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Leveraging Horseradish's Bioactive Substances for Sustainable Agricultural Development

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ABSTRACT

The main purpose of the article is to study the peculiarities of the use of biologically active substances of horseradish in the system of sustainable development of the agricultural sector of the country. The key idea of the article is to determine the effectiveness of horseradish in the framework of the optimization process of sustainable agricultural development. Expanding the range of fruit and vegetable products in the diet gives necessary vitamins, micronutrients, amino acids and other phytonutrients that are necessary for the normal functioning of the human body. Horseradish remains a well-known but underrated vegetable. Horseradish is cultivated for the sake of the root with a specific spicy gust. This plant is a source of valuable phytonutrients for the human body. As a result, the key aspects of use of biologically active substances of horseradish in the system of sustainable development of the agricultural sector of the country were characterized. The current review highlights the issues related to the evidence of bioactivity of horseradish leaves and roots, related to the presence of glucosinolates and phenolic compounds that display anticarcinogenic, antibacterial, fungicidal, anti-inflammatory and antioxidant efficacy. These results and evidence will form the basis for a possible increase in consumption, which will contribute to the growth of primary production of horseradish and optimize the development of processing on the industrial level.

1. INTRODUCTION

The problem of ensuring access to healthy food has been increasingly in the scope of attention since the Second International Conference on Nutrition (ICN2) in 2014, becoming particularly up-to-date within the framework of the UN Decade of Action on Nutrition (2016-2025). After all, healthy diet helps avoid the problem of poor nutrition in all its forms, as well as prevent a number of non-communicable diseases (NCDs), including diabetes, heart diseases, stroke and cancer. If the current patterns of food consumption are maintained, diet-related annual expenses in the field of health care, triggered by NCDs and the cause-specific mortality, are projected to reach USD 1.3 trillion by 2030. On the other hand, it is projected that the transition to a healthier diet will reduce direct and indirect health care expenses by 97%, freeing up significant funds that could be invested in reducing the cost of nutritious foods.

The United Nations action in the framework of sustainable development of agriculture and nutrition over the past 10 years has not significantly addressed the issue of horseradish. Research on horseradish and its biological aspects can contribute to food security, and in a secure environment, sustainable development is also possible.

Dietary quality is determined by four aspects: assortment and variety (within food groups and among them), adequacy (sufficient amounts of nutrients or food groups in accordance with guidelines), moderation (foods and nutrients consumed in limited amounts), as well as overall balance (ratio of nutritional macronutrients in the consumed food) [1]. If the exact composition of a healthy diet depends on individual characteristics, cultural environment, locally available food products and formed food traditions, then the basic principles of healthy nutrition are universal. A healthy diet should contain wholegrain products, legumes, as well as a wide range of fruit and vegetables. Expanding the range of fruit and vegetable products in the diet provides for necessary vitamins, micronutrients, amino acids and other phytonutrients necessary for normal functioning of the human body. It is believed that today we consume for food barely a quarter of about 600 types of vegetable crops [2].

The other the vegetable crops may sometimes be referred to as secondary, minor, rare or wild vegetables. Regular consumption of forgotten or underexploited vegetables is an effective way to maintain a varied and healthy diet and to combat micronutrient deficiencies or hidden hunger, as well as some other nutrient deficiencies, especially among rural populations and more vulnerable social groups in developing countries in the context of ensuring sustainable development of the country's agricultural sector [3]. The probable cause for the low consumption of underexploited vegetables, despite their recognized importance, is insufficiency of quality seeds, lack of data regarding their productivity and input requirements, as well as the lack of information on how they can fit into sustainable production systems. At the same time, underutilized vegetables easily adapt to poor and degraded soils, withstand drought, flooding or salinity and can be resistant to extreme climatic events [4]. Besides, they can be used as medical plants, for fodder production and as industrial raw materials. Moreover, the consumption of underutilized vegetables can become the instrument of improvement of food security to address the nutritional needs of the constantly growing population of the world [5] and expanding the range of food products. After all, the underexploited vegetables may often contain specific spicy-aromatic and coloring components which provides for their use as functional additives to food products and as enrichment of foods with necessary phytonutrients [6]. In addition, underexploited vegetables are highly profitable, which makes them a good source of income for smallholder farmers and the right marketing strategies will help increase their consumption in the context of ensuring sustainable development of the country's agricultural sector.

