from cultivation (leaves, stems, inflorescence, and roots) and processing (seeds) has a high potential for refining extractable micro (elements) that are usable as starting material not only for food and animal feed production processes but with higher value for pharmacy, cosmetic industries. The chemical composition of the micronutrients of different morphological parts of the raspberry are presented in Figure 4.



Note. Values were expressed as means with standard deviation error bars.

Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis

Figure 4. Micronutrient content in morphological parts of raspberry

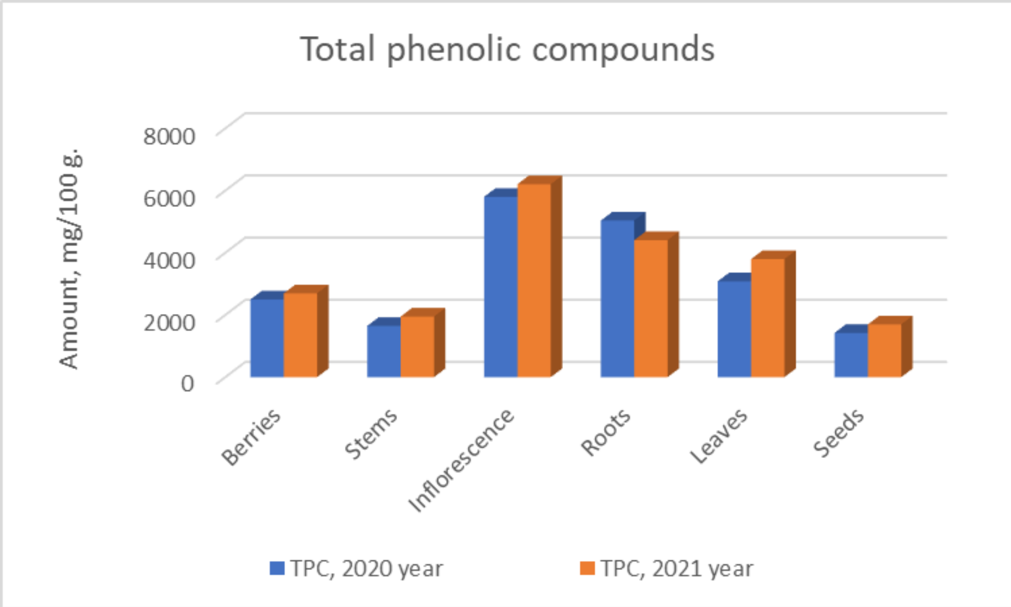
4 paveikslas. *Mikroelementų kiekis aviečių augalo morfologinėse dalyse*

The results regarding the mineral composition of various morphological parts of raspberry parts (mg/kg) indicated significant differences (Article 2). The mineral content of raspberry leaves, roots, and inflorescence was found to be greater than that of raspberry fruits and seeds. When comparing the values obtained with the FoodData Central database [163], The contents of individual minerals in the investigated databases differ from each other. Raspberry fruits from the FoodData Central database have a lower content of calcium, magnesium, and copper.

According to the Food Data Central database, the content of sugars in raspberry fruit is 2.68 g/kg. In this research, raspberry fruits contained 6.39 g/kg, and the lowest sugar content was in found int the roots. No information was found on other parts of the raspberry plant in official food databases. This is important for food and beverage manufacturers and is relevant in the future, so that they are additional, and manufacturers can compare the quality of the raw material they receive with the standards. Micro and macro elements from raspberry waste can be incorporated into food products as inexpensive, non-caloric bulking agents for partial replacement of flour, fat, or sugar, and to improve emulsion or oxidative stabilities.

The amount of total phenolic content ranged from 1700 to 6500 mg/100 g. The highest value was detected in berries, which is 26% higher than it was detected in the lowest value in the seeds. The amount of ascorbic acid content ranged from 60 to 140 mg/100 g of dry weight. The highest value was detected also in berries. In this work, the phenolic compounds of raspberry plant parts were also compared by year. According to the certificate submitted by the Lithuanian Hydrometeorological Service to the Ministry of the Environment about the amount of monthly precipitation (mm) in 2020 and 2021 - from September to June in Užventis (Kelmės district) according to the Šiauliai Meteorological Station, 2021 was characterized by the fact that in August a lower amount of precipitation fell than in 2020, and during the harvest, in the months of August-September, when the samples were collected, on the contrary, a higher amount of precipitation fell than in 2020. In Figure 5, we can see that the total amount of phenolic compounds in the parts of the raspberry plant was higher in 2021, except for the roots. Other parts of the plant showed a higher total amount of phenolic compounds. It can be concluded that the content of raspberry phenolic compounds is influenced by irrigation. The total phenolic compounds of different raspberry plant cultivations at different harvest (2020 and 2021) is presented in Figure 5 below.

The results, in Figure 5 show that the total phenolic compound depends on weather conditions. Total phenolic compounds were lower in 2020 when it was rainier except for the roots. Sunny and dry weather during harvest made the total phenolic compound higher. From the obtained data it can also be concluded that the lowest total phenolic compound contains raspberry seeds and stems. Therefore, it is recommended for producers aiming to obtain higher-value phenolic compounds in their products to separate stems from leaves or berries from seeds.



Note. Values were expressed as means with standard deviation error bars.
Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis.

Figure 5. Total phenolic compounds of different morphological parts of the raspberry at different harvest (2020 and 2021)

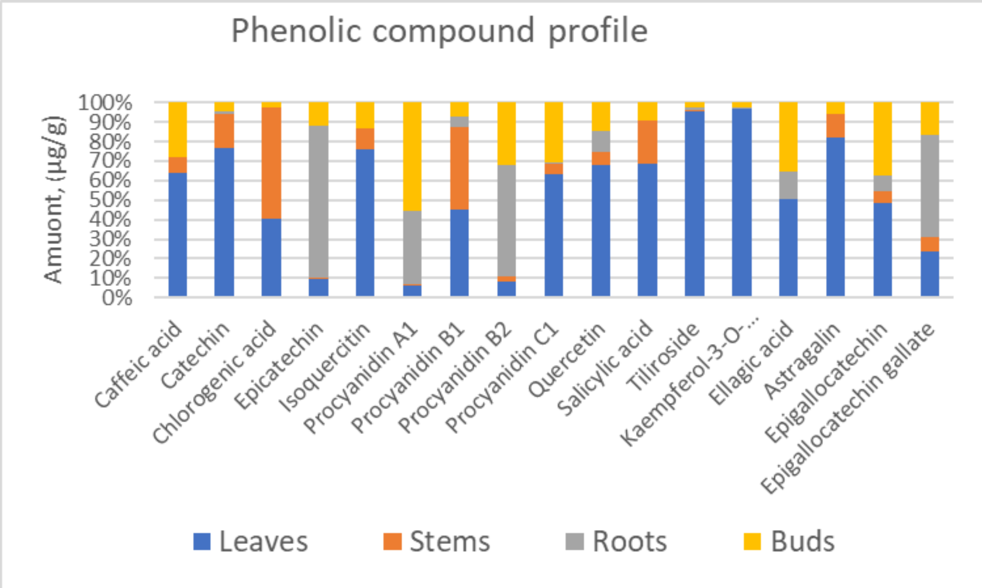
5 paveikslas*. Bendras fenolinių junginių kiekis aviečių augalo morfologinėse dalyse skirtingais metų derliais (2020 ir 2021 m.)*

The phenolic compounds in berries have been reported to have antioxidant, anticancer, anti-inflammatory, and anti-neurodegenerative biological properties [164-172]. The study also revealed that to provide consumers with products with a high total phenolic content, they need to be produced from raspberry flowers or roots. The data is shown in descending order in Figure 4 below.

The biological properties are often associated with berry fruits, and the identification of their antioxidant activity is necessary for the evaluation of raspberry consumption on human health, but it would be much more beneficial to include products made from raspberry blossoms or roots in the diet. All raspberry plant parts are an economically important berry crop that contains many phenolic compounds with potential health benefits and can be used as an easily accessible source of natural phenolic compounds and as a possible food supplement or in the pharmaceutical industry.

The total phenol content of the raspberries plant parts ranged from 6000 mg GAE/100 g DW to 1558 mg GAE/100 g DW. The inflorescence had the considerably highest total phenol content. Following roots with 4719 mg., leaves 3437 mg., fruits – 2596 mg, stems – 1796 mg, and the lowest content was found in the seeds – 1558 mg. (Article 2). The concentration of total phenol quantified in raspberry fruits was higher than found in the literature [169-171]. For example, Sariburun et al. (2010) [172] declared that in their research the total phenol content of the raspberry fruits ranged from 1040.95 ± 15.91 mg GAE/100 g fw to 2062.27 ± 4.13 mg GAE/100 g fw what is much lower than in this work 2596 mg GAE/100 g.

Producers need to differentiate the raw material in the production processes, which is why in this part raspberry plant parts are separated by classifying as follows: by-products from primary production (the main product is fresh raspberries) are leaves, stems, flowers, roots, buds, and by-products from secondary production (the main product juice) are seeds. The individual phenolic compounds of these parts are shown separately in Figures 6 and 7 below as they are released in the production process.

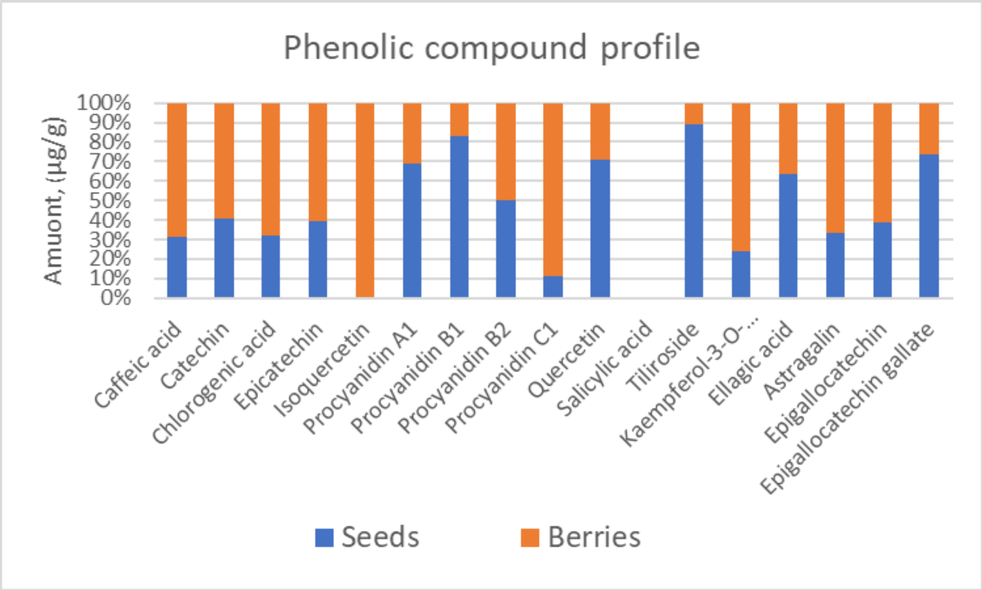


Note. Values were expressed as means with standard deviation error bars.
Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis

Figure 6. Individual phenolic compounds (µg/g; dw) in the raspberry plant morphological parts

6 paveikslas. *Atskiri fenolio junginiai (µg/g; s.m.) aviečių augalo morfologinėse dalyse*

The individual phenol content is completely different between the raspberry plant parts. These results suggest that they could be used as nutraceutical resources and functional food ingredients. These bioactive compounds found in different plant parts exert their beneficial biological effects, and hence, may promote human health through a different mechanism of action. The results are described in additional detail in the article and the obtained data are compared with other research results of scientists. See Article 2.



Note. Values were expressed as means with standard deviation error bars.
Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis.

Figure 7. Individual phenolic compounds (µg/g) in raspberries secondary production

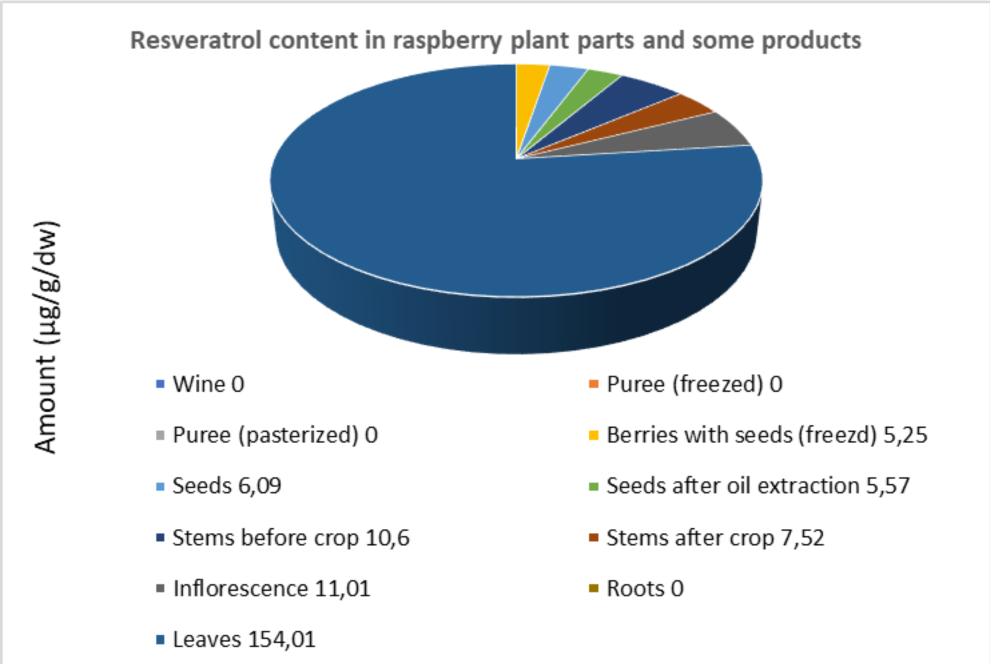
7 paveikslas. *Atskiri fenoliniai junginiai (µg/g) aviečių antrinėje gamyboje*

Resveratrol

Resveratrol is the most effective stilbene phytoalexin synthesized naturally or induced in plants as part of their defense mechanism, is a key component of natural phenolic compounds, and is being considered as a treatment option for a variety of diseases. It is a small, inexpensive, simple-to-obtain, and functionalized molecule. It has a low toxicity and a variety of biological effects that could be used commercially [173-176]. The demand for resveratrol has rapidly increased and new sources of this natural product such as berries, and particularly grapes, have become a genuine reality. Or, there isn't data on resveratrol in raspberry plant parts.

The raw material used in the fermentation process and or plant additives in various foods have good antioxidant properties and may help reduce the risk of some chronic diseases associated with aging. During fermentation, the amount of biologically active compounds in the vegetable raw material increases. When increasing processing efficiency, it is important to select enzymes and their compositions. The issue of fermentation process management is also related to the testing of innovative technological solutions to increase the activity of enzymes or microorganisms in bioprocesses.

There is not enough research on fermented drinks that are produced at the moment, to meet the needs of the user, and there is a lack of innovative solutions offered by science for business, from the organization, production methods, and evaluation of such drinks. Determining the amount of resveratrol in all parts of the raspberry plant and some products can reveal its potential for further research and product development. The results are shown in Figure 8.



Note. Values were expressed as means with standard deviation error bars.

Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis

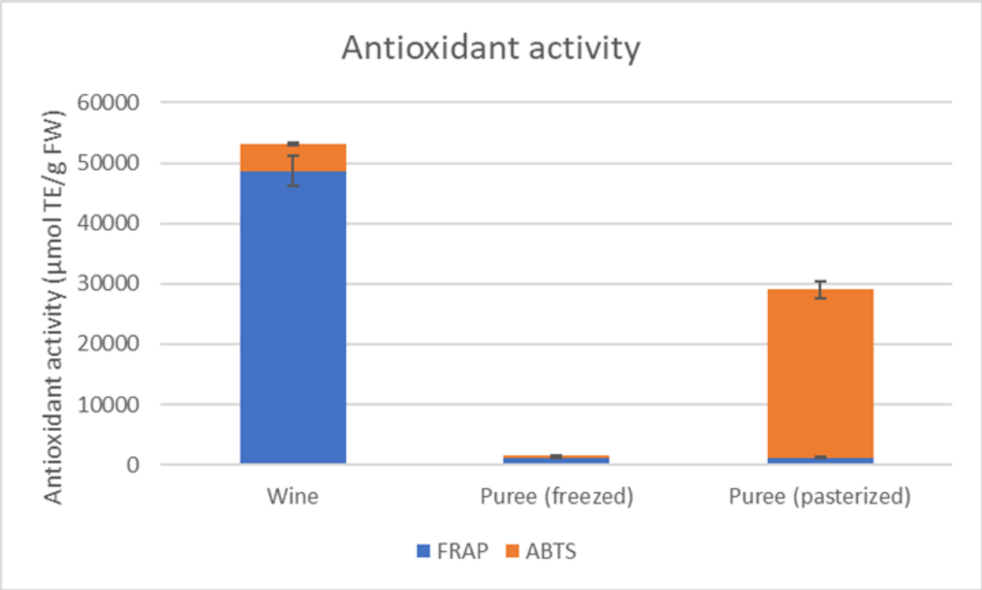
Figure 8. Resveratrol in raspberry plant morphological parts and their products (µg/g dw)

8 paveikslas*. Resveratrolis aviečių augalo morfologinėse dalyse ir jų produktuose (µg/g dw)*

The results from the data presented in Figure 8 show, that raspberry leaves contained much more trans-resveratrol than other parts. Summarizing the data obtained in the study, it can be concluded that resveratrol is a natural polyphenol that can be found most of all in raspberry leaves but not in puree or wine. Natural products from raspberry leaves can be as one of the most valuable tools in drug production and show a wide variety of biological activities for disease prevention, defense, and treatment.

3.1.2. Antioxidant activity

The antioxidant activity of raspberry morphological parts was assessed by the DPPH method and ranged from 145.1 to 653.6 µmol TE/g FW, by the ABTS method ranged from 1091.8 to 243.4 µmol TE/g FW, and by FRAP – from 720.0 to 127.0 µmol TE/g FW. Antioxidant activity is discussed in the Article No. 2. Additional data obtained to reveal the influence of processing technology on the amount of antioxidants in raspberry products, results are presented in Figure 9 below.



Note. Values were expressed as means with standard deviation error bars.
Pastaba. Vertės buvo išreikštos kaip vidurkiai su standartinio nuokrypio juostomis

Figure 9. Antioxidant activity in some raspberry's products

***9 paveikslas**. Antioksidacinis aktyvumas kai kuriuose aviečių produktuose*

In this context, raspberry by-products are promising new sources of products full of antioxidant activity. The present study suggested that products from raspberry plant parts may be considered sources of natural antioxidants and consumption of these products may supply substantial antioxidants which may provide health-promoting and disease-preventing effects. From the results presented in Figure 9, it can be concluded that fermentation, as a berry processing method, is good for healing the amount of antioxidants in the product, while they are lost during pasteurization or freezing.

In general, all raspberry plant parts have considerable amounts of micro and macro elements and phenolic compounds. The knowledge about the biochemical composition of different raspberry plant parts could be useful when selecting row materials during cultivation and processing for innovative, with high phenolic content. The study revealed the importance of differentiating plant parts in production for the quality of the final product.

3.2. Raspberry seeds oil content and physico-chemical properties (Articles 1, 3 and unpublished data)

3.2.1. Physico-chemical properties

Raspberry seed oils obtained by different extraction methods presented high or very high levels of carotenoid concentration. Detailed results are presented in Article No 3 and additional information is shown in Figure 10 below.

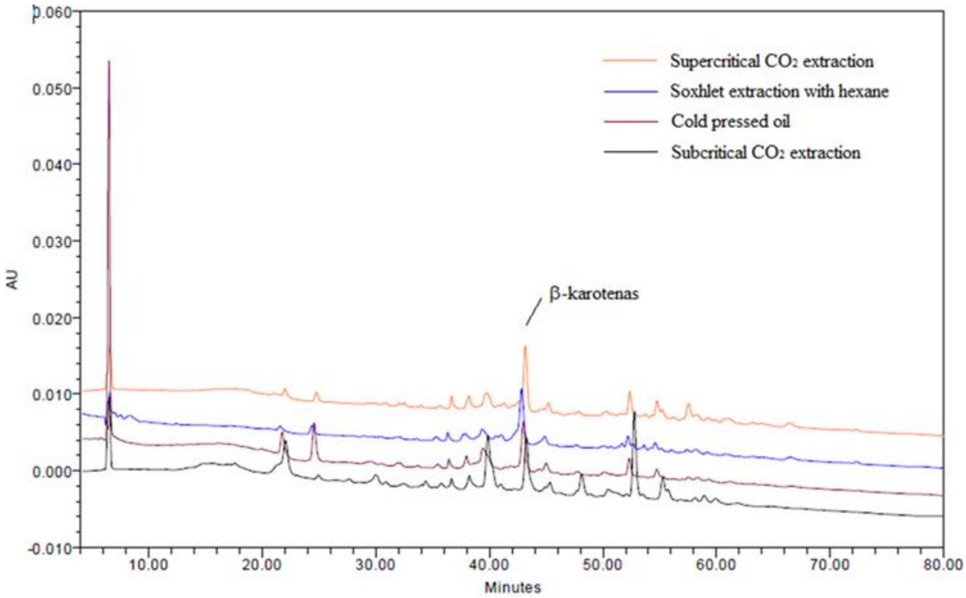


Figure 10. Chromatogram of carotenoids from raspberry oils separated with different extraction methods

***10 paveikslas**. Aviečių aliejų, išgautų skirtingais metodais, karotenoidų chromatograma*

Carotenoids are one of the most important groups of natural pigments in fruits and vegetables, well known for their ability to scavenge reactive oxygen species and for their role in photosynthesis and photoprotection [183-186]. ß-carotene has long been known to be an efficient quencher of singlet oxygen and, as such, is an effective antioxidant. The oil extracted by supercritical extraction has the highest amount of carotenoids, while oil extracted with subcritical CO_2 has the lowest, and cold-pressed and hexane have intermediate amounts. Due to this, oil extracted by supercritical CO_2 extraction has protective the best properties against free radical damage that is believed to be responsible for numerous degenerative diseases such as atherosclerosis, arthritis, and carcinogenesis.

No less important in raspberry production is the quantitative indicator - oil yield. Unfiltered oil extracted by different methods is shown in Figure 11. This is relevant for producers when calculating the planned profit and other economic indicators. As can be seen in the figure, oil filtration is necessary for oil extraction with supercritical and supercritical CO_2 methods, hexane, due to its invisible residual content. After filtering, the yields are significantly different from the original ones, before filtering.

Tocopherols are methylated phenols, a group of chemical compounds in vitamin E. α, β, γ and δ tocopherols are distinguished according to the amount of methyl groups and the place of attachment in the molecule. The most biologically active form found in nature is α-tocopherols. Antioxidants neutralize active forms of oxygen, protect proteins and unsaturated fatty acids from oxidation. Since humans and animals do not synthesize their own vitamin E, they obtain tocopherols primarily from plants, which are the only species capable of producing vitamin E. It is an important antioxidant that protects the body from the harmful effects of free radicals, suppresses the effects of many harmful substances that cause the risk of developing cancer. The vitamin is also needed to maintain the stability of cell membranes, protects the inner wall of arteries from calcification, atherosclerosis, promotes wound healing, strengthens the body's immunity, and can protect against the harmful effects of ultraviolet rays. Vitamin E prevents the appearance of or removes existing circulatory disorders, as it reduces blood clotting and prevents the formation of blood clots. Vitamin E is also called the "vitamin of youth" because it inhibits the formation of free radicals in the skin and slows down the aging process of the skin, improves the condition of the skin and nails. Scientists say that although α-tocopherol is indeed a very important, if not the most important component of vitamin E, γ-tocopherol can also make a significant contribution to human health, and although compared to α-tocopherol, γ-tocopherol is slightly a weaker antioxidant, but γ-tocopherol, in contrast to α-tocopherol, has an anti-inflammatory effect [187-191].

This study revealed that raspberry seed oil contains the most γ-tocopherol - from 16.1 mg/100 g up to 26.4 mg/100 g. The amount of α-tocopherol was found to be about eight times lower than that of γ-tocopherol, from 2.1 mg/100 g up to 3.2 mg/100 g. The amount of δ-tocopherol was found to be even lower - from 1.1 mg/100 g up to 1.8 mg/100 g. Only traces of β-tocopherol are detected. The extraction method also affects the total amount of tocopherols: the most tocopherols are extracted by CO_2 supercritical, and the least by solvents (hexane), 31.4 mg/100 g and 19.4 mg/100 g, respectively (Article 3).

The physical properties of the oil are also important for the consumer when choosing a product. The color of raspberry seed oil is shown in the Figure 11 below. Other raspberry seeds oil quality properties are described in detail in Article 1 and 3.

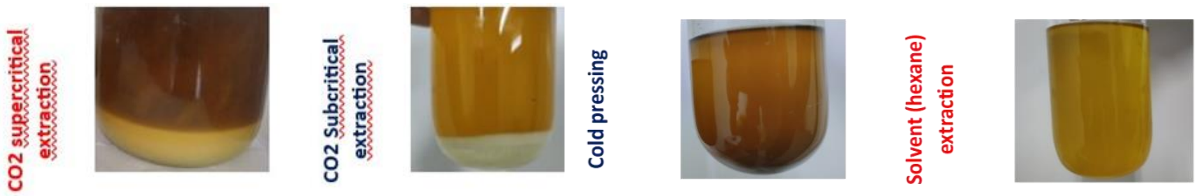


Figure 11. Raspberry seed unfiltered oil photos

***11 paveikslas**. Nefiltruotas aviečių sėklų aliejus*

Raspberry seed oil is slightly cloudy, and yellowish in color. The color perceptions of the extracted raspberry seed oils are Oil type CIE system and CIE L*a*b* system was L* (%) - 38.53 ± 0.06; a* - 5.43 ± 0.01; b* - 29.2 ± 0.01 (L* - lightness; a* - red hue; b* - yellow hue). The oil obtained by hexane extraction should look most attractive to the consumer, but it is necessary to be aware that the hexane is invisible, and its residues may remain in the oil if high production control has not been ensured. Meanwhile, from the producer's point of view, oil extracted using supercritical extraction is risky due to the high required investment in equipment, and the obtained oil contains a high percentage of other impurities, lipids, which contributes to additional costs for investment in filtration, and the processes take longer. It means that the main product oil has a very high cost and a long process that produces a large amount of waste. All this makes marketing particularly difficult, increases costs, and the percentage of consumers with high purchasing power decreases.

3.2.2. Oil production optimization

The yield of raspberry seed oil depends on varieties and extraction with different methods and other factors, like how dry the seeds are, how finely they are ground, their temperature, and the pressure during pressing. This study demonstrates the potential of different varieties of raspberry by-products and shows the influence of different oil extraction methods on the fatty acid composition of the oil and the economic potential of such products.

3.3. Sustainability in raspberry production (Article 4)

3.3.1. Economic, environmental and social sustainability

The last task of this work was to analyze sustainable development directions for efficient raspberry production (growing and processing) without waste. Detailed results are presented in Article No 4 and the additional information is provided in this section. The analysis helps small raspberry growers and processors make decisions for economic, environmental, and social performance.

Content analysis revealed the characteristics of the production made from a raspberry plant that has valorization potential, services that can be provided during the cultivation and processing of raspberries and receive additional income, create economic added value, identify factors influencing the quality of such production, the potential amount and the factors affecting it. The results from this stage present sustainability indicators for improving the qualitative and quantitative indicators of higher-value raspberry production.

For qualitative evaluation, descriptive analysis revealed sustainable activity solutions in economic, environmental, and socio areas. The results of the study show that product quality, income from additional activities, product realization through short food chains, cultivation, and processing principles, permanent jobs for farmers and their family members, training, and education for them according to the needs and working hours for seasonable employees are most sustainable areas in raspberry growing and processing. Raspberry growers and processors can use created digital models for the sustainability, efficiency, and development directions of their farms.

Descriptive analysis results are presented in Article 4 and the percentage distribution of interviewers' answers is presented below in Pictures 12, 13, and 14 of this work.

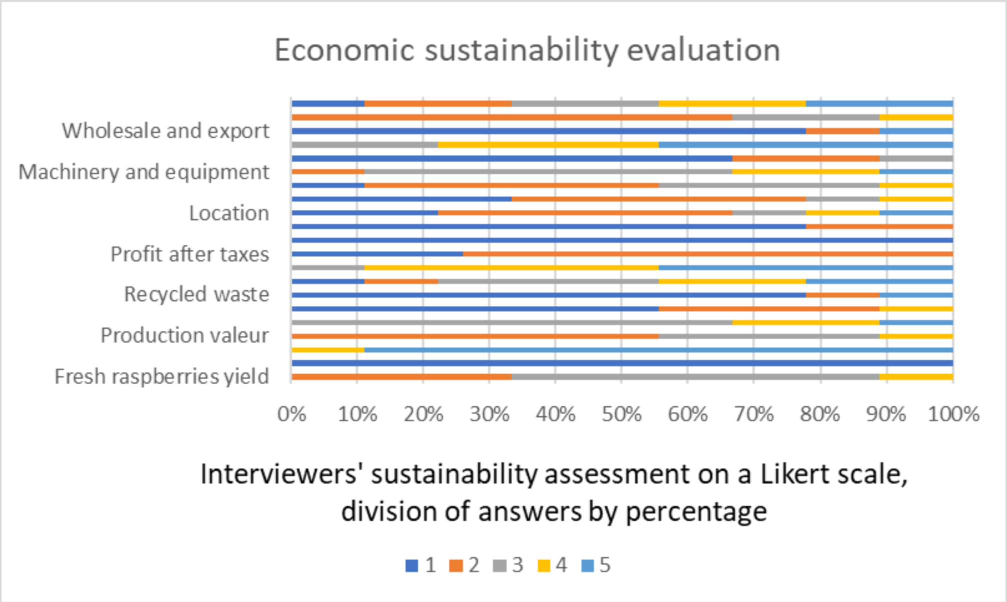


Figure 12. Economic sustainability evaluation in raspberry production in Lithuania

12 paveikslas. *Ekonominio tvarumo vertinimas aviečių produktų gamyboje Lietuvoje*

Economic sustainability evaluation by farmers shows that most of them agree about high taxes, the absence of wholesale and export, and very good production quality. Also, all farmers noted that in the primary production of raspberries (growing stage), no one collects leaves for production, all waste is thrown away, and the grown mass is used irrationally, which may lead to a drop in competitiveness. Utilizing the full potential of the plant could solve food waste problems, bio-based materials can also open new opportunities in product development by providing novel product characteristics and by using biomass for new purposes.

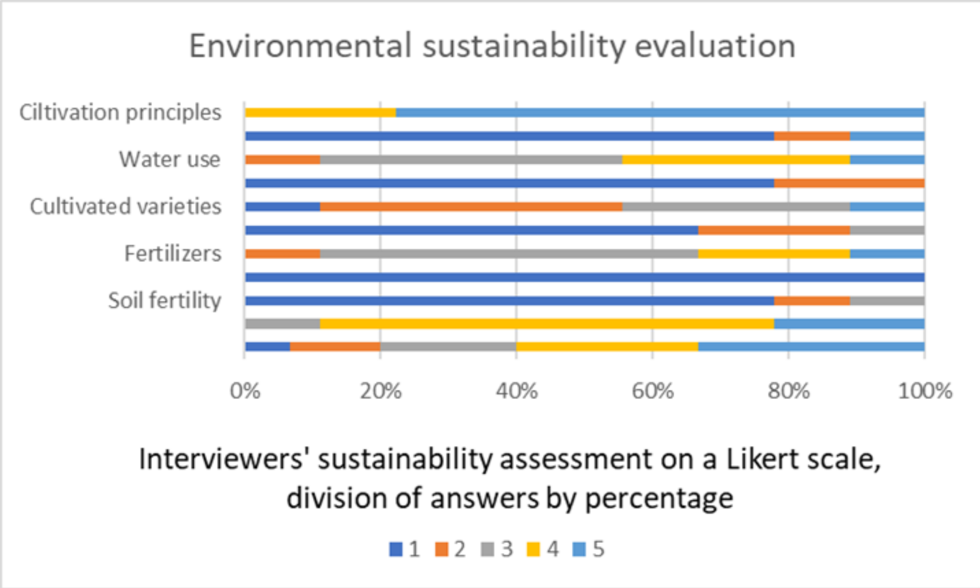


Figure 13. Environmental sustainability evaluation in raspberry farms in Lithuania

13 paveikslas. *Aplinkosauginio tvarumo vertinimas aviečių produktų gamyboje Lietuvoje*

Environmental sustainability evaluation by farmers shows that most of them agree that cultivation principles and pest and chemical management are the most sustainable sides of raspberry growing and processing. Interviewees argue that soil erosion, undetermined soil properties, and biodiversity are the least sustainable.

