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Mineral bioaccumulation in stinging nettle: a tool for enhancing functional food safety

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Abstract

Urtica dioica L., popularly known as stinging nettle, is a versatile plant and has been used as a wild herb for centuries. Due to its ability to accumulate minerals from the soil, nettle can significantly contribute to improving the nutritional profile of foods, being a valuable natural source of minerals that support metabolism, and bone health. Stinging nettle can be used also as a bioindicator of soil quality, which might contribute to the development of safe and nutritious food products relevant to future nutrition and sustainable food security. The bioaccumulation factor is an essential key indicator with double meaning, an environment quality indicator as well as a potential plant nutritional marker. First of all, it is an environmental quality factor because it reflects the health and fertility of the soil, the probability of contamination with various pollutants, and secondly, it offers essential information about the nutritional potential of plants. The study aims to evaluate the bioaccumulation factor of stinging nettle plants as a role of food engineering to refine growing and processing techniques, to enhance the levels of important minerals like potassium, calcium, iron, and magnesium in food products. The stinging nettles and soil samples were collected from five different areas in Romania (Timis County-Timisoara, Bazos; Hunedoara County-Vadu-Dobrii; Gorj County-Turcinesti). All these were dehydrated and then geared up for X-ray fluorescence. K>Ca>Cu>Mo>Zr>Zn shows the rank of the maximum average values of bioaccumulation factors, proving the high accumulation potential of nettles.

Key words: bio-concentration, mathematical model, future nutrition, functional.

1. Introduction

Stinging nettle is a markable plant that has attracted people's consideration for a long time. These plants are well-known for their ability to cause a stinging sensation on contact with the leaves, due to the trichomes histamine and formic acid presence [1]. It has an important capacity in industries: food, cosmetics, and pharmacological. Also, it is a source of green pigments for food coloring, being applied in the production of nutritional supplements [7]. Being used for a long time in the medical field as a treatment, nettle increased blood circulation, and blood pressure in joint diseases. Nettles are applied nowadays as a therapy for hair loss, scalp dandruff, and against seborrhea in cosmetics and in medicine [2]. The vitamins and trace elements present in nettle help to strengthen the immune system and the body's resistance to bacterial and viral infections. Due to the concurrent presence of minerals and vitamins like vitamin C, vitamin E, iron, selenium, zinc, and manganese, stinging nettles have antioxidant properties. Nettle can reduce the risk of cardiovascular diseases due to its high content of potassium. The chlorophyll in nettle leaves contributes to detoxifying and cleaning the body, as well as healing wounds [21]. Stinging nettle provides essential minerals required to sustain health in people [23] and is a great source of minerals, where the content of microelements and macro elements differs depending on the ecological