Horseradish (Armoracia rusticana) remains a well-known yet underappreciated vegetable. Horseradish has been cultivated for its root for more than 2,000 years. Its exact origin is unknown. Most likely it is Eastern Europe and Western Asia. Its commercial production is currently taking place mainly in North America and Europe with exclusively vegetative propagation. It is a perennial culture, a well-known traditional medicinal plant, a natural preservative and seasoning for dishes, a base for hot sauces [7].

Both roots and leaves of the plant are used for food. The fresh root is mainly used grated or processed into a sauce for fried and boiled meat and fish. The root is also preserved in white vinegar, beetroot juice, being used in mayonnaise-based sauces and sauces for fish [8]. After harvesting, the roots are usually stored under the conditions of cooling to prevent spoilage and loss of turgor [9]. In Albania, horseradish roots are used for pickling pears or added to fermented vegetable products such as cabbage, tomatoes and peppers. Horseradish leaves are widely used in Eastern European countries for preparation of fermented cucumbers [10]. Furthermore, it is believed that horseradish leaves prevent food spoilage [11], whereas oil and water extracts of horseradish root are used to store tomatoes and peppers [12]. Horseradish root is also used as a cheaper alternative to wasabi.

In recent years, scientists have been paying more and more attention to horseradish due to its high content of biologically active compounds. The specificity of these compounds provides horseradish with antioxidant [13], antimicrobial, antifungal, tumoricidal properties. Nowadays, the development of physical (spray drying, lyophilization), physic-chemical and chemical methods of encapsulation allows to obtain healthier and more acceptable bioactive compounds from horseradish, which have good perspectives of application for food technologies in the context of ensuring sustainable development of the country's agricultural sector [14]. It has been established that microencapsulated horseradish juice is effective for extending the shelf life and stabilizing the quality of raw pork [15]. The addition of horseradish processing products to butter biscuits (leaf cake and microencapsulated horseradish root and leaf juice) is proposed for enrichment bakery products with bioactive compounds [16]. At the same time, the potential of this plant is still not used to the full.

Focusing on the health benefits of horseradish, the main purpose of this review was to discuss some relevant topics for new research that could be essential for agricultural and industrial production and impact the regional economy and sustainable development of the country's agricultural sector. Thus, the consolidation of the conducted research on horseradish as a promising crop lays a theoretical basis for more conscious smart consumption and can stimulate new directions in research aimed at strengthening the field of production of horseradish and its processing products and identifying the issues that still need to be clarified.

The main purpose of the article is to study the peculiarities of the use of biologically active substances of horseradish in the system of sustainable development of the agricultural sector of the country. The structure of our article can be divided into several parts: part of the analysis of the literature, part of the description of the methodology and main methods, part of the presentation of the results of the study, part of the discussion of the results of the study, part of the description of opinions in the form of conclusions and subsequent studies.

2. METHODS

2.1 A review of the literature on the subject of effective methods

Methods of analysis and synthesis of information based on the literature review were used. An abstract logical method was used to form conclusions. The method of biological analysis and synthesis was also used.

Horseradish as well as other Brassica crops contains secondary metabolites classified as glucosinolates (GSL). GSL are an important chemical group among the many phytocompounds beneficial to human health. This is a group of sulfur-containing glucosides that play an important role in the system of plant defense against insects, some food bacteria and fungi [17]. The content and composition of GSL in Brassica vegetables depend on the type of tissue as well as on the genotype type of the plant. The total GSL concentration is highest in seeds, followed by sprouts, roots and shoots [18]. GSL content can be low to moderate in leaves, ranging from 1,000 ppm in some plants to 3,000 ppm in Brussels sprouts. GSL concentration in roots and seeds can be higher, up to 30,000 ppm in horseradish root and 60,000 ppm in mustard [19]. GLS content reaches more than 10% of dry weight in horseradish root. Researchers currently report of 46 individual GLS in horseradish. However, the main GSL of horseradish are sinigrin (on average 83% of the total amount of GSL), gluconasturtin (about 11%), glucobrassicin (about 1%), with other glucosinolates reaching in total up to 5% in the root. At the same time, Alazzam et al. [20] shows that certain varieties contain more glucobrassicin than gluconasturtin, with the predominant content of sinigrin.