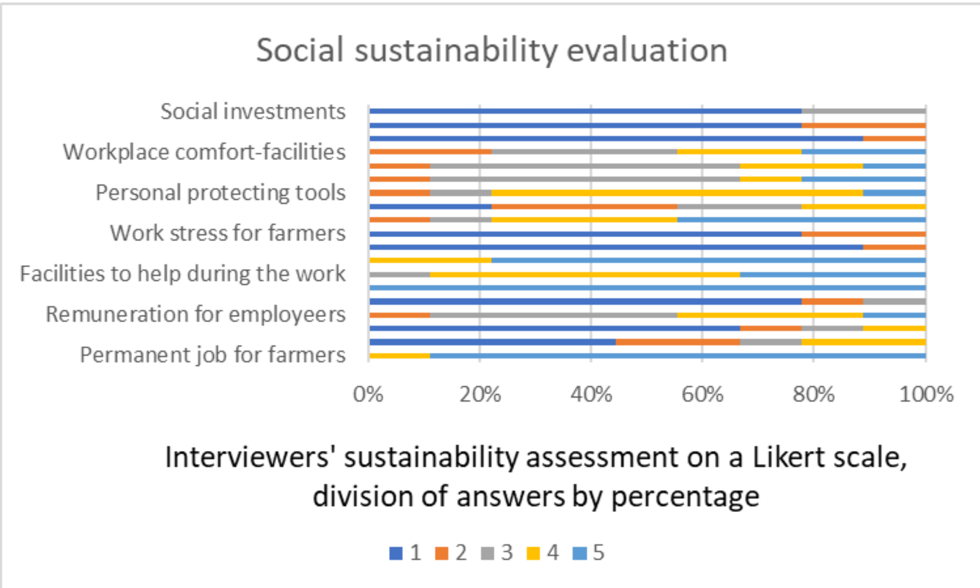


Figure 14. Social sustainability evaluation in raspberry farms in Lithuania

14 paveikslas. *Socialinio tvarumo vertinimas aviečių produktų gamyboje Lietuvoje*

From the results of such an analysis, it can be concluded that the highest percentage of farmers think that the most sustainable are permanent jobs for farmers and their family members, training and education for them and the most unsustainable are working conditions, and stress. safety concerns in raspberry growing and processing in Lithuania are important to address to ensure the well-being of workers and consumers. Raspberry farming involves physical labor and operating machinery, which can pose risks to workers' health and safety. Collaborative work environments can contribute to positive social interactions, support networks, and a sense of community well-being.

3.3.2. Sustainability evaluation for zero-waste raspberry production

The research data revealed how sustainability is evaluated by 9 farmers according to the established categories. Disclosed unsustainable categories such as production loss in the growing stage, high taxes, bad product realization, undetermined soil properties and erosion, lack of biodiversity, unlimited working hours with profit depending on severe weather conditions or political decisions, and workplace comfort are directions for sustainable activity solutions for raspberry growing and processing in Lithuanian farms. Sustainable intensification targets go beyond production, environmental, economic, or social performance.

Raspberry growing and processing in Lithuania can indeed contribute to sustainable development solutions. Lithuania has a favorable climate for raspberry cultivation. Raspberries thrive in temperate regions, and Lithuania's moderate temperatures, with warm summers and cold winters, provide suitable conditions for their growth. Raspberry growing and processing can contribute to local economic development by creating employment opportunities and supporting rural communities. By promoting value-added products, such as jams, juices, or frozen raspberries, the industry can attract both domestic and international markets, enhancing income generation and regional growth.

Establishing a robust waste management system is essential. Raspberry processing generates by-products such as stems, seeds, and leaves. These can be utilized for various purposes, such as animal feed, composting, or even extracting valuable compounds for other industries, promoting a circular economy approach.

Implementing sustainable farming practices is essential for environmentally friendly raspberry production. This includes minimizing the use of synthetic fertilizers and pesticides, promoting crop rotation, conserving water through efficient irrigation methods, and managing soil health through organic practices like composting and mulching. Raspberry cultivation can be integrated with efforts to preserve biodiversity. By adopting agroforestry systems, farmers can plant raspberry bushes alongside native trees and shrubs, creating habitats for beneficial insects, birds, and other wildlife. This approach enhances ecosystem resilience and reduces the need for chemical inputs. Efficient water management is crucial for sustainable raspberry growing. In Lithuania, implementing drip irrigation systems or rainwater harvesting techniques can help conserve water resources, reduce water usage, and prevent soil erosion. Embracing renewable energy sources for raspberry processing facilities can significantly contribute to sustainability. Installing solar panels, utilizing biomass energy, or employing other clean energy technologies can help reduce greenhouse gas emissions and decrease the carbon footprint of the processing operations.

Promoting knowledge sharing among raspberry growers and processors is crucial for sustainable development. Providing training programs, workshops, and access to resources on sustainable farming practices, efficient processing techniques, and market trends can empower individuals and communities to adopt sustainable approaches and improve the overall sector's sustainability.

By integrating these sustainable development solutions, raspberry growing and processing in Lithuania can contribute to environmental conservation, economic growth, and social well-being, fostering a more sustainable and resilient agricultural sector. It's important to note that promoting the well-being of individuals involved in raspberry growing requires fair working conditions, equitable pay, access to healthcare, and other social support systems. Creating a positive and supportive work environment is crucial for maximizing the well-being of all stakeholders in the raspberry industry in Lithuania.

By integrating cultivation and processing principles, raspberry growers and processors in Lithuania can work towards reducing emissions, mitigating climate impact, and contributing to a more sustainable and environmentally friendly raspberry industry. By investing in R&D, Lithuania can enhance its raspberry industry's competitiveness, improve productivity, and address emerging challenges.

Income from additional activities, product realization through short food chains, cultivation, and processing principles, permanent jobs for farmers and their family members, training and education for them according to their needs, and working hours for seasonable employees are the most sustainable directions in raspberry growing and processing for effective transformation. Although the results of the study do not show the situation of the entire population in the sector, it can be used for further research, and raspberry growers can use it as a digital model for the sustainability, efficiency, and development directions of their farm. Additional policy efforts are needed to manage sustainability in the berry sector.

CONCLUSIONS

1. Evaluated phytochemical compounds composition of individual parts of the raspberry plant and antioxidant activity identified biochemical composition indicated significant differences and affirmed that differentiation of plant parts in the processing is essential for the optimization of the quality of production and for creating innovations. The antioxidant activity of raspberry morphological parts assessed by DPPH, ABTS and FRAP methods showed good possibilities for the development of products with high added value and it was observed that fermented products can significantly improve antioxidant activity. The present study revealed the biochemical diversity of raspberry plant parts and identified a high content of phenolic compounds, and antioxidant activity for use to improve the quality of the final product. These results could help in making rational use of this high polyphenol extract from raspberry leaves, inflorescence, stems, and roots. Such extracts of plant materials might be a potential antioxidant supplement for food and pharmaceutical products.

2. The study revealed the influence of different processing methods on the amount of raspberry seed oil production, physical and chemical composition, and production optimization possibilities and acknowledged how raspberry varieties influence the quantity and quality of the obtained production. The analysis of raspberry seed oil showed that there are 3 predominating fatty acids in the 17 raspberry varieties. Raspberry 'Polka' seed oil contained linoleic (ω-6) (44.79%), α-linolenic (ω-3) (37.2%) and oleic (ω-9) (10.4%) fatty acids amounts and the best ratio of ω-6 and ω-3 fatty acids, i.e. 1.2:1.

The study revealed the influence of processing methods on the amounts of fatty acids, carotenoids and tocopherols in the oil. Amount of carotenoids in the oil can vary from 0.81 mg/100 g to 3.25 mg/100 g. The extraction method also affects the total amount of tocopherols. Raspberry seed oil contains the most γ-tocopherol. Only traces of β-tocopherol are detected. The oil yield can be increased by grinding the seeds into a finer fraction. Economic profit depends significantly on the chosen production method, which affects the quantity and quality of the product.

3. A sustainability measurement model was created to evaluate the production process and the results shows that all raspberry waste in the first and second processing stages can be valorized via different valorization routes to produce a wide range of natural products. The first study comparing the chemical composition of individual parts of the different morphological parts of raspberry cultivated under the same conditions is particularly significant in the development of waste-free technologies, increasing the economic value of raspberry farms. It is certain that with efficient raspberry plant parts collection, distribution, sorting, and assuming 100% waste use, raspberry plant parts could also focus on bio-refining the waste to high-end products such as; flavonoids,

carotenoids, tocopherols, fatty acids, antioxidants, micro and macronutrients being the most promising bioresources.

4. The directions of sustainable production in economic, environmental and social dimensions were revealed as well. This study is one of the first holistic sustainable waste valorization studies, and it shows that a significant amount of waste can be collected and valorized, which could be a great input in the bioeconomy of the food sector. Further, the results of the study can inform policy-making on waste management systems and establish the directions for future surveys on the competitiveness, productivity, and efficiency of horticulture. Results from descriptive analysis make assumptions to conclude sustainability in raspberry growing and processing, designing and assessing alternative scenarios of raspberry valorization, and can help farmers and processors to identify the feasibility and pathways to move towards a circular economy.

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SANTRAUKA

Pasaulis susiduria su iššūkiais dėl nuolat didėjančio gyventojų skaičiaus ir maisto poreikio, gamtos išteklių išeikvojimo, didėjančio poveikio aplinkai ir klimato kaitos. Ilgalaikėje strategijoje „Europa 2050“ [1], Europos žaliajame susitarime [2] raginama sukurti augimo modelį, galintį spręsti būsimus Europos socialinius, ekonominius ir aplinkos iššūkius. Toks augimas turi būti tvarus, pagrįstas tausiai išteklius naudojančia, ekologiškesne ir konkurencingesne ekonomika, dideliu užimtumu, socialine ir teritorine sanglauda [3].

Ne tik politinės strategijos, bet ir vartotojai visame pasaulyje tampa sąmoningesni, labiau išsilavinę, pageidauja įsigyti saugius, kokybiškus, sveikatą stiprinančius produktus [4]. Maisto, kosmetikos, farmacijos ir kitos pramonės reguliavimo agentūros ieško novatoriškų technologijų, kurios užtikrintų saugius ir stabilius produktus savo klientams [5]. Pasaulyje vykstanti intensyvi aplinkos veiksnių kaita leidžia ieškoti įvairių naujų būdų žemės ūkio verslui tobulinti, kurti aukštos pridėtinės vertės produktus tarptautiniu mastu, plėtoti produktą atrandant naujas panaudojimo galimybes, plėtoti perdirbimo be atliekų technologijas [6–9].

Pagal apsodintą plotą raudonosios avietės yra ketvirta pagal svarbą uogų kultūra pasaulyje. Remiantis 44 šalių palyginimu 2021 m., Rusija užėmė aukščiausią vietą (197 700 tonų) aviečių auginime, po jos rikiuojasi Meksika ir Serbija. Remiantis FAOSTAT (Jungtinių Valstijų maisto ir žemės ūkio organizacija), bendra aviečių produkcija 2021 m. pasiekė 886 539 tonas pasaulyje. Tai 32,4 % daugiau nei prieš 10 metų [10]. Dauguma jų naudojami perdirbimui. Šviežios ir perdirbtos avietės yra geras biologiškai vertingų medžiagų šaltinis [11–15]. Jų paklausa didėja visame pasaulyje, sėkmingai plėtojamas auginimas ir perdirbimas, vertės suvokimas nuo paprasčiausių perdirbimo produktų, tokių kaip sultys, uogienė, pereinama prie aukštos pridėtinės vertės gaminių iš atliekų, susidarančių atliekų gamybos procesuose [16,17].

Atsiradus skaitmeninėms technologijoms ir plėtojant inovatyvius įrenginius, labai sparčiai vystosi ir perdirbimo technologijos, kurios sukuria sąlygas tvariai gamybai iš auginimo ar gamybos procese gautų atliekų, aukštos pridėtinės vertės, turinčių vertingų bioaktyvių medžiagų, produktų kūrimui. Tačiau auginant ir perdirbant avietes, daugiausia dėmesio skiriama pačioms uogoms ir jų išspaudoms, nuošalyje paliekant kitas augalo dalis: lapus, stiebą, šaknis, žiedus ir kitus šalutinius produktus.

Kadangi auginant ir perdirbant uogas gaunami dideli likutinės žaliavos ir nepanaudotų šalutinių produktų kiekiai, o mokslininkai pateikia vis daugiau tyrimų rezultatų [18–23], pabrėžiančių iš natūralių šaltinių gaunamų bioaktyvių junginių naudą ir jų gebėjimą daryti teigiamą įtaką gyvybinėms žmogaus organizmo funkcijoms, visiškai suprantamas susidomėjimas natūraliais produktais iš uogų, polinkis ieškoti naujų funkcinių ingredientų, kurti vertingus produktus iš bio likutinės žaliavos. Tačiau teigiama, kad maisto ir gėrimų gamybos sektorius turi procesus valdyti tvariau. Tai pabrėžia ne tik naujausi moksliniai tyrimai [18–21], bet ir tokios programos kaip: Jungtinių Tautų aplinkos programa [22], Europos Komisijos darbo programa 2018–2020, Europos žaliasis kursas [23]. Norint įgyvendinti tikslus, būtina atlikti detalius skaičiavimus ir kokybinius tyrimus, reikia gerai planuoti aviečių auginimo aplinkosauginius, socialinius ir ekonominius rodiklius.

Ūkio subjektams, pramonei, tyrėjams trūksta biologiškai aktyvių avietėse esančių avietėse tyrimų, skirtų naujiems produktams kurti, informacijos, kaip pagerinti atliekų tvarkymą visuomenės labui, nuoseklios beatliekių perdirbimo technologijų sistemos, rekomendacijų didelės vertės produktų iš aviečių kūrimui, panaudojant visą aviečių augalo potencialą, siekiant žemės ūkio užsibrėžtų tikslų, kurių esmė – padėti užtikrinti maksimalią finansinę naudą [24–26], t. y. uždirbti maksimalų pelną su minimaliomis sąnaudomis, optimizuoti gamybos procesus: panaudoti visas atliekas ir sukurti kuo didesnę vertę turinčius produktus, kurie derėtų su vartotojų, visuomenės pageidavimais ir gerąja ūkininkavimo bei perdirbimo praktika.

Bendra intensyvi aplinkos veiksnių kaita tampa rimtais argumentais ieškant būdų optimizuoti aviečių perdirbimą, racionalų išteklių naudojimą, detalų aviečių, ne tik uogų, bet ir atskirų augalo dalių pažinimą, nustatyti teisingas beatliekes technologijas, kurios sudarytų prielaidas kurti ir pateikti rinkoje naujus tvarius produktus, kokybiškai patenkinti vartotojų poreikius, gauti daugiau ekonominės naudos ir pasiekti geresnį bendrą rezultatą. Beatliekių technologijų plėtra šiuolaikiniame kontekste leistų uogų augintojams analitiškiau mąstyti apie aviečių derlių, perdirbimą ir jo aplinką, parodytų įvairias veiklos galimybes ir perspektyvas, apsaugotų nuo išorinės aplinkos keliamų grėsmių.

Apibendrinant galima teigti, kad nepaisant vis daugėjančių uogų šalutinių produktų tyrimų, žinios apie aviečių augalo morfologinių dalių sudėtį ir biologinį aktyvumą bei tvarią jų gamybą vis dar nepatenkinamos. Aviečių fitocheminės sudėties ir biologinio aktyvumo įvertinimas yra svarbūs nustatant vietinės augalinės žaliavos kokybę ir racionaliai naudojant augalinius išteklius. Atsižvelgiant į didelę aviečių perdirbimo šalutinių produktų svarbą, sveikatos stiprinimą ir tvarumą, moksliniai tyrimai, siekiantys šios žinių spragos, yra labai svarbūs.

Tyrimo hipotezė

Tikėtina, kad aviečių (*Rubus Idaeus*) morfologinių dalių ir šalutinių produktų fitocheminių junginių sudėties ir antioksidacinio aktyvumo įvertinimas gali būti pagrindas tvarios beatliekės gamybos plėtrai ir aukštos pridėtinės vertės produktų kūrimui.

Tyrimo tikslas

Nustatyti aviečių morfologinių dalių fitocheminių junginių sudėtį ir antioksidacinį aktyvumą bei pateikti tvarios gamybos be atliekų kryptis.

Tyrimo uždaviniai

1. Įvertinti atskirų aviečių morfologinių dalių fitocheminių junginių sudėtį ir antioksidacinį aktyvumą pridėtinės vertės kūrimui.

2. Ištirti aviečių sėklų aliejaus fizikines ir chemines savybes, skirtingų perdirbimo būdų įtaką jo kiekiui, kokybei ir ekonominiam pelnui.

3. Išanalizuoti tvarias vystymosi kryptis efektyviai aviečių gamybai (auginimui ir perdirbimui) be atliekų.

Ginamieji teiginiai

1. Fitocheminių junginių kiekiai ir sudėtis bei atskirų aviečių augalo morfologinių dalių antioksidacinis aktyvumas labai skiriasi, todėl augalo dalių diferencijavimas perdirbant yra būtinas siekiant optimizuoti produkcijos kokybę ir kurti inovacijas.

2. Aviečių veislės ir gavybos metodai iš esmės lemia aliejaus kiekį ir ekonominį pelną, bet ne riebalų rūgščių profilį.

3. Tvarumo matavimas sukuria prielaidas plėtoti aviečių gamybą (auginimą ir perdirbimą) be atliekų.

Tyrimo mokslinis naujumas

Pirmą kartą nustatyta vienodomis sąlygomis auginamų skirtingų aviečių augalo morfologinių dalių biocheminė sudėtis ir maistinė vertė. Taip pat atliktas pirminės gamybos šalutinių aviečių antioksidacinių savybių palyginimas ir palyginimas. Šie rezultatai yra svarbus žingsnis kuriant aviečių gamybos duomenų bazę. Gauti tyrimų rezultatai taip pat suteikia naujų žinių ir vertingos informacijos apie skirtingų veislių aviečių sėklų aliejaus fizinę riebalų rūgščių sudėtį, aliejaus gavybos technologijų įtaką kiekybei ir kokybei. Įvertintos antrinio perdirbimo galimybės ir pagrįsti technologiniu požiūriu aviečių atliekų valorizacijos metodai bei sukurti gaminių prototipai. Kokybinis tyrimas atskleidė aviečių gamybos tvarumo veiksnius Lietuvoje Likerto skalėje nuo labai netvaraus iki labai tvaraus ekonominiu, aplinkos ir socialiniu aspektu. Pristatė tvarius veiklos sprendimus aviečių auginimui be atliekų ir sukūrė skaitmeninį tvarumo modelį, kuris gali būti naudojamas efektyvumo įvertinimui ir plėtros krypčių nustatymui.

Praktinė tyrimo reikšmė

Šis tyrimas atskleidė biocheminio ir antioksidacinio aktyvumo skirtumus tarp aviečių dalių. Apsvarstykite tai, gaminiai gali būti praturtinti norima verte gamyboje, kad atitiktų vartotojų poreikius, sukuriant didesnės vertės produktus. Šie rezultatai reikšmingi ne tik avietėms, bet ir kitiems uogų ar vaisių perdirbėjams, nes atskleidžia viso augalo potencialą. Rezultatų panaudojimas ūkiuose ar gamyboje prisidėtų prie pasaulinių strateginių planų, kurių tikslai – verslui diegti technologijas be atliekų ir dirbti žiedinės ekonomikos principais.

Gauti rezultatai taip pat gali būti naudojami siekiant išryškinti informaciją vartotojams gaminio ženklinimo etiketėje. Išanalizuoti mikro ir makro elementų kiekiai, fenolių kiekis, riebalų rūgštys, karotenoidai ir tokoferoliai, antibakterinis ir antioksidacinis aktyvumas, ekonominis pelnas ir tvarumo analizė atskleidė labai svarbias žinias ir rodo daug žadančius rezultatus, kurie gali naujai nušviesti aviečių kokybės standartų metodikas. maisto, farmacijos, kosmetikos, pakavimo pramonėje. Tyrimo pateikti duomenys sudaro galimybę tinkamai padidinti aviečių produkciją, išnaudojant visas augalo dalis pagal jo biocheminius ir bioaktyvumo junginius, sustiprinti beatliekinę aviečių gamybą ekonominiu, aplinkos ir socialiniu aspektu, siekiant darnaus vystymosi. Tyrimo rezultatai pristatyti Lietuvos uogų augintojų, perdirbėjų ir prekybininkų asociacijos nariams ir paskelbta LAMMC rekomendacija. Žinios pritaikomos vykdant investicinę veiklą, optimizuojant išteklius, tobulinant veiklą, kuriant inovatyvius produktus, teikiant informaciją vartotojams.

Tyrimo rezultatų aprobavimas

Ši daktaro disertacija parengta remiantis keturiais moksliniais straipsniais, kurie dauginami leidėjui leidus. Straipsniai publikuojami žurnaluose, indeksuotuose Clarivate Analytics Web of Science duomenų bazėje. Audronė Ispiryan yra pirmoji visų straipsnių autorė. Šio tyrimo metu gauti rezultatai buvo pristatyti 7 mokslinėse konferencijose.

Disertacijos struktūra ir apimtis

Ši daktaro disertacija parašyta anglų kalba (49 puslapiai) su santrauka lietuvių kalba (14 puslapių), įskaitant 1 lentelę ir 14 paveikslų. Ją sudaro šie skyriai: Straipsnių sąrašas, Įvadas, Literatūros apžvalga, Medžiaga ir metodai, Rezultatai, Išvados, Literatūra (191 šaltiniai), Apie autorių, Padėka, Santrauka ir Priedas su 4 straipsnių kopija.

LITERATŪROS APŽVALGA

Apibendrinant literatūros apžvalgą, galima teigti, kad nėra pakankamai duomenų apie biologiškai aktyvių junginių kiekius avietinių augalo morfologinėse dalyse. Mokslinėje literatūroje nėra pateikta išsamių duomenų apie kitų produktų iš aviečių (žiedų, stiebų, šaknų, lapų, sėklų) fitocheminę sudėtį ir antioksidacinį aktyvumą, procesų optimizavimą atliekoms valorizuoti tvariai auginimo ir perdirbimo metu.

Išsamus aviečių auginimo ir perdirbimo supratimas yra svarbus ir būtinas ieškant naujų galimybių tvarumo požiūriu. Atliktas tyrimas papildytų ir patikslintų turimas žinias apie aviečių produktų auginimo ir perdirbimo kiekius ir kokybę. Tarp daugelio veiksnių uogų atliekų poveikis buvo nustatytas kaip pagrindinė problema. Aviečių augalo morfologinių dalių naudojimas gamyboje gali padėti pagerinti šalutinių produktų įgyvendinimą tvarioje sistemoje.

Šiuo darbu buvo siekiama atsakyti, koks yra atskirų aviečių augalo dalių fitocheminis profilis, antioksidacinis aktyvumas, kokios yra aviečių sėklų aliejaus fizinės ir cheminės savybės, skirtingų perdirbimo būdų įtaka jo kiekiui, kokybei ir ekonominiam pelnui bei koks yra aviečių atliekų valorizacijos tvarumas, kurios yra geriausios kryptys beatliekės gamybos plėtrai, kaip sumažinti aviečių atliekas auginant ir gaminant, kokios jų panaudojimo galimybės. Atliekų prevencija, atliekų ekologinis projektavimas galėtų padėti uogų augintojams ir perdirbėjams būti draugiškiems aplinkai ir veiklą vykdyti tvariai.

MEDŽIAGA IR METODAI

Medžiagos ir metodai yra detaliai aprašyti 2, 3 ir 4 straipsniuose

Tyrimas atliktas 2019–2022 m. Lietuvos agrarinių ir miškų ūkio tyrimų centro Sodininkystės ir daržininkystės instituto Biochemijos ir technologijos laboratorijoje. Aviečių (*Rubus idaeus*) augalų dalys buvo surinktos Audronės Ispiryan aviečių ūkyje ir Lietuvos agrarinių ir miškų mokslų centro sodininkystės medelyno. Tyrimo variantus sudarė: neprinokusios avietės, prinokusios avietės, lapai, stiebai, šaknys, sėklos, žiedai.

Pirmajame etape tirtos remontantinės avietės (veislė '*Polka*') iš Audronės Ispiryan ūkio, esančio Šiaurės Lietuvoje (55◦47055.000 N 22◦44057.400 E 55.798603, 22.749268). Atsitiktinai atrinktos aviečių dalys buvo nuskintos 2020 ir 2021 metų rugpjūčio mėnesį fiziologinės brandos metu (BBCH sistemoje 8 fenologinė fazė (vaisių branda)) ryte ir vežamos į Lietuvos agrarinių ir miškų tyrimų centro Sodininkystės ir daržininkystės instituto laboratoriją. Aviečių augalų dalys (lapai, stiebai, šaknys, žiedai, sėklos ir vaisiai) buvo renkamos atskirai ir atsitiktine tvarka maždaug 50 m^2 plote. Visos laukuose esančios aviečių augalo dalys buvo sugrupuotos ir nedelsiant nuvežtos į Lietuvos agronomijos ir miškų ūkio instituto laboratoriją, kur buvo užšaldytos ir liofilizuotos. Aviečių sėklos buvo gautos atskiriant jas „Voran“ kauliukų šalinimo ir išspaudimo mašina. Sėklos džiovinamos maždaug 40 °C temperatūroje. Antrame etape visos dalys buvo sumaltos sukamajame plaktukiniame malūne SR 300, 200–240 V, 50/60 Hz Retch (Vokietija), naudojant 0,5 mm sietą ir laikomos stikliniuose induose iki analizės.

Medžiagos paruošimas antrajam etapui (aliejaus laboratoriniams tyrimams) buvo padalintas į dvi dalis:

Pirma dalis. 16 veislių avietės iš Lietuvos agrarinių ir mokslų miškų centro: 'Polka', 'Austrijas Remontanta', 'Bristol', 'Volnica', 'Willamette', 'Malling Seedling', 'Ariadne', 'Novokitajevskaja', 'Meeker', 'Helkala', 'Zorinka' ', 'Toma', 'Peresvet', 'Sputnica', 'Nagrada' ir 'Canby' surinkti iš Lietuvos agrarinių ir miškų ūkio tyrimų centro, Sodininkystės ir daržininkystės instituto. Nuėmus derlių, uogos nedelsiant užšaldomos ir laikomos -30 °C temperatūroje, kol prireiks. Prieš analizę uogos buvo atšildytos kambario temperatūroje. Po uogų presavimo sėklos surenkamos ir džiovinamos konvekcinėje džiovykloje (storis apie 0,5 cm) 40 °C temperatūroje 24 val., retkarčiais pamaišant. Aviečių sėklos buvo sumaltos centrifūginiame - rotoriniame malūne ZM200 (Retsch, Haan, Vokietija), naudojant 0, 2 mm dalelių dydžio sietą, tačiau procesas buvo sustabdytas 15 s kas 15–30 s, kad mėginys nekaitintų. Aliejus buvo išgautas iš aviečių sėklų ekstrahavimo tirpikliu (heksanu).

Antra dalis. Išsamesniems tyrimams pasirinkta lenkiškoji remontantinė aviečių veislė ‘Polka’ iš Audronė Ispiryan ūkio. Nustatyta superkritinio CO_2, superkritinio CO_2, šalto spaudimo ir heksano ekstrakcijų įtaka aviečių aliejaus kiekiui ir cheminei sudėčiai. Ši veislė pasirinkta kaip šiuo metu populiariausia ir viena iš pagrindinių pasaulyje auginamų kultūrinių aviečių veislių, pasižyminčių puikios kokybės desertinėmis uogomis ir gausiu derliumi. Ši veislė taip pat sulaukė didelio mokslininkų susidomėjimo. Avietės buvo surinktos Audrone Ispiryan ūkyje, nedelsiant iškaulintos naudojant kauliukų šalinimo mašiną EP500 (VORAN Maschinen GmbH, Pichl, Austrija). Sėklos natūraliai išdžiovintos maždaug 25–28 °C temperatūroje ir sumalamos sukamajame plakimo malūne SR 300 (Retsch, Vokietija) naudojant 1 mm sietą (vidutinis dalelių dydis 1 mm) ir laikomos hermetiškai uždarytuose stikliniuose induose. tamsioje, sausoje patalpoje, kol bus išgautas aliejus. Siekiant nustatyti aviečių sėklų malimo įtaką aliejaus derliui, sėklos buvo sumaltos naudojant 1 mm, 0,75 mm ir 0,5 mm sietus (vidutinis dalelių dydis 1 mm, 0,75 mm ir 0,5 mm). Aliejus buvo išgaunamas keturiais skirtingais būdais: šaltasis ekstrahavimas / spaudimas, ekstrahavimas subkritiniu CO_2 ir ekstrahavimas superkritiniu CO_2 ir tirpiklio (heksano) ekstrahavimu.

Trečiojoje tyrimo dalyje vertinant tvarumą, pasirinkti socialinių mokslų kokybiniai tyrimo metodai., t. y. turinio ir aprašomoji analizės. Šio tyrimo metu buvo analizuojami tvarumo aspektai beatliekei gamybai. Naudodamiesi turinio analize tyrinėjome mokslinę literatūrą ir dokumentus bei ieškojome krypčių, kaip nustatyti tvarumo kriterijus. Naudodami kodavimo tekstinius duomenis, kurie vėliau buvo suskirstyti į kategorijas, sudarėme ekspertų interviu anketinę apklausą. Tyrime buvo naudojamas pusiau struktūrizuotas asmeninis interviu, kurioje respondentai prašomi įvertinti aviečių auginimo ir perdirbimo tvarumą Likerto skalėje pagal savo kompetencijas ir patirtį. Kiekvienas elementas buvo įvertintas penkių balų Likerto skalėje, pagal kurią dalyvis turėjo pasirinkti rodiklio prioriteto lygį: 1 – labai netvarus, 2 – netvarus, 3 – vidutinis, 4 – tvarus, 5 – labai tvarus. Surinkus visus pašnekovų atsakymus, buvo išvestas vidurkis, kuris buvo panaudotas aprašomojoje analizėje ir pateikiamas šio tyrimo rezultatuose. Duomenys buvo apdoroti ir susisteminti pagal tris tvarumo sritis: ekonomiką, aplinką ir sociologiją darbe.

Statistinė analizė

Rezultatai statistiškai įvertinti naudojant GraphPad Prism 8 programinę įrangą (GraphPad, JAV). Visi rezultatai pateikti kaip vidurkis, standartinis nuokrypis (SN). Be to, siekiant palyginti vidurkius, buvo apskaičiuotas vienpusis ANOVA, po kurio buvo atliktas Tukey HSD testas, ir parodė reikšmingą skirtumą ($p < 0,05$). Visi laboratoriniai pakartojimai buvo atlikti mažiausiai tris kartus.

REZULTATAI

Aviečių morfologinių dalių biocheminė sudėtis ir antioksidacinis aktyvumas (2 straipsnis)

Pirmosios dalies pagrindinis tikslas – įvertinti aviečių augalo morfologinių dalių fitocheminę sudėtinę sudėtį ir antioksidacinį aktyvumą dėl pridėtinės vertės. Tyrimams pasirinkta Lietuvoje ir Lenkijoje plačiausiai auginama rudeninio derliaus aviečių veislė '*Polka*'. Nustatyta uogų (prinokusių ir neprinokusių), lapų, stiebų, lapų, žiedyno, sėklų ir šaknų bendrųjų ir atskirų fenolio junginių, askorbo rūgšties (vitamino C), titruojamosios rūgšties, sausųjų medžiagų ir mikroelementų biocheminė sudėtis. Apdorojant svarbiausius ir pirminius rodiklius buvo tiriamas invertuotasis cukrus, sacharozė, bendras cukrus, askorbo rūgštis (vitaminas C), titruojamas rūgštingumas ir sausoji medžiaga. Be to, šios produkto savybės, tokios kaip saldumas, rūgštingumas ir sultingumas, yra svarbios vartotojams.

Šiuo tyrimu taip pat buvo siekiama išanalizuoti ir palyginti aviečių augalų dalis pagal pasirinktų mikro ir makro elementų (kalcio, magnio, boro, cinko, vario, geležies, mangano) kiekį, nes atlieka daugybę funkcijų ir yra atsakingi už tinkamą ląstelių ir organų darbą, labai svarbūs mūsų sveikatai ir gerai savijautai,. Mikro elementai yra gyvybiškai svarbūs tinkamam visų mūsų kūno sistemų funkcionavimui: nuo kaulų augimo iki smegenų funkcijos. Lapuose yra daugiausia kalcio (Ca) ir jo kiekis gerokai skiriasi nuo kitų augalo dalių. Magnio yra žymiai mažiau nei kalcio aviečių augalo dalyse, tačiau paties augalo dalyse išlaikomas proporcingumas, t. y. magnio daugiausia yra lapuose, o mažiausiai – uogose ir sėklose. Aviečių auginimo šalutiniai produktai (lapai, stiebai, žiedynai ir šaknys) ir perdirbimo (sėklos) turi didelį potencialą išgaunant mikro (junginius), kurie gali būti naudojami kaip pradinė medžiaga ne tik maisto ir pašarų gamybos procesuose, bet ir gaminant vertingesnius produktus farmacijos, kosmetikos pramonėse.