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conditions [19]. From a nutritional perspective, nettle leaves are plentiful in essential minerals for the human body, such as calcium, potassium, iron, zinc, copper, manganese, magnesium and sodium [22]. The consumption of wild plants has a positive capacity to support food and nutritional security [22]. Fresh nettle leaves have a higher content of iron and calcium than processed leaves which according to Rutto et al have a lower content of these minerals [20]. Environmental factors and soil characteristics influence the bioavailability of mineral elements [25]. Fluctuations in the availability of mineral nutrients in the soil, various stress factors, and the constantly changing environmental conditions strongly influence the growth and development of plants [25]. A range of environmental factors that can modify the plant's ability to accumulate minerals influence the transfer of minerals from soil to plants. Soil pH affects mineral availability, soil structure, and texture, which affects nutrient retention and mobility. Soil moisture, which sustains the transport of absorbed minerals, has an essential role [13]. The processes through which the minerals are taken from the soil are the interception of the roots, the mass transport of nutrients dissolved or transported by water from the soil, and their spreading in the soil layer. Minerals can be transported dynamically as well as passively. Dynamic transport is carried out through different mechanisms such as carrier proteins mediated transport, through selective capture or diffusion. Passive transport is passed out depending on the different concentrations [25]. Most of the elements, which include mineral substances and heavy metals, are accumulated as a result of the process of bioaccumulation, translocation from the soil, and the impact of the geological framework, such as climatic factors [2]. The bioaccumulation factor (BAF) of a plant, is an indicator that highlights the accumulation of some substances, mostly minerals, in the tissues against the concentration of the same substance in the environment, generally soil or water. This parameter is important in appraising a plant’s capacity to assimilate precise substances from its environment [3]. The bioaccumulation factor is one of the most important parameters that describe the relationship between the metal content in soil and plant [28]. The level of BAF shows the ability of a plant to transport a substance, or metal from the soil to the plant [28]. All the factors that concentrate different metals play a vital role in the environmental analyses, providing an extended view in the context of possible hazards, for example, heavy metals. They offer extended knowledge of the movement of substances in the food chain. Detailed analyses of the bioaccumulation factors are essential in evaluating the environmental pollution. BAF was calculated by dividing the concentration of mineral ions in the root of the nettle plant by their concentration in the soil [3]. The Translocation Factor (TF) is an indicator that can show the uptake of minerals, highlighting the balance reached between the mineral’s concentrations in the shoots and roots [5, 24]. Although there are an impressive number of factors that can be calculated to assess the mineral transfer from soil to plant, we focused on BCF, because calculating the Bioconcentration Factor (BCF) is crucial for functional food safety because it provides a detailed measure of a plant's ability to absorb minerals at the root-soil interface. This information enables better control of soil quality, helps in the selection of safer harvesting sites, and enhances the use of nettles as nutrient-rich and safe ingredients in functional foods. The BCF offers direct insights into food safety and supports the goal of ensuring the safety and improving the nutritional value of nettles used in food production. According to Vracko, 2015, “The bioconcentration factor (BCF) describes the readiness of chemicals to concentrate in organisms when the compounds are present in the environment. It is a required eco-toxicological parameter for chemical regulation” [27]. The bio-concentration factor (BCF) is an indicator of plants that accumulate minerals in their roots. Nettle BCF constitutes the ratio between the concentration of mineral ions in the root of the nettle plant and the mineral ion concentration in the soil where the roots are placed [5]. BCF quantity >1 shows that the nettle can accumulate minerals in its roots in high concentrations, then the soil in which they are located [5]. BCF ≤ 1 expresses that the nettle plant absorbs minerals but doesn’t accumulate it. If the BCF value>1 the nettle can have the capacity to assimilate the mineral [18]. The ability of nettle plants to absorb mineral elements from the soil is influenced by: their characteristics, the texture and temperature of the soil, the cationic exchange potential, the content of organic matter, and the available levels of the elements [30]. Stinging nettle can be considered a bioindicator of environmental changes according to its sensitivity to unpropitious soil conditions, mainly to mineral transfer [16]. This study aimed to provide a detailed overview of the transfer of minerals from the soil to the nettle plant by applying the bioaccumulation factor to enhance the importance of minerals for creating new food products.

2. Material and methods

2.1. Collection and preparation of samples

The roots of nettle plants and soil samples have been collected from Romania: Bazos, Recas, Timisoara - Timis County, Vadu-Dobrii – Hunedoara, Turcinesti - Gorj County. Laboratory analysis of soil, nettles, and root samples: soil samples were passed through a 2mm sieve to eliminate any material other than soil, then they were mixed using a grinder, dried in a controlled area, and transferred to closed containers for storage; the roots were cleaned with potable water, removing soil and dust particles. The roots were separated from the nettle stems and leaves. All samples were subjected to air drying and were ground in a laboratory mill for homogenization.

2.2. XRF analysis of soil and plant sample

The mineral content of samples was determined using a Hitachi X-MET8000 XRF spectrophotometer. Hitachi X-MET8000 XRF spectrophotometer determines the total form of the elements. XRF spectrometry is of great value because it determines the concentration [26] and the existence of chemical elements in a quick and precise way [17, 29].

2.3. Calculation of bioconcentration factor (BCF)

The bio-concentration factor is calculated using the formula:

$$BCF = \frac{[\text{Minerals}]_{\text{roots}}}{[\text{Minerals}]_{\text{soil}}}$$

where: $[\text{Minerals}]_{\text{roots}}$ represents the concentration of a mineral contained in the roots of nettle mg/kg, and $[\text{Minerals}]_{\text{soil}}$ is the concentration of that mineral contained in the soils that the roots inhabitmg/kg.

BCF values >1 show that nettles can accumulate minerals in their roots at higher concentrations than the soil in which they grow [5].