Li and Kushad [21] evaluated the content of glucosinolates in 27 varieties of horseradish and suggested that plant origin does not affect the total GLS in the root. However, the total GLS of horseradish varies widely and, depending on a variety, can range from 2 to 296 μmol/g dry weight in root and leaves tissue. Came to the conclusion that the genotype has an important influence on the content of volatile compounds of horseradish, which is the product of GLS decay [22]. Moreover, certain studies have shown that different varieties of horseradish demonstrate differences in their aroma profile when grown under the same conditions. GLS concentration in plants varies significantly depending on climatic factors. The comparison of GLS content in plants of the same variety for two production years, which differed in temperature and rainfall, showed that low average 10-day rainfall and high average temperature of the growing season significantly increased the GLS content [23]. While genetic factors largely determine the type of GSL, environmental factors influence their number. The analysis of De Maria et al. [24] of four different types of horseradish grown on different soils established that the accumulation of biologically active substances is influenced with climatic and soil factors. A number of studies show that agro-technical factors, such as the application of N and S can be one of the means of changing the level of GLS in plants. Italian researchers confirm that the concentration of GLS in horseradish increases when growing horseradish with N and S fertilization [24].

2.2 Characteristics of the efficiency of the methods

Horseradish leaves contain significant amounts of GLS, but their level is lower than in roots. Sinigrin is the dominant glucosinolate in leaves, as well as in roots, accounting for an average of 92% of total GLS [25]. Leaves also contain gluconasturtin, but in a much lower concentration than in roots. Unlike root tissue, leaf tissue contains neoglucobrassicin (2.5% of the total) instead of glucobrassicin. Several studies have shown that the GLS content changes both in the roots and in the leaves of horseradish during the season of growing [25]. Young leaves show much higher concentration of GLS. Young tissues of roots and leaves tend to accumulate more glucobrassicin and neoglubrassicin, respectively (Table 1).

Table 1. Main glucosinolates content in horseradish

Compounds	Content, μmol g^{-1} DW			
	Roots		Leaves	
	Young	Ripe	Young	Ripe
Total GLS	74.7	295.8	150.2	126.0
Sinigrin	58.0	258.0	77.6	114.8
Gluconasturtin	0.2	20.1	0.5	0.1
Glucobrassicin	13.4	2.8	-	-
Neoglucobrassicin	-	-	66.2	1.2
Residual GLS	3.1	14.9	2.3	1.1

Alnsour, unlike Li and Kushad [21], shows, that young leaves of the horseradish of the East and the Badisch variety also contain higher amounts of sinigrin, than the ripe ones [25]. The predominant content of sinigrin both in leaves and in roots on all stages of growth has also been remarked by Ciska et al. [23]. The share of sinigrin in leaves of the total GLS ranged from 92% for the Danish variety of horseradish in June up to more than 98% for the Creamy and Bavarian varieties of horseradish in July. The highest content of sinigrin (94-96%) was observed in August in the roots of the Hungarian variety, whereas the lowest content (89%) was observed in the roots of the Creamy and the Bavarian horseradish variety. It has been reported that the decrease of sinigrin levels in the last stage of leaf development (August) and the increase in GLS content in roots in October could be caused by the senescence of aboveground tissues or the transfer of GLS from leaves to roots. Alnsour showed similar results [25] and noted a rapid drop in GLS concentration in fully matured horseradish leaves at the end of the growing season.

Indicate that the concentration of GLS in a fully developed leaf is five times higher than in a horseradish root [23]. Li and Kushad [21] found that the concentration of GLS could be higher in leaves and roots depending on the sample. The pattern of variation between aboveground and belowground tissues may be related to different regulation of GLS biosynthesis and metabolism in different plant organs [26].

When horseradish cells are mechanically damaged, the endogenous enzyme myrosinase is released hydrolyzing GSL. As a result of GSL breakdown, various compounds are formed, including isothiocyanates (ITCs), nitriles, thiocyanates, epithionitriles, oxazolidines, the composition of which depends on pH, metal ions and other factors [27]. These compounds are highly volatile and are responsible for the biological activity and specific taste of horseradish. ITCs have been intensively researched recently, as they are recognized to have antitumor, bactericidal and fungicidal effects [28]. Zhang [29] reported the inhibition of tumor cells proliferation by extracts from horseradish roots. Several studies have also been conducted that prove the antitumor effectiveness of allyl isothiocyanate, which is the result of the hydrolysis of sinigrin. The potential of sinigrin to prevent the growth of cancer cells is well established. Allyl isothiocyanate inhibited bladder cancer growth and blocked muscle invasion. It has been established that sinigrin significantly inhibited the proliferation of liver tumor cells and reduced the number of surface tumors in the liver of rats. ITCs have been studied as anticancer agents, showing that they are the promising compounds not only because they inhibit the development of cancer cells [30], but there is also evidence that they can destroy cancer cells [31]. According to a recent review, ITCs show potential antitumor activity against breast, lung, colorectal cancer, glioblastoma, oral cavity cancer, ovarian and prostate cancers. Consuming more GLS and ITCs correlates with a lower risk of cancer.