Laboratorinių tyrimų rezultatai atskleidė, kad bendras fenolinių junginių kiekis svyravo nuo 1700 iki 6500 mg/100 g galo rūgšties ekvivalento (GAE) viename grame sausos masės (mg GAE/100 g DW). Didžiausia vertė nustatyta uogose, o tai 26% didesnė, nei nustatyta mažiausia sėklose. Askorbo rūgšties kiekis svyravo nuo 60 iki 140 mg/100 g sausos masės. Didžiausia vertė nustatyta ir uogose. Bendrojo fenolinių junginių koncentracija aviečių dalyse buvo didesnė, nei nustatė kiti mokslininkai. Šie skirtumai gali atsirasti dėl auginimo principų, aplinkos savybių ir dirvožemio savybių.

Šiame darbe taip pat buvo lyginami aviečių augalų dalių fenoliniai junginiai pagal metus. Bendras fenolinių junginių kiekis aviečių augalo dalyse, išskyrus šaknis, 2021 metais buvo didesnis. Galima daryti išvadą, kad aviečių fenolinių junginių kiekiui įtakos turi tais metais iškritę daugiau kritulių. Bendras fenolinių junginių kiekis buvo mažesnis 2020 m., kai buvo lietingiau, išskyrus šaknis. Saulėtas ir sausas oras derliaus nuėmimo metu padidino bendrą fenolio junginių kiekį. Iš gautų duomenų taip pat galima daryti išvadą, kad mažiausias bendras fenolinių junginių kiekis yra aviečių sėklose ir stiebuose. Todėl gamintojams, siekiantiems savo produktuose gauti didesnį kiekį fenolinių junginių, rekomenduojama atskirti stiebus nuo lapų arba uogas nuo sėklų. Tyrimas taip pat atskleidė, kad norint vartotojams pateikti produktus su dideliu bendrojo fenolių kiekiu, jie turi būti gaminami iš aviečių žiedų ar šaknų.

Biologinės savybės dažnai siejamos su uogų vaisiais, jų antioksidacinio aktyvumo nustatymas būtinas vertinant aviečių vartojimą žmogaus sveikatai, tačiau daug naudingiau būtų į racioną įtraukti produktus, pagamintus iš aviečių žiedų ar šaknų. Visos aviečių augalo dalys yra ekonomiškai svarbi uogų kultūra, kurioje yra daug fenolinių junginių, galinčių turėti naudos sveikatai ir gali būti naudojamas kaip lengvai prieinamas natūralių fenolinių junginių šaltinis ir kaip galimas maisto papildas arba farmacijos pramonėje.

Atskirų fenolių kiekis skirtingose aviečių augalų dalyse statistiškai reikšmingai skiriasi. Šie laboratorinių tyrimų rezultatai rodo, kad aviečių augalų dalys gali būti naudojamos kaip maistinis šaltinis ir funkcinis maisto ingredientas. Šie biologiškai aktyvūs junginiai, randami skirtingose augalų dalyse, daro teigiamą biologinį poveikį, todėl gali skatinti žmonių sveikatą skirtingu veikimo mechanizmu. Rezultatai išsamiau aprašomi 2 straipsnyje ir gauti duomenys lyginami su kitų mokslininkų tyrimų rezultatais.

Rezultatai taip pat atskleidė, kad aviečių lapuose buvo daug daugiau trans-resveratrolio nei kitose dalyse. Apibendrinant tyrimo metu gautus duomenis, galima daryti išvadą, kad resveratrolis yra natūralus polifenolis, kurio daugiausiai galima rasti aviečių lapuose, bet ne tyrėje ar vyne. Natūralūs produktai iš aviečių lapų gali būti vieni vertingiausių vaistų gamybos priemonių, daryti teigiamą poveikį žmogau sveikatai.

Tyrimo duomenys patvirtina būtinybę tinkamai optimizuoti aviečių perdirbimą, išnaudojant visas augalo dalis pagal biocheminius junginius, stiprinti parduodamų produktų rinkodarą kaip ženklinimą, vartotojų informavimą ir tikrosios sudėties pateikimą. produktas. Šiame kontekste aviečių šalutiniai produktai gali tapti perspektyviais inovatyviais produktais, turinčiais antioksidacinį aktyvumą. Šis tyrimas aiškiai parodė, kad produktai iš aviečių augalų dalių gali būti laikomi natūralių antioksidantų šaltiniais, o vartojant šiuos produktus galima gauti daug antioksidantų, kurie gali turėti sveikatos stiprinimo ir ligų prevencijos poveikį. Iš gautų rezultatų galima daryti išvadą, kad fermentacija, kaip uogų perdirbimo būdas, yra geriausias, kad produkte būtų didelis kiekis antioksidantų, o jų netenkama pasterizuojant ar užšaldant.

Apibendrinant galima teigti, kad visos aviečių augalų dalys turi aukštos vertės biocheminę sudėtį ir antioksidacinį aktyvumą. Žinios apie atskirų aviečių augalo morfologinių dalių biocheminę sudėtį gali būti naudingos renkantis žaliavas auginimo ir perdirbimo metu aukštos pridėtinės vertės produktų gamybai, kurie turėtų didelį askorbo rūgšties, mikro ir makro elementų, fenolių kiekius. Tyrimas atskleidė augalų dalių diferencijavimo svarbą gamyboje galutinio produkto kokybei. Pavyzdžiui, pašalinus sėklas ar atskirus lapus nuo stiebų, galima gauti visiškai kitokios cheminės sudėties produktų. Tai galima pabrėžti pateikiant informaciją galutiniam vartotojui produkto etiketėje. Tyrimai parodė, kad aviečių augalų dalys yra potencialus natūralių maisto ingredientų šaltinis, gali suteikti maistui sveikų savybių, kai naudojamos kaip priedas, kuris gali būti ekonomiškai patrauklus vartotojams.

Aviečių sėklų aliejaus fito-cheminė sudėtis (1, 3 straipsniai ir neskelbti duomenys)

Pirmas etapas. Iš viso 16 aviečių veislių (‘Polka’, ‘Zorinka’, ‘Willamette’, ‘Volnica’, ‘Nagrada’, ‘Austrijos remontanta’, ‘Toma’, ‘Helkal’, ‘Novokitajevskaja’, ‘Sputnica’, ‘Canby’, ‘Bristol’, ‘Ariadne’, ‘Malling Seedling’, ‘Peresvet’ ir ‘Meeker’) sėklos buvo tiriamos siekiant nustatyti riebalų rūgštis aliejuje. Aviečių sėklų aliejuje yra 26 riebalų rūgštys, iš kurių svarbiausios yra linolo (C18:2) ir α-linoleno (C18:3) rūgštys. Linolo rūgšties (ω-6) kiekis skirtingų veislių aviečių aliejuje svyravo nuo 57,7 (‘Willamette’) iki 44,8 % (‘Polka’), o α-linoleno rūgšties kiekis (ω-3) svyravo nuo 25,2 ('Helkal') iki 37,2 % ('Polka'). Trečias pagal kiekį aviečių sėklų aliejuje yra oleino rūgšties (C18:1), o įvairių veislių sėklų aliejuje jos kiekis svyravo nuo 7,8 ('Bristol') iki 16,9 % ('Helkal').

Aviečių sėklų aliejui skirtingi ekstrahavimo būdai turėjo didelę arba labai didelę įtaką karotinoidų koncentracijai. Geriausias karotinoidų koncentracijos kiekis gautas iš superkritinės CO_2 ekstrakcijos, o mažiausia koncentracija nustatyta aliejuje, gautame subkritiniu CO_2 metodu. Mažiausias β-karotino kiekis taip pat randamas aliejuje, ekstrahuotame subkritiniu CO_2 (0,35 mg/100 g), tačiau β-karotino procentas tokiu būdu išgautame aliejuje yra didžiausias ir siekia 43,21 % .

Karotinoidai yra viena iš svarbiausių natūralių vaisių ir daržovių pigmentų grupių, gerai žinomų dėl savo gebėjimo pašalinti reaktyviąsias deguonies rūšis ir vaidmens fotosintezėje bei fotoapsaugoje [183,184]. ß-karotenas jau seniai žinomas kaip veiksmingas vienetinio deguonies gesiklis, todėl yra veiksmingas antioksidantas. Daugiausia karotinoidų turi superkritinės ekstrakcijos būdu išgautas aliejus, mažiausiai – subkritiniu CO_2, o tarpiniai – šalto spaudimo ir heksano. Dėl šios priežasties aliejus, išgautas superkritinės CO_2 ekstrakcijos būdu, geriausiai apsaugo nuo laisvųjų radikalų žalos, kuri, kaip manoma, yra atsakinga už daugybę degeneracinių ligų, tokių kaip aterosklerozė, artritas ir kancerogenezė.

Tokoferoliai yra metilinti fenoliai, vitamino E cheminių junginių grupė. Pagal metilo grupių kiekį ir prisijungimo vietą molekulėje skiriami α, β, γ ir δ tokoferoliai. Gamtoje randama ir biologiškai aktyviausia forma yra α-tokoferoliai. Antioksidantai, neutralizuoja aktyviąsias deguonies formas, apsaugo baltymus ir nesočiąsias riebalų rūgštis nuo oksidacijos. Kadangi žmonės ir gyvūnai nesintetina savo vitamino E, jie tokoferolius pirmiausia gauna iš augalų, kurie yra vienintelės rūšys, galinčios gaminti vitaminą E. Tai svarbus antioksidantas, kuris saugo organizmą nuo laisvųjų radikalų žalingo poveikio, slopina daugelio kenksmingų medžiagų, sukeliančių riziką susirgti vėžiu, poveikį. Taip pat vitaminas reikalingas ląstelių membranų stabilumui palaikyti, saugo arterijų vidinę sienelę nuo kalkėjimo, aterosklerozės, skatina gyti žaizdas, stiprina organizmo imunitetą, gali apsaugoti nuo kenksmingo ultravioletinių spindulių poveikio. Vitaminas E neleidžia atsirasti arba šalina jau atsiradusius kraujotakos pažeidimus, nes sumažina kraujo krešėjimą ir neleidžia susidaryti trombams. Dar vitaminas E vadinamas „jaunystės vitaminu“, nes stabdo laisvųjų radikalų susidarymą odoje ir lėtina odos senėjimo procesą, pagerina odos ir nagų būklę. Mokslininkai teigia,, kad nors α-tokoferolis tikrai yra labai svarbus, jei ne pats svarbiausias vitamino E komponentas, tačiau γ-tokoferolis taip pat gali reikšmingai prisidėti prie žmonių sveikatos ir, nors ir palyginti su α-tokoferoliu, γ-tokoferolis yra šiek tiek silpnesnis antioksidantas, tačiau γ-tokoferolis priešingai nei α-tokoferolis, turi priešuždegiminį poveikį [187–191].

Aviečių sėklų aliejuje yra daugiausia γ-tokoferolio – nuo 16,1 mg/100 g (ekstrahavimas tirpikliu) iki 26,4 mg/100 g (superkritinė CO_2 ekstrakcija). Nustatyta, kad α-tokoferolio kiekis yra maždaug aštuonis kartus mažesnis nei γ-tokoferolio – nuo 2,1 mg/100 g (ekstrahavimas tirpikliu) iki 3,2 mg/100 g (superkritinė CO_2 ekstrakcija). Nustatyta, kad δ-tokoferolio kiekis yra dar mažesnis – nuo 1,1 mg/100 g (ekstrahavimas tirpikliu) iki 1,8 mg/100 g (superkritinė CO_2 ekstrakcija). Aptinkami tik β-tokoferolio pėdsakai. Ekstrahavimo būdas turi įtakos ir bendram tokoferolių kiekiui: daugiausiai tokoferolių išgaunama CO_2 superkritiniu būdu, o mažiausiai – tirpikliais (heksanu), atitinkamai 31,4 mg/100 g ir 19,4 mg/100 g.

Aviečių gamyboje ne mažiau svarbus kiekybinis rodiklis – aliejaus išeiga. Tai aktualu gamintojams, skaičiuojant planuojamą pelną ir kitus ekonominius rodiklius. Aliejaus filtravimas yra būtinas jo gavybai superkritiniais ir superkritiniais CO_2 metodais, heksanu, dėl jo nematomo likučio kiekio. Po filtravimo išeiga reikšmingai skiriasi nuo pradinių, prieš filtravimą. Aviečių sėklų aliejaus derlius priklauso nuo veislių ir ekstrahavimo įvairiais būdais bei kitų faktorių, tokių kaip sėklų sausumas, smulkumas, temperatūra, slėgis spaudžiant. Šis tyrimas parodo skirtingų aviečių šalutinių produktų veislių potencialą bei skirtingų aliejaus gavybos metodų įtaką aliejaus riebalų rūgščių sudėčiai ir tokių produktų ekonominiam potencialui.

Aviečių gamybos tvarumas (4 straipsnis)

Šios darbo dalies tikslas – Išanalizuoti aviečių atliekų valorizacijos tvarumą ir pateikti kryptis beatliekei gamybai. Atliktos analizės rezultatai gali padėti smulkiems aviečių augintojams ir perdirbėjams analizuoti ekonominius, aplinkosaugos ir socialinius rodiklius. Tyrimo duomenys atskleidė, kaip tvarumą pagal nustatytas kategorijas vertina aviečių augintojai ir perdirbėjai.

Įvertinus ekonominę tvarumo sritį nustatyta, kad produkcijos potencialo išnaudojimas auginimo stadijoje, dideli mokesčiai, blogas produktų realizavimas yra ypatingai netvarūs. Aviečių augintojai turėtų gerinti pagamintų žaliavų (pvz., lapų) surinkimą ir pardavimą, taip prisidėdami prie beatliekių technologijų ir mažindami maisto švaistymą. Be to, realizacijos stoka taip pat turi įtakos konkurencingumui tarptautiniu mastu; todėl būtina atlikti mokslinius tyrimus ir įstatymų bei dokumentų analizę, kuri atskleistų, kokios valstybės masto priemonės pagerintų padėtį šiame sektoriuje. Labai svarbu sukurti tvarią šalutinių produktų tvarkymo sistemą, kurie susidaro auginimo ir perdirbimo metu, kaip stiebai, sėklos ir lapai, kurie gali būti naudojami įvairiems tikslams, pavyzdžiui, pašarams, kompostavimui ar net vertingų cheminių junginių gavybai kitoms pramonės šakoms, skatinant žiedinę ekonomiką. Aplinkos apsaugos srityje reikėtų gerinti dirvožemio tyrimų atlikimo sistemingumą. Mokymai, kaip apskaičiuoti trąšų kiekį pagal dirvožemio tyrimų rezultatus, padėtų ūkininkams sutaupyti, pagerėtų dirvožemio struktūra. Socialinio tvarumo srityje reikėtų tobulinti rizikos valdymo veiksnius, tokius kaip verslo draudimas, kad ūkininkai patirtų mažiau streso dėl auginamos produkcijos kiekio ar kokybės.

Tyrimas atskleidė tvarias veiklos kryptis ir rodo, kad aviečių augintojai ir perdirbėjai turi gerą potencialą kurti ir realizuoti aukštos kokybės produktus, atitinkančius šių dienų vartotojų reikalavimus (natūralumas, ekologiškumas ir kt.). Auginimo ir perdirbimo principai atitinka aukštus standartus ir yra draugiški aplinkai. Geros darbuotojų darbo sąlygos rodo, kad ūkininkai stengiasi pritraukti darbo jėgą, tačiau neišnaudoja visų turimų priemonių veiklos tęstinumui šioje srityje, pavyzdžiui, parama bendruomenėms, įsitraukimui į vietos tradicijas, jas remiančius renginius. Kokybinio tyrimo rezultatai rodo, kad produkcijos kokybė, pajamos iš papildomos veiklos, produkto realizavimas per trumpas maisto grandines, auginimo ir perdirbimo principai, nuolatinės darbo vietos ūkininkams ir jų šeimos nariams, jų mokymas ir švietimas pagal poreikius, o sezoninių darbuotojų darbo valandos yra tvariausios aviečių auginimo ir perdirbimo kryptys, siekiant veiksmingos transformacijos. Taip pat atkreiptinas dėmesys, kad norint valdyti tvarumą uogų sektoriuje, reikalingos ir papildomos politinės pastangos. Nors tyrimo rezultatai neatspindi visų sektoriaus gyventojų padėties, jie gali būti panaudoti tolesniems tyrimams, o aviečių augintojai gali panaudoti kaip skaitmeninį modelį savo tvarumui, efektyvumui ir plėtros krypčių nustatymui auginime ir perdirbime.

IŠVADOS

1. Įvertinta atskirų aviečių augalų dalių fitocheminių junginių sudėtis ir nustatytas antioksidacinis aktyvumas. Reikšmingi biocheminių sudėties skirtumai ir patvirtinta, kad augalų dalių diferencijavimas perdirbant yra būtinas produkcijos kokybės optimizavimui ir inovacijų kūrimui. DPPH, ABTS ir FRAP metodais įvertintas aviečių morfologinių dalių antioksidacinis aktyvumas parodė geras galimybes kurti aukštos pridėtinės vertės produktus ir pastebėta, kad fermentacija gali ženkliai pagerinti produkcijos antioksidacinį aktyvumą. Šis tyrimas atskleidė aviečių augalų dalių biocheminę įvairovę ir nustatė didelį fenolinių junginių kiekį bei antioksidacinį aktyvumą, skirtą galutinio produkto kokybės tobulinimui. Šie rezultatai gali padėti racionaliai panaudoti šį didelius polifenolinių junginių kiekius turinčius ekstraktus iš aviečių lapų, žiedynų, sėklų, stiebų ir šaknų. Tokie augalinių medžiagų ekstraktai gali būti potencialus maisto ir farmacijos produktų antioksidantų šaltinis.

2. Tyrimas atskleidė skirtingų perdirbimo būdų įtaką aviečių sėklų aliejaus gamybos kiekiui, fizinei ir cheminei sudėčiai bei produkcijos optimizavimo galimybėms bei pripažino, kaip aviečių veislės įtakoja gaunamos produkcijos kiekį ir kokybę. Aviečių sėklų aliejaus analizė parodė, kad

17 aviečių veislių vyrauja 3 riebalų rūgštys. Aviečių ‘Polka’ sėklų aliejuje buvo linolo (ω-6) (44,79 %), α-linoleno (ω-3) (37,2%) ir oleino (ω-9) (10,4 %) riebalų rūgščių kiekiai ir geriausias riebalų rūgščių ω -6 ir ω-3 santykis, t. y. 1,2:1. Tyrimas atskleidė perdirbimo metodų įtaką riebalų rūgščių, karotinoidų ir tokoferolių kiekiui aliejuje. Karotinoidų kiekis aliejuje gali svyruoti nuo 0,81 mg/100 g. iki 3,25 mg/100 g. Ekstrahavimo būdas taip pat turi įtakos bendram tokoferolių kiekiui. Aviečių sėklų aliejuje yra daugiausia γ-tokoferolio. Aptinkami tik β-tokoferolio pėdsakai. Didesnė aliejaus išeiga gaunama sumalant sėklas į smulkesnę frakciją. Ekonominis pelnas labai priklauso nuo pasirinkto gamybos būdo, kuris įtakoja ir gaminio kiekį bei kokybę.

3. Gamybos procesui įvertinti buvo sukurtas tvarumo matavimo modelis, kurio rezultatai rodo, kad visos aviečių atliekos pirmajame ir antrame perdirbimo etapuose gali būti perdirbamos jas valorizuojant skirtingais būdais tam, kad būtų galima pagaminti platų asortimentą natūralių produktų. Pirmojo mokslinio tyrimo, kurio metu nagrinėtos visos aviečių, morfologinės dalys, augusių vienodomis sąlygomis, rezultatai atskleidė, kad cheminė sudėtis yra ypač reikšminga kuriant beatliekes technologijas, gali reikšmingai didinanti aviečių ūkių ekonominę vertę. Įrodyta, kad naudojant efektyvų aviečių augalų dalių surinkimą, paskirstymą, rūšiavimą ir darant prielaidą, kad atliekos bus naudojamos 100 %, aviečių augalų dalys gali būti panaudotos kuriant ir vystant aukštos pridėtinės vertės produktus, kurie būtų flavonoidų, karotenoidų, tokoferolių, riebalų rūgščių, antioksidantų, mikro ir makroelementų perspektyviausi šaltiniai.

4. Taip pat atskleistos tvarios gamybos kryptys ekonominiu, aplinkosauginiu ir socialiniu aspektu. Šis tyrimas yra vienas iš pirmųjų holistinių tvaraus atliekų įvertinimo tyrimų ir parodo, kad galima surinkti ir įvertinti nemažą kiekį atliekų, o tai galėtų būti puikus indėlis į maisto sektoriaus bioekonomiką. Be to, tyrimo rezultatai gali padėti formuoti atliekų tvarkymo sistemų politiką ir numatyti būsimų sodininkystės konkurencingumo, produktyvumo ir efektyvumo tyrimų kryptis. Aprašomosios analizės rezultatai sudaro prielaidas, leidžiančias daryti išvadas apie aviečių auginimo ir perdirbimo tvarumą, kuriant ir vertinant alternatyvius aviečių vertės didinimo scenarijus, ir gali padėti ūkininkams ir perdirbėjams nustatyti galimybes ir būdus pereiti prie žiedinės ekonomikos.

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Audronė Ispiryan gimė 1978 m. spalio 17 d., Naujojoje Akmenėje, Lietuvoje. 1996 m. baigė Naujosios Akmenės „antrąją“ gimnaziją ir 1999 m. Lozanos universitete (Šveicarija) pradėjo prancūzų kalbos ir edukologijos bakalauro studijas. Nuo 2005 m. ji tęsė studijas Dižono universitete (Prancūzija), o 2008 m. įgijo prancūzų kalbos kaip užsienio kalbos bakalauro laipsnį. 2011–2015 metais studijavo Aleksandro Stulginskio universitete (nuo 2019 m. Vytauto Didžiojo universiteto Žemės ūkio akademija) ir įgijo vadybos ir verslo administravimo bakalauro laipsnį. Studijas tęsė Šiaulių universitete ir įgijo švietimo vadybos magistro laipsnį. 2019-2023 m. studijavo Lietuvos agrarinių ir miškų ūkio tyrimų centre (LMC) doktorantūroje, buvo mokslinių projektų vykdytoja Sodininkystės ir daržininkystės institute, LAMMC Biochemijos ir technologijos laboratorijoje.

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ARTICLE 1

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Review

Red Raspberry (*Rubus idaeus* L.) Seed Oil: A Review

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Abstract: Raspberry (*Rubus idaeus* L.) seed oil (RSO) is considered as a source of high value bioactive compounds as fatty acids, tocopherols, tocotrienols, carotenoids, flavonoids, phytosterols, antioxidants, monoterpenes and many other chemical constituents. These compounds are appreciated as a source of nutrition for humans, as additives in cosmetic production, has immense therapeutic potential. Raspberry seed oil exerts many pharmacological effects included antimicrobial, antioxidant, anti-inflammatory activity and many other effects. The various databases like PubMed and Science Direct were used to identify, analyze and summarize the research literature on raspberries. This review will highlight recent developments of the chemical constituents and nutraceutical and cosmetical effects of RSO. Practical application: analyzed recent researches and international patents containing raspberry seed oil can help practitioners of various industries create new high-value products.

Keywords: bioactive compounds; red raspberry; nutritional value; seed oil

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1. Introduction

Recently has been observed a considerable openness and greater attention of researchers concerning the characterization of essential oils and secondary metabolites on known and lesser known plants which have highlighted how natural resources on this particular issue can still provide new scientific data scientific data which can be useful for human health [1,2]. Berries are a valuable source of a wide range of secondary metabolites, which can be used in pharmaceutical, agronomic and food industries [3–6].

In 2019, world production of raspberries was 822.49 K metric tons (mt), with Russia as the leading producer, supplying 22.0% of the world total. Other major producers were Mexico (16.3%), Serbia (15.2%), United States (13%) and Poland (9.6%) [7]. Most of raspberries are used for processing juices, jams, wine, etc. [4]. During the processing a large amount of berry by-products (pomace, seeds, etc.) are produced. Raspberry seeds are considered as by-product or waste [8]. Oil from raspberries seeds is receiving increasing attention among scientists, farmers, processors and consumers. This kind of berry oils often have a unique fatty acid profiles and has interesting other minor bioactive components that are in demand on the market [9].

Furthermore, raspberry seed oil (RSO) production provides the use of a renewable resource, adding value to agricultural products and improving the environment. Raspberry seeds contain up to 12.2% protein and has 11–23% oil. These oils have unique characteristics that makes interest to the cosmetics and medical industries [10]. The fruit and berry oils are characterized by gentle processing (no refining, cold pressing, etc.), unique aroma and health-promoting attributes, low production yield and high price [11].

Food industry is interested in creating more added value products through the applications of by-products [12]. Berry seed oils are often considered to be specialty oils with unique bioactive components [13]. These kinds of oils also have the most valuable plant fats [14]. Due to the various bioactive compounds, they can be included in functional foods [15], are appreciated as a diet component and preventing the development of various diseases [16].

The main aim of the work was to analyze the quantitative and qualitative characteristics of raspberry seeds oil. This review also proposes an overview of the possible RSO processing technologies and quality factors, pros and cons, significance of RSO for human health, nutrition and cosmetical value. Starting from this, an analysis of the most recent international patents related to RSO was carried out, in order to provide farmers, company managers, customers and other stakeholders an insight into the most suitable solution for the economic and environmental sustainability of the raspberry seeds oil in management chain.

2. Raspberry Seeds Oil Processing Technologies and Quality Factors

The quality of fruit seed oil highly depends on fruit genotype, growing region and conditions, seed pretreatment, drying parameters and oil extraction techniques. These factors significantly affect the extracted oil yield, it's bioactive compounds, antioxidant activity and oxidative stability [17].

The bioactive compounds of by-products can be extracted with Soxhlet extraction, hydro-distillation, maceration, cold-pressing and supercritical fluid extraction (SFE). SFE utilizes solvents (such as carbon dioxide) in its supercritical state, in which the solvent acts simultaneously as a liquid and as a gas, resulting in a more efficient extraction process [18].

Cold-pressing and SFE are the green methods for the extraction of valuable compounds from berry seeds, it does not use hazardous organic solvents. The only drawback of these green methods is that higher extraction yields are obtained with solvent extraction than SFE [19]. The advantages of working with SFE and cold-pressing are reduced solvent use, lower energy consumption, shorter extraction time and better quality [20]. There is still a need to utilize more novel and green techniques to the waste materials to achieve higher biologically active compounds retrieval rates.

3. Physico-Chemical Characterization

Raspberry seed oil is slightly cloudy, yellowish in color. This yellowish tinge to the oils is given by carotenoids. A yellowish tint is desirable because it gives the oil the characteristic butter-like appearance specifically to the oil without the addition of conventional dyes that are often used in the food industry [21].

Oil yield from the seeds is 10–23% [6,16]. Raspberry seed oil has a high content of *n*-6 and *n*-3 essential fatty acids and is an important qualitative characteristic of an oil. The acidic value of raspberry seed oil is ranging from 17.18 to 18.74 mg KOH g^{-1}. The increasing acidity can be due to longer storage time of the berries [21].

The most unsaturated fatty acids in RSE are linoleic acid, a-linolenic acid and oleic acid. RSE if a good nutrient due to high content (78.9–85.5%) of polyunsaturated fatty acids and phytosterols (5384.1 μg g^{-1}) [6,16].

Fatty acids are vital components of human diet and are required by cells of the body in the form of phospholipids for structural membrane integrity [22]. The content of polyunsaturated fatty acids in red raspberry seed oil was reported as of 85%, of which (as percentage of total fatty acids) had 54% of linoleic acid and 32% of α-linolenic acid.

In RSO there are also polyphenol compounds (2.65 mg 100 g^{-1}), phytosterols (5.38 mg g^{-1}), including campesterol, stigmasterol, sitosterol, avenasterol, cytrostadienol; and carotenoids, including zeaxanthin, β-carotene, lutein and cryptoxanthin [23]. RSO also contains large amounts of vitamin E (301.9 mg 100 g^{-1}); tocopherols (295.19 mg 100 g^{-1}), including α-tocopherol (71 mg 100 g^{-1}), γ-tocopherol (272 mg 100g^{-1}), Δ-tocopherol (17.4 mg 100 g^{-1}); and tocotrienols (6.73 mg 100 g^{-1}) [23,24].

Antioxidants are another very important dietary components, including vitamin E, phenolic compounds and tocopherols, which protects the body from free radical damage among other functions. These components are prevalent at significant levels in raspberry seed oils [25,26].

Summarizing the research literature, RSO is a unique source of bioactive phytochemicals containing high levels of antioxidant components. Oil yield from the raspberry seed is not high (from 10 to 20%). RSO well-known for its components: fatty acids, vitamin E so appreciated in cosmetics and pharmaceuticals industries. RSO is also known for its high antioxidant capacity and exhibits anti-inflammatory, anti-mutagenic and antimicrobial properties [27]. RSO is also used in cosmetics as an efficient moisturizer and emollient which helps to reduce the oxidative stress in skin, is used in cosmetic emulsions for UV protection [6].

4. Significance of RSO for Human Health

4.1. Nutritional Value

Safe and natural medicinal foods are gaining significance in mainstream healthcare [28–30]. An increasing number of studies in recent years have shown the health benefits of using raspberry seed oil as a dietary supplement in the global scientific literature. The main ingredients of RSO are essential fatty acids (C18:2 *n*-6, linoleic and C18:3, *n*-3, α-linolenic acid) with a 1.8-fold prevalence of linoleic acid [26,31,32]. The human organism cannot synthesize them, but they are required for a good health [33]. The ratio of omega-6 to omega-3 fatty acids in the RSO is very favorable for nutrition (approximately 1.4:1).

According to the European Scientific Committee on Food (ESCF), 2% of the total daily energy intake should be derived from omega-6 and 0.5% from omega-3 polyunsaturated fatty acids [34], which corresponds to a daily intake of approx. 6 g per day for woman (5 g of omega-6 and 1 g of omega-3) and 8 g per day for men (6.4 g of omega-6 and 1.6 g of omega-3) [35]. A diet rich in fatty acids and low in dietary fiber increases the risk of obesity, type 2 diabetes, cardiovascular and many other diseases [36]. Meanwhile the World Health Organization (WHO) recommends a 2.5–9% of omega-6 intake and 0.5–2% of omega-3 fatty acid intake of daily energy. These differences between ESCF and WHO recommendations occurs due to different nutritional goals, where ESCF recommendation is based on the amounts necessary to correct a clinically overt deficiency, WHO recommendation is based on considerations of cardiovascular health and neurodevelopment [37]. Due to the presence of fatty acids in raspberry seed oil, it can be used as a dietary supplement and has a positive effect against many diseases [38].

The RSO is also rich in tocopherols—3.3–3.5 mg g^{-1} (compounds with vitamin E activity). A health claim has also been confirmed for this vitamin: "Vitamin E helps protect cells from oxidative damage". The recommended daily allowance for vitamin E is from 4 mg for children to 15 mg for adults. This means that 3–5 g of oil per day fully supplies the human body with vitamin E, which helps to protect cells from the damage caused by free radicals, boosts immune system, helps to keep blood from clotting with blood vessels, might help to prevent Alzheimer's disease, maintain brain health and carry out many other important functions [39–41].

4.2. Cosmetical Value

RSO is gaining increasing attention by cosmetics industry. It is used as an ingredient in body and face moisturizers because of its high concentrations of Vitamins A and E. These vitamins are essential for the maintenance and repair of skin cells. The oil works by creating a lipid barrier that stops skin from losing natural moisture. Retaining moisture helps to keep skin cells looking young and full. Raspberry oil can be used as a base for makeup applications. It adds adding hydration, sun protection and nourishing vitamins.

The primary factors that contribute to premature aging of the skin include UV from the sun, illness, smoking and drinking. Raspberry seed oil is packed with carotenoids—a plant derived source of Vitamins A and E. These compounds are widely used in many anti-aging skin care products to help promote youthful skin [25,42]. Vitamin A is a popular antioxidant and ingredient in anti-aging skincare products because it adds moisture, reduces the appearance of wrinkles and smooths skin texture. Vitamin E is another highly praised antioxidant in the anti-aging industry. It helps to protect cells from oxidative damage and assists with maintaining collagen structure [43].

Research has demonstrated that people with higher levels of antioxidants have fewer and less pronounced wrinkles than those with low levels. This oil is of particular interest to medical experts (and us natural product enthusiasts) because it naturally contains sun protective compounds in addition to its beneficial antioxidants [42].