2.4. Statistical analysis

Excel and MVSP, version 3.22 software were used for statistical analysis and mathematical modeling. Cluster analysis has the role of recognizing clusters in a set of data based on their similarity or differences [26].

Principal Component Analysis provides observations that are represented by a set of dependent variables that are correlated [12]. It can choose the information from the data and evaluate the obtained bioaccumulation factor [15]. Principal Component Analysis (PCA) presumes a specific evaluation of a covariance or correlation matrix obtained from the initial values [4].

3. Results and Discussion

To determine the ability of nettle plants to bio-accumulate minerals, we studied the bioconcentration factor analyzing the transfer of minerals from soil to plant. The results are presented in Table 1 and Figure 1.

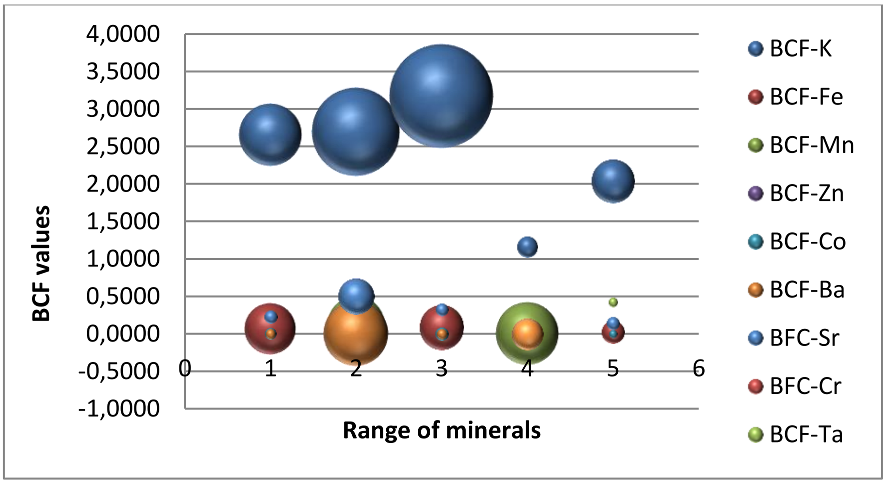

Figure 1. Range of minerals

Table 1. The bioconcentration factor

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
BCF-K	2.65	2.69	3.17	1.16	2.04	2.34
BCF-Ca	1.68	3.33	4.61	0.18	0.80	2.12
BCF-Fe	0.07	0.04	0.09	0.00	0.02	0.04
BCF-Cu	1.12	1.12	0.83	0.00	0.22	0.66
BCF-Mn	0.13	0.12	0.35	0.00	0.00	0.12
BCF-Mo	0.00	1.40	0.00	1.67	0.00	0.61
BCF-Zn	0.75	0.40	0.49	0.06	0.08	0.35
BCF-Ni	0.00	0.20	0.00	0.00	0.00	0.04
BCF-Co	0.00	0.00	0.00	0.00	0.00	0.00
BCF-Ti	0.05	0.03	0.07	0.02	0.03	0.04
BCF-Ba	0.00	0.00	0.00	0.00	0.00	0.00
BFC-Zr	0.04	1.80	0.04	0.00	0.00	0.38
BFC-Sr	0.23	0.50	0.33	0.00	0.14	0.24
BFC-Rb	0.07	0.54	0.06	0.02	0.07	0.15
BFC-Cr	0.00	0.15	0.13	0.00	0.00	0.06
BCF-Sn	0.00	0.00	0.00	0.00	0.00	0.00
BCF-Ta	0.00	0.53	0.55	0.00	0.42	0.30
BCF-Pb	0.00	0.00	0.00	0.00	0.03	0.01
BCF-Th	0.00	0.31	0.00	0.00	0.00	0.06
BCF-Sb	0.00	0.00	0.00	0.00	0.00	0.00
BCF-Hg	0.38	0.56	0.00	0.00	0.31	0.25
BCF-V	0.00	0.00	0.00	0.00	0.00	0.00
BCF-Cd	0.00	0.00	0.00	0.00	0.00	0.00
BCF-Sc	0.00	0.00	0.00	0.42	0.00	0.08

The bio-concentration factor was calculated based on the mineral analyses of soil and plant root samples. The range of the elements are K > Ca > Cu > Mo > Zr > Zn > Ta > Hg > Sr > Mn > Th > Cr > Fe > Ni > Ti > Pb > Co, Ba, Sn, Sb, V, Cd.