Other important properties of ITCs include their ability to show antibacterial activity against the so-called hospital strains of pathogenic bacteria. ITCs extracted from horseradish roots in the concentration of more than 2,000 μg/ml showed an inhibitory effect against antibiotic-resistant bacteria Staphylococcus aureus, Acinetobacter baumanii, Pseudomonas aeruginosa. Extract and distillates of horseradish (roots and leaves) effectively inhibited ESKAPE hospital multi-resistant strains (Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa and Enterobacter species), which are responsible for the majority of nosocomial infections, as well as the bacteria which successfully “escape” from the action of commercial antimicrobial drugs [31].

ITCs display the high level of activity against fungal infections. The activity of alkyl/aryl isothiocyanates of horseradish roots against Candida albicans yeast has been described [32]. Popović et al. [31] evaluated the antifungal activity against an isolate of the opportunistic Candida albicans yeast from the environment and food isolates of the food spoilage molds Penicillium notatum and Aspergillus niger [31]. It was established that horseradish root and leaf distillates inhibit fungi at the amounts from 0.12 to 3.125 μg/ml, depending on the type of pathogens and distillate. In addition, the authors note that the three main volatile substances of horseradish (2-Phenylethyl isothiocyanate, 3-phenylpropanenitrile, and allyl isothiocyanate) have a potential synergistic antimicrobial effect. ITCs of horseradish show high antifungal activity against dermatopathogens that cause onychomycosis. ITCs also showed fungicidal activity against Aspergillus flavus, Aspergillus parasiticus, Botrytis cinereal and Penicillium expansum [32]. Several mechanisms of bactericidal and fungicidal activity have been proposed, although clear understanding of the aforesaid mechanisms is still absent.

The biological activity of the ITCs of horseradish is not limited only to the considered effects. There have been proven their antioxidant [33, 34], anti-inflammatory effects. The active discussion of the potential application of GLS and ITCs against chronic pain is held, as well as their application for relief of asthma symptoms, delay of the progression of brain diseases, protection against age-related dementia [35].

However, the methods of application of GLS and ITCs in clinical therapy require further research. Additional research is needed to study the effects of ITCs which are still unknown, as well as to disclose the mechanism of their action, due to which their biological activity is unraveled.

3. SYNOPSIS OF EXISTING RESEARCH

3.1 Effect of processing technologies on glucosinolates and isothiocyanates

Technological processing has a complex effect on the content of nutritious and non-nutritious substances in the vegetables. Due to highly volatile nature of ITCs, their amount depends on numerous variables related to the storage and preparation of horseradish products.

After harvesting and before processing, horseradish roots are usually stored in a cold room for a long time. During the 10 months' period of storage at the temperature of 0-1℃, the total content of isothiacyanates decreases in the root of horseradish of the Polish type from 1,651 mg·kg^{-1} of raw weight (f.w.) to 1,424, while the isothiacyanates content in the the Hungarian type horseradish falls from 1028 mg·kg^{-1} f.w to 923. At the same time, the average level of these compounds remains relatively high, which is important for the vegetable processing and the product quality [36].

Fine crushing or grinding horseradish root into powder is an important step in making the horseradish sauce. Conventional grinding as a rule is done at room temperature, which accelerates the evaporation of ITCs. After slicing and holding the horseradish at 5℃ for 12 hours, the profile of volatile compounds changed and new compounds were found. Some of these decreased in concentration, with 2-phenylethyl isothiocyanate becoming the most common compound. According to Wang et al. [36], when horseradish is ground in a ball mill, which can be done at the temperature of 4℃, the number of ITCs increases within 15, 30 and 60 min of grinding. When the grinding time is increased to 120 min, the content of isothiocyanates decreases due to the acceleration of evaporation and degradation. Ground horseradish slowly loses its sharp flavor and taste even when cooled. Kosson and Horbowicz showed that the industrially produced horseradish cream, which is not subject to heat treatment, contains from 645 to 631 mg·kg^{-1} f.w. isothiocyanates. When the finished product is stored, the concentration of ITCs decreases. However, lower storage temperatures of 2℃ slow down the degradation of ITCs compared to storage at 8℃ and 18℃ [37].