Raspberry seed oil is a very lightweight gentle moisturizing solution. Unlike other emollients, it does not clog pores and encourages natural water retention in the cells. This keeps them looking full, giving a more youthful appearance and reduces the appearance of fine lines and wrinkles. RSO is also noncomedogenic, meaning it will not clog your pores. Use it to moisture your face without blocking your pores [44]. Additionally, raspberry oil's sun protective qualities offer added benefit to people looking for a mild, non-irritating moisturizer with a sun protection factor (SPF) [45,46].

Raspberries contain antimicrobial properties that are powerful enough to stop the growth of harmful bacteria such strains such as salmonella and *E. coli* (*Escherichia coli*). Although there is no substitute for proper oral hygiene, raspberry seed oil might be beneficial in destroying harmful bacteria found in the mouth. It might also assist in healing painful and inflamed gums that have been irritated by the plaque deposits [47,48]. RSO can also moisturize and soften the skin as well as reduce skin irritations such as itching, swelling and redness [49,50].

Oomah et al. [6] reports that RSO can be used as a broad-spectrum UV protectant and provide protection against both UV-A and UV-B. However, not many other SPF tests on raspberry seed oil have been made, but the interest in RSO has accelerated [51]. Meanwhile, a very recent research by Ácsová et al. [49] in 2021 has revealed that the oil may not be as effective as concluded in Oomah et al. [6] research. In the latest study SPF values of the RSO in vitro was 0.4, in vivo 2.6, and it is significantly lower than the values reported in the controversial studies. Ácsová et al. [49] showed that the overestimated SPF values of RSO was determined by authors who did not strictly followed Mansur's original methodology.

It is sure that RSO can make a great addition to an organic product because of its abundant amount of antioxidants, including Vitamin E, which helps to block free radicals. Not to mention plenty of the incredibly beneficial micronutrients called polyphenols. Therefore, with the growing demand for natural sunscreen products, it would be useful to conduct in-depth research to substantiate or refute one or another author.

5. Patents on RSO

When an inventor finds a solution to a particular problem, one needs to make sure the solution is new. In addition, the description of the invention must indicate and compare solutions to similar problems with the patented solution. Determining the state of the art makes it possible to see which technical field is already protected by patents and to predict the direction in which new solutions can be sought. The search for raspberry seeds oil novelty and technical level (also called patent search) was carried out in publicly available free international patent databases containing data on issued patents [52]. Table 1 illustrates an updated report on application of RSO.

Table 1. Updated list on patents of raspberry seeds oil.

Patentscope	Patent's Title	Publication Number	Publication Year and Office
1. Technologies	1.1. Dimethicone copolyol raspberriate as a delivery system for natural antioxidants;	6630180	2003, USA
	1.2. Raspberry amido amines and betaines as a delivery system for natural antioxidants;	7078545	2006, USA
	1.3. Synergistic super potent antioxidant cold pressed botanic oil blends;	20070243310	2007, USA
	1.4. Method of making edible oil with unsaturated fatty acid content of more than 90% by extracting roasted bramble seed with hexane purpose;	1020070080027	2007, Korea
	1.5. Immune enhancement by seed oil;	20090324759	2009, USA
	1.6. Ultrasonic wave auxiliary extraction method for extracting raspberry seed oil;	102864012	2013, China
	1.7. Composite extract of black raspberry oil, raspberry oil and mulberry oil;	WO/2015/137633	2015, Korea
	1.8. Preparation method of raspberry seed oil and product prepared therefrom;	106947583	2017, China
	1.9. Raspberry seed oil extraction technology;	109022136	2018, China
2. Pharmaceutical products	2.1. Raspberry seed oil compsns—with antiinflammatory activity, for cosmetic and pharmaceutical use;	2255055	1975, France
	2.2. Topical steroid spray with botanic seed oils;	20090304603	2009, USA
	2.3. Berry oils and products;	20110280971	2011, USA
	2.4. Raspberry seed oil soft capsule and preparation method thereof;	102687861	2012, China
	2.5. Dietary supplement to treat dry eyes;	2013101038	2013, Australia
	2.6. Traditional chinese medicine essential oil for relieving fatigue and preparation method of traditional chinese medicine essential oil;	104800783	2015, China
	2.7. Complex extract of black raspberry oil, raspberry oil and mulberry oil;	1020160047055	2016, Korea
	2.8. Soft-capsules containing sea buckthorn seed oil;	108497499	2018, China
3. Cosmetic products	3.1. Cleansing sheet;	2003226637	2003, Japan
	3.2. Compositions, to reinforce and restore functional barrier of skin and to control inflammation, comprises insaponifiable fraction of rape oil;	2912652	2009, France
	3.3. Skin care compositions with botanic seed oils;	20090123578	2011, USA
	3.4. Natural korean herb cosmetics capable of being applied to sensitive skin;	101262557	2013, Korea
	3.5. Anti-aging cosmetic composition;	WO/2013/066623	2013, USA
	3.6. Cream pack containing raspberry;	106955249	2017, China
	3.7. Eye cream containing raspberry;	107041862	2017, China
	3.8. Healthcare chest-enlarging weight-losing molding multifunctional massage oil for external use and preparation method thereof;	106667859	2017, China

Table 1. *Cont.*

Patentscope	Patent's Title	Publication Number	Publication Year and Office
	3.9. Novel herbal sunscreen formulation and method thereof;	201611003234	2017, India
	3.10. Anti-aging, soothing and moisturizing gel and preparation method thereof;	108852928	2018, China
	3.11. Environmental-protection facial mask base material and preparation method and application thereof;	108926504	2018, China
	3.12. Anti-wrinkle oil-control acne-removing repair mask and preparation method thereof;	108904371	2018, China
	3.13. Sun-protection lipstick and preparation method thereof;	111789782	2020, China
4. Bathing products	4.1. Dandruff treatment compositions with anti-inflammatory agents including botanic seed oils;	20090317502	2009, USA
	4.2. Raspberry soap composition having antibiotic and antioxidant function by comprising raspberry seed oil and raspberry wine;	1020120052467	2012, Korea
	4.3. Cosmetic or bathing product containing rubi fructus seed extract and antioxidative ingredients purpose;	1020110129606	2012, Korea
	4.4. Silicon oil free shampoo capable of preventing alopecia and preparation method of shampoo;	106473994	2017, China
	4.5. Anti-soap formulation;	20190133921	2019, USA
	4.6. Preparation method of de-oil shampoo;	109925228	2019, China
	4.7. Oil-control shampoo;	109925231	2019, China
5. Oral care	5.1. Novel composition for herbal mouthwash and process for the preparation of the same;	1376/DEL/2012	2014, India
	5.2. Whitening and anti-sensitivity aloe gel and preparation method thereof;	108714130	2018, China
6. Food	6.1. fruit products containing omega-3 fatty acids.	WO/2010/011712	2010, USA

The oldest registered patent relating to raspberry seed oil is in 1975 in France. The invention relates to cosmetic or pharmaceutical compositions, more particularly products for dental care, skin creams and lotions, shampoos and make-up. One frequently meets in cosmetology phenomena of inflammation, such as that of the gums, called gingivitis, that of the epidermis, called erythema, eczemas or other skin lesions. The origin of these inflammations can be very varied: biological deficiency, allergy, the effect of the sun's rays and often the ingredients of the beauty products themselves.

Substances with an anti-inflammatory effect are well known, such as cortisones, phenylbutazone, salicylates, indomethacin, anthranilic acid derivatives, proteases, which, besides their effectiveness, also cause side effects. The subject of the invention is the incorporation into cosmetic or pharmaceutical products of a new anti-inflammatory substance of natural origin, pressure oil or raspberry seed extraction oil, hereinafter called raspberry seed oil. Raspberry seeds, capable of preventing or suppressing inflammatory phenomena, for example of the gums or the epidermis.

The patent authors state that RSO, expressed or extracted from raspberry seeds have anti-inflammatory activity and are useful in anti-sunburn preparations, dental preparations, mouth-washes, after shaving preparations, antiperspirants, shampoos, lipsticks, etc. RSO as a dietary supplement has multiple functions of lowering blood lipid, cholesterol and blood pressure, resisting thrombus and arteriosclerosis, preventing cardiovascular disease, enhancing memory and preventing Alzheimer's disease and cancer and has a high nutritional value and health care function. The authors also note that changing waste (raspberry seeds) into high value products having great significance for the development of the red raspberry industry and the comprehensive utilization of byproducts.

The countries that have registered the most patents are China (17 patents) and USA (11 patents). It can be concluded that the fatty acids, vitamins A and E help in resorting skin elasticity, skin hydration, thus, finding its implication as anti-aging and in various other skin diseases as a result, oil has found a large niche in the cosmetics industry and is also significant in the pharmaceutical industry (Figure 1).

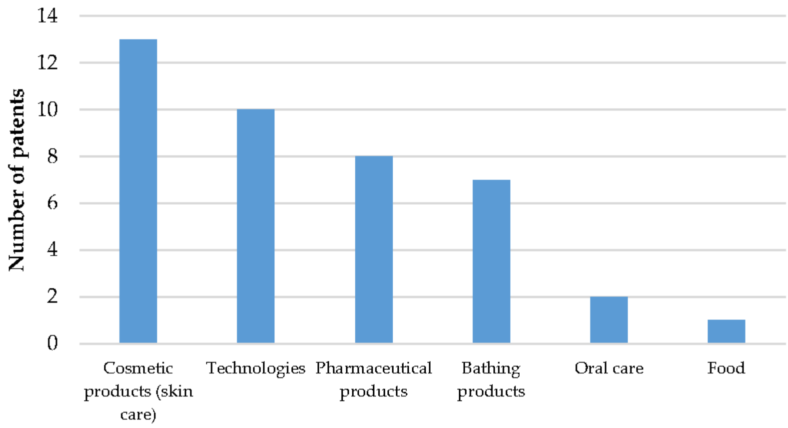

Figure 1. International patents relating to raspberry seeds oil.

6. Conclusions

Raspberry seeds oil can be used in food, pharmaceutical, cosmetic and chemical industries, it has a medicinal and therapeutic value. The so-called green oil production methods (SFE and cold-pressed techniques) ensure the sustainable realization of high-value products that meet the needs of the consumer of this time, the development of zero-waste technology in the circular economy. RSO has high content of polyunsaturated fatty acids, tocopherols, polyphenols and fatty acids which help in the prevention and treatment of various disorders. The benefits of RSO for external use have been extensively studied, products are widespread and recognized by consumers in the cosmetics industry. However, there is a lack of information on RSO as food consumption.

To conclude this review, RSO represents a potential source of natural ingredients for food, cosmetics and pharmaceutical industries. Due to the high nutritional value of raspberry by-products, it can be exploited as food additives or supplements providing the high valuable products which may be economically attractive for consumers. Both internal and external consumption of raspberry seed oil have a significant impact on human health, but there is a lack of data on internal consumption dosing and treatment for the prevention of specific diseases.

In the future, it would be useful to examine the influence of the oil on the internal consumption. It would be appropriate and interesting to confirm or deny the properties of the oil for sun protection as well. There is also a lack of information on the impact of different oil extraction technologies on its yield and quality, which would be valuable in practice for business representatives.

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ARTICLE 2

plants

MDPI

Article

Biochemical and Antioxidant Profiling of Raspberry Plant Parts for Sustainable Processing

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Abstract: The optimization of innovation and food technological processes not only increases the profits of companies but also allows them to achieve the set goals of the green trajectory. This research aimed to collect data on the biochemical composition of different parts of the raspberry variety 'Polka', including the various morphological parts, to present the importance of differentiating plant parts in food processing, and to show the potential of usage for primary processing in different fields of the food industry. Fruits, stems (cane), leaves, flowers, seeds, and roots were evaluated according to their chemical composition and mineral (Ca, Mg, B, Zn, Cu, Fe, and Mn) contents, phenolic compounds, and antioxidant activity. In our study, the contents of inverted sugar, saccharose, and total sugar varied from 51.8 ± 2.46 %, 18.9 ± 0.31 %, and 69.7 ± 4.36 % in raspberry puree to 5.9 ± %, 1.51 ± %, 7.39 ± % in the seeds, respectively. The results regarding the mineral composition of various raspberry parts (mg/kg) indicated significant differences ($p < 0.05$). The contents of manganese and iron (57.6 ± 0.50; 36.9 ± 0.59) were the highest in all the parts in the plant. Manganese varied from 246 ± 10.32 in inflorescence to 40.1 ± 0.87 in the seeds. Iron fluctuated from 1553 ± 44.03 in the roots to 35.5 ± 0.15 in the seeds. The highest statistically significant boron content ($p < 0.05$) was found in the leaves (41.8 ± 0.33), while the lowest was in the seeds (7.17 ± 0.19). The total phenol content of the raspberry's distinct parts ranged from 6500 mg GAE/100 g DW to 1700 mg GAE/100 g DW. The inflorescence had the considerably highest total phenol content. Our study found that the highest amount of epicatechin is found in the roots (9162.1 ± 647.86 mg), while the fruits contain only 657.5 ± 92.99, and the lowest value is in the stems (130.3 ± 9.22). High levels of procyanidin B2 were found in the raspberry roots (7268.7 ± 513.98), while the stems had the lowest value–368.4 ± 26.05. The DPPH of the raspberry morphological parts ranged from 145.1 to 653.6 µmol TE/g FW, ABTS—from 1091.8 to 243.4 µmol TE/g FW, and the FRAP—from 720.0 to 127.0 µmol TE/g FW. The study revealed the importance of differentiating plant parts in production for the quality of the final product. Studies showed that raspberry plant parts represent a potential source of natural food ingredients, and can be a potential raw material for products rich in phenolic compounds or dietary fiber, which can provide healthy properties to food when used as an additive that may be economically attractive for consumers.

Keywords: raspberry morphological parts and characteristics; micronutrients; antioxidant activity; phenolic profile

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1. Introduction

Food waste and the formation of by-products present a major problem, with adverse environmental, economic, and social impacts. The agri-food industry generates a large proportion of waste and by-products, which account for 40–50% of all emissions from various plant sources, such as peel, pulp, skin, roots, stems, leaves, and seeds [1]. Reducing food waste is a common goal worldwide, and there is a known seriousness about the problem; thus, the EU and many other countries are promoting action plans to reduce food waste, such as the farm-to-table strategy, the circular economy action plan, and EU waste legislation. Reducing food waste could be an important solution for reducing production costs and creating more efficient food systems. In addition, more environmentally sustainable food systems can be developed, and food safety and nutrition can be improved [2].

Berry fruits contain a significant number of diverse bioactive compounds, which individually or in combination can have a positive effect on human health. Therefore, raspberries can be recommended as a natural source of antioxidants. Small fruits are an excellent source of natural antioxidant substances, which is one of the major reasons for their increasing popularity in the human diet. Extracts of fruits from various blackberry, raspberry, and gooseberry cultivars act effectively as free radical inhibitors [3].

Fruits are also abundant in different bioactive compounds, including phytochemicals (phenolic acids, flavonoids, carotenoids, tannins, lignans, and stilbenes), vitamins (provitamin A, C, E, and K), minerals (potassium, calcium, and magnesium), phenolic compound, antioxidant activity and dietary fibers, which play a critical role in human health by alleviating several chronic diseases, mainly coronary heart diseases, cancers, diabetes, cataracts and so on [4–6]. Polyphenols are secondary metabolites from plant metabolism, and this category of compounds can be classified into phenolic acids (C6-C1 and C6-C3 skeleton for hydroxybenzoic and hydroxycinnamic acids, respectively), flavonoids (C6-C3-C6 skeleton), stilbenes (C6-C2-C6 skeleton), lignans (C6-C3), and other polyphenols (variable skeleton, such as tyrosol) [7]. As such, raspberries contain vegetative and fructifying organs. Different parts of the raspberry plant have different profiles of bioactive compounds and possible target extraction. For these reasons, they can be differentiated in the food, beverage, and cosmetic industries. Vegetative organs serve to maintain the life of the individual and are differentiated into roots, stems, and leaves. Fructifying organs or reproductive organs (fruits, flowers, and seeds) enable the survival of the species. The biochemical and antioxidant profiling of raspberry fruit and leaves has been widely studied [8–11]. In addition, globalization has increased the demand for different types of products. Food processing is the set of methods and techniques used to transform raw ingredients into finished and semi-finished products. A significant aspect of food technology is to promote sustainability to avoid waste, save and utilize all the food produced and ensure safe and sustainable processing practices. Professionals in food processing need to be knowledgeable about the general characteristics of raw food materials and the principles of food preservation. Therefore, scientific novelty was revealed by identifying the raw materials formed during the processing of raspberries using different technologies.

Primary processing involves cutting, cleaning, packaging, and the storage, and refrigeration of raw foods to ensure that they are not spoilt before they reach the consumer. These minimally processed foods retain the original properties, i.e., the nutritive, physical, sensory, and chemical properties as in the unprocessed form, and are ready for further processing by the food industry (secondary processing). Secondary food production involves converting raw food ingredients into more useful or edible forms. Secondary food products are refined, purified, extracted, or transformed from minimally processed primary food products.

Some positive impacts of primary food processing are, for example, the increase in shelf life and nutrient bioavailability. However, food processing can also have negative impacts, such as a high content of artificial additives and loss of nutrients. This study shows how different methods of extracting raspberry seed oil, which is what remains after the oil has been extracted, affect the result in creating products based on circular economy principles.

Therefore, the goal of all production is to grow a cultivar with high yield and excellent quality, to create high-quality products, and sell a maximum amount. The study aimed to compare the chemical characteristics as well as the content of antioxidants (anthocyanins, vitamin C, and total phenolics) in different parts of the raspberry plant.

Ponder and Hallman in 2019 tested the content of phenolic compounds in the leaves of raspberry plants of different cultivars (including 'Polka') [12]. Their results showed significant differences between the raspberries from organic and conventional systems. Lebedev et al., in 2022, compared the phenolic content of fruits and leaves of raspberry cultivars. Majewski, in 2020, evaluated the phenolic compound content of raspberry seeds [13]. In 2023, Kobori et al. profiled the phenolic compound composition of raspberry flowers [14].

However, all these authors analyzed only one or a few of the plant parts, and there are not enough research studies or published articles evaluating the potential of all the different parts of raspberries and their quality characteristics from one region, the same climatic conditions, and the same soil management and cultivation principles. Therefore, the goal is to highlight and determine the differences in the plant parts of raspberries grown under the same conditions and to evaluate the individual parts of the plant 'Polka', the most widely grown raspberry variety in Europe, according to their quality characteristics for waste-free processing.

Potential differences in the biochemical composition and micronutrient capacity of the analyzed raspberry plant parts may be useful in making production decisions in the processing or development of new products and in improving commercial performance accordingly. This means that comparing individual parts of the plant with different nutritional and antioxidant values, in addition to the standard product, can increase the number of products, be competitive, and successfully develop waste-free raspberry processing technologies. It is useful to compare the level of basic compounds from different parts of the plants to underline these differences and to point out the most interesting and promising parts for the food, cosmetic, and pharmaceutical industries. It is important to study all parts of the plant, especially for the determination of phenolic compounds. This research aimed to collect data on the biochemical composition of different morphological parts of the raspberry variety 'Polka', to present the importance of differentiating plant parts in food processing, and to show the potential for usage for primary processing in various fields of the food industry.

2. Materials and Methods

2.1. Plant Material and Its Preparation

In the first stage, the primocane fruiting red raspberry cultivar 'Polka' was acquired from the raspberry farm, located in North Lithuania (55°47′55.0″ N 22°44′57.4″ E 55.798603, 22.749268). The average air temperature in Lithuania in August was 16.1 °C. Randomly selected raspberry parts were harvested in August 2021 at physiological maturity (phenological phase 8 (fruit maturity) in the BBCH system) in the morning, and transported to the laboratory of the Institute of Horticulture of the Lithuanian Research Centre for Agriculture and Forestry. Raspberry plant parts (leaves, stems, roots, buds, inflorescence, and fruits) were collected separately and randomly in an area of approximately 50 m^2. All parts of the raspberry plant in the fields were grouped and immediately taken to the laboratory of the Lithuanian Institute of Agronomy and Forestry, where they were frozen and lyophilized. Raspberry seeds were obtained by separating them using a "Voran" destoning and pulping machine. The seeds were dried at approximately 40 °C. In the second stage, all parts were grounded in a rotary hammer mill SR 300, 200–240 V, 50/60 Hz Retch (Germany) using a 0.5 mm sieve and stored in glass jars until analyses.

2.2. Reagents

Analytical and HPLC-grade solvents and reagents were used for chemical analyses. Acetonitrile (99.9%) and methanol (99.9%), potassium persulphate (99%), and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (98%) (ABTS), and the reference compounds were obtained from Sigma-Aldrich (Steinheim, Germany); trifluoroacetic acid (≥99%), Trolox (≥98%) and apigenin were supplied from Fluka Chemika (Buchs, Switzerland). The purified deionized water (18.2 mΩ/cm) was produced using the Millipore Simpak1 Synergy 185 ultra-pure (Bedford, MA, USA) water system.

2.3. Extraction and Analysis

The powdered samples of approximately 1 g (accuracy 0.0001 g) were extracted with 10 mL of 70% acetone for 15 min in an ultra-sonic bath; 480 W ultrasonic power at 35 kHz was used in the study by using the Sonorex Digital 10 P ultrasonic bath (Bandelin Electronic GmbH & Co. KG, Berlin, Germany). The extracts were filtered through 0.22 µm PDVF syringe filters (Carl Roth GmbH & Co. KG, Berlin, Germany) and stored at 4 °C until analysis. HPLC analysis was performed according to Raudone et al. [15]; the quantitative determination of the compounds identified in the extracts was carried out using five-level calibration graphs of reference compounds for each analyte, and was based on the dependence of the area of the chromatographic peak of the analyte on the concentration of the analyte in the analyzed extract. The amounts of dihydrochalcones, monomeric and oligomeric flavan-3-ols in the tested extracts were calculated at a wavelength of 280 nm, phenolic acids at 320 nm, and flavanols at 360 nm.

2.4. Determination of Antioxidant Capacity

An ABTS + radical cation decolorization assay was adjusted according to the methodology described by Re and colleagues, with some modifications. A volume of 3 mL of ABTS + (2,2′-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid)) solution (absorbance 0.800 ± 0.02) was mixed with 20 µL of samples. The absorbance decreasing of each sample was measured at 734 nm in a Cintra 202 (GBC Scientific Equipment, Knox, Braeside, VIC, Australia) spectrophotometer after 30 min. The DPPH• free radical scavenging activity was established using the method suggested by Brand Williams, Cuvelie, and Berset [16], with some modifications: 2 mL DPPH• (2,2-diphenyl-1-picrylhydrazyl) solution in 96.0% v/v ethanol was mixed with 20 µL of samples. A decrease in absorbance was determined at 515 nm in a Cintra 202 (GBC Scientific Equipment, Knox, Australia) spectrophotometer after 30 min. The ferric-reducing antioxidant power (FRAP) assay was accomplished as described by Benzie and Strain, with some modifications. The FRAP solution consisted of TPTZ (0.01 M dissolved in 0.04 M HCl), $FeCl_3 \times 6H_2O$ (0.02 M in water), and acetate buffer (0.3 M, pH 3.6) at the ratio of 1:1:10. A volume of 3 mL of a recently prepared FRAP reagent was mixed with 2 µL of samples. The absorbance increase was established at 593 nm in a Cintra 202 (GBC Scientific Equipment, Knox, Australia) spectrophotometer after 30 min. Calculation of all antioxidant activity assays was carried out using Trolox calibration curves, and expressed as µmol of the Trolox equivalent (TE) per one gram of dry weight (µmol TE/g DW) [17].

2.5. Determination of Titratable Acidity

A portion of the premixed sample is taken and filtered through cotton wool, filter paper, or cloth. Transfer 25 mL of the filtrate to a 250 mL volumetric flask, dilute to the mark with water, and mix well. Depending on the expected acidity, add 25 mL, 50 mL, or 100 mL of the diluted sample to a conical flask, add 3–5 drops of phenolphthalein, and titrate with 0.1 M sodium hydroxide solution.

2.6. Determination of Ascorbic Acid (Vitamin C) Content

A total of 20 mL of 1% HCl is added to 10 g of the test substance in a mortar and quickly crushed to a homogeneous mass. The resulting mass is poured through a funnel into a measuring flask with a capacity of 100 mL. The mortar is washed with a 1% oxalic acid solution, pouring the washing solution into the same measuring flask. The contents of the flask are diluted to the mark with a 1% oxalic acid solution. The flask is closed with a cork, shaken, and left to stand for 5 min. The mixture in the flask is filtered through a dry filter into a dry flask. Two portions of 10 mL each are taken from the filtrate and poured into 50 mL flasks. Titrate with micro burettes with 0.001 N 2,6-dichlorophenolindophenol solution until a bright pink color does not disappear for 0.5–1 min.

2.7. Determination of Sugars

Monosaccharides, sucrose, and total sugar content in samples were determined by the Bertrand method, which is based on the reducing action of sugar on the alkaline solution of tartrate complex with cupric ion; the cuprous oxide formed is dissolved in a warm acid solution of ferric alum. The ferric alum is reduced to $FeSO_4$ which is titrated against standardized $KMnO_4$; Cu equivalence is correlated with the table to obtain the amount of reducing sugar.

2.8. Determination of Dry Matter

Dry matter content was determined gravimetrically by drying apple samples to a constant weight at 105 °C.

2.9. Determination of the Amount of Macro-and Microelements

The amount of macro- and microelements in the raspberries was determined by the spectrometric method. Mineralization of dry raw material was carried out with a microwave mineralizer Multiwave GO (Anton Paar High-precision Instruments, Austria). A total of 0.5 g of dry raw material was poured into 5 mL of 65% nitric acid and 3 mL of 30% hydrogen peroxide. The samples were mineralized in several stages, using time and temperature regimes: 1st stage—a temperature of 150 °C was reached in 3 min and held for 10 min; 2nd stage—a temperature of 180 °C was reached within 10 min and held for 10 min. After the mineralization steps, the sample was diluted to 50 mL with deionized water. The composition and quantity of macro- and microelements were measured using an inductively coupled plasma optical emission spectrometer (ICP-OEC) SPECTRO GENESIS (Spectro Analytical Instruments, Germany). ICP-OEC parameters: power 1300 W, plasma flow rate 12 L min^{-1}, make-up flow rate 1 L min^{-1}, nozzle flow rate 0.8 L min^{-1}, and sample aspiration rate 1 mL min^{-1}. Identification wavelengths of individual elements: B (249.773 nm), Ca (445.478 nm), Cu (324.754 nm), Fe (259.941 nm), K (766.491 nm), Mg (279.079 nm), Mn (259.373), Na (589.592 nm), P (213.618), S (182.034 nm) and Zn (213.856 nm). Calibration standards were prepared by diluting the multi-element standard solution (1000 mg L^{-1}, Merck, Germany) with 6.5% nitric acid. Sulfur and phosphorus standard solutions (1000 mg L^{-1}, Merck, Germany) were diluted with deionized water. The amount of macronutrients was expressed in mg g^{-1}, and micronutrients in μg g^{-1} dry weight.

Soil studies were conducted in the "Agrochemical Research Laboratory" accredited by the LAMMC Institute of Agriculture. In the spring, the combination of 500 g of soil samples from the arable layer (0–20 cm deep) was taken from each option in the repetition box (from 5 compartments). Soil samples in the laboratory were dried to the mass of the air, crushed in a porcelain mortar, and sifted through a 2 mm sieve.

2.10. Determination of Soil Properties

Soil studies were conducted in the "Agrochemical Research Laboratory" accredited by the LAMMC Institute of Agriculture. In the summer, the combination of 1000 g of soil samples from the arable layer (0–20 cm deep) was taken from each option in the repetition box (from 10 compartments). Soil samples in the laboratory were dried to the mass of the air, crushed in a porcelain mortar, and sifted through a 1 mm sieve.

The following soil agrochemical parameters are estimated:

- Humus content (%) is determined by the amount of organic and general carbon in the sample after dry burning (ISO 10694: 1995).
- Soil reaction pH-potentiometric method, pH-meter 1n KCl excerpt (LST ISO 10390: 2005).

- The amount of mineral nitrogen (MG KG -1) is calculated by adding nitrate, nitrite, and ammonia nitrogen (ISO 14265-2: 2005).
- The amount of mobile phosphorus (P_2O_5) and mobile potassium (K_2O) is calculated using the Egner–Rimo–Domingo (A–L) method [18].

2.11. Statistical Analysis

All the experiments were carried out in triplicate. In the statistical processing of the data obtained from the analysis of the chemical composition of the fruits, the standard deviation was calculated and presented together with the mean values. MS Excel (USA) and IBM SPSS Statistics (USA) software packages were used for statistical analysis. One-way analysis of variance (ANOVA), along with the post hoc Tukey's HSD test, was employed for statistical analysis. Differences were considered to be significant at $p < 0.05$. The antioxidant activity was evaluated by using ABTS, DPPH, and FRAP assays. Values were expressed as means with standard deviation error bars.

3. Results and Discussion

T. Turmanidze et al. [19] and E. Carvalho et al. [20] reported that whole berry extracts usually contain significant amounts of ascorbic acid and carotenoids. According to our data, the ascorbic acid contents ranged from 0.063 to 0.147 g/100 g DW, with raspberry puree holding the highest content and roots having the lowest content. In a study of 24 different raspberry cultivars, Yu et al. found that the contents of total sugar and reducing sugar varied from 50.78 ± 1.99 to 82.64 ± 0.21 g/100 g DW, and 30.26 ± 0.33 to 55.76 ± 2.66 g/100 g DW, respectively [21]. In our study, contents of inverted sugar, saccharose, and total sugar varied from 51.8 ± 2.46, %, 18.9 ± 0.31, %, and 69.7 ± 4.36, % in the raspberry puree to 5.9 ± %, 1.51 ± %, 7.39 ± % in the seeds, respectively. The values of dry matter varied from 98.4 ± 3.55 in the stems and 98.4 ± 4.44 in the leaves to 83.8 ± 3.83 in the raspberry fruits.

The values of titratable acidity (TAC) varied from 20.9 ± 0.32 a, %, in the unripe raspberries to 2.07 ± 0.06 f. Comparing raspberries with seeds, raspberry puree, and non-billed raspberry acidity, there were significant differences in total acidity, which is extremely important in fermented drinks and wine production. The TAC values were higher than most of the data determined by others [22], where the values of TAC varied from 4.90 ± 1.19 to 17.51 ± 0.51 g/100 g DW. This might be due to the strong relationship between the berry's acidity and climate conditions. In August 2021, when the raw materials were collected for investigations, unusually high rainfall (127 mm/month) was collected, while in 2020 precipitation was only 46.7 mm/month in the same month (data obtained from Šiauliai Meteorological Station). According to the meteorological data obtained, it can be stated that the year 2021 was less favorable for raspberry development and growth, which may have created stressful conditions for plants and encouraged larger amounts of some secondary metabolites. The inverted sugar, saccharose, total sugar, ascorbic acid (Vitamin C), titratable acidity, and dry matter are shown in Table 1.

Product characteristics such as sweetness, acidity, and juiciness are important for consumers, so it is necessary to take this into account when processing fruit. Quality is influenced by the amount and composition of sugar accumulated in the fruit. Sweet and sour are produced by sugar and acid, respectively. Their contributions to the taste depend not only on the levels of sugar and acid but also on the types and relative proportions of sugar and acid. Therefore, it is very important to determine the composition and amounts of sugar and acids in berries, and for improving the quality of raspberry production it is worth conducting experiments that would help determine the amounts of additional chemicals, preservatives, and food additives, because they can stimulate their production and better meet the needs of the consumer.

Table 1. Quality indexes of different dried raspberry plant parts.

Sample	Inverted Sugar %	Saccharose %	Total Sugar %	Vitamin C mg %	Titratable Acidity %	Dry Matter %
Raspberry with seeds	51.7 ± 0.56 a	13.4 ± 0.58 b	63.9 ± 2.85 b	140.0 ± 3.45 a	15.4 ± 0.58 c	83.8 ± 3.83 c
Raspberry puree	51.8 ± 2.46 a	18.9 ± 0.31 a	69.7 ± 4.36 a	147.0 ± 6.35 a	20.9 ± 0.32 a	86.1 ± 3.17 bc
Unripe raspberry	15.5 ± 0.53 b	1.9 ± 0.11 e	17.1 ± 0.77 c	117.0 ± 3.99 b	17.4 ± 0.81 b	95.0 ± 5.74 abc
Inflorescence	14.4 ± 0.45 b	1.25 ± 0.05 e	16.0 ± 0.5 c	95.0 ± 3.57 c	13.2 ± 0.36 d	93.3 ± 2.99 abc
Leaves	11.2 ± 0.64 c	3.36 ± 0.05 d	14.7 ± 0.55 c	82.0 ± 2.48 d	8.4 ± 0.25 e	98.4 ± 4.44 a
Seeds	5.9 ± 0.23 d	1.5 ± 0.03 e	7.4 ± 0.33 d	720 ± 4.21 de	2.6 ± 0.09 f	96.6 ± 3.84 ab
Stems	10.3 ± 0.59 c	5.6 ± 0.15 c	15.9 ± 0.23 c	93.0 ± 0.94 c	3.0 ± 0.17 f	98.4 ± 3.55 a
Roots	3.7 ± 0.15 d	1.8 ± 0.05 e	5.6 ± 0.17 d	62.0 ± 1.93 e	2.1 ± 0.06 f	96.2 ± 4.55 ab

Note: data are expressed as average value ± standard deviation of three replicates and the different letters in each column indicate significant differences ($p < 0.05$).