If we continue the analyses, we can show that the range of concentration follows the subsequent, and the elements Co, Ba, Sn, Sb, V, Cd are 0, which proves that these elements were not detected or were in low amounts.

The main elements that have a high BCF are potassium and Ca. K shows high BCF values in all samples, ranging from 1.15 to 3.17, with an average value of 2.34 showing the high capacity of nettle to absorb K in all analyzed samples. Constantly high values indicate a constant source of K in the soil and a selective uptake of K by the nettle. Potassium is vital for the acid-base balance in the organism as well as for the osmotic pressure [6].

Calcium accumulates to high levels: 2.12 on average, with values ranging from 0.79 to 4.6. The Ca variation between samples may specify a difference in soil Ca availability. Ca is necessary for cell structure and cell wall stability.

Iron has lower BCF values, ranging from 0 to 0.086, with an average of 0.041. Although the total iron content in soil is high, the bioavailability or uptake by nettle plants remains low, as demonstrated by the BCF value.

Cu has a moderate to high BCF, with a mean of 0.657 and a range of 0 to 1.17. Copper is essential for plants, being involved in nitrogen metabolism [11]. Since soil samples differ by region, indicating differences in composition, the existence of higher Cu levels indicates superior availability of this mineral. Samples 1 and 3 present higher values of Cu indicating a more abundant source of copper in the soil samples.

Zn has an average BCF of 0.35, with values from 0 to 0.75. Zn is required for plant growth enzymes, but upper values in some samples, for example, 0.75 in sample 1, indicate point contamination or an additional source of zinc [9].

Molybdenum has an average value of 0.61. In sample 4 we observe an elevated value of 1.66 compared to the other samples. A high concentration value indicates a local source of molybdenum contamination. Molybdenum is essential in small amounts for nitrogen fixation in plants [8].

Mercury has an average value of 0.24. The highest values were found in samples 1, 2, and 3 (0.37, 0.55, and 0.30). Being a toxic element, these values represent mercury contamination of the soil. The accumulation of mercury is dangerous and the stinging nettles present in these three samples can be used as a bio-indicator for the presence of this element [14].

Cobalt, lead, and tantalum have very low or zero BCF values, indicating that either their concentration in the soil is very low or the nettles cannot absorb them efficiently.

Cadmium BCF has zero levels, which is a positive sign from the point of view of environmental safety since cadmium is a toxic element [10].

In almost all samples, the BCF for thorium and scandium was 0 because it was not assimilated from the soil. The exception was sample 2 for Th and sample 4 for Sc, where the BCF indicates the presence of thorium/scandium in the soil.

BCF zirconium has an average value of 0.37 with a maximum value of 1.80 in the sample from location 2, indicating an elevated zirconium concentration in this zone.

The PCA analysis represented graphically in Figure 2 shows the distribution of BCF for different minerals according to their locations.