GLS are believed to undergo thermal degradation above 100℃ [38]. However, the degree of GLS degradation is affected by the method of heat treatment. Steaming, microwaving and roasting preserve the GLS content of Brassica vegetables. In contrast, according to other data, the antioxidant activity of individual ITCs is triggered when heated above 100℃. Thermal treatment of sulforaphane and erucin leads to the formation of organosulfur antioxidants that can increase the oxidative stability of food. Cedrowski et al. [34] suggest that the thermal decomposition of ITCs can form secondary compounds capable of scavenging peroxyl radicals. As reported by Tomsone et al. [39], the major volatile compound in fresh horseradish leaf extracts was allyl isothiocyanate. On the other hand, when the pomace was dried by different methods, it was not found in any of the dried samples, although the antioxidant activity is pertinent to dried pomace [39].

The behavior of GLS and ITCs under the influence of high temperatures in different ways of processing plant tissues still needs additional research.

Phenolic substances show high biological activity. These compounds are classified into several groups, such as phenolic acids, flavonoids, xanthones, stilbenes, lignins, tannins, etc., as well as into various subgroups. Various phenolic acids (gallic, protocatechin, caffeic, ferulic, isoferulic, chlorogenic, p-hydroxybenzoic, p-coumaric, syringic and sinapic acids) and flavonoids (catechin, epicatechin, quercetin, kaempferol, luteolin, apigenin, isorhamnetin and rutin) have been identified in the roots and leaves of horseradish [32]. These compounds lay a protective role for such degenerative diseases as cardiovascular diseases, cancer, diabetes, inflammation and many others [40]. Their impact on health is widely known due to their strong antioxidant effect. Scientists particularly highlight the antioxidant activity of flavonoids.

Horseradish roots and leaves are characterized with a rather high total content of phenolic compounds in general (TPC) and high total flavonoid content (TFC) in particular (Table 2).

Table 2. Content of phenolic compounds in horseradish

Compounds	Content	
	Roots	Leaves
Total phenolic content, mg GAE× g^{-1} DW	2.89 - 1.74	3.85 -2.56
Total flavonoid content, mg QE×g^{-1} DW	1.26 - 0.75	1.71-0.95

Table compiled from data of study by Galova et al. [40]. Total phenolic content was expressed as mg of gallic acid equivalents (GAE)×g^{-1} dry mass (DW) of sample. Total flavonoids content was expressed as mg of quercetin equivalent (QE)×g^{-1} dry mass of sample.

However, the biosynthesis of phenolic compounds in plants depends on such factors as genotype, agricultural cultivation techniques, the stage of plant development, soil composition, environmental conditions and other abiotic and biotic factors [41].

Different genotypes of horseradish show significant difference in content of polyphenolic compounds. According to Tomsone et al. [42], out of 9 analyzed horseradish genotypes collected in different regions of Latvia and Belarus, the highest TPC was found in the root of horseradish genotype G280 (Malnava region, Latvia), collected in September (503.54 mg GAE ×100 g^{-1} DW). Instead, the lowest TPC was found in the root of horseradish genotype G26B, grown in the same region and also collected in September (160.14 mg GAE×100 g^{-1} DW) [42]. Later, the same author analyzed other horseradish genotypes and found that the horseradish root of the GM genotype (Marupe region, Latvia) contains only 109.93 mg GAE ×100 g^{-1} DW. Despite the fact that horseradish roots can be harvested from mid-summer until the frosty weather, it is believed that the best time for harvesting is September. Comparing harvesting dates, the TPC of horseradish roots fluctuated, and in September the highest TPC was found only in 6 of the 12 horseradish genotypes researched. That is, the general trend of TPC differences in horseradish roots depending on the genotype and time of harvest was not revealed [42].