Total sugars include all sugars, whatever their food source (whether added or naturally present in foods), i.e., all monosaccharides and disaccharides. The amount of total sugars is provided in nutrition labeling in the EU. Regulation (EU) No 1169/2011 on the provision of food information to consumers harmonizes how sugars must be labeled. The nutrition declaration must indicate the amount of total sugars, and in the ingredients list the types of sugars added must be declared.

Sugars play a key role in different foodstuffs. As well as bringing sweetness, they also have important biological, sensory, physical, and chemical properties. For example, sugars help provide the taste, texture, and color of foods and extend their shelf-life, which preserves the safety and quality of the food. Sugars can in some cases be reduced/replaced, but no other single ingredient can replace all the functions of sugars.

An important indicator of raspberry quality is the chemical composition, especially the sugar content, and the acidity in wine production; the soluble dry matter is important in the production for fruit respiration and weight loss. Sugars and acidity are also important indicators determining the organoleptic properties of fruits [23–25].

3.1. Mineral Composition of Raspberry Parts

An adequate ratio of micronutrients and their favorable content in the soil, whose uptake can be affected by low soil pH, ensures the plant's optimal supply [26]. The chemical analysis of an average soil sample showed that the soil had a slightly acid reaction (pH 5.6), a high level of humus (6.1%), a moderate content of available phosphorus (136 mg/kg) and a high content of available potassium (167 mg/kg) [27]. Soil properties in the raspberry growing area are presented in Table 2 below.

The results regarding the mineral composition of different raspberry parts (mg/kg) indicated significant differences ($p < 0.05$). The contents of manganese and iron (57.6 ± 0.50; 36.9 ± 0.59) were the highest in all parts of the plant; manganese varied from 246 ± 10.32 in inflorescence to 40.1 ± 0.87 in the seeds, and iron varied from 1553 ± 44.03 in the roots to 35.5 ± 0.15 in the seeds. The highest statistically significant boron content ($p < 0.05$) was found in the leaves (41.8 ± 0.33), while the lowest was in the seeds (7.17 ± 0.19). The lowest contents, i.e., Ca (0.13 mg), Mg (0.11 mg), B (7.23 mg), Cu (2.93 mg), and Fe (35.6 mg) were found in the seeds. The chemical composition of the micronutrients of different morphological parts of the raspberry is presented in Table 3.

Table 2. Soil properties in the raspberry growing area.

Soil Properties	Description
Soil location	55°47′42.2″ N 22°44′59.0″ E
Granulometric composition	Loam
pH 1 mol/l KCl in suspension	5.6 ± 0.2
The concentration of mobile phosphorus (P_2O_2), mg/kg	136 ± 14
The concentration of mobile potassium (K_2O), mg/kg	167 ± 11
Nitrogen (sum of nitrate plus nitrite), mg/kg	109.05 ± 7.90
The concentration of nitrogen (ammonia), mg/kg	5.67 ± 1.04
The concentration of mineral nitrogen, mg/kg	114.72 ± 4.66
Organic carbon concentration %	3.89 ± 0.43
Humus concentration	6.71 ± 0.74

Note: data are expressed as average value ± standard deviation of three replicates.

Table 3. Micronutrient content (% or mg/kg) of different raspberry morphological parts.

Research Parameter	Sample Name and Test Results						
In Dry Matter	Ripe Berries	Unripe Berries	Leaves	Stems	Inflorescence	Seeds	Roots
Calcium (Ca), %	0.13 ± 0.00 e	0.59 ± 0.03 d	1.15 ± 0.06 a	0.64 ± 0.03 d	0.73 ± 0.03 c	0.13 ± 0.00 e	0.82 ± 0.02 b
Magnesium (Mg), %	0.14 ± 0.01 d	0.31 ± 0.01 c	0.47 ± 0.01 a	0.15 ± 0.01 d	0.37 ± 0.01 b	0.11 ± 0.00 e	0.16 ± 0.03 d
Boron (B), mg/kg	17.40 ± 0.49 e	29.00 ± 0.98 c	41.80 ± 0.33 a	22.00 ± 0.10 d	31.70 ± 1.03 b	7.17 ± 0.19 f	17.57 ± 0.35 e
Zinc (Zn), mg/kg	21.10 ± 0.77 c	26.10 ± 0.33 b	17.90 ± 1.08 d	17.10 ± 0.70 d	38.50 ± 1.26 a	18.10 ± 0.95 d	18.87 ± 0.25 cd
Copper (Cu), mg/kg	6.79 ± 0.31 b	10.30 ± 0.45 a	4.96 ± 0.30 d	3.20 ± 0.15 e	6.04 ± 0.15 c	2.90 ± 0.10 e	6.06 ± 0.06 c
Iron (Fe), mg/kg	36.90 ± 0.59 e	57.50 ± 2.76 c	81.80 ± 2.73 b	45.90 ± 0.30 d	59.20 ± 2.27 c	35.50 ± 0.15 e	1553.00 ± 44.03 a
Manganese (Mn), mg/kg	57.60 ± 0.50 e	178.00 ± 7.29 b	166.00 ± 8.84 b	119.00 ± 6.79 c	246.00 ± 10.32 a	40.10 ± 0.87 e	76.4 0± 0.44 d

Note: data are expressed as average value ± standard deviation of three replicates and the different letters in each column indicate significant differences ($p < 0.05$).

The minimum values were for Ca and Mg (from 0.13 in the seeds to 1.15 in the leaves for calcium and from 0.11 in the seeds to 0.47 in the leaves for magnesium). Manganese and iron were mainly found (manganese content was from 40.4 mg/kg in the seeds to 248.7 mg/kg in the flowers. Iron content was from 35.6 mg/kg in the seeds to 1551 mg/kg in the roots). High iron content can be explained by the iron content in the environment, since raspberries accumulate large amounts of iron from the environment. However, in 2022 the Sikirić et al. study showed that no significant correlation was found between the content of Fe in the soil and plant organs, or between the Fe in leaves and fruits [28].

The copper contents determined by the above-mentioned Karaklajić-Stajić et al. were slightly lower than our results for the leaves. Cu content in raspberry leaves from Serbia ranged from 3.00 ± 0.07 to 4.00 ± 0.08 µg/g, compared to ours of 4.96 ± 0.30 d. The highest result for copper was found in the unripe raspberries—10.3 ± 0.45 a.

Dresler et al. [29], who studied raspberry leaves, found that, depending on the region of cultivation, the mean content of Mg in the raspberries ranged from 0.26% to 0.45%, compared to our 0.47%, and the mean Ca content ranged from 0.72% to 1.55%, compared to our 1.15%. The raspberry leaves were characterized by a very high content of Mn; the mean concentration of this element was 702 mg kg^{-1}, compared to our 166 mg kg^{-1}. The mean Fe concentration in the plants was 191 mg kg^{-1}, compared to our 81.8 mg kg^{-1}. The B concentration in the raspberry leaves ranged from 25.5 to 128.5 mg kg^{-1}, compared to our 41.8 mg kg^{-1}. The mean Zn concentration in the raspberry leaves was 40.3 mg kg^{-1}, while our results for Mg were 0.47%.

3.2. The Total Phenolic Content

Phenolic compounds are the most common secondary metabolites of plants [30]. Plant extracts and phenolic compounds exert protective effects against oxidative stress and inflammation caused by airborne particulate matter, in addition to a range of anti-inflammatory, anticancer, anti-aging, antibacterial, and antiviral activities [31]. Phenolic acids, readily absorbed through intestinal tract walls, are beneficial to human health, due to their potential antioxidants, and avert the damage of cells resulting from free-radical oxidation reactions. On regular eating, phenolic acids also promote the anti-inflammation capacity of human beings.

The total phenol content of the raspberry's different parts ranged from 6500 mg GAE/100 g DW to 1700 mg GAE/100 g DW (Table 1 and Figure 1). The inflorescence had a considerably highest total phenol content. The high value was also detected in berries, and was 26% higher than that detected for the lowest value in the seeds. The amount of ascorbic acid content ranged from 60 to 140 mg/100 g of dry weight. The concentration of total phenol quantified in raspberry parts was higher than other scientists have determined [32]. These differences could be due to cultivation principles, environmental characteristics, and soil characteristics.

In addition to exploring the potential protective effects, phenolic compounds provide health benefits against chronic diseases, considering the modifications during food processing techniques, and therefore, overall bioavailability is essential. Plant extracts and phenolic compounds exert protective effects against oxidative stress and inflammation caused by airborne particulate matter, in addition to a range of anti-inflammatory, anticancer, anti-aging, antibacterial, and antiviral activities [33]. Therefore, phenolic compounds can be used in the pharmaceutical industry as therapeutic agents. The antioxidant and antimicrobial properties enable phenolic compounds to function as food preservatives and additives. Thus, they also have applications in the food industry. Innovations in technology and production force countries to compete for high-value products. The distribution of raspberry plant parts and the conducted research help to optimize production processes, to use berry pomace and to identify sustainable valorization processing methods.

3.3. Individual Phenolic Profile

Kaempferol-3-beta-O-glucuronide is a flavonoid glucuronide, which can be found in plants and is deconjugated by microsomal β-glucuronidase from various human cells. It has a role as a metabolite. It is a kaempferol O-glucuronide and a trihydroxyflavone. Kaempferol shows a wide range of pharmacological activities, including anti-inflammatory and antioxidant effects, has a liver-protecting effect, and may be associated with a reduced risk of developing Alzheimer's disease. This natural compound also has great pharmacological capability, and is now considered to be an alternative cancer treatment [34].

The highest statistically significant amount of kaempferol O-glucuronide was found in leaves (4088.6 ± 289.11 a). However, this element was found very little in other parts of the plant, for example, the lowest value—only 4.0 ± 0.29 b—was found in the stems, so to extract this element, the leaves should be separated from the stems in production.

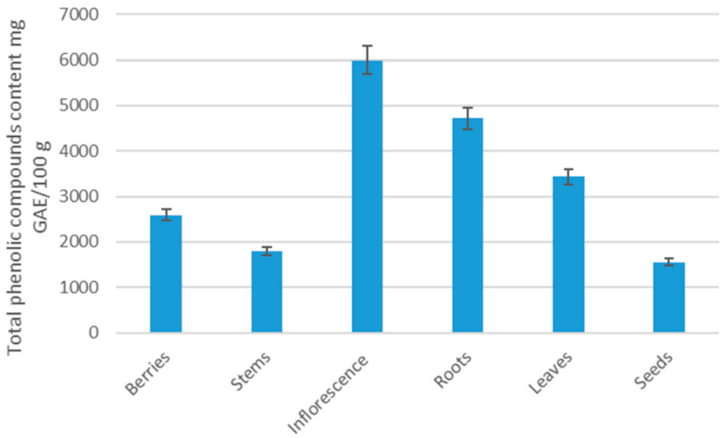

Figure 1. Total phenolic content in the samples of morphological parts of the raspberry plant, mg GRE/100 g DW.

Epicatechin is one of the most investigated catechins, due to its diverse biological properties [35]. People who regularly consume a plant-based diet will have a good amount of epicatechin circulating in their blood. These compounds have demonstrated diverse biological functions such as anti-proliferative, anti-inflammatory, antioxidant, antimicrobial, and cardio-protective activities. The major biological properties of epicatechin are studied using both in vitro and in vivo models. In vitro studies suggested that the antioxidant activity of epicatechin is mainly due to its ability to scavenge free radicals through the multiple phenolic groups attached. Similarly, epicatechins also showed significant antimicrobial activity against various multidrug-resistant pathogens, which is a serious need of today's healthcare system; epicatechin also increases the capacity for muscle aerobic metabolism, thereby delaying the onset of fatigue [36].

In the scientific literature, the authors indicate that epicatechin is found in smaller concentrations in berries and most of the regularly consumed fruits, chocolates, and non-alcoholic beverages. However, our study found that the highest content of epicatechin is found in the roots (9162.1 ± 647.86 mg), while the fruits contain only 657.5 ± 92.99, and the lowest value is in the stems (130.3 ± 9.22). The highest content of epigallocatechin was determined in the inflorescence (5882.6 ± 415.96) and leaves (3444.3 ± 243.55 b). The lowest values of epigallocatechin were in the stems (449.2 ± 31.76) and roots (542.9 ± 38.39).

High levels of procyanidin B2 have been found in raspberry roots (7268.7 ± 513.98), while the stems had the lowest value—368.4 ± 26.05. The highest statistically significant amount of chlorogenic acid was found in stems and leaves (3017.6 ± 213.38 and 2154.8 ± 152.37, respectively), while the seeds had only (7.2 ± 0.51). The obtained research results are significant because they reveal what is especially important to know in food and pharmaceutical production, i.e., which part of the plant contains the most, to highlight and offer a product that meets the consumer's expectations (Table 4).

3.4. *Antioxidant Activity*

The antioxidant activity (AA) of raspberry parts was evaluated using DPPH, ABTS, and FRAP assays. It was observed that different raspberry parts vary significantly in the quantity of antioxidant activity. The DPPH of raspberry morphological parts ranged from 145.1 to 653.6 µmol TE/g FW, and ABTS—from 1091.8 to 243.4 µmol TE/g FW— and the FRAP—from 720.0 to 127.0 µmol TE/g FW. According to all assays, inflorescence showed the highest antioxidant activity from 1091.8 µmol TE/g FW using ABTS to 653.6 µmol TE/g FW using DPPH. The lowest AA was in the seeds (DPPH—145.1 µmol TE/g FW and

FRAP—127.0). It was established that different morphological parts of the raspberry plant have statistically significantly different antioxidant activity.

Table 4. Phenolic compound profile (μg/g) in different morphological parts of the raspberry plant.

Part of the Berry	Leaves	Stems	Roots	Buds	Inflorescence	Seeds	Berries
Caffeic acid	110.2 ± 7.79 a	13.1 ± 0.92 d	0.3 ± 0.02 e	48.6 ± 3.43 c	82.9 ± 5.86 b	2.7 ± 0.19 de	5.9 ± 0.84 de
Catechin	461.9 ± 32.67 a	104.1 ± 7.36 d	8.3 ± 0.59 e	28.5 ± 2.02 de	270.5 ± 19.12 c	363.4 ± 25.7 b	525.9 ± 74.37 a
Chlorogenic acid	2154.8 ± 152.37 b	3017.6 ± 213.38 a	15.9 ± 1.13 c	129.1 ± 9.13 c	171.0 ± 12.09 c	7.2 ± 0.51 c	15.2 ± 2.15 c
Epicatechin	1108.2 ± 78.36 bc	130.3 ± 9.22 d	9162.1 ± 647.86 a	1380.1 ± 97.59 b	606.4 ± 42.88 cd	432.9 ± 30.61 cd	657.5 ± 92.99 cd
Isoquercitrin	222.3 ± 15.72 a	31.3 ± 2.22 c	N.D.	39.1 ± 2.77 c	73.4 ± 5.19 b	N.D.	5.8 ± 0.82 d
Procyanidin A1	22.9 ± 1.62 d	1.5 ± 0.11 d	134.3 ± 9.49 b	198.8 ± 14.06 a	86.5 ± 6.12 c	202.4 ± 14.31 a	91.6 ± 12.95 c
Procyanidin B1	130.5 ± 9.23 a	122.8 ± 8.68 a	14.8 ± 1.05 c	21.2 ± 1.5 c	12.1 ± 0.86 c	94.1 ± 6.65 b	19.1 ± 2.7 c
Procyanidin B2	1079.3 ± 76.32 d	368.4 ± 26.05 e	7268.7 ± 513.98 a	4174.4 ± 295.18 b	1806.5 ± 127.74 c	780.6 ± 55.2 de	781.8 ± 110.57 de
Procyanidin C1	1145.9 ± 81.03 a	86.5 ± 6.12 d	13.6 ± 0.96 d	557.4 ± 39.41 c	853.9 ± 60.38 b	60.5 ± 4.28 d	487.4 ± 68.92 c
Quercetin	27.4 ± 1.94 a	2.8 ± 0.2 d	4.1 ± 0.29 cd	6.0 ± 0.42 c	4.9 ± 0.35 cd	10.0 ± 0.71 b	4.1 ± 0.58 cd
Salicylic acid	28.1 ± 1.99 b	8.9 ± 0.63 c	N.D.	3.9 ± 0.28 d	36.6 ± 2.59 a	N.D.	N.D.
Tiliroside	533.7 ± 37.74 a	1.3 ± 0.09 c	8.6 ± 0.61 c	14.4 ± 1.02 c	59.9 ± 4.2 b	4.8 ± 0.34 c	0.6 ± 0.08 c
Kaempferol-3-O-glucuromide	4088.6 ± 289.11 a	4.0 ± 0.29 b	12.9 ± 0.91 b	114.3 ± 8.08 b	267.6 ± 18.92 b	3.4 ± 0.24 b	10.6 ± 1.49 b
Ellagic acid	176.3 ± 12.47 b	N.D.	48.5 ± 3.43 d	123.9 ± 8.76 c	439.9 ± 31.1 a	201.7 ± 14.26 b	115.6 ± 16.35 c
Astragalin	67.2 ± 4.75 a	10.2 ± 0.72 c	0.1 ± 0.01 d	4.7 ± 0.33 d	20.8 ± 147 b	0.3 ± 0.02 d	0.6 ± 0.08 d
Epigallocatechin	3444.3 ± 243.55 b	449.2 ± 31.76 e	542.9 ± 38.39 de	2681.6 ± 189.62 c	5882.6 ± 415.96 a	642.9 ± 45.46 de	1031.3 ± 145.85 d
Epigallocatechin gallate	408.4 ± 28.88 b	130.1 ± 9.2 d	925.5 ± 65.44 a	287.6 ± 20.34 c	496.9 ± 35.14 b	479.8 ± 33.93 b	174.8 ± 24.71 d

Note: data are expressed as average value ± standard deviation of three replicates and the different letters in each line indicate significant differences ($p < 0.05$).

The research results in the Table 5 and Figure 2 demonstrate the high antioxidant activity of raspberry inflorescence. This should encourage food and pharmaceutical manufacturers to create products from them in response to consumer demand for such products. Raspberry roots are also a very good source of natural antioxidants, and can be alluded to as “superfoods” or “functional foods”.

Table 5. Antioxidant activity (µmol TE/g FW) of raspberry morphological parts.

Sample	DPPH	ABTS	FRAP
Fruits	163.1 ± 21.7 e	243.4 ± 50.5 d	273.9 ± 61.9 c
Stems	235.8 ± 22.9 d	408.5 ± 9.5 c	142.2 ± 21.7 d
Inflorescence	653.6 ± 27.3 a	1091.8 ± 35.0 a	720.0 ± 80.6 a
Roots	468.7 ± 52.1 b	977.6 ± 83.5 a	410.8 ± 48.8 b
Leaves	292.7 ± 12.6 c	559.8 ± 50.0 b	271.5 ± 36.8 c
Seeds	145.1 ± 14.3 e	285.5 ± 9.9 d	127.0 ± 15.1 d

Note: data are expressed as average value ± standard deviation of three replicates and the different letters in each column indicate significant differences ($p < 0.05$).

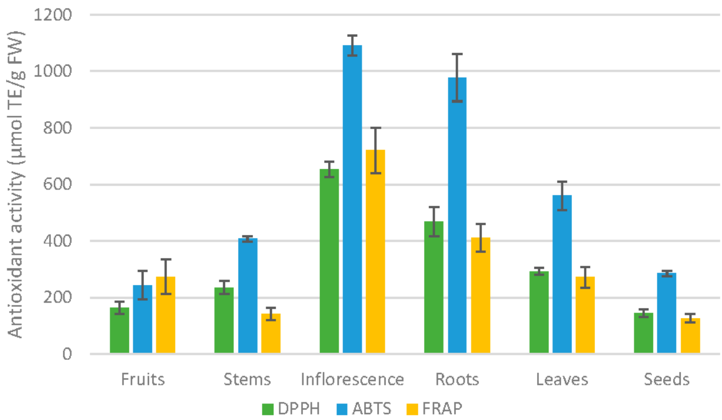

Figure 2. The antioxidant activity of the raspberry plant's different morphological parts was evaluated by using ABTS, DPPH, and FRAP assays. Values were expressed as means with standard deviation error bars.

4. Conclusions

In conclusion, this research shows that different morphological parts of the raspberry plant represent a potential source of natural food ingredients. To extract certain elements from the plant, it is necessary to find out which part of it has most of the required elements. Dissecting the different morphological parts of the plant in production would give them added value (nutritional and functional) and obtain higher productivity and higher quality production. The first study comparing the chemical composition of individual parts of the different morphological parts of the raspberry is particularly significant in the development of waste-free technologies, increasing the economic value of raspberry farms.

More and more people are analyzing product label information and paying close attention to ingredients. Regulation (EU) of the European Parliament and Council outline the requirements established by 1169/2011, which apply to food sold throughout the European Union, according to which the food manufacturer must provide all information about the composition or nutritional content of the product. Food labeling rules are created to inform and protect the consumer, because it is the information provided on the food product package, on the label attached to it, or next to the food product that helps the consumer to evaluate and choose the right food product. Voluntarily provided information about the product draws the attention of consumers and encourages consumer choice. It should be noted that not only technical parameters are regulated, but also claims about nutritional properties and health benefits of products, which must be scientifically proven, and manufacturers or importers must be able to provide scientific documents supporting this. Therefore, from a future perspective, this study can help the manufacturer to inform the consumer in more detail when providing information on vitamins and minerals under Annex XIII of the regulation, and supplement scientific research by conducting a consumer needs study according to the above-mentioned regulation. Our study revealed the importance of differentiating plant parts in production for the quality of the final product. For example, by removing the seeds or separating the leaves from the stems, products with a completely different chemical composition can be obtained. This can be highlighted by providing information to the end user in the product labeling.

The data provided by the study confirm the need to properly optimize the processing of raspberries by exploiting all parts of the plant according to its biochemical compounds, to strengthen the marketing of the products sold through areas such as labeling, consumer information, and presentation of the actual composition of the product. Studies revealed that raspberry plant parts represent a potential source of natural food ingredients and can be considered as a potential raw material for products rich in phenolic compounds or dietary fiber, which can provide healthy properties to food when used as an additive that may be economically attractive for consumers. In the future, it would be appropriate to study the processing technologies of plant parts such as flowers or roots, as they have been little researched.

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ARTICLE 3

plants

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Article

Physico-Chemical Properties, Fatty Acids Profile, and Economic Properties of Raspberry (*Rubus idaeus* L.) Seed Oil, Extracted in Various Ways

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Abstract: In Europe, the green course is becoming increasingly relevant, and there are more and more suggestions for its improvement. The valorization of food waste attracts increasing attention and is one important current research area. The aim of this study was to examine oils from 16 raspberry variety seeds and to compare their yields and fatty acid contents. The next task was to extract oil from the raspberry variety 'Polka' by four different methods and to compare the yield, colors, fatty acids content and composition, and kinematic and dynamic viscosity. The last task was to analyze the economic profitability of oil extraction by different methods. This study demonstrates the potential of different varieties of raspberry by-products and shows the influence of different oil extraction methods on the fatty acid composition of the oil and the economic potential of such products. The analysis revealed that the predominating fatty acid in the raspberry variety 'Polka' seed oil was linoleic acid (44.0–44.8%), followed by α-linolenic acid (37.9–38.1%) and oleic acid (10.2–10.6%). Of the 16 raspberry cultivars tested, 'Polka' seed oil had the least linoleic (ω-6) (44.79%) and the most α-linolenic (ω-3) fatty acids and the best ratio of ω-6 to ω-3 fatty acids—1.2:1. Raspberry variety 'Polka' seed oil contains a lot of carotenoids; their total amount depending on the extraction method varies from 0.81 mg/100 g (extracted with subcritical CO_2) to 3.25 mg/100 g (extracted with supercritical CO_2). The oil yield can be increased by grinding the seeds into a finer fraction. The most expensive method of oil production is supercritical CO_2 extraction, and the cheapest method with the fastest payback of equipment is the cold-pressing method. The results of the research have revealed the influence of different oil recovery methods on the yield of oil, the composition of the fatty acid, colors, and viscosity. The results are very important for producers wishing to commercialize raspberry seed oil.

Keywords: raspberry seed oil; sustainable products; extraction; fatty acids; by-products

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1. Introduction

Due to various application possibilities and its economic impact, the valorization of food waste has attracted increasing attention. The valorization of food waste is one important current research area because it solves both environmental and economic problems. Fruit waste valorization has gained recent significance as it can be used as an important tool to meet sustainable development goals and help to combat the carbon footprint and greenhouse gas emissions that are mostly caused by these wastes. Although some fruit by-products contain even more bioactive ingredients than the original fruit itself, they are typically seen as waste and thrown away [1].

The red raspberry (*Rubus idaeus*), a species widely known for its edible fruits, is a fruit in the genus *Rubus*, grown as a perennial crop. There are about 200 raspberry species, and most of these have red berries (European) [2,3]. Raspberry is one of the oldest fruits, has medicinal purposes, and is the fourth most important berry crop in the world. From 2010 to 2020, raspberry production has increased from 373 thousand tons to 684 thousand tons in the world [4,5]. Raspberries are greatly used in food manufacturing for purees, juices, jams, wines, etc. Raspberry seeds are an important by-product in the production process of raspberry wines and juices, but usually discarded and thus underexploited. Various researchers have discovered that due to raspberry seeds' high content of antioxidants, phenolic acids, flavonoids, polyphenols, and fibers, as well as the high amount of waste released during industry manufacturing, these by-products could be successfully recovered and used for different industry purposes. Furthermore, it is known by recent works that raspberries are particularly high not only in anthocyanin content, but also in total phenolic content [6–8].

During the processing, predominantly in the fruit and beverage industry for juice and jam production, a large number of their by-products (pomace, consisting mostly of the seeds) are produced. Since blackberry and raspberry seeds contain lipids, these by-products are very interesting as a raw material for oil manufacturing in small facilities. Therefore, berry oils are specialty oils and have been in demand on the market. These oils have a unique fatty acid profile, and they possess interesting minor components [9].

Raspberry seed components can be separated into two parts: oil and flour. The flour remains following oil extraction, which is performed by many methods, including solvent extraction and cold pressing. Seeds have very different and complex chemical compositions that are nutritionally grouped as macronutrients, micronutrients, and other components. Other components include other phytochemicals, such as phenolic antioxidants, which have demonstrated potential beneficial health properties. Seed oils also have other properties that include oxidative stability and color. These components and properties of seeds are valuable and need to be examined and reported, which may ultimately lead to increased crop values and increased farm gate profits for growers and processors [10].

The choice of a method to obtain maximum yield and highest purity varies according to the nature of the target compound. Numerous chemical and mechanical processes like solvent extraction, enzymes-assisted extraction, pulsed electric field-assisted extraction, and steam distillation are used for the extraction of compounds from plants [11–13]. In the last few years, supercritical fluid extraction (SFE) has received significant attention as a promising alternative to conventional technology for separation of various valuable compounds from natural sources [14–17]. The oil obtained in this way is much more expensive on the market than that obtained by cold pressing, and consumers have formed the opinion that such oil is correspondingly more valuable; its properties are exceptional [18].

Raspberries' bioactive compounds are recommended for use not only in daily consumption but also for helping manage or prevent various human diseases such as cancer, diabetes, neurodegenerative disorders, and cardiovascular and heart disease [19–22]. The use of pomace in the food industry can create some opportunities to lower production costs and to create a new food source for human consumption [23,24].

This paper demonstrates the potential of raspberry seed oils from 16 different raspberry varieties and physicochemical properties and, after considering the latest scientific knowledge and market trends, extracted oil from the raspberry seeds of the 'Polka' variety using different oil extraction methods. The aim of this study was also to determine the yield and fatty acid content of the oil obtained by different methods and to determine the effect of grounding the seeds into a smaller fraction on oil yield, to compare the yield, colors, fatty acids, kinematic and dynamic viscosity, moisture, and volatile matter content.

With the rapid development of technology and increasing competition, raspberry growers need to be committed to long-term investment to stay in the market. To increase the value of business entities, which is most affected by capital investments in new technologies, existing and new business areas, and production development, research, and improvement, it is necessary for companies to properly coordinate the capital investment system, plan raw materials and production volumes, and thus select the most suitable investment projects. This study also considered the economic aspects of raspberry production. The results of the analyses will serve as a starting point for expanding and continuing the research on the influence of various factors on raspberry yields and the economic effectiveness of production.

2. Results and Discussion

In the food industry, seeds are usually thrown away as waste from the production process, but they can be used to create valuable products using zero-waste processing technologies, thereby reducing losses for producers. When processing raspberries into juice or puree, the pomace of the studied raspberry varieties ranges from 18.9% ('Toma') to 7.6% ('Willamette') (Figure 1), the average of 16 varieties is 13.1%. The seeds contain quite a lot of oil. According to the literature, the oiliness of seeds of plants of the genus Rubus varies in the range of 12–21%, black currant seeds contain up to 26.15% oil, blackberry seeds contain up to 15.68%, blueberry seeds contain up to 13.27%, and quince seeds contain up to 17.30%. When extracting the seeds of 16 raspberry cultivars grown in Lithuania with the solvent hexane, the average oil yield was 15.50%. The highest oil content was obtained from 'Volnica' raspberry seeds (20.40%) and the lowest from 'Nagrada' seeds (12.10%). The yield of 'Polka' oil, the most widely grown variety in Europe and Lithuania, was 13.50%. Raspberry seed oil yield from different varieties is presented in Figure 2.

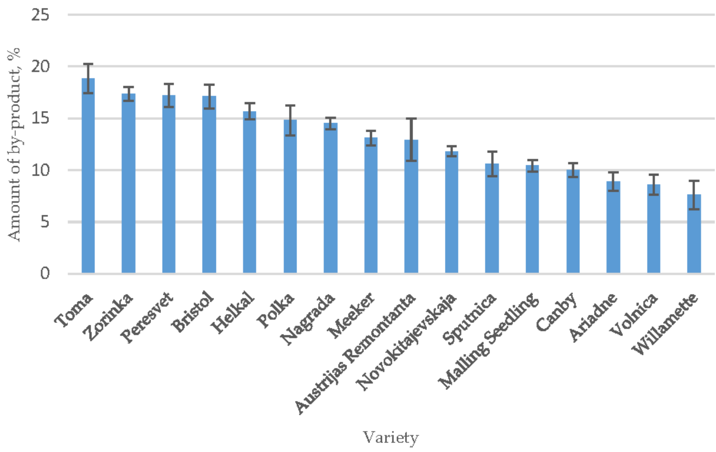

Figure 1. Amount of by-products of different raspberry berry varieties.

Edible seed oil contains saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids and other valuable bioactive substances, such as tocopherols and tocotrienols, polyphenols, phytosterols, lignans, triterpene, carotenoids, and chlorophylls [25]. Polyunsaturated fatty acids are further classified into ω-3, ω-6, and ω-9 fatty acids. Omega-3 and 6 (ω-3 and ω-6) are called essential fatty acids, because they are acquired only through food consumption and cannot be synthesized by mammals on their own. A pilot study on major depressive disorder and cardiovascular disease patients showed a strong association with polyunsaturated fatty acids, and the authors concluded that it confirms its preventive role in these diseases [26]. A total of 16 raspberry varieties ('Polka', 'Zorinka', 'Willamette', 'Volnica', 'Nagrada', 'Austrijas remontanta', 'Toma', 'Helkal', 'Novokitajevskaja', 'Sputnica', 'Canby', 'Bristol', 'Ariadne', 'Malling Seedling', 'Peresvet', and 'Meeker') seeds were studied to identify fatty acids. Raspberry seed oil contains 26 fatty acids, of which the most important are linoleic (C18:2) and α-linolenic (C18:3) acids. The amount of linoleic acid (ω-6) in different varieties of raspberry oil ranged from 57.7 ('Willamette') to 44.8% ('Polka'), and the amount of α-linolenic acid (ω-3) ranged from 25.2 ('Helkal') to 37.2% ('Polka') (Table 1). The third in the amount of raspberry seed oil contains oleic acid (C18:1), and its amount in different varieties of seed oil ranged from 7.8 ('Bristol') to 16.9% ('Helkal'). Linoleic acid is very important for health; it is the most common acid in human epidermis, directly related to the synthesis of ceramides, which support healthy skin barrier function [27,28].