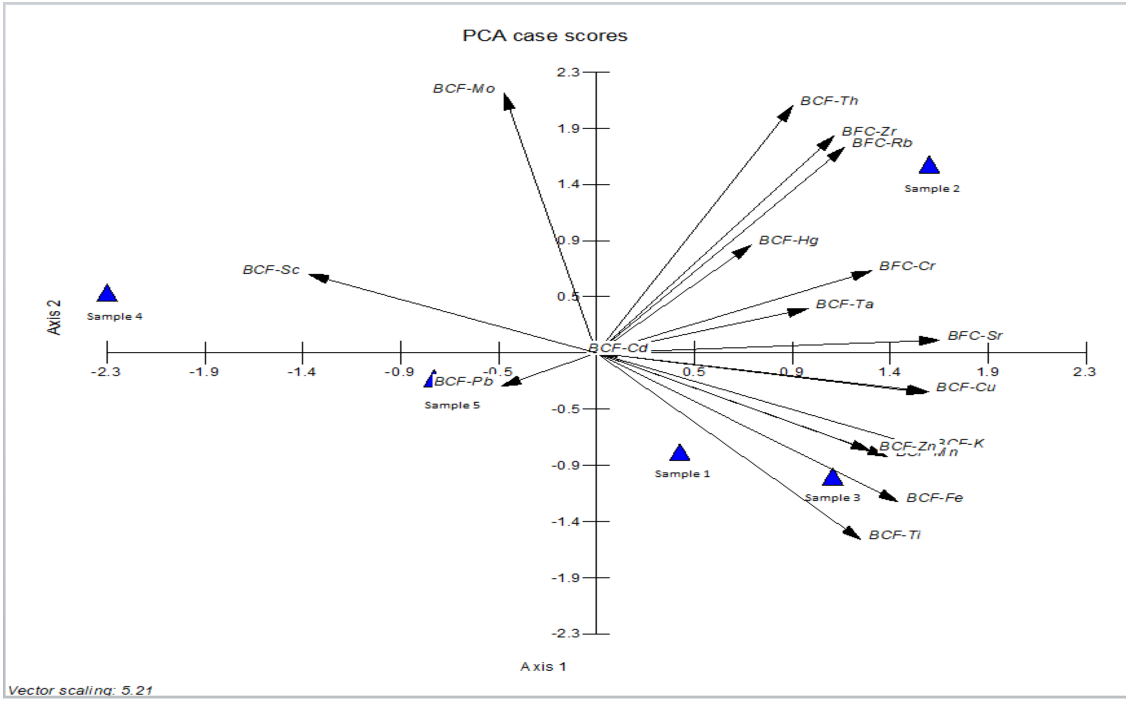

Figure 2.PCA joint plot

In the first quarter are the vectors for Th, Zr, Rb, Hg, Cr, Ta, Sr; in quarter 2 we have the vectors for scandium and molybdenum elements characteristic for location 4; in quarter 3 we see only a short vector, one corresponding to BCF-Pb- location 5; in quarter 4 we see the distribution of the most important minerals (Cu, K, Fe, Mn, Zn, Ca, Ti) characteristic to locations 3 and 1. At the same time, we can mention that in these areas locations 1 and 3 we have no heavy metals contamination.

The fingerprint provides a visible comparison of the proportions of the different calculated BCFs for all analyzed samples (Figure 3), which offers information about the BCF variations.

The cluster representation shown in Figure 4 was created using MVSP Software after transforming the data in square roots, transposed, and standardized. As we can observe we have two main clusters: BCF-K and BCF-Ca and BCF-Mo with BCF-Zr, BCF-Sc, BCF-Cu, BCF-Ta, BCF-Hg, BCF-Rb, BCF-Sr, BCF-Zn, BCF-Pb, BCF-Cd, BCF-V, BCF-Sb, BCF-Sn, BCF-Ba, BCF-Co, BCF-Mn, BCF-Th, BCF-Ni, BCF-Cr, BCF-Ti, BC-Fe.