The content of phenolic compounds in leaves is 7-10 times higher than in horseradish roots. Tomsone [43] notes that the genotype with the highest TPC in the leaf does not have the highest TPC in the roots. Out of 12 horseradish genotypes, the highest TPC was identified in the leaves of horseradish genotype G12B Preili region, Latvia (5406.2 mg GAE×100 g^{-1} DW), and the lowest one was found in the leaves of genotype GJ Jelgava region, Latvia (710.89 mg GAE×100 g^{-1} DW). The season of collection has a strong influence on the formation of the TPC complex in horseradish leaves. The highest content of phenolic compounds in horseradish was in the period from May to June, which coincides with the period of development of horseradish before flowering and during the period of flowering [43].

The data regarding the content of flavonoids in the roots and leaves of horseradish, received by different authors, differ significantly. So, Alazzam et al. [44] show that TFC in leaves is just slightly higher than in roots (Table 2). Latvian researchers demonstrate that TFC in leaves reaches 5889.85 catehin equivalents (CE) mg CE ×100 g^{-1} DW and is ten times higher than in roots, achieving the level of 242.32 mg CE×100 g^{-1} DW. Biosynthesis of flavonoids is induced by UV radiation, light intensity, exposure to ozone, which explains the higher content of flavonoids in aerial parts of plants. In horseradish leaves, collected in August, depending on their genotype, TFC varied from 2485.8 to 15510 mg CE ×100 g^{-1} DW, which confirms the opinion about the significant influence of varieties, species and genotypes on the processes of flavonoid synthesis.

3.2 Effect of processing technologies on the phenolic compounds

Technological processes can significantly affect TPC and individual phenolic compounds. TPC and TFC of horseradish roots differ significantly depending on the applied technological processes. Freezing horseradish roots leads to 11-12% TPC and 21% TFC increase in almost all groups of phenolic compounds compared to their content in the fresh product, whereas the total content of phenolic acids does not change significantly [16]. Instead, there are changes in individual phenolic compounds. The content of kaempferol and luteolin decreases, quercetin, which is present in fresh samples, is not identified in the processed ones. Freezing triggers the growth of the amount of gallic acid, whereas the content of caffeic acid decreases.

The processes of drying are held at elevated temperatures, which causes thermal oxidation of phenolic substances. Microwave-vacuum drying reduces TPC by 19.6% and freeze-drying by 29.5%. Similar trends are observed in the technological processing of horseradish leaves. After freezing horseradish leaves the content of phenolic compounds increases and drying leads to significant losses of phenolic compounds [45].

Drying horseradish leaves pomace obtained after pressing the leaves for juice resulted in a significant decrease in TPC and TFC and depended on the method of drying. Freeze drying causes a 29% reduction in phenolic compounds, while convective drying results in a 53-59% reduction. Freeze drying is also a more effective method for preserving flavonoids.

The effect of the horseradish root ball mill grinding time on TPC is similar to that on ITCs. When the grinding time was shorter than 60 min, the TPC increased with the increase of the grinding time. Grinding in a lower temperature environment may promote the release and simultaneous retention of phenolic compounds. However, when milling time increased to 120 min, TPC tended to decrease due to oxidative degradation of phenolic compounds. In contrast to TPC, due to the decrease in horseradish powder particle size, TFC increased with milling time.

Let's highlight the key theses of the research results (Table 3).

Table 3. The key theses of the research results

Theses	Results
Product Importance	Horseradish remains a famous but undervalued vegetable in the sustainable development of the agricultural sector
Product consumption	Increasing consumption of the product will contribute to sustainable agricultural and food development

Thus, the use of technological methods for processing horseradish roots and leaves leads to changes in the complex of biologically active compounds of horseradish, and the nature and direction of these changes depend on many factors and require additional research. The information on the quantitative and qualitative transformation of biologically active compounds in various horseradish processing products is insufficient.

4. DISCUSSIONS

There are a number of gaps in the scientific literature [40-45] and they concern that they underestimate the importance of horseradish in the framework of sustainable agricultural development. Discussing the economic usefulness of horseradish in the framework of sustainable agricultural development, it should be noted that, by examining its biological compounds, we came to the conclusion of its usefulness and effectiveness in the food industry. Bioactive compounds of horseradish contribute to its proper use and restoration of food safety.

Many farms have become interested in the cultivation of rare crops recently in the context of ensuring sustainable development of the country's agricultural sector. The economic benefits of their cultivation are obvious and consist in high purchase prices and the availability of free niches on the market for the sale of the produce. Due to the good market prices and high yields that can be obtained from the cultivation of horseradish, a large number of farmers are interested in its production in the context of ensuring sustainable development of the country's agricultural sector. Despite good agro-ecological production conditions and constant demand from the processing industry, horseradish is still grown on relatively small areas.