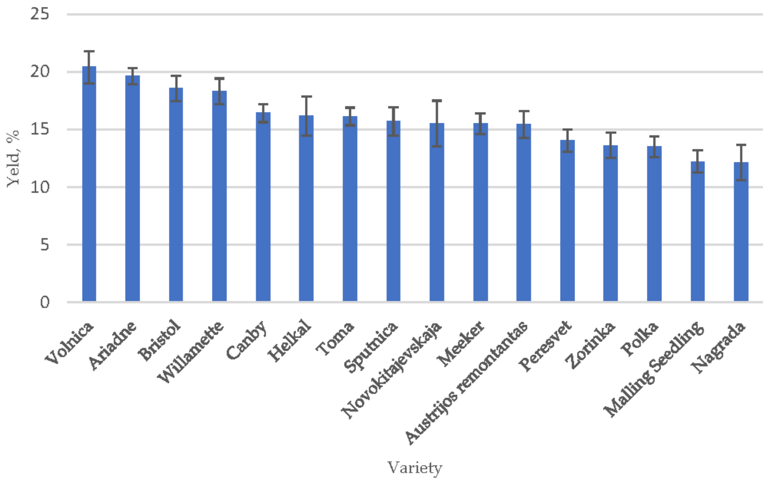

Figure 2. Oil yields from the raspberry seeds.

Table 1. Fatty acid composition of raspberry seed oil of different varieties, %.

Raspberry Varieties	α-Linolenic Acid (ω-3)	Linoleic Acid (ω-6)	Oleic Acid (ω-9)	Palmitic Acid
'Ariadne'	28.8 ± 2.1 bcd	54.1 ± 2.5 a	11.8 ± 0.8 b	2.6 ± 0.2 ab
'Austrijas Remontanta'	29.9 ± 2.0 bcd	53.8 ± 2.2 a	10.4 ± 1.0 bc	2.8 ± 0.3 ab
'Bristol'	33.2 ± 2.0 ab	54.3 ± 2.1 a	7.8 ± 0.9 c	1.9 ± 0.2 ab
'Canby'	26.5 ± 1.7 d	55.8 ± 2.4 a	11.1 ± 0.9 bc	3.0 ± 0.2 a
'Helkal'	25.2 ± 2.0 d	53.0 ± 2.9 a	16.9 ± 1.2 a	2.1 ± 0.2 ab
'Malling Seedling'	32.5 ± 2.1 abc	51.4 ± 2.9 ab	10.3 ± 1.9 bc	2.5 ± 0.5 ab
'Meeker'	29.7 ± 1.9 bcd	54.4 ± 2.0 a	10.2 ± 1.0 bc	2.8 ± 0.6 ab
'Nagrada'	30.5 ± 2.2 bcd	51.4 ± 2.2 ab	12.3 ± 0.9 b	2.5 ± 0.4 ab
'Novokitajevskaja'	27.0 ± 1.8 cd	56.9 ± 1.6 a	10.5 ± 1.3 bc	2.6 ± 0.4 ab
'Peresvet'	30.8 ± 2.1 bcd	53.8 ± 2.2 a	9.9 ± 1.0 bc	2.5 ± 0.4 ab
'Polka'	37.2 ± 1.9 a	44.8 ± 2.0 b	10.6 ± 1.0 bc	1.8 ± 0.3 b
'Sputnica'	30.3 ± 2.1 bcd	54.9 ± 2.1 a	9.7 ± 1.1 bc	2.4 ± 0.4 ab
'Toma'	29.5 ± 1.9 bcd	55.4 ± 2.1 a	10.1 ± 1.0 bc	2.4 ± 0.4 ab
'Volnica'	30.1 ± 1.9 bcd	54.3 ± 2.3 a	10.0 ± 1.1 bc	2.6 ± 0.6 ab
'Willamette'	25.7 ± 2.1 d	57.7 ± 2.1 a	11.2 ± 1.1 b	2.5 ± 0.5 ab
'Zorinka'	28.0 ± 1.0 bcd	54.1 ± 2.0 a	12.0 ± 2.0 b	2.6 ± 0.4 ab

Values are expressed as the mean ± standard deviation ($n = 3$). Values with different letter superscripts at different columns are considered significantly different at $p < 0.05$.

Raspberry seed oil was characterized by a low (close to optimal) ω-6 and ω-3 fatty acid ratio (Figure 3). The optimal ω-6/ω-3 fatty acid ratio is 1:1 to 2:1 [29]; their balance is an important determinant in decreasing the risk for coronary heart disease, arthritis, diabetes, hypertension, cancer, and other autoimmune and possibly neurodegenerative diseases. The ratio of ω-6 to ω-3 fatty acids in raspberry seed oil tested ranged from 1.63:1 ('Bristol') to 2.25:1 ('Willamette'). Of the 16 raspberry cultivars tested, 'Polka' seed oil had the least linoleic (ω-6) (44.79%) and the most α-linolenic (ω-3) fatty acids and the best ratio of ω-6 to ω-3 fatty acids—1.2:1. The content of saturated fatty acids in raspberry seed oils amounted to less than 5% of the total fatty acids (Table 1).

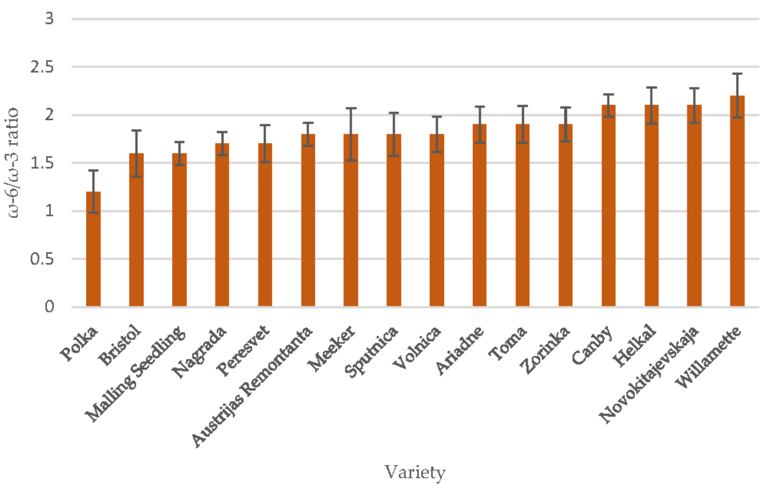

Figure 3. ω-6/ω-3 fatty acid ratio of raspberry seed oil of different varieties.

The unique composition of fatty acids and other useful physical and chemical properties indicate the potential for the use of raspberry seed oil in the food, pharmaceutical, cosmetic, and other industries. Raspberry seed oil is rich in ω-3 fatty acids, so it is nutritionally valuable and can be used as a food additive or supplement. It is certain that raspberry seed oil makes a great addition to an organic product because of its fatty acid composition. The ratio of ω-6 (linoleic) to ω-3 fatty acids in the oil is very favorable for nutrition (approximately 1.4:1), while a diet rich in saturated fatty acids increases the risk of obesity, type 2 diabetes, cardiovascular disease, and many other diseases [30–33]. In addition, the extraction of oil from raspberry seeds would allow the full use of natural resources and thus reduce environmental pollution.

The yield of raspberry seed oil depends on varieties and extraction with different methods and other factors, like how dry the seeds are, how finely they are ground, their temperature, and the pressure during pressing.

In the second stage, the amount of oil from the raspberry seed variety 'Polka' obtained by different methods was determined. The study found that the highest amount of oil was obtained by supercritical extraction (18.81%), and the lowest amount was obtained by cold pressing (11.2%). The separation of extraneous substances and water by centrifugation and filtering from the oil changed the amount of pure oil obtained. The lowest yield of pure oil is obtained by subcritical CO_2 extraction (7.8%), and the highest yield is obtained using the solvent hexane (13.5%). The results of the study showed that grinding raspberry seeds into a smaller fraction can yield a larger amount of oil. In this case, grinding raspberry seeds through a 1 mm sieve gave an oil yield of 16.79%, while grinding through a 0.5 mm sieve increased the yield to 18.81%, i.e., 2.02% more oil was obtained by supercritical extraction. Crude and pure raspberry seed oil yields extracted with different methods are presented in Table 2.

Table 2. Oil yield of raspberry variety 'Polka' seeds extracted with different methods.

Method of Extraction	Crude Oil Yield, %	Pure Oil Yield, %
Solvent (hexane)	13.5 ± 0.4 [a]	13.5 ± 0.7 [d]
Cold pressing	11.2 ± 0.3 [b]	9.1 ± 0.3 [e]
Subcritical CO_2	11.9 ± 0.5 [c]	7.8 ± 0.4 [a]
Supercritical CO_2 (particle size of 1 mm)	16.79 ± 0.6 [d]	12.1 ± 0.4 [b]
Supercritical CO_2 (particle size of 0.75 mm)	17.98 ± 0.6 [e]	12.6 ± 0.6 [b]
Supercritical CO_2 (particle size of 0.5 mm)	18.81 ± 0.8 [f]	12.9 ± 0.5 [bc]

Values are expressed as the mean ± standard deviation. Values with different letter superscripts at different columns are considered significantly different at $p < 0.05$.

Raspberry seed oil is rich in essential fatty acids, primarily linoleic and linolenic acids. Because of its composition, raspberry seed oil possesses superior anti-inflammatory qualities, which makes it a nice addition to face, lip, and sunscreen products [34–36]. In practice, it is very important to know the most efficient way and quality of product extraction. In this context, fatty acids in oils extracted in different ways were analyzed. The results revealed that the oil extraction methodology is not significant for the fatty acid content in the oil (Table 3).

Table 3. Fatty acid composition of seed oil (variety 'Polka') extracted with different methods, g/100 g.

Extraction Method	Linoleic (ω-6)	α-Linolenic (ω-3)	Oleic (ω-9)	Palmitic
Solvent (hexane) extraction	44.8 ± 2.0 [a]	37.2 ± 1.9 [a]	10.6 ± 1.0 [a]	1.8 ± 0.3 [a]
Cold pressing	44.8 ± 0.9 [a]	37.7 ± 0.6 [a]	10.4 ± 0.7 [a]	1.9 ± 0.2 [a]
Supercritical CO_2 extraction	44.0 ± 0.7 [a]	37.9 ± 0.8 [a]	10.2 ± 0.7 [a]	2.1 ± 0.3 [a]
Subcritical CO_2 extraction	44.0 ± 0.4 [a]	38.1 ± 1.1 [a]	10.3 ± 0.9 [a]	2.1 ± 0.6 [a]

Values are expressed as the mean ± standard deviation. Values with different letter superscripts at different columns are considered significantly different at $p < 0.05$.

Another very important active substance is carotenoids, which cannot be produced by humans, and carotenoid-rich foods and supplements are their main dietary sources. The major carotenoids in foods and the most studied in relation to human health are the three hydrocarbon carotenes: α-carotene, β-carotene, and lycopene. β-carotene is the most widely distributed and the most important provitamin A carotenoid.

Raspberry seed oil contains a lot of carotenoids; their total amount, depending on the extraction method, varies from 0.81 mg/100 g (extracted with subcritical CO_2) to 3.25 mg/100 g (extracted with supercritical CO_2) (Figure 4). Britton and Khachik (2009) suggested a useful criterion to facilitate the categorization of carotenoid content in a particular food so that the level of a specific carotenoid can be classified into four different concentration groups: low (0–0.1 mg/100 g), moderate (0.1–0.5 mg/100 g), high (0.5–2 mg/100 g), or very high (>2 mg/100 g).

Regarding the obtained results, it can be said that raspberry seed oils obtained by different extraction methods presented high or very high levels of carotenoid concentration. The best concentration level of carotenoids obtained is from supercritical CO_2 extraction, and the lowest concentration was detected in the oil obtained by the subcritical CO_2 method (Figure 4). The lowest amount of β-carotene is also found in the oil extracted with subcritical CO_2 (0.35 mg/100 g), but the percentage of β-carotene in the oil extracted in this way is the highest and reaches 43.21% of the total amount of carotenoids.

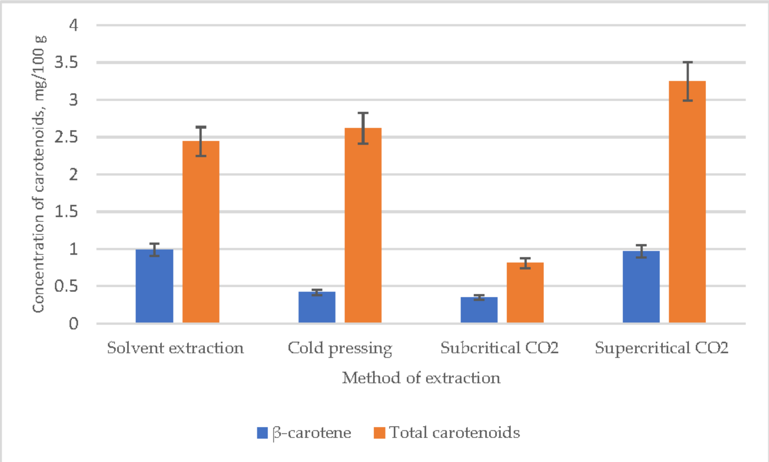

Figure 4. Effect of different extraction methods on the total carotenoids and *β*-carotene content.

In addition to carotenoids, another very important group of fat-soluble antioxidants and vitamins are tocopherols. *α*-tocopherol is also known as vitamin E. Raspberry seed oil contains from 19.8 to 888 mg/100 g of carotenoids depending on the raspberry variety and extraction method [37,38]. Different amounts of tocopherol isomers are found in raspberry variety 'Polka' seed oil depending on the oil extraction method (Figure 5).

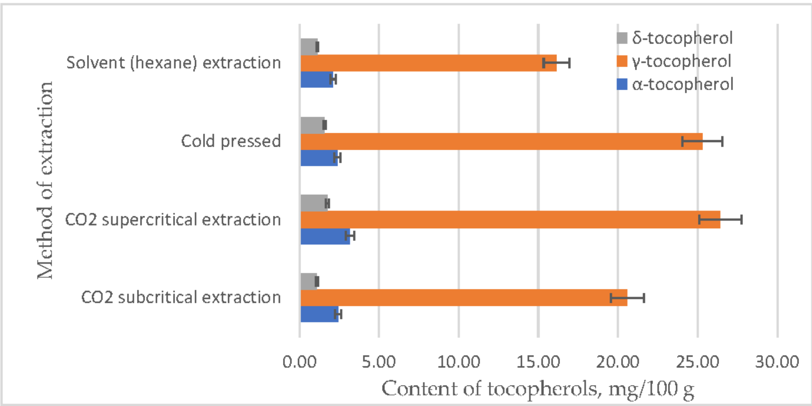

Figure 5. Effect of different extraction methods on the tocopherol isomers content in raspberry seed oil.

Raspberry seed oil contains the most γ-tocopherol, from 16.1 mg/100 g (solvent extraction) to 26.4 mg/100 g (CO_2 supercritical extraction) (Figure 5). The amount of α-tocopherol is found to be about eight times less than that of γ-tocopherol, from 2.1 mg/100 g (solvent extraction) to 3.2 mg/100 g (CO_2 supercritical extraction) (Figure 5). The amount of δ-tocopherol is found to be even lower, from 1.1 mg/100 g (solvent extraction) to 1.8 mg/100 g (CO_2 supercritical extraction). Only traces of β-tocopherol are detected. The extraction method also affects the total amount of tocopherols: the most tocopherols are extracted by CO_2 supercritical extraction and the least by solvents (hexane), at 31.4 mg/100 g and 19.4 mg/100 g, respectively.

Crude raspberry seed oil is slightly cloudy and yellowish in color. Raspberry seed oil can range from clear yellow to light brown, depending on how the oil is extracted. This yellowish tinge to the oils is given by carotenoids. A yellowish tint is desirable because it gives the oil the characteristic butter-like appearance, especially in the case of oils without the addition of conventional dyes that are often used in the food industry.

The lightest in tint (L—44.9%) was the oil extracted with subcritical CO_2. Other extraction methods had little effect on the brightness of the oil. The oil extracted with subcritical CO_2 was distinguished from the oil extracted by other methods by the lowest *a** color coordinate (*a**—3.5 NBS units), which indicates that its red color component is small and it is neither red nor green. The larger *b** color coordinate (*b**—39.8 NBS units) shows a large dominance of the yellow component compared to the blue one (Figure 5). This is also confirmed by the chroma (C—40.0 NBS units) and the hue angle of 85.0°, which shows that the color of the oil is very close to pure yellow. Meanwhile, the oil extracted by other methods has a greater shade of red, characteristic of the carotenoid lutein.

Refractive index (n) and density (d) are very important physicochemical indicators characterizing oil. There are very few studies characterizing red raspberry seed oil. Parry and co-authors found [38] that red raspberry seed cold-pressed oil had a refractive index of 1.4788 and a density of 0.929 g/mL. It was found that the influence of different extraction methods on the refractive index and density of red raspberry Polka seed oil is not significant (Table 4). The changes in refractive index and oil density during the extraction of raspberry seed oil by different methods probably depend on the fatty acid composition of the extracted oil.

Table 4. Effect of extraction method on the refractive index and density of red raspberry variety 'Polka' seed oil.

Method of Extraction	Refractive Index at 20 °C	Oil Density, g/cm^3
Solvent (hexane) extraction	1.4832 ± 0.22 ^{a}	0.9258 ± 0.19 ^{a}
Cold pressing	1.4831 ± 0.23 ^{a}	0.9311 ± 0.21 ^{a}
Supercritical CO_2 extraction	1.4829 ± 0.19 ^{a}	0.9334 ± 0.21 ^{a}
Subcritical CO_2 extraction	1.4835 ± 0.17 ^{a}	0.9366 ± 0.18 ^{a}

Values are expressed as the mean ± standard deviation. Values with different letter superscripts in different columns are considered significantly different at $p < 0.05$.

As viscosity changes the flow properties of liquid food and influences the appearance and consistency of a product, this measuring variable is important in most production stages. Viscosity is a major factor in determining the forces that must be overcome when fluids are used in lubrication and transported in pipelines. It controls the liquid flow in such processes as spraying, injection molding, and surface coating. So, this criterion is important for oil producers when choosing equipment for production, packaging, or offering products to customers. In the chemical and cosmetic industry, viscosity testing is a very important parameter for quality control. By measuring the viscosity of products such as toothpaste, cough syrup or ointment, ink, paint, and coatings, manufacturers can predict how products will behave once they are in the hands of the consumer. Analyzing the viscosity to simulate the sample's processability during production, as well as the application behavior to ensure customer satisfaction, is one of several test methods in quality control.

Research results show that the dynamic viscosity of raspberry seed oil decreases exponentially (Figure 6, Table 5) with increasing temperature. The coefficient of determination of the temperature dependence of the dynamic viscosity of raspberry seed oil obtained by various methods is high (R^2 is from 0.988 to 0.991) (Table 5), which indicates a very strong correlation between the dynamic viscosity and temperature. If at a temperature of 0 °C (simulating storage conditions), differences in oil dynamic viscosity are visible depending on the method of oil extraction, then close to human body temperature (which is relevant when using oil as a cosmetic), the dynamic viscosity is practically the same and reaches 22.3 ± 1.45 mPa·s. Analogous regularities are also observed when analyzing kinematic viscosity (Table 5).

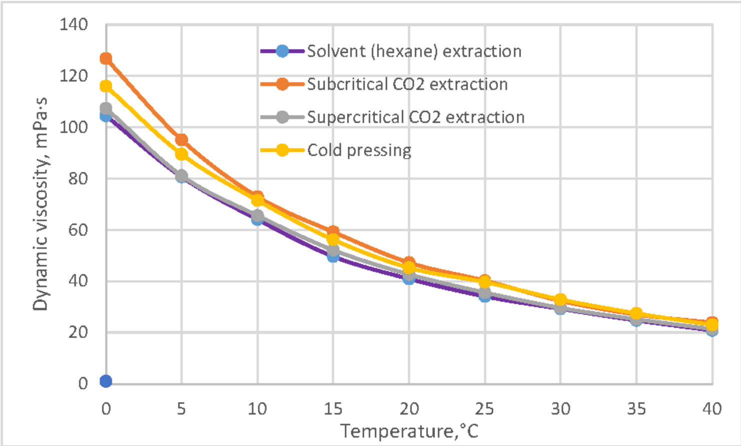

Figure 6. Dynamic viscosity of raspberry seeds oil extracted by various methods.

Table 5. Temperature dependence of dynamic and kinematic viscosity of Polka raspberry seed oil extracted by various methods.

Method of Extraction	Dynamic Viscosity, mPa·s		Kinematic Viscosity, $mm^2 \cdot s^{-1}$	
	Regression Equation	Coefficient of Determination R^2	Regression Equation	Coefficient of Determination R^2
Solvent (hexane) extraction	$y = 96.527e^{-0.04x}$	0.991	$y = 104.98e^{-0.04x}$	0.991
Cold pressing	$y = 107.91e^{-0.04x}$	0.991	$y = 116.2e^{-0.04x}$	0.991
CO_2 supercritical extraction	$y = 99.178e^{-0.04x}$	0.990	$y = 106.79e^{-0.04x}$	0.991
CO_2 subcritical extraction	$y = 115.49e^{-0.042x}$	0.988	$y = 128.46e^{-0.043x}$	0.987

For the calculation of variable and fixed costs, average prices in Lithuania were taken: an average salary of 10.49 EUR/h, electricity cost of 0.167 EUR/kWh, water cost of 2.5 EUR/m^3, packaging cost for oil glass bottle with a label of 0.7 EUR/unit, packaging cost for puree—bag-in-box 3 kg—of 0.9 EUR/pc, and raw material production (raspberries) cost of 3.5 EUR/kg. To calculate other fixed costs of the company's own production, administration, maintenance, marketing, communication services, and insurance fees were included. When the company chose to buy the service during the production, the following service prices were calculated: seed boning service cost of 0.2 EUR/kg, seed drying service cost of 0.7 EUR/kg, seed milling service cost of 1.5 EUR/kg, oil extraction service with solvent cost of 3.0 EUR/kg, seed cold-pressing cost of 12.0 EUR/kg, seeds CO_2 extractions service cost of 4.0 EUR/kg, and puree pasteurization and bottling service costs of 1.0 EUR/kg.

The average market price of raspberry seed oil in the EU is 12.5 EUR/100 mL, and that of 100% raspberry puree is 8 EUR/kg. Equipment prices were calculated based on a survey of EU, Chinese, and US standard equipment suppliers and their commercial offers.

Biorefining 1 ton of raspberry variety 'Polka' yielded 85.5% pulp and 14.5% by-product of 9% seeds. The production of puree from one ton of raspberries leaves an average of 90 kg of seeds. After drying (till the moisture content of seeds is 8.64%), about 34% of the material remains, which is 30.6 kg.

Different production methods have revealed the need to assess the potential risks of investing in raspberry biorefining processes (oil and puree production). The maximum oil content of 4131 mL is obtained by using the solvent hexane. It has been found that investing in equipment requires a minimum of 29.04 kg raspberry seeds to be processed to pay off the annual depreciation of the equipment, but such oil is negatively evaluated by scientists and consumers due to the possible residues of the chemical solvent in the oil, which may cause the company to have difficulties in marketing such a product.

The lowest oil content is obtained by extracting raspberry seeds by subcritical CO_2. This method also stands out as one of the highest depreciations of fixed assets. A total of 119,920 mL of oil is required to cover the annual depreciation costs of the equipment.

The most expensive method of oil production is supercritical CO_2 extraction. As much as 159,920 mL of oil is needed to cover the annual cost of this equipment. The most optimal way to extract the oil is by cold pressing, because it is obtained in the "green" way, the payback costs of the equipment are not high, it takes the least time to produce it, and no special knowledge is required during operation.

From the data obtained, it can be concluded that it would be unprofitable for a company to invest in fixed assets to produce a small amount of production per year, as the profit obtained does not fully cover the depreciation costs. Profits can be made by choosing to purchase a service, or the company should provide the services itself and produce larger quantities to offset the costs.

The yield of oil and puree from the raspberry variety 'Polka', the costs of producing products in economically different ways, the cost of equipment and annual depreciation, the cost of production of oil and puree services, and the potential sales revenue, profit, and the need for raw material to cover the annual depreciation costs of the equipment are given in Table 6.

Table 6. Economic indicators of raspberry processing.

Raspberry Production	RSO Solvent (Hexane) Oil Extraction	RSO Cold Pressing of Oil	RSO CO_2 Subcritical Oil Extraction	RSO CO_2 Supercritical Oil Extraction	Puree Production
Production yield from 1 ton of raspberries (30.6 kg dry molded seeds and 855 kg puree) mL	*Pure oil 4131*	*Pure oil 3397*	*Pure oil 2387*	*Pure oil 3703*	*Puree (100% berries) 855,000*
Independent production from 1 ton of raspberries					
Investment in equipment	*Solvent extraction equipment (2000 mL) is EUR 5000*	*Oil press machine (10–30 kg seeds per hour) is EUR 13,000*	*10 L extractor is EUR 150,000*	*10 L extractor is EUR 200,000*	*Heating 150 L tank with volumetric filling machine EUR 45,000*
1. **Fixed costs per year**					
1.1. Annual depreciation amount of equipment	*490*	*1290*	*14,990*	*19,990*	*4490*
1.2. Other fixed costs per year	*15,000*	*15,000*	*15,000*	*15,000*	*15,000*
2. **Variable costs**					
2.1. Working hours 2.2. salary	*9* *94.41*	*2* *41.96*	*16* *167.84*	*7* *73.43*	*8* *83.92*
2.3. Electricity and water	*32.56*	*15.86*	*55.94*	*25.88*	*29.22*
2.4. Packaging	*28.70*	*23.80*	*16.80*	*25.90*	*270.00*
2.5. Raw material	*350.00*	*350.00*	*350.00*	*350.00*	*3150.00*
Total	***15,995.67***	***16,721.62***	***30,580.58***	***35,465.21***	***23,023.14***

Table 6. *Cont.*

Raspberry Production	RSO Solvent (Hexane) Oil Extraction	RSO Cold Pressing of Oil	RSO CO_2 Subcritical Oil Extraction	RSO CO_2 Supercritical Oil Extraction	Puree Production
Production of products by purchasing a service of 1 ton of raspberries					
Seed boning service	*180*	*180*	*180*	*180*	*180*
Seed drying, milling, and extraction service	*201*	*170*	*231*	*231*	-
Puree pasteurization and bottling service	-	-	-	-	*900*
Packaging	*29*	*24*	*17*	*26*	*270*
Raw material	*350*	*350*	*350*	*350*	*3150*
Total	***759***	***724***	***778***	***787***	***4500***
Summary and comparison of economically different productions					
Potential sales revenue (average market price in EU)	*516*	*425*	*298*	*462*	*7200*
Profit (loss) (Independent production)	*−15,479*	*−16,296*	*−30,282*	*−35,003*	*−15,823*
Profit (loss) (service)	*−243*	*−300*	*−480*	*−325*	*2700*
The amount of production required to cover the depreciation costs of the equipment in mL	*3920*	*10,320*	*119,920*	*159,920*	*62,361*
The need for raw material to cover the annual depreciation costs of the equipment (dry molded seeds/kg)	*29*	*93*	*1537*	*1322*	*62,361*

3. Materials and Methods

3.1. Plant Material and Its Preparation

In the first stage, raspberry seeds (*Rubus idaeus* L.) were of the 16 varieties: 'Polka', 'Austrijas Remontanta', 'Bristol', 'Volnica', 'Willamette', 'Malling Seedling', 'Ariadne', 'Novokitajevskaja', 'Meeker', 'Helkal', 'Zorinka', 'Toma', 'Peresvet', 'Sputnica', 'Nagrada', and 'Canby'. After pressing the berries, the pomace was collected and dried in a convection dryer (thickness of approx. 0.5 cm) at temperature (40 °C) for 24 h, with occasional stirring. Raspberry seeds were ground in an ultra-centrifugal rotor mill ZM200 (Retsch, Haan, Germany) using 0.2 mm particle size sieve, but the process was stopped for 15 s at 15–30 s intervals to avoid heating the sample.

In the second stage, the Polish primocane raspberry variety 'Polka' was selected for more detailed research. This variety has been chosen as currently the most popular and one of the main cultivated raspberry varieties grown in the world, with excellent quality dessert berries and a rich harvest. This variety has also attracted a great deal of interest from scientists.

Fresh raspberries were taken from Audrones Ispiryan's Lithuanian national quality certified farm (GPS coordinates: 55°47′42.2″ N 22°44′59.0″ E). The cultivation process on the farm is distinguished by its naturalness, nutrition, and environmental aspects. It has limited use of protective equipment and no use of environmentally harmful plant protection products. Raspberry seeds were obtained by separating them by using de-stoning machine EP500 (VORAN Maschinen GmbH, Pichl, Austria). The seeds were dried naturally at approximately 25–28 °C and grounded in a rotary beater mill SR 300 (Retsch, Germany) using a 1 mm sieve (with an average particle size of 1 mm) and stored in hermetically closed glass jars in a dark, dry room until the oil was extracted. To determine the effect of raspberry seed grounding on oil yield, seeds were grounded using 1 mm, 0.75 mm, and 0.5 mm sieves (with an average particle size of 1 mm, 0.75 mm, and 0.5 mm). The moisture content of seeds was 8.64%. Humidity was determined with moisture analyzer MOC63u (Shimadzu).

In the third stage, oil was extracted from raspberry seeds via 4 different methods: solvent extraction, cold extraction/pressing, extraction with subcritical CO_2, and extraction with supercritical CO_2.

3.2. Solvent Extraction

A total of 1 kg of the ground raspberry seeds were placed in a 3 L glass vessel and filled with hexane. The extraction is carried out for 24 h at a temperature of 25 ± 2 °C in dark with stirring. The solvent was removed by vacuum filtration, and the sample was extracted twice. After the last filtration, the extract was pooled, hexane was removed with a vacuum rotary evaporator Rotavapor R-205 (BÜCHI Labortechnik AG, Flawil, Switzerland) at 35 ± 2 °C and 170 mbar pressure, purged with nitrogen, and stored at −18 °C until analysis.

3.3. Cold Extraction/Pressing

Cold extraction/pressing of the oil was carried out with the cold pressing Machine PR-H100/1 (1Head) (Oil press GmbH & Co. KG, Reut, Germany) at a speed of 10 Hz (8 RPM), capacity of 2.38 kg/h, and yield of oil of 0.3 kg/h. The oil was extracted from 9 kg of raspberry seeds and stored at −18 °C until analysis.

3.4. Extraction with Subcritical CO_2

The oil was extracted with subcritical CO_2 at a pressure of 5 MPa and a temperature of 10 °C for 16 h with a subcritical extractor Eco Extractum, Lithuania [39]. Pure oil was purged with nitrogen and stored at −18 °C until analysis.

3.5. Extraction with Supercritical CO_2

The supercritical extraction experiments were carried out using supercritical fluid extractor SFT-150 (Supercritical Fluid Technologies, Newark, DE, USA). Each extraction was performed using 50 g of ground dried raspberry seed sample. Each sample was loaded into 150 mL thick-walled stainless cylindrical extractor vessel with 5-micron frits. The temperature (60 ± 2 °C) of the extraction vessel was controlled by a surrounding heating jacket. The volume of CO_2 consumed was measured by a gas flow meter Gallus 2000 (Schlumberger Industries, Guebwiller, France) and expressed in standard liters per minute (SL/min). Flow rates were 1.4 SL/min. The process consisted of static (120 min) and dynamic (300 min) extraction steps. The static extraction time was included in the total extraction time of 420 min.

Pure oil was purged with nitrogen and stored at −18 °C until analysis.

3.6. Chemicals, Solvents, and Gasses

CO_2 and N_2 were obtained from Gaschema (Jonava, Lithuania); α-tocopherol, β-tocopherol, γ-tocopherol, δ-tocopherol, β-carotene, and hexane were obtained from Sigma-Aldrich (Steinheim, Germany).

3.7. Determination of Fatty Acid

Fatty acid composition for raspberry seed oil was determined as described by ISO 12966-1: 2015 [40]; ISO 12966-2: 2017 [41]. All oil analyses were performed with filtered oil.

3.8. Determination of Carotenoids

The total amount of carotenoids and *β*-carotene content were determined by HPLC method according to [17], with slight modifications. The oil samples (1.0 ± 0.01 g) were extracted with a 10 mL of n-hexane containing 1% butylhydroxytoluene (BHT), then filtered through a 0.45 mm polyvinylidene fluoride (PVDF) syringe filter (Millipore, Burlington, MA, USA). The total carotenoids and *β*-carotene contents were analyzed using the HPLC method on a Waters HPLC system consisting of 2695 liquid separation module, UV–Vis detector UV–Vis 2489 (Waters Corporation, Milford, MA, USA), and equipped with an RP-C30 column, (5 µm, 4.6 × 250 mm, YMC™ Europe, Dinslaken, Germany) connected to a C30 guard column (5 µm, 10 × 4.0 mm, YMC Europe, Dinslaken, Germany). The flow rate was 0.65 mL/min, column temperature was 22 °C, and *β*-carotene was detected at 450 nm. The mobile phase consisted of methanol (solvent A) and methyl-tert-butyl ether (solvent B). The samples were injected at 1% B (held 1 min), and the gradient then changed to 100% B (1−90 min) and again to 1% B in 5 min (held 5 min). For quantification, a calibration curve was produced using an authentic all-trans-*β*-carotene standard (concentration range was from 0.1 to 5.0 mg/100 mL).