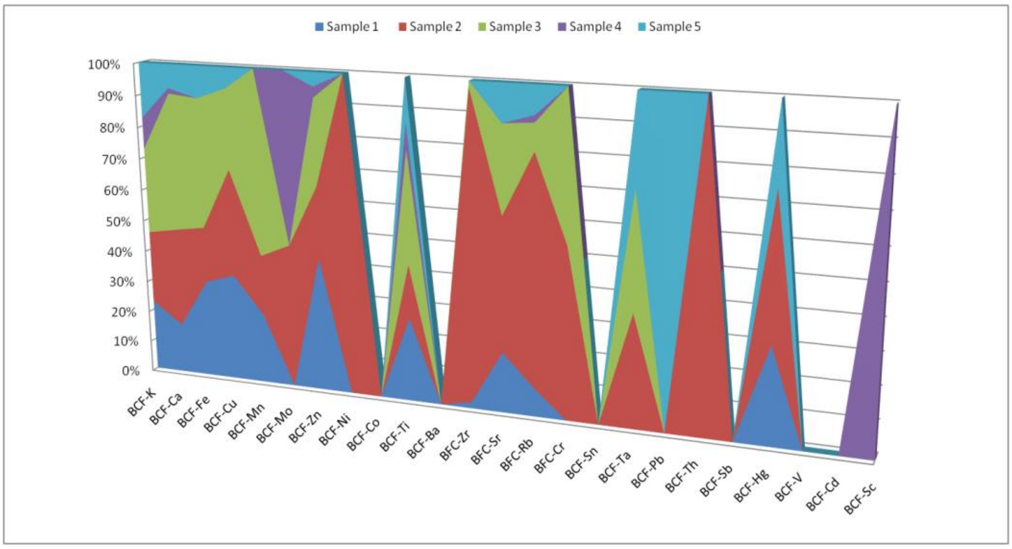

Figure 3. Fingerprint of BCF minerals content

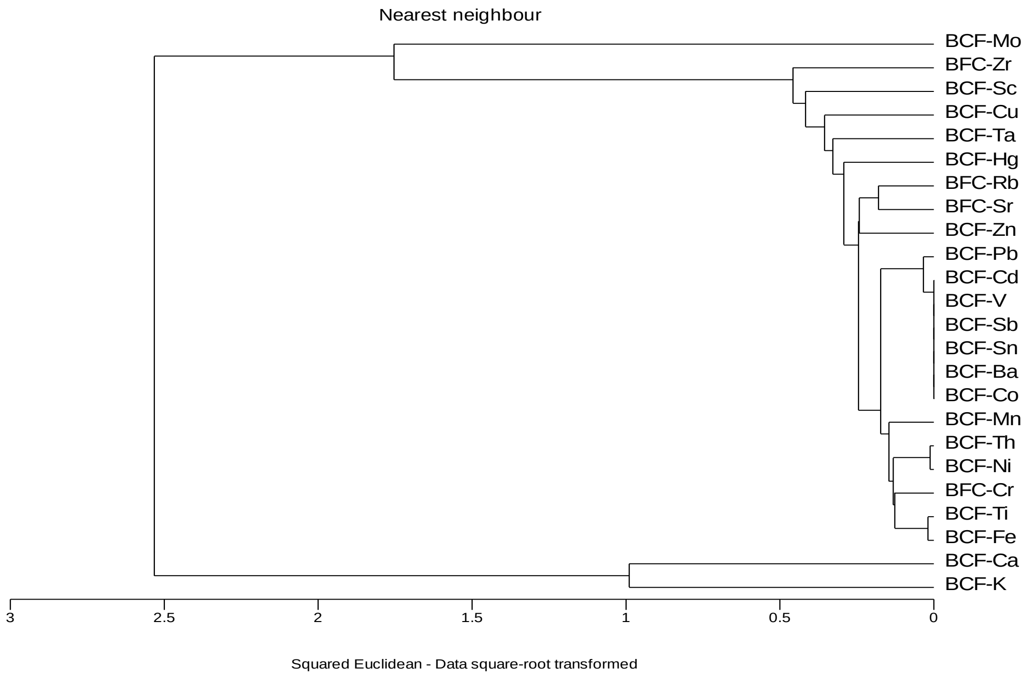

Figure 4. The cluster analyses of BCF based on Euclidian distance of nearest neighbor

4. Conclusion

Following these results, we can conclude that nettle is an extraordinary source of minerals such as calcium, potassium, or iron, supporting the proper functioning of the body.

To determine the bioaccumulation of minerals in nettle plants, we analyzed the transfer of minerals from soil to plant using the bio-concentration factor. The BCF of nettle is the ratio of mineral ion concentration in the root to that in the surrounding soil.

The elements are ordered from highest to lowest as follows: K, Ca, Cu, Mo, Zr, Zn, Ta, Hg, Sr, Mn, Th, Cr, Fe, Ni, Ti, Pb, Co, Ba, Sn, Sb, V, Cd. The main bioconcentration elements were potassium and calcium, demonstrating that stinging nettle is very good at taking up those elements. The nettle from sample 3, which has the highest content of BCF-Ca, BCF-K, BCK-Fe, and BCF-K, has the best ability to absorb and transfer minerals, followed by the values corresponding to stinging nettle from location 2.

We can also emphasize that the nettle plant accumulates and transfers essential minerals from the soil (Ca, K, Cu, Mo, Zr).

The mathematical model is recommended to be used to reduce unneeded soil-root interference and to simplify their interpretation. The fingerprint of the bioaccumulation of the mineral content can be applied as a barometer of the quality of the products of vegetable origin, for the creation of new functional foods.

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