Cultivation and agricultural technology of horseradish are not difficult. Horseradish is a frost-resistant, moisture- and light-demander. Its rhisome can withstand temperature drops down to minus 25°C. The optimal temperature for regeneration of the root system is 17-20°C. Although the plant will grow in any type of soil, it grows best in deep, well-drained, moist, fertile, loamy soil high in organic matter with a soil pH of 5-7.5 (6.8). It grows in the sun and in partial shade [46].

Horseradish is propagated vegetatively by planting root cuttings. To do this, the roots are dug up in late autumn, cleaned of soil, lateral roots are cut and buds are removed. When planting, cuttings are placed at an angle of 45°, deepened by 10-15 cm at a distance of 40 cm from each other. Under the conditions of Ukraine, roots can be planted both in autumn and in early spring. Horseradish responds well to the application of organic and mineral fertilizers. Rivelli et al. [46] reported an increase in productivity and the content of glucosinolates in response to the application of nitrogen and sulfur-containing fertilizers [47]. Perlaki and Djurovka show that yield increased with increasing potassium rates. The highest total yield and the largest mass of the main root was recorded when applying 40 t/ha manure + Cropcare 600 kg/ha. Horseradish needs regular watering, soil loosening and weed removal.

Horseradish can be grown under annual and perennial cultivation systems, as it can remain productive for 10 to 20 years and even more. The largest production of horseradish is concentrated in Illinois, USA. The preference is given to an annual system there because the perennial system leads to clogging of the soil and a decrease in the quality of roots [48]. Before harvesting, roots and leaves are cut, packed and sold. During the growing season, horseradish leaves (as a commercial product) can be mowed 1-2 times, but this significantly reduces the mass of the roots. It is recommended to dig up the roots in late autumn: in September-October. Marketable rhizomes have a length of at least 20 cm, a thickness of 1-5 cm or more, a weight of 200-500 g. The yield of horseradish depends on the age of the plant. In the case of a one-year crop, it is 5-10 t/ha, in the second year it reaches 10-15 t/ha. According to the data of the State Statistics Service, the average yield of horseradish in Ukraine for 2021 was 7.2 t/ha, but in private farms it reached 7.8 t/ha. However, with sufficient moisture and appropriate agricultural technology, a yield of 11.5 t/ha is achieved from one-year plantations and 24.3 t/ha from two-year plantations. At the process of harvesting many annual roots with a diameter of 0.5-1 cm are obtained in addition to commercial product, which can be used as planting material for the following year [48]. Serbian researchers prove that the use of whole root cuttings as planting material provides for the highest yields and the highest proportion of first-class roots in the total yield as well as a stable number of planting cuttings [49-54]. If the purpose of cultivation is the intensive reproduction of planting material to increase the production of cuttings for planting, the most effective is the use of crown cuttings.

The advantages of growing horseradish as a business are the quick payback of capital investments, minor upfront investment, low labor intensity of production, simple agricultural cultivation techniques, as well as the constant demand for products from processing companies. The problematic issues of growing horseradish in Ukraine are the difficulty of access to high-quality planting material, the need for cultivation and fertilization of the soil, difficulties in the formation and sale of a wholesale batch of the product. However, according to manufacturers, the profitability of growing horseradish roots is about 70%, which is reasonably good.

5. CONCLUSIONS

The current review highlights the issues related to the evidence of the bioactivity of horseradish leaves and roots, coming from the presence of glucosinolates and phenolic compounds that display anticarcinogenic, antibacterial, fungicidal, anti-inflammatory, antioxidant efficacy. Overall, more in vivo data, including clinical trials, are needed to understand the mechanisms of action. These results and evidence will form the basis for a possible increase in consumption, which will contribute to the growth of primary production of horseradish and optimize the development of processing on the industrial level in the context of ensuring sustainable development of the country's agricultural sector.

The implications of our study imply the effect of the possibility of optimizing horseradish as a food product for the purpose of its correct industrial use in the context of sustainable agricultural development. Further research should be devoted to the study of other components of nutrition in the framework of sustainable agricultural development. Investigate, for example, the effect on the influence of food additives and their control in order not to allow the destruction of constancy.

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