3.9. Determination of Tocopherols

Analysis of tocopherols was performed by HPLC according to Brazaityte et al.'s [25] methodology with some modifications. About 1 mg of oil was weighed in an Eppendorf tube, and then 1 mL of n-hexane with 1% of BHT was added to the tube. Afterward, the samples were filtrated through a 0.45 µm polytetrafluoroethylene (PTFE) membrane syringe filter (VWR International, Radnor, PA, USA) and were analyzed by HPLC/FLD (fluorescence detector) (Agilent Technologies, Santa Clara, CA, USA). The HPLC measurements were performed using a normal phase column (Phenomenex Luna Silica, 5 µm, 250 mm × 4.6 mm). The HPLC 10A system, equipped with an RF-10A fluorescence detector (Shimadzu, Japan), was used for analysis. Peaks were detected at an excitation wavelength of 295 nm and an emission wavelength of 330 nm. The mobile phase (0.5% isopropanol in hexane) was used at a flow rate of 1 mL min^{-1}. The α-tocopherol, γ-tocopherol, and δ-tocopherol were identified according to the analytical standard. The α-tocopherol, γ-tocopherol, and δ-tocopherol content were expressed per 100 g of oil.

3.10. Color Measurement

The color coordinates of the oil samples in the CIE L*a*b* color space were measured with a MiniScan XE Plus spectrophotometer (Hunter Associates Laboratory, Inc., Reston, VA, USA). The parameters evaluated during reflected-color measurements were L*, a*, and b* (brightness and red and yellow coordinates according to the CIE L*a*b* scale, respectively), and color saturation (the chroma value) was calculated ($C = (a^{*2} + b^{*2})^{1/2}$). The values L*, a*, b*, and C* were measured in NBS units. The NBS unit is a unit of the U.S. National Bureau of Standards and meets one color resolution threshold, i.e., the smallest difference in a color that can be captured by a trained human eye. Prior to each series of measurements, the spectrophotometer was calibrated with a light trap and a white standard with the following color coordinates in the XYZ color space: X = 81.3, Y = 86.2, and Z = 92.7. The value of L* indicated the ratio of white to black, the value of a* indicated the ratio of red to green, and the value of b* indicated the ratio of yellow to blue. Five replications were taken for the analysis. The color coordinates were processed by the Universal Software V. 4-10.

3.11. Determination of Kinematic and Dynamic Viscosity

The dynamic viscosity of raspberry oil was determined with a Höeppler Viscometer' B3 (Carl Zeiss Jena, Leipzig, Germany) using a Hoeppler falling ball viscometer in a 10° cylinder filled with oil. The dynamic viscosity is calculated according to the equation

$$\eta = t \cdot (\rho_1 - \rho_2) \cdot K,$$

where

η—viscosity, mPa·s;
t—time of descent from top to bottom annular mark, s;
ρ_2—density of liquid, g/cm^3;
ρ_1—density of ball, g/cm^3;
K—ball constant, mPa·cm^3/g.

Thermostating was performed with refrigerating/heating circulators PolyScience Model 912 (Niles, IL, USA), at temperature stability ±0.1 °C.

3.12. *Assay of Raspberry Oil Density*

Density was determined picnometrically according to AOAC Official Method 9201.212 at 20 °C. The accuracy of the density determination was about 1×10^{-4} g/cm^3.

3.13. *Determination of Refractive Index*

The refractive index was determined according to ISO 6320:2017 at 20 ± 0.1 °C temperature with a Carl Zeiss Abbé refractometer Model I. The measurement was repeated five times.

3.14. *Determination of Need for Raw Material to Cover the Annual Depreciation Costs of the Equipment*

A cost–benefit analysis method was used to assess the economic efficiency of the technologies. A cost–benefit analysis (CBA) is the process used to measure the benefits of a decision or taking action minus the costs associated with taking that action. A cost–benefit analysis is a systematic process that businesses use to analyze which decisions to make and which to forgo. The cost–benefit analysis sums up the potential rewards expected from a situation or action and then subtracts the total costs associated with taking that action. CBA involves measurable financial metrics—as revenue earned or costs saved as a result of the decision to pursue the project of a raspberry (*Rubus idaeus* L.) seed oil extracted in various ways. The economic situation was modeled, and the costs were calculated on the example of Lithuanian raspberry farms and processing companies. The potential sales revenue is calculated by taking the average price of oil in Europe per 100 mL/EUR 12.5 and the price of 100% puree, 1 kg/EUR 8. Calculations were performed by biorefining (dividing one product into several separate) raspberries into raspberry pulp (product—100% raspberry puree) and seeds (product—oil). The costs of two economically different production processes were compared. Depreciation of equipment was calculated using the straight-line method of depreciation and is calculated using the following formula:

$$N = (V_1 - V_2)/T$$

where
N—annual depreciation amount;
V_1—acquisition value of tangible fixed assets (cost of production);
V_2—the liquidation value of tangible fixed assets;
T—useful life of equipment in years.

3.15. *Statistical Analysis*

For the statistical processing of the data obtained from the analysis of the chemical composition of the oil, means and standard deviations were calculated with STATISTICA 10 StatSoft, Inc., Tulsa, OK, USA) and Excel (Microsoft, Redmond, WA, USA) software. One-way analysis of variance (ANOVA) along with post hoc Tukey's HSD test was employed for statistical analysis. Differences were considered to be significant at $p < 0.05$.

4. Conclusions

The results demonstrate the potential of raspberry by-products focusing on mainstream sectors such as the food, nutraceutical, pharmaceutical, and cosmetic industries.

Raspberries bioactive compounds are known to be beneficial for health and can be utilized in cosmetic or pharmaceutical industries.

All studies have been conducted with unfiltered oil to see if there is a misleading view that oils extracted in one way or another may be more valuable, of better quality, etc. In this case, the fatty acid composition does not change significantly. It can also be concluded that in research on oil filtration, the determination of the quantity and quality of pure oil would be relevant.

This research has a very important practical significance as it has revealed that processors wishing to place raspberry seed oil on the market because of its omega acid properties should opt for a cold oil production method, as the investment in equipment is significantly lower and the processing time is lower, resulting in the lowest cost and quality of the product using the market ways of extracting oil.

It can be concluded that in order to maximize profits and the value of their property, companies must invest and implement only those projects whose average expected return is higher than the cost of capital. With the data obtained during the study, raspberry processors can prepare an investment project by calculating whether the equipment in which the investment will be used will be used efficiently. The economic evaluation revealed the potential benefits of the project in relation to the cost of capital, and the company, having the data identified in the study, can model them with its own data to estimate the potential cost of breaking even, which would show how much production is needed to bring sales revenue into line with their production costs (variable and fixed). These measures can be used to decide which investment projects to finance and what priority to give them to ensure that the optimal return on investment will be obtained and the risk of the project will be minimal.

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Sustainable Development Solutions: Growing and Processing Raspberries on Lithuanian Farms

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Abstract: The EU's goals by 2050 are to ensure food security, prevent bio-diversity loss, and strengthen the EU food system's resilience. Recent scientific research and the situation in the global market show that the cultivation and processing of raspberries is currently completely unsustainable. This sector is experiencing a huge decline in Lithuania. Therefore, we chose the sustainability of raspberry growing (from farm) and processing (to fork) as an object. The aim of this article was (i) to analyze the raw material of the raspberry plant for product sustainable processing, (ii) to create a digital sustainability measurement model, and (iii) to present sustainable development solutions for effective raspberry growing and processing on Lithuanian farms using content and descriptive methods. This paper discusses how to help small raspberry growers and processors achieve sustainable economic, environmental, and social performance from field raw material to processed products. Analysis of the scientific literature has revealed qualitative and quantitative sustainability indicators for improving raspberry production. The assessment of the sustainability according to our created model revealed the (un)sustainable factors and the current situation in raspberry farms on a Likert scale from very unsustainable to very sustainable. Based on the evaluation we have determined sustainable development solutions. Raspberry growing and processing in Lithuania can contribute to environmental conservation, economic growth, and social well-being, fostering a more sustainable and resilient agricultural sector by investing in R&D, improving productivity, creating employment opportunities and supporting rural communities, establishing a robust waste management system, and embracing renewable energy sources. Raspberry growers and processors can use the digital model we created for the sustainability, efficiency, and development directions of their farm.

Keywords: food loss and waste; raspberry products; value-added cultivation and processing; holistic management and economy; sustainable; digital transformation

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1. Introduction

In the modern conditions of economic, environmental, and social development, as hallmarks of scientific and technological progress, a number of new phenomena and circumstances have emerged. Understanding and responding to them inevitably leads to the need to delve into the so-called sustainable development problems and strive to solve these problems adequately to challenge the new ones arising in society [1–3]. The importance and significance of sustainable development issues are shown by the fact that understanding and solving these problems is one of the main priorities implemented in modern scientific research practice. A shift to an effective sustainable food system can bring environmental, health, and social benefits, as well as offer fairer economic gains. The international community is currently on track to realize the Sustainable Development Goals (SDGs) [4–8].

The aim of this article was (i) to analyze the raw material of the raspberry plant for product sustainable processing, (ii) to create a digital sustainability measurement model, and (iii) to present sustainable development solutions for effective raspberry growing and processing on Lithuanian farms using content and descriptive methods.

Background of the Literature

Existing studies indicate that practitioners of sustainable agriculture must seek to integrate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. Every person involved in the food system—growers, food processors, distributors, retailers, consumers, and waste managers—can play a role in ensuring a sustainable agricultural system [9–12].

The link between healthy people, healthy societies, and a healthy planet puts sustainable food systems at the heart of the European Green Deal, the EU's sustainable and inclusive growth strategy. It is designed to boost the economy, improve people's health and quality of life, and care for nature. The European agriculture and food system, supported by the Common Agricultural Policy, is already a global standard in terms of the safety and security of supply, nutrition, and quality. Now, it must also become the global standard for sustainability. Sustainable development is considered a key issue faced in the 21st century [13]. Some studies have pointed out that putting our food systems on a sustainable path also brings new opportunities for operators in the food value chain. New technologies and scientific discoveries, combined with increasing public awareness and demand for sustainable food, will benefit all stakeholders [14–18].

However, Serbia is struggling with climate problems [19] and Poland is struggling with problems related to the availability of labor during harvesting and low prices of raspberries [20]. There is too little private sector initiative in the field of sustainability in the Lithuanian raspberry market, and insufficient application of sustainable activity solutions in raspberry cultivation and processing on Lithuanian fruit farms. From 2017 to 2022, the declared area of raspberry cultivation in Lithuania decreased from 559.67 ha to 398.37 ha, which is 49%, while the total area around the world is increasing due to the benefits of the plant (Figure 1). Therefore, it can be concluded that the raspberry cultivation farms are unsustainable. And naturally the question arises as to who influences it and what measures should be implemented.

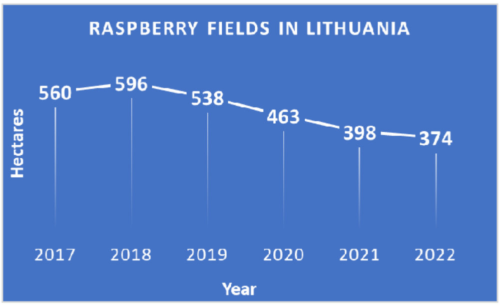

Figure 1. Agricultural land areas declared for raspberry cultivation in Lithuania. Source: State Enterprise Agricultural Data Center.

When measuring sustainability, it is usually indicated that it consists of three aspects: environmental, economic, and social factors. However, there are contradictions between these factors because what is good for the economy and brings profit to the farmer, is sometimes unfavorable and negatively affects the environment or people [21,22]. To meet the ever-increasing interest towards agricultural sustainability, many methodologies and tools have emerged, introducing integrated and holistic assessment approaches.

There is still no consensus on the standardization of agricultural sustainability assessment as part of a unified concept of sustainable development. Newly introduced frameworks propose mostly case-specific tools that focus on resource use and their impact on the sustainability of farming practices. In the reviewed studies, stakeholder participation has proved crucial in the determination of the level of sustainability. The effect of resource use and input management is usually the most examined issue in the reviewed studies.

Researchers contribute to the advancement of raspberry growing techniques and sustainable practices. They conduct studies, experiments, and trials to improve crop productivity, disease resistance, and environmental sustainability. The EU's field-to-fork sustainability targets for fruit and berries cover key processes such as cultivation and primary, secondary, and tertiary processing This food system involves the safe handling (i.e., distribution/transport/supply, storage, and sale/trade) of primary and secondary food products. It also addresses the management of consumer needs and demands as well as broader issues such as minimizing food waste.

In this context, it is essential to demonstrate the contribution of primary and secondary food processing to the wellbeing of the entire food and beverage industry and our economy and environment in general, as well as its contribution to job growth and the improvement of sustainable food production. Numerous studies have revealed that, for sustainability achievement and balanced development, companies must apply strategies and activities that protect, strengthen, and increase human and natural resources for future generations.

Ludwig-Ohm et al.'s (2023) observations that digitization and automation offer great opportunities for horticulture are particularly important. Robotics, innovative sensor-controlled solutions, data management systems, and artificial intelligence can increasingly fulfill complex tasks in the control and management of production systems and help make horticultural production more competitive and sustainable. Thus, digital methods are essential for horticultural production, but their development and use are still in the early stages [23,24].

In a recent study, Liu et al., (2022) pointed out that there is a lack of research on the specific relationship between the digital economy and industrial eco-efficiency, and their study proved that the digital economy has a significantly positive effect on industrial eco-efficiency at the national scale, with diminishing marginal returns [25]. Yang et al., (2022) suggested that managerial relevance is important for decision-makers facing sustainable development challenges [26]. Li et al., (2023) revealed that heterogeneous environmental regulatory instruments (pollution charges and environmental protection subsidies) can jointly improve the green-technology innovation of corporations [27].

Taking into account the importance of digitalization, we have studied and tried to understand what farmers are doing (un)sustainably through our created models. This tool can be used as an example to accelerate management and planning in the raspberry farms. The main goal was to propose sustainable development solutions which can impact the future of the raspberry cultivation and processing industry in Lithuania.

2. Research Design

First, we used scientific content analysis to characterize production and identify possible valorization scenarios, sustainability categories, and indicators in growing and processing raspberries. Second, we collected data from raspberry growers and processors about their activities' sustainability. And lastly, we evaluated the sustainability of raspberry production in Lithuania and presented possible development solutions for improving the sustainability of operations.

In the current article, content and descriptive methods are combined into an original multi-methodology to highlight more than each individual methodology allows. Research results obtained from different methods supplement each other in order to effectively examine sustainability, implementing circular economy principles in raspberry cultivation and processing in Lithuania. In addition, it is important to use a multi-method approach, combining design and research methods with complementary methods in other research fields and disciplines, as this seeks to address complex new research paradigms such as the circular economy, which requires a systemic vision and lifelong thinking. The core of this paper is based on the following research activities: content analysis, data collection, descriptive analysis, and interpretation. The actions performed using the methods are presented in Table 1.

Table 1. Research methods and processes applied in the present paper.

Methods	Actions	Data and Information Used	Date
STAGE 1 Content analysis	4.1. Performing exhaustive review, analysis, synthesis of the literature and documents, grouping, and comparison 4.2. Characterizing production and identifying possible valorization scenarios 4.1. Identifying sustainability categories and indicators in growing and processing raspberries	Web of ScienceTM (WOS) and Scopus databases, media, project results, laws, EU and Lithuanian strategic documents	March 2023
STAGE 2 Data collection	Collecting data from raspberry growers and processors: 4.1. Interview based on a semi-structured questionnaire. 4.2. Farmers evaluation of farm's sustainability	Interviewees' answers	April–May 2023
STAGE 3 Descriptive analysis	4.1. Evaluating the sustainability of raspberry cultivation and production development for digital model 4.2. Presenting raspberry growing and processing sustainability factors in five levels from low to high	Farmers answers from questionnaires	June–July 2023

As shown in the table above, the research started with content analysis. A literature review was carried out in March 2023 across the Web of ScienceTM (WOS) and Scopus databases. Conducting a literature review and looking at recent actual documents in this field aims to identify specific research and knowledge gaps, and to discover valuable knowledge and information. In the present paper, the literature survey is completed by investigations into the industrial ground both to obtain new empirical data and to characterize production, identify possible valorization scenarios, sustainability categories, and indicators in growing and processing raspberries, and to test the usability of a proposed method or tool in a raspberry growing and processing environment through real world case studies.

We used content analysis to explore scientific literature and documents and find directions to establish sustainability criteria. This straightforward and very popular method examines the presence, concepts, and subjects in different content formats such as text, image, audio, or video and was chosen to classify important information about the sector into categories and identify key themes and meanings. Using coding text data that was later categorized, we were able to provide valuable insights, making it the perfect mix of qualitative (interview of experts and questionnaire survey assessment of sustainability in farms) analysis.

Secondly, we collected data from raspberry growers and processors. We interviewed nine respondents from the Šiauliai, Klaipėda, Panevėžys, Kaunas, and Alytus districts, and collected farmer-assessed sustainability levels based on their experience and farms' data through questionnaires. The method of selecting interviewees is probabilistic as the probability of each element of the studied population to be included in the sample is known, and the method of criterion selection is chosen for the formation of the target samples of respondents, which is detailed in Table 2. The selection of respondents was purposeful, and the farms were selected to highlight the meanings discovered. For selected entities, a natural environment is chosen.

Table 2. Interviewers' data.

Criteria for the Selection of Respondents		**Interviewers**								
		E001	**E002**	**E003**	**E004**	**E005**	**E006**	**E007**	**E008**	**E009**
Area of cultivated raspberries	1–2 ha			+	+			+		+
	2–3 ha	+	+				+			
	3–20 ha					+			+	
Raspberry processing	Primary processing	+	+	+	+	+	+	+	+	+
	Secondary processing					+			+	
Experience in cultivation and processing	From 3 to 5 years			+	+		+	+		
	From 5 to 10 years									+
	10 years and more	+	+			+			+	
Number of permanent employees	Up to 2			+	+		+	+		+
	From 2–5	+	+			+			+	
	More than 5									
Number of seasonable workers	Up to 2									
	From 2–5						+			
	More than 5	+	+	+	+	+		+	+	+

The research used a semi-structured personal interview in which the main questions and the entire procedure were planned in advance, but, at the same time, they could be supplemented and simulated during the interview. For research interviews, the questions were structured in such a way that respondents could freely provide formulated answers where neither content nor form is restricted. The survey was conducted in 2023, in the months of April–May, and experts were interviewed directly; two of them were interviewed by phone, and the rest by going to the farm. This method of questioning is superior to others in that the questions that the respondent does not understand can be explained by the researcher.

For qualitative evaluation, a questionnaire was prepared asking farmers to rate the sustainability of raspberry cultivation and processing on a Likert scale. Each item was rated on a five-point Likert scale, which required the participant to choose the indicator's priority level: 1—very unsustainable, 2—unsustainable, 3—moderate, 4—sustainable, 5—very sustainable. After collecting all the interviewees' answers, an average was derived, which was used in descriptive analysis and is presented in the results of this study.

The data obtained from the first and second stages were processed using the Microsoft Excel program, divided, and systematized according to three areas of sustainability: economics, environment, and sociology at work. We used the data obtained from the experts for the interpretive explanation, highlighting data by focusing on essentials and grouping individual facts.

Finally, we conducted applied descriptive analysis to examine the occurrences within this particular sector. One of the principal advantages of descriptive analysis lies in the high degree of objectivity and neutrality maintained by the researchers. However, researchers need to exercise extra caution because descriptive analysis reveals various characteristics of the extracted data, and, if these data points deviate from the expected trends, this may lead to significant data distortion. Compared to other quantitative methods, descriptive analysis is considered more comprehensive, providing broader perspectives of an event or phenomenon. It is flexible in its approach, accommodating the use of any number of variables or even just a single variable to conduct the descriptive research. The sort of analysis used in our study is regarded as a superior strategy for acquiring information since it depicts relationships in a natural way while correctly representing the current environment. Because all of the trends are generated through investigating real-life data habits, this analysis is incredibly authentic and human centric. Furthermore, it aids in the identification of factors and the generation of novel hypotheses that may be investigated further through experimental and inferential investigations. The study is appreciated for its low margin of error, as it draws trends directly from the data's fundamental features [28].

Descriptive analysis: data received from interviewees' grouping and graphic presentation enabled us to evaluate the sustainability of raspberry cultivation and production development and revealed unsustainable to very sustainable farms aspects. Results from the descriptive analysis allow us to make assumptions and draw conclusions about the sustainability of raspberry growing and processing in Lithuania. Designing and assessing alternative scenarios of raspberry valorization, creating a digital model for management, and improving sustainability can help farmers and processors to identify the feasibility and pathways to move towards a circular economy. However, the assessment of alternative scenarios is challenged by the complex nature of agrifood networks.

3. Results and Discussion

3.1. Characterization of Production

The aim of the first step was to characterize the production of raspberry plants that have valorization potential and services that can be provided during the cultivation and processing of raspberries that receive additional income, create economic added value, and identify factors influencing the quality of such production, the potential amount, and the factors affecting it.

Raspberries are caneberries from the genus Rubus that have been cultivated as a food and used as a medicine for centuries. Raspberries are categorized as composite fruits and are made up of several 'drupelets', each with a single seed. There are both vegetative and fructifying organs in raspberries. Vegetative organs, which are classified as root, stem, and leaf, serve an important function in supporting the life of the individual plant. The fructifying organs, also known as reproductive organs, on the other hand, are critical for the survival and propagation of the species. These include flowers, seeds, and fruits [29]. Harvesting red raspberry leaves for herbal use should be completed before the plant blooms in mid-morning, once the dew has evaporated and while the leaves' essential oils and flavor are at their peak. Like most herbs, once the plant begins to bloom, the leaves turn bitter.

Because of these properties, farmers cannot collect the leaves during crop time, and they cannot be considered as wasted food. However, after picking the berries, many stems and leaves remain, which can be used as biofuel or raw material for the production of packaging. Failure to use such raw material is considered as a loss of potential production.

Another unique feature is that when growing raspberry seedlings you can not let the berries ripen in order to develop a good root system. Considering these morphological features of the plant, the farmer must decide in advance what will be his main product in the first growing stage:

- berries (3–5 t/ha);
- leaves (data not found);
- seedlings (12,000 pieces/ha);
- stems (data not found).

When growing raspberries, the farmer can provide the following additional services to increase the sustainability of the farm: agrotourism, education, and training.

The plant material is first received from a qualitative and quantitative point of view. Many factors can influence the amount and quality of raspberry raw material grown. The main references to them in scientific publications are as follows: Berries are very fragile and improper handling during or after harvest can make the berries unsuitable for the fresh market. Berries may therefore be better suited for sale in the processed market where value can be added to the product so it can be sold in processed forms. To be sustainable, the farm must produce adequate yields of high-quality raw material for processing high-quality products, be profitable, protect the environment, conserve resources, and be socially responsible in the long term.

Fresh berries suffer from post-harvest losses at the retail level due to their short shelf life, which limits profitability and reduces the sustainability of production by increasing food waste. Accordingly, sustainable production is an important aspect of berry cultivation and farmers must ensure that the quality and nutritional standards are maintained or improved. Smart production systems and advances in agricultural biotechnology are required to meet these challenges. Berries are widely recognized as one of the best food sources, appropriate for eating raw or processed into juice. The remaining material left after extracting the juice is commonly referred to as berry pomace or a press cake, and it contains components such as the skin, stem, and seeds. Berries include a variety of dietary fiber components, including pectin, lignin, cellulose, hemicellulose, and others. Valorization technology is concerned with the long-term transformation of agri-food waste into useful goods. Despite their potential, these wastes are frequently underused, with only limited uses as bio-compost or biofuel [30].

According to the existing research, agri-food wastes can be a valuable source of useful bioactive chemicals. These bioactive chemicals have been scientifically shown to have antioxidant, antiviral, antibacterial, cardioprotective, anti-tumor, and anti-obesity activities [31–33]. Notably, significant volumes of waste are produced as a result of the post-processing extraction of pulp needed to make juice, jams, and purees [34]. Bio actives found in the food processing industry waste include dietary fibers, pigments, vital minerals, fatty acids, antioxidant polyphenolic chemicals, and others. The extraction of these value-added chemicals from trash involves the adoption of environmentally friendly and long-term methods.

A person who wants to grow raspberries in Lithuania must register their individual activities according to the economic activity classification A 01.25, and if they want to process them they must register their activities separately according to the product received or the services provided. It is necessary to note that for each product or service providing a higher added value (e.g., education), the farmer must separately register the economic activity, have certificates from the relevant institutions that they can carry out this activity, and relevant qualifications. In Lithuania, most of the farmers grow one-year raspberry shoots, from August to mid-October, referred to as "autumn raspberries". The plants are grown unsupported, often directly in the ground. The most popular "autumn" cultivars grown in Lithuania are 'Polka' and 'Polana', which can be conveniently machine-harvested and used in the processing industry mainly for frozen fruit production. Currently, 374 ha of cultivated raspberries are declared in Lithuania.

Within the food processing sector, substantial parts of the raw materials that enter the factory are ultimately traded as by-products. Directly utilizing these streams for food would require alternative (and generally technically more complex) processing than the chains' primary product. Hence, a large part of these side streams is only poorly valorized for animal feed, technical applications, and fertilizer production (through composting). Higher value applications, however, can increase the total value generation of the food processing chain.

Growing raspberries for processing entails many of the same efforts required for selling fresh fruit wholesale, such as contacting buyers, filling orders, and delivering. Growers who process the products themselves must follow appropriate state and federal sanitation, processing, and labeling regulations. This may include undergoing regular inspections, purchasing stainless steel equipment, and using water treatments. Contact your state or province department of agriculture and/or health department for details.

Value-added products, such as jams and jellies, may generate a higher profit margin than fresh fruit, but the inputs are much greater. Labor costs will be higher, and appropriate cooking tools will be needed, as well as a steady supply of ingredients, jars, labels, shipping boxes, and so forth. Nevertheless, properly processed products provide the advantage of having year-round, quality, locally produced, specialty foods to sell directly to consumers or through wholesalers. Specialty foods are well suited for distribution in tourist destinations such as wine trails, popular parks, and regional fairs.

Bio-based materials can also open new opportunities in product development by providing novel product characteristics and by using biomass for new purposes. Raspberry production from cultivation to zero-waste processing is described in Table 3 below.

Table 3. Raspberry production from cultivation to zero-waste processing.

	Activity Sector	Main Production	Possible Quantity of Production from 1 ha	Additional Products or Services Available
0 WASTE ← CULTIVATION	1. Raspberry cultivation	Fresh raspberries (raw material for processing)	Raspberries—2, 6 t	Agrotourism and educational services. Leaves, stems
	2. Food and drink	Frozen raspberries, juices, jams, wine, dry products, etc.	Juice—87 proc. Seeds—12–13 proc.	Seeds
	3. Cosmetics	Oils, seeds after extractions, extracts	Aprox. 14 proc of oil from dry seeds (8–14% humidity)	Seeds after extractions for biofuel, animal feed
	4. Pharmacy	Food supplements, vitamins (ex. E), omega acids, dietary fibers, etc.	Vitamin E 0.87 mg/100 g fresh berries [xx]; α-Linolenic ($\omega - 3$) 37.7 g/100 g	Seeds after extractions for biofuel, animal feed
	5. Other industries	In perspective—packaging, micronutrient fertilization	No scientific or practical data found *	Biofuel

* Additional research is needed.

Next, we analyzed the factors affecting the quality of fresh raspberries, which are the main raw material, and all other derived, high-value-added products related to raspberries. After analyzing the scientific literature, we found that the quality of obtained fresh raspberries is more influenced by:

1. Cultivation principles.

1.1. Raspberries can be grown in open ground or under cover or in greenhouses. Growing in greenhouses creates optimal conditions for all pests and diseases, which forces farmers to use significantly more pesticides. As a result, significantly lower quality fruits with poorer sensory, chemical, and bioactive substances are obtained.

1.2. Raspberries can be grown intensively or certified (National, local certificated, ecological, biodynamic 'Demeter international', other). A higher quality of raw material is always obtained when the production is certified because independent control is ensured, less pesticide is used, biodiversity is ensured, etc.

2. Plant variety.

The quantity and quality of the desired production depends on the variety, chemical composition, biologically active elements, and antioxidant activity [35].

3. Climatic conditions and soil.

The properties of fresh raspberries in particular depend on the climatic zone and the weather conditions of that time. For example, during the rainy season, the sweetness of raspberries will drop significantly. The latter indicator is measured with a refractometer. It will only be about 9 Brix. Therefore, the manufacturer needs to add significantly more sugar to the product at the end so that the usual taste characteristics of the products do not change for the consumer [36–38].

Measuring sustainable development in terms of its results is nearly identical to measuring it in terms of the strategies employed to attain those objectives. Assessing sustainability in terms of inclusive well-being goals is essentially to the same as measuring it in terms of inclusive wealth, which serves as the productive basis that allows individuals to achieve those goals. However, both theoretical understanding and real-world experiences show that, when measuring long-term sustainable development, it is generally easier to gauge the stocks of resources that influence it (the means) rather than the flows of goods and services consumed, which constitute its ultimate end, i.e., inclusive well-being.

To sum up the first research stage, it can be concluded that the characteristics of the products made from a raspberry plant have valorization potential; services can be provided during the cultivation and processing of raspberries that create additional income, create economic added value, and identify factors influencing the quality of such production, the potential amount, and the factors affecting it. These results present sustainability indicators for improving the qualitative and quantitative indicators of higher-value raspberry production.

3.2. Economic Sustainability

Indicators represent quantitative tools that synthesize and simplify the data which are crucial for the assessment of certain phenomena. They are used in communication, evaluation, and decision-making [39,40]. The presented analysis of sustainable development concept implementation is a general assessment focused on selected aspects, meeting which affects the overall implementation of the sustainable development concept. The selection of variables for the study referred to each of the spheres responsible for sustainable development, i.e., the social, economic, and environmental spheres.

This study was conducted to discuss the perception of raspberry growers and processors, as it is perceived by small farmers in Lithuania. The study identified some criteria and sub-criteria related to the sustainability of raspberry cultivation and processing.

In order to find out the economic sustainability of raspberry cultivation and processing, farmers were primarily asked how much and what quality of produce they produce, what their income is, what it depends on, what their capital is, how and how much the produced produce is sold, and what activities the farmers undertake to develop new products, processes, or services, or improve those that already exist. Economical sustainability categories with explanations and interviewees' answers are given in Table 4 below.

Table 4. Digital model for measuring economical sustainability in raspberry farms.

Sustainability Measurement Category	Subcategory with Explanation	Results from Informants' Open Questions	Intervieweers Data	Score Average
1. Productivity	1.1. Fresh raspberry yield can be from 1.5 to 6.15 t/ha	1.4–2.3 t./ha.	E001, E003 E005, E008	2.78
	1.2. Leaves yield. No data found	0	E001–E009	**1.00** **
	1.3. Production quality can be from category III to I (best)	1 category	E001–E009	**4.89** *
	1.4. Valeur/price is 1.2–16.50 USD/kg, average—6 USD/kg	3.00 eur/kg	E001–E009	2.56
	1.5. Secondary production output subcategory is not set.	About 500–750 kg puree	E005, E008	3.44
	1.6. Third production output subcategory is not set.	Oil 3 L	E008	1.67
	1.7. Recycled waste on the farm	9 m^3 of stems for biofuel	E005	1.56
	1.8. Other services (education, training, agritourism). The subcategory is not set	2 events	E002, E006	3.33
		Agritourism for average 20 people	E001, E003, E008, E009	**4.33** *

Table 4. *Cont.*

Sustainability Measurement Category	Subcategory with Explanation	Results from Informants' Open Questions	Interviewers Data	Score Average
2. Profit	2.1. Standard production profit EUR per 1 ha—1028	Profit after taxes 700–1000	E002, E005, E006, E008	**1.22** **
	2.2. VAT taxes—lowest—0% (Poland, Ireland, Malta), 5%—Latvia. The highest—27% (Hungary)	High VAT taxes—21 proc.	E001–E009	**1.00** **
	2.3. GPM, other taxes	GPM—15 proc.	E001–E009	1.22
3. Capital	3.1. Location of a land (close to town min 5 km)	Location is not good	E004, E007	2.44
	3.2. Infrastructure	Bad infrastructure	E003, E004	2.00
	3.3. Berries are grown on own land/lease from private individuals/lease from the state.	Own land	E001–E009	2.44
	3.4. Procurement of machinery and equipment (tractor, implements, refrigeration chambers, etc.)	Average. Missing digitized technologies	E002; E004, E005, E008	3.33
4. Realization	4.1. Realization in proc. from the received production (grown or produced).	From about 50 to 80 proc.	E001–E009	1.44
	4.2. Food supply chains (long and short)	Realisation through short supply chains 100%	E001–E007	**4.22** *
	4.3. Wholesale and export	20% from all production	E008, E009	1.56
5. R&D	5.1. Techniques and technologies used	Minimum or not at all	E001–E009	2.44
	5.2. Investments in human resources	Minimum or not at all	E001–E009	3.33
	TOTAL ECONOMICAL SUSTAINABILITY SCORE: 53.11/100			

* Most sustainable, ** Least sustainable. The economical sustainability categories in the table are prepared based on the following literature sources [34,41–48].

From this digital model created to measure economical sustainability in raspberry farms, it is clear that the economic dimension includes five main categories and twenty-one subcategories (Table 4) which measure the economic sustainability of raspberry growers and processors, considering both agricultural productivity, profit, capital, realization, and R&D. To measure economic sustainability productivity categories, interviewees highlighted aspects of product quality and generated additional incomes:

<<*. . .an important measure of productivity and can vary depending on factors such as cultivar, management practices, and environmental conditions. . .*>>; (E001, E003)

<<*. . .monitoring primary production indicators, such as acreage, yield per hectare, and input costs, helps assess the overall performance of raspberry farming operations. Secondary production in the context of raspberries refers to value-added products derived from fresh raspberries, such as processed goods like jams, jellies, juices, or frozen raspberries. . .*>>. (Informants E006, E007 and E008)

Another interviewee noticed that:

<<*. . .recycling raspberry waste, such as stems and other by-products, for biofuel production contributes to sustainability and waste reduction efforts. We obtain about 8 m*^{3}*/ha of stems for biofuel. . .*>>. (E005)

<<*. . .during fresh berry season, about 20 people visit our farm and pick the berries, spend time in nature with their family. . .*>>. (E001, E003, E008, E009)

All interviewees underline the importance of crop losses as leaves:

<<*We do not pick and sell the leaves at all due to the high costs, the need for a workforce, and the lack of realization*>>. (E009)

<<*Raspberry leaves are also of value in various industries, such as herbal teas and natural health products*>>. (E007, E008)

When measuring the profit category, the interviewees were pessimistic, and everybody agreed that farms are not competitive internationally due to the percentage tax paid compared to other countries that do not apply or apply very low taxes in order to encourage the consumer to buy as much of the produce as is good for his health. Raspberry growers and processors in Lithuania may be subject to other taxes, including corporate income tax, personal income tax, social security contributions, and local taxes. Specific financial figures, and percentages related to profit, taxes, and charity contributions, can vary based on individual business operations, market dynamics, production scale, and other factors. Interviewees justified their argument as follows:

> <<*Profit in raspberry growing and processing in Lithuania is influenced by various factors such as production costs, sales revenue, taxes, and charitable contributions. Standard Production Profit is calculated by subtracting total production costs (including labor, inputs, overheads, etc.) from the sales revenue generated from raspberries and related products*>> (E002, E008)

Some participants referred to:

> <<*The specific VAT rates and regulations may vary based on the nature of the products and current tax laws. Gross Profit Margin is a financial metric that indicates the profitability of a business*>>. (E005, E006)

> <<*The price in Lithuania is influenced by the price of imported production from Poland, Ukraine and Serbia with much smaller taxes*>>. (informants E005, E007, E008)

According to the interviewees, the location of the land for raspberry cultivation and processing and adequate infrastructure, procuring machinery and equipment, are crucial factors. Interviewees present this argumentation as follows:

> <<*Ideally, the land should be situated within a reasonable distance (minimum 5 km) from towns or markets to facilitate transportation and access to labor and resources…* (E001–E009); *…adequate infrastructure is essential for raspberry growing and processing operations: access to roads, water sources, electricity, and other necessary utilities* (E003, E004, E007)>>.

Interviewees E002 and E007 argued that:

> <<*For efficient raspberry cultivation and processing we need more: tractors, implements (such as plows, harvesters, and sprayers), refrigeration chambers, sorting and packaging equipment, and other tools necessary for field operations and processing activities*>>.

Interviewees E004, E007 and E008 noted: << *Raspberry growers and processors to assess their specific capital needs based on their business plan, scale of operation, and growth projections*>>.

Realization category refers to the process of selling and distributing the raspberries and raspberry products that have been grown or produced. Food supply chains in raspberry growing and processing can involve both long and short chains. The supply chain includes activities such as packaging, quality control, marketing, and sales to reach the end consumers or buyers. Long supply chains typically include multiple intermediaries, such as wholesalers, distributors, and retailers, before reaching the end consumer.

Interviewees recognized that they realize 100 proc of production through short chains which is very sustainable for the economy. At the same time, the farmers emphasized that they throw away up to 45% of the production because they cannot sell it. They presented some disenchanted views on this issue:

> <<*We are forced to throw away about 50% of the production because we have nowhere to sell it…* (E001, 003–007); *…the local market is small. Our product is classified as a luxury product and not everyone can afford to buy it…* (E002, E009); *…local manufacturers do not buy our products because they import cheap products from neighboring countries. We cannot compete with these countries because our products are taxed much higher…* (E008, E009); *…we can't sell production wholesale because we don't have the necessary*

quantities or can't ensure the realization for several years to come for suppliers. . . (E005, E007, E008)>>.

Some interviewees justified their arguments as follows:

<<. . .*exporting raspberries requires compliance with international quality standards, proper packaging, and adherence to import regulations of target countries*. . . (E001, E003–E005); . . .*marketing includes creating a strong brand presence, advertising campaigns, participation in trade shows or exhibitions, online marketing, and social media engagement to create awareness and demand for the raspberries and raspberry products*. . . (E008) >>.

This shows that building relationships with buyers, understanding consumer preferences, and staying informed about market trends can contribute to successful realization strategies in the raspberry industry in Lithuania.

Another research and development (R&D) category involves the exploration and implementation of various techniques, technologies, and investments in human resources. The interviewees placed emphasis on the advancements in irrigation systems, precision farming methods, disease and pest management techniques, soil fertility management, and post-harvest handling technologies:

<<. . .*R&D activities emphasize the adaptation of techniques and technologies to the specific climatic, soil, and environmental conditions in Lithuania* (E004); . . .*R&D initiatives often involve collaboration between research institutions, universities, agricultural extension services, and industry stakeholders. Best practices, and joint research projects aimed at addressing specific challenges in raspberry growing and processing. These investments enhance the expertise and skills necessary to conduct R&D and drive innovation in raspberry cultivation and processing*. . . (E001, E004); . . .*government grants, research programs, and agricultural development initiatives provide financial support for R&D projects* E002, E005, E008>>.

According to interviewees E007 and E009, industry collaborations, partnerships, and cooperative research efforts contribute to the availability of resources for R&D activities. Interviewee E004 noted that:

<<*These efforts contribute to the development of sustainable practices, the adoption of advanced technologies, and the continuous improvement of raspberry cultivation and processing methods*>>.

Evidence from the interviews suggests that product quality, income from additional activities, and realization through short chains are the sustainable sides of the farms. According to the interviewees, farmers do not use the full potential of the grown production, e.g., they do not collect leaves, they pay high taxes compared to neighboring countries, and they do not realize a lot of production. These areas are inefficient and unsustainable on farms. From all the economic subcategories, assuming that each of them is rated with the highest rating of five points, they could score a maximum of 100 points. Lithuanian raspberry growers rated their activity 53.11 points out of 100 possible which is 53.11%. This shows that there are issues to be addressed in the sector.

In recent years, other scientists have increased their emphasis on the relationship between the economy and sustainable development. Milic et al. (2013) pointed out that the increased economic efficiency of raspberries can be achieved from its primary production, as well as its processing and improved product quality. The economic importance of raspberry consists of a relatively large amount of profit per unit of invested capital and labor [49]. Pantic et al. (2017) proposed that the growth, profitability, and competitiveness of the sector must be improved through investments in all phases (production, processing, and distribution) and changes in the export structure [50]. Qattan et al. (2021) analyzed economic factors influencing the supply and demand of raspberries. They underlined as a general conclusion that macroeconomic indicators are very important factors in the success of production, but also in the demand for raspberries. In addition, they noticed that exporting unprocessed raspberries is lucrative, but it is even more profitable to export raspberry-based products [51]. Our research reveals that manufacturers in Lithuania pay very little attention to wholesale trade and export. However, it is a positive thing that investments are made in the processing of high-value products.

3.3. Environmental Sustainability

To find out the environmental sustainability of raspberry cultivation and processing, farmers were asked what the fertility of their land is, whether they do land surveys, how often, whether they know the damage caused by soil, wind, and water erosion to their farm, how much and what quantities of fertilizers and pesticides they use, how they determine what quantity to use, what quality and varieties their seedlings are, whether they use bio-increase measures, how much and what kind of water and energy they use for the farm, how accounting is kept, what cultivation and processing principles are applied on the farm, who controls the quality, and what the emissions from growing and processing their raspberries are. Environmental sustainability categories with explanations and interviewee answers are given in Table 5.

Table 5. Digital model for measuring environmental sustainability on raspberry farms.

Sustainability Measurement Category	Subcategory with Explanations	Results from Informants Open Questions	Interviewees Data	Score Average
1. Soil	1.1. Land performance score	38 to 50 points	E001–E009	**4.11** *
	1.2. Soil fertility: amount of organic carbon and humus (organic matter) in the soil; Contaminants, the amount of nutrients and salts; Biodiversity in soil; Covering crops, Soil compaction, acidity; Landscape heterogeneity	Soil properties are not determined	E001–E009	1.33
	1.3. Soil, water, and wind erosion	Not determined	E001–E009	**1.00** **
	1.4. Amount of fertilizer used t/ha	Fertilizers are used at low rates without soil testing	E001–E004 E007, E008	3.33
	1.5. Pest and agricultural chemical management. Amount of pesticides and chemicals used l., kg/ha	Farmers use pest and disease prevention and weed control measures. Strict state control	E001–E009	1.44
2. Plant	2.1. Variety. High quality planting material, resistant to pests and environmental factors, adapted to the region	Cultivate primocane varieties Polka, Kwanza, Kweli	E001–E009	2.56
	2.2. Biodiversity	No biodiversity measures	E001–E009	**1.22** **
3. Other resources	3.1. Water use	Rarely use irrigation system. Pay taxes	E001, E002, E005, E008	3.44
	3.2. Energy use	Use their own green energy	E002, E008	1.56
4. Emissions	4.1. Cultivation and processing principles	Sustainable cultivation system	E002–E009	**4.78**
	4.2. Carbon foodprint	Does not count	E001–E009	**1.00** **
			TOTAL ENVIRONMENTAL SUSTAINABILITY SCORE: 25.78/55	

* Most sustainable, ** Least sustainable. The environmental sustainability categories in the table are prepared based on the following literature sources [52–60].

Another important environmental sustainability measurement dimension was divided into four categories: soil, plant, other resources, and emissions. The majority of interviewees recognized that soil plays a crucial role in determining the success and sustainability of the crops. Land performance score is a measure of soil quality and fertility, taking into account various factors such as nutrient content, organic matter levels, pH, drainage, and soil structure. Maintaining soil fertility is essential for optimal raspberry growth. This involves balancing nutrient levels through practices like soil testing, organic matter additions (such as compost or manure), and targeted application of fertilizers based on crop requirements. Encouraging beneficial soil organisms such as earthworms, bacteria, fungi, and other microorganisms helps enhance soil structure, nutrient cycling, and overall soil health. Measuring the environmental sustainability soil category, interviewees presented some disenchanted views on this issue:

<<*. . .an important measure of productivity and can vary on many factors. . .* (E001); *. . .soil is an ever-changing system. . .* (E002); *. . .in our area, erosion and parent material, soils vary very much. . .*(E006); *. . .it is important to minimize compaction by avoiding excessive machinery traffic on wet soils, utilizing appropriate tire inflation pressures, and implementing controlled traffic farming techniques. . .* (E009); *. . .raspberry fertilizing needs are very basic and not hard to keep up with. . .* (E008)>>.

Interviewees underlined some traits of erosion:

<<*. . .in raspberry growing and processing in Lithuania, cover crops help prevent erosion, improve soil structure, suppress weeds, and increase organic matter content. . .*>>; (E002)

<<*. . .implementing field edges, hedgerows, or buffer zones with diverse plant species can provide a habitat for beneficial insects, pollinators, and wildlife. . .*>>; (E005)

Another interviewee added:

<<*. . .implementing erosion control measures such as contour plowing, terracing, windbreaks, and vegetative cover helps minimize soil erosion caused by water and wind, preserving soil fertility and reducing sediment runoff into water bodies. . .*>> (E008)

All participants recognized that:

<<*. . .farmers don't know how detected erosion damage and how this could be done. . .*>>. (E001–E009)

Interviewees focused more of their attention on fertilizers and chemical management:

<<*. . .assessing crop nutrient requirements through soil testing and adopting precision fertilization techniques can optimize fertilizer use and minimize environmental impacts. Specific data on the amount of fertilizer used, pesticides, and chemicals applied in raspberry growing and processing in Lithuania may vary depending on individual farm practices, crop conditions, and adherence to sustainable agricultural standards and regulations. . .* (E006); *. . .fertilizers are an essential tool to help us to grow a good crop and to be competitive. . .* (E004, E007); *. . .the intensity of use of chemical fertilizers and pesticides is several times higher than ten years ago. However, the efficiency of agrochemical use is low. . .* (E003, E009)>>

Everybody agreed that:

<<*. . .the accounting of fertilizers and pesticides is very strictly controlled by state institutions, and we waste a lot of time in inspections. . .* (E001–E009); *. . .chemical pesticides and fertilizers are important for sustaining and boosting our production. . .* (E001–E009)>>.

Interviewees justified their arguments as follow:

<<*. . .the prices of fertilizers and pesticides are very high, so farmers have to calculate the required amount very carefully. . .* (E002, E005, E008); *. . .chemical fertilizers allow farmers to increase their yields, but using only chemical fertilizers without organic or biological fertilizers makes the soil unproductive and less profitable. To solve this problem, the state promotes and supports production that uses less fertilizer and is ecological. Using support, we grow better quality berries. . .* (E003, E007–E009)>>.

Another important element of environmental sustainability is the plant itself: its variety and quality. Interviewees illustrated such points of view about this element:

<<*. . .in Lithuania, several raspberry varieties are cultivated, taking into consideration factors such as high-quality planting material, resistance to pests and environmental conditions, and adaptation to the region. It's important for farmers to select raspberry varieties that are well-suited to local conditions, resistant to prevalent pests and diseases, and capable of thriving in the Lithuanian climate. . .*>> (E002, E007)

<<*. . .consulting with local agricultural extension services, nurseries, or raspberry experts can provide valuable guidance on the most suitable varieties for specific regions in Lithuania. Promoting biodiversity in raspberry cultivation is essential for maintaining ecosystem resilience and sustainability. By incorporating a diverse range of plant species, farmers can provide habitats for beneficial insects, pollinators, and other wildlife. . .*>>. (E004)

Some interviewees highlighted other such aspects:

<<*. . .water use and energy use are important resources to consider in raspberry growing and processing in Lithuania. Techniques such as drip irrigation or micro-sprinklers can deliver water directly to the root zone, minimizing water loss through evaporation and improving water efficiency. . .* (E002); *. . .utilizing soil moisture sensors or weather-based irrigation systems can aid in efficient water management. . .* (E003); *. . .installing rainwater harvesting systems can help reduce reliance on groundwater or municipal water sources, especially during periods of low rainfall. . .* (E007); *. . .treating and reusing process water for non-potable purposes such as irrigation or cleaning can contribute to water conservation efforts. Generating on-site renewable energy can offset energy consumption and contribute to environmental sustainability. . .* (E008)>>.

Regarding the emissions in raspberry cultivation, the farmers had no knowledge, and this is reflected in their answers:

<<*. . .implementing sustainable farming practices can help reduce emissions in raspberry cultivation. This includes minimizing the use of synthetic fertilizers and pesticides, adopting organic farming methods, practicing crop rotation, and optimizing irrigation techniques to minimize water usage. . .*>>; (E005)

<<*. . .implementing recycling and composting programs, minimizing food waste, and using by-products for animal feed or other value-added products can contribute to waste reduction and lower environmental impact. . .*>>. (E008)

Interviewee E009 agreed that:

<<*. . .efficient transportation and logistics strategies can help reduce emissions associated with the distribution of raspberries. . .*>>.

From the results of the interviews and explanations mentioned above, it can be concluded that using energy-efficient machinery and equipment, optimizing lighting systems, and implementing insulation measures make it possible to conserve energy. By focusing on water conservation and efficient energy use, raspberry growers and processors in Lithuania can reduce their environmental impact, lower their operational costs, and contribute to sustainable agricultural practices. Farmers adhering to recognized sustainability certifications and standards, such as organic certifications, can ensure that raspberry production meets specific environmental criteria. Investing in research and innovation can lead to the development of new technologies and practices that further reduce emissions in raspberry growing and processing.

From all the environmental sub-categories, assuming that each of them is rated with the highest rating of five points, the farmers could score a maximum of 55 points. Lithuanian raspberry growers rated their activity as 25.78 points out of a possible 55, which represents 51.56%. This shows that there are issues to be addressed in the sector. Interviewees argued that soil erosion, undetermined soil properties, and biodiversity are the least sustainable areas, but cultivation and processing principles and high land performance score are the most sustainable environmental areas.

Comparing environmental sustainability in raspberry growing and processing with other studies, our results show that cultivating and processing principles are the strongest areas with, farmers adhering to recognized certifications and standards, such as organic certifications which ensure that raspberry production meets specific environmental criteria. Krishkova et al. (2020) [61] pointed out that improving the economic performance parameters of raspberry production can be achieved through the optimization of alternative agricultural management practices. Vasquez-Ibarra et al. (2021) revealed that the variability in the environmental categories can be associated with three main causes: the quantity of agrochemicals used, the type of agrochemicals, and the yield obtained in each orchard [62]. These causes can individually or jointly influence the variability in the environmental impact categories, as is the case of the quantity of agrochemicals applied and yield obtained. Fertilizers make the greatest contribution to the environmental impact categories studied, followed by pesticides, and pruning waste management. Our study revealed that soil fertility and pest and agricultural management are the weakest areas in raspberry growing in Lithuania.

3.4. Social Sustainability

In the third part of the interview, on social sustainability, farmers were asked about their how work functions and their responsibilities, and the specifics of well-being, safety, and comfort in the workplace. Social sustainability categories with explanations and interviewees answers are given in Table 6.

Table 6. Digital model for measuring social sustainability on raspberry farms.

Sustainability Measurement Categories	Subcategories with Explanations	Results from Informants Open Questions	Interviewees Data	Score Average
1. Worker categories	1.1. Farmer and his family members	Permanent job, up to two	E001–E009	**4.89** *
	1.2. Employee	Seasonable up to five per 1 ha	E001–E009	2.11
2. Working conditions	2.1. Remuneration and overtime payment	*Farmer*: Payed from annual profit	E001–E009	1.67
		Employee: Minimum		3.44
	2.2. Working hours	*Farmer*: 48 h per week and more	E001–E009	1.33
		Employee: 40 h per week or less	E001–E009	**5.00** *
3. Well being	3.1. Facilities to help during the work, rights, and benefit	Fully equiped	E001, E002, E005, E008	4.22
	3.2. Training and education.	*Farmer*: according to the need	E003, E006	**4.78** *
		Employee: none	E001–E009	**1.11** **
	3.3. Work stress	*Farmer*: high level	E001–E009	**1.22** **
		Employee: none	E003, E009	4.11
	3.4. Physical demand	The job requires good physical condition	E001–E009	2.44
4. Safety concerns	4.1. Personal protecting tools	Fully equipped	E001–E009	3.78
	4.2. Warnings, instructions, and others displayed in the workplace	Everything is clearly indicated	E001–E009	3.44
	4.3. Accident data, expenditure on illness, and accident prevention	Very rare and without serious consequences	E001–E009	3.33
5. Workplace comfort	5.1. Facilities to help workers during the work, controls, displays, and proper support	Tools that facilitate work are optimized and used as much as possible	E003, E005, E006, E008, E009	3.44
	5.2. Temperature, noise, lighting, and vibration	Depends on weather conditions in the fields and...	E001–E009	**1.11** **
	5.3. Toxic or radioactive chemicals or other hazards	All farmers work with pesticides, herbicides, etc.	E001–E009	**1.22** **
	5.4. Social investments and principles (e.g., coffee makers, free meal breaks, sports, and activities, vacations, insurance, etc.)	Organize holidays, make free meal beaks	E002, E005, E007, E008	1.44
			TOTAL SUSTAINABILITY SCORE:	**54.11/75**

* Most sustainable, ** Least sustainable. The social sustainability categories in the table are prepared based on the following literature sources [63–72].

The last and third digital model for measuring social sustainability in raspberry farms is divided into five main categories. Interviewees primarily distinguished two completely different categories of workers on the farm. They detail the job functions and responsibilities of farm owners:

<<*. . .farmers are the primary individuals responsible for owning and managing the raspberry farms. They make decisions related to cultivation practices, and overall farm management. There are responsible for inspecting and ensuring the quality of raspberries at different stages of production. . .* (E002, E006); *. . .farmers coordinate shipping logistics, track inventory, and ensure timely delivery. They develop marketing strategies, manage customer relationships, negotiate contracts, and work to expand the market reach and demand for raspberries. . .* (E001, E004) *. . .family members in many cases, family members of the farmers actively participate in the raspberry cultivation process. They contribute to tasks like planting, weeding, harvesting, and other farm activities. . .* (E008); *Family involvement often strengthens the sense of ownership and continuity of the farm operation. . .* (E005)>>.

Meanwhile, differences in salaried or seasonal workers are highlighted by these interviewees as follows:

<<*. . .field workers assist farmers during the various stages of raspberry cultivation, including planting, weeding, pest management, and harvesting. Field workers often work on a seasonal or temporary basis, especially during peak farming. . .* (E002); *. . .employees working in raspberry processing plants are responsible for transforming harvested raspberries into various products. . .* (E005, E009); *. . .seasonable workers may be involved in sorting, washing, packaging, operating machinery, and producing value-added products such as jams, juices, or frozen raspberries. . .* (E003, E006, E008)>>.

It is important to note that the size and scale of raspberry farms and processing facilities can vary, which influences the number and composition of employees. According to one interviewee:

<<*. . .field workers provide crucial support to farmers during peak seasons, such as during planting and harvesting. . .* (E007); *workers assist in tasks like transplanting young raspberry plants, weeding, mulching, and maintaining irrigation systems. During harvest time, field workers carefully pick the ripe raspberries, ensuring quality and proper handling. . .* (E008); *employees involved in logistics and distribution manage the transportation and delivery of raspberries from farms or processing plants to markets or retailers. They ensure proper packaging, storage, and handling of raspberries to maintain product freshness and quality throughout the supply chain. . .* (E003)>>

Talking about well-being on the raspberry farms, interviewees emphasized the owners and their family members undertaking training and education:

<<*. . .farmers and workers can acquire knowledge about agricultural practices, plant biology, soil management, pest control, and more. . .*>>; (E003, E006)

Another noted that:

<<*. . .providing proper training, ensuring the use of safety equipment, implementing safe working procedures, and regularly inspecting machinery and equipment are essential to prevent accidents and injuries. . .*>>. (E004)

And another interviewee continued that:

<<*. . . providing ergonomic tools, training on correct posture and lifting techniques, and scheduling breaks can help minimize the risk of injuries and promote the well-being of workers. Raspberry processing often involves the use of machinery, such as sorting, washing, and packaging equipment. Ensuring proper maintenance, operator training, and safety guards on machinery are necessary to prevent accidents and injuries. . .*>> (E008)

Others illustrated their point of view on work stress, safety, and physical demand:

<<. . .*raspberry growing involves physical labor, which can contribute to overall fitness and well-being*. . . (E004); . . .*farmers and field workers engage in activities such as planting, pruning, weeding, and harvesting, which provide exercise and promote physical health*. . . (E001, E007); . . .*working in raspberry fields allows individuals to connect with nature and experience the benefits of spending time outdoors. Being in natural environments has been shown to improve mental well-being, reduce stress, and increase feelings of calmness and relaxation*. . . (E002); . . .*seeing the fruits of their labor grow and contribute to the production of a valuable crop can enhance job satisfaction and overall well-being*. . . (E008); . . .*raspberry growing often involves working in teams or within a community of farmers. This fosters social connections, cooperation, and a sense of belonging*. . . (E009)>>.

Creating a comfortable workplace environment for workers involved in raspberry growing and processing in Lithuania is crucial for their well-being and productivity. Some participants referred to the workplace comfort:

<<*we ensure that workers have access to clean water, restroom facilities, and handwashing stations. . . (E003); . . .we implement safety controls such as emergency response protocols, fire safety measures, and proper ventilation systems*. . . (E005), . . .*farmers control noise levels by implementing soundproofing measures or providing personal protective equipment (e.g., earplugs)*. . . (E006); . . .*we try to optimize lighting conditions, utilizing natural light or providing appropriate artificial lighting to minimize eye strain. Address vibration hazards associated with machinery or equipment to prevent long-term health issues. Provide appropriate personal protective equipment (PPE) and ensure workers are trained on proper handling, storage, and disposal procedures*. . . (E008); . . .*farmers implement strict protocols for chemical handling, including labeling, safety data sheets, and regular monitoring and provide support mechanisms, such as employee assistance programs or counseling services, to address physical and mental health needs*. . . (E009); . . .*farmers offer free meal breaks or subsidized meal options to support nutrition and well-being*. . . (E001)>>.

From the results of such an analysis, it can be concluded that it is important to address safety concerns in raspberry growing and processing in Lithuania to ensure the well-being of workers and consumers. Raspberry farming involves physical labor and operating machinery, which can pose risks to workers' health and safety. Collaborative work environments can contribute to positive social interactions, support networks, and a sense of community well-being.

To address these safety concerns, it is essential to have regulatory frameworks in place, enforce compliance with safety standards, provide training and education to workers, and conduct regular inspections and audits to ensure adherence to safety protocols. Collaboration between government agencies, industry stakeholders, and workers' organizations can play a significant role in promoting safety in raspberry growing and processing in Lithuania. It is important to align these workplace comfort initiatives with applicable labor laws and regulations in Lithuania to ensure compliance and the well-being of workers. Regular assessments, feedback mechanisms, and continuous improvement efforts can help monitor and enhance the comfort and safety of the work environment.

The third social sustainability measurement dimension was divided into five categories: worker categories, working conditions, well-being, safety, and workplace comfort. From all the environmental sub-categories, assuming that each of them is rated with the highest rating of five points, they could score a maximum of 75 points. Lithuanian raspberry growers rated their activity 54.11 points out of 55 possible, which comes to 72.15%. This social dimension was rated by the highest percentage of farmers as the most sustainable. Finally, it is worth mentioning that there are no previous studies that analyze the social sustainability of raspberry growing and processing.

All the participants agreed that permanent jobs for farmers and their family members, training, and education for them according to the need, and working hours for seasonable employees are the most sustainable socio-areas. However, working hours for owners/farmers last too long and they often go without remuneration. Their profit depends on lots of factors (e.g., weather, prices) and workplace comfort depends on severe weather conditions. The sustainability of raspberry cultivation and processing in Lithuania, rated on a Likert scale from very unsustainable to very sustainable, is presented in Table 7.

Table 7. Results from digital models for measuring sustainability of the raspberry farms.

	Unsustainable	→			Sustainable
	1	**2**	**3**	**4**	**5**
Economy	Productivity—no leaves yield, low profit after taxes, high taxes, bad realization, a large amount of wasted food, no high tertiary processing.	Productivity—recycled waste, GPM taxes. Capital—location, infrastructure, land ownership. Realization—wholesale and export. R&D—techniques and technologies used	Productivity—fresh berries, primary and secondary production processing, other services. Capital—procurement of machinery and equipment. R&D—investments in human resources	Productivity—agrotourism and other services like education, events. Almost 100 percent of the production is realized through short food chains	Productivity—high production quality, production is certified, farmers participate in food quality schemes, processes are controlled by state institutions.
Environment	Soil fertility plays a crucial role in determining the success and sustainability of the crops. Pest and agricultural management. Biodiversity	No green energy use. Generating on-site renewable energy can offset energy consumption and contribute to environmental sustainability	Amount of fertilizer used should be assessing crop nutrient requirements through soil testing and adopting precision fertilization techniques. High plant quality and good variety. Accounting and control of water consumption.	Soil—land performance score. A measure of soil quality and fertility, taking into account various factors such as nutrient content, organic matter levels, pH, drainage, and soil structure.	Cultivation and processing principles. Farmers adhering recognized certifications and standards, such as organic certifications which ensure that raspberry production meets specific environmental criteria
Social	Well-being—no training and education for seasonable employees. High stress level for farmers. No social investments and principles. It could secure the workforce in the future.	Working conditions—remuneration and working hours for farmers. Well-being—job requires good physical condition. Workplace comfort—depends on weather conditions, farmers work with pesticides, chemicals, etc.	Working conditions—remuneration for seasonable workers. Workplace comfort—facilities to help during the work. Collaborative work environments can contribute to positive social interactions, sup-port networks, and a sense of community well-being.	Well-being—facilities. Safety—fully equipped personal protecting tools, warnings, instructions, and others clearly indicated, accidents are very rare and without serious consequences.	Worker categories—farmer. Working conditions—working hours for seasonable employees. Well-being—training and educations for farmers.

The research data revealed how sustainability is evaluated by nine farmers according to the established categories. Disclosed unsustainable categories such as production loss in the growing stage, high taxes, bad product realization, undetermined soil properties and erosion, lack of biodiversity, unlimited working hours with profit depending on severe weather conditions or political decisions and workplace comfort are directions for sustainable activity solutions in raspberry growing and processing on Lithuanian farms. Sustainable intensification targets go beyond production, environmental, economic, or social performance.

Raspberry growers should improve the collection and sale of produced raw materials (e.g., leaves), thus contributing to zero-waste technologies and reducing food waste. In addition, the lack of realization also affects competitiveness on an international scale; therefore, scientific research and analysis of laws and documents are necessary, which would reveal what measures at the state level would improve the situation in this sector. In the field of environmental protection, the systematicity of conducting soil tests should be improved. Training on how to calculate the amount of fertilizer based on the results of the soil tests would help farmers save money, and the structure of the soil would improve. In the area of social sustainability, risk management factors such as business insurance should be improved in order for farmers to experience less stress due to the quantity or quality of the produce they grow.

The strengths of sustainability show that raspberry growers and processors have a good potential for the development and realization of high-quality products and they meet the requirements of today's consumers (naturalness, ecology, etc.). The principles of cultivation and processing are of high standards and are friendly to the environment. Good working conditions for workers show that farmers are trying to attract labor, but do not use all available means for continuity of activity in this area, such as support for communities, involvement in local traditions, and events supporting them.

The results of the qualitative study show that product quality, income from additional activities, product realization through short food chains, cultivation and processing principles, permanent jobs for farmers and their family members, training and education for them according to the needs, and working hours for seasonable employees are the most sustainable directions in raspberry growing and processing for effective transformation. Disclosed unsustainable categories such as production losses in the growing stage, high taxes, bad product realization, undetermined soil properties and erosion, lack of biodiversity, unlimited working hours with profit depending on severe weather conditions or political decisions, and workplace comfort are directions for sustainable activity solutions for raspberry growing and processing on Lithuanian farms. Although the results of the study do not show the situation of the entire population in the sector, they can be used for further research, and raspberry growers can use it as a digital model for the sustainability, efficiency, and developmental directions of their farm. Additional policy efforts are needed to manage sustainability in the berry sector.

4. Conclusions

The results of a comparative analysis of the scientific literature determined the sustainability of raspberry production, including potential quantities from cultivation to zero-waste processing, and described the factors influencing the quality of primary raspberry cultivation. This aspect is crucial for valorization and the creation of high-quality products. We identified and selected sustainability indicators for improving the qualitative and quantitative raspberry production and revealed sustainable development solutions in three dimensions: economic, environmental, and social, which can improve raspberry growing and processing in Lithuania.

The results from our qualitative study revealed raspberry cultivation and processing sustainability factors in Lithuania on a Likert scale from very unsustainable to very sustainable in the economic, environmental, and social dimensions. Therefore, the criteria presented in Tables 4–6, as well as the created model, could be a great start for business self-assessment, and setting future goals for sustainable business.

By integrating the above-mentioned sustainable development solutions in three dimensions, raspberry growing and processing in Lithuania can contribute to environmental conservation, economic growth, and social well-being, fostering a more sustainable and resilient agricultural sector. By integrating cultivation and processing principles, raspberry growers and processors in Lithuania can work towards reducing emissions, mitigating climate impact, and contributing to a more sustainable and environmentally friendly raspberry industry. By investing in R&D, Lithuania can enhance its raspberry industry's competitiveness, improve productivity, and address emerging challenges.

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Doctoral Dissertation

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