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# Distribution of minerals in the organs of green pea and snap bean plants that could be used in Industry 4.0

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**ABSTRACT**

**Objective**: To determine the minerals, essential trace elements, toxic trace elements, and rare earth element composition of the organs of green pea (*Pisum sativum*) and snap bean (*Phaseolus vulgaris*) plants that could be potentially used in Industry 4.0.

**Design/Methodology/Approach**: The concentration of mineral elements was determined through inductively coupled plasma mass spectrometry (ICP-MS). The distribution of minerals in the flours of the different organs (root, stem, leaves, and fruits) of pea (*P. sativum* L.) and snap bean (*P. vulgaris*) was likewise determined.

**Results**: The leaves are an important fraction of the dry matter (30-40%) of the evaluated plants and they are rich in minerals (calcium, magnesium, phosphorus, and potassium), essential trace elements (manganese, iron, selenium, and zinc), toxic trace elements (aluminum, strontium, boron, tin, and barium), and rare earth elements (cerium, yttrium, lanthanum, and neodymium).

**Study Limitations/Implications**: The production condition of the crops —on which the mineral elements content largely depend on— is unknown.

**Findings/Conclusions**: The organs of the pea and snap bean plants contain a significant concentration of minerals, essential trace elements, toxic trace elements, and rare earth elements; therefore, these organs could be used as raw materials for various processes in Industry 4.0.

**Keywords**: minerals, *Pisum sativum* L., *Phaseolus vulgaris* L.

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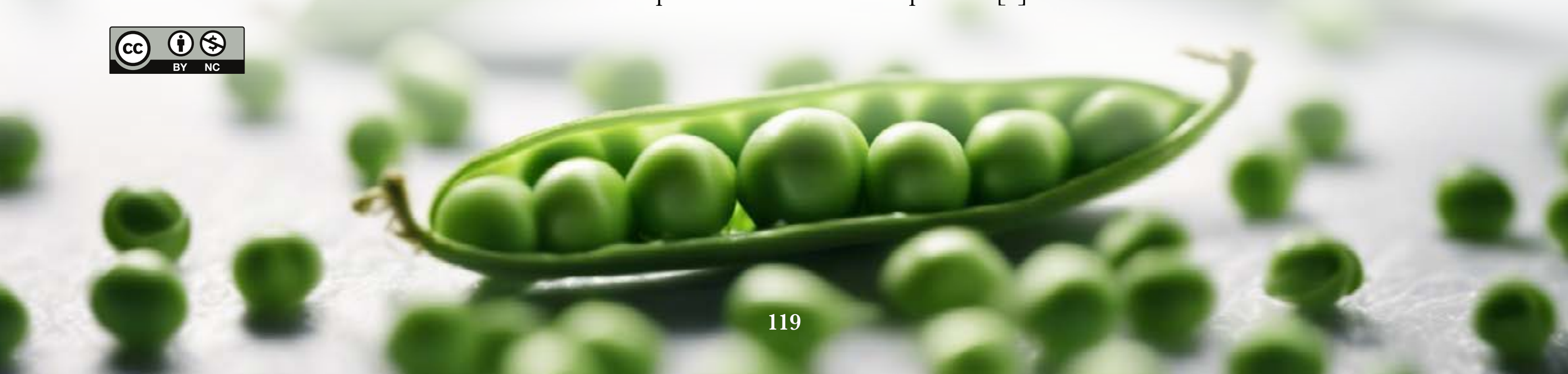
## INTRODUCTION

By 2050, human population is expected to reach 9.7 billion worldwide [1]. This constant demand for resources will impact the biodiversity of the planet, as well as the health and well-being of the population [2]. Therefore, new sources of affordable and low-cost quality food and biomaterials are required. Additionally new technologies for the management, reduction, and elimination of waste should be introduced and the quality and quantity of food and non-food products should be improved [3].



Mexico has a great diversity of biological resources and their study provides information for a better use of the organs of these plants and for a better management of the agricultural and industrial waste. Although this waste does not represent the main value of the transformation, it can be used as raw material for many other products [4].

Organic waste can help to achieve a nutritional balance based on macro and micronutrients. In order to increase food quality, crops that reduce the vitamin and mineral deficiencies of the population must be included in the diet as a long-term sustainable alternative [5].

The leaves or other organs of plants from the Potosi-Zacatecas highland region are commonly used unaware of their chemical composition. Although they could be unsuitable for human consumption, they could be transformed into medicinal products, cosmetics, and industrial biomaterials [6]. In this sense, their mineral content should be established. In addition, whether or not these minerals are found in harmful concentrations should be determined [3]; these minerals include the so-called rare earths, which have been found in trees, grass, cabbage, and other plants [7].

Currently, rare earth elements are used in banknotes (to prevent counterfeiting), smartphones, green technologies, hybrid cars, wind turbines, military equipment (such as night vision goggles, missiles, and other weapons), etc.

Mineral content depends on various factors, including the species, genetic origin, and geographical location, as well as the organ and the stage of development of the plant. However, the data on the content of mineral elements in different plants are scarce.

The objective of this research was to determine the composition of minerals, essential trace elements, toxic trace elements, and rare earth elements of the organs of green pea (*Pisum sativum*) and snap bean (*Phaseolus vulgaris*) plants that could be potentially used in Industry 4.0.

## MATERIALS AND METHODS

### Plant material

Nine green pea plants (*Pisum sativum* L.) and nine snap bean plants (*Phaseolus vulgaris* L.) cv 'Pinto Saltillo' were randomly selected for this experiment. The plants were grown in the open air and under rainfed conditions in July 2020. The green pea samples were collected from a plot in Ejido de Moras, Mexquitic de Carmona, San Luis Potosí (22° 29' 62.95" N, −100° 99' 97.97" W). The snap bean plants were collected in a rainfed plot in the municipality of Zacatón, Salinas de Hidalgo, San Luis Potosí (22° 45' 15.3" N, −101° 59' 47.4" W).

### Experimental site

The analyses were carried out in the Water-Soil-Plant Laboratory of the Colegio de Postgraduados - San Luis Potosí Campus (22° 63' 22" N and 101° 71' 25" W) and in the Chemistry and Biochemistry Laboratory of the Coordinación Académica Región Altiplano Oeste (CARAO) of the Universidad Autónoma de San Luis Potosí (22° 38' 28.5" N and −101° 42' 10.0" W).

### Open acid digestion of samples

The plants were dried at 60 °C, grounded, and stored in Ziploc bags at room temperature until the trials. A 0.5 g sample was weighed on an H-5276 analytical scale (OhausAdventurer) and transferred into a 50 mL flat Teflon tube. Subsequently, 25 ng $mL^{-1}$ of iridium and indium were added to each sample as an internal standard to perform the recovery of the method. In addition, 10 mL of ultra-pure concentrated $HNO_3$ were added to the mixture, which was kept at room temperature for 12 h.

The samples with the $HNO_3$ were placed on a BZH29 heating plate (NJBZH) and heated until the evaporation point (hot acid digestion), without allowing it to dry to prevent the loss of mercury (Hg). When the tubes had approximately 1 mL of the concentrated sample, 10 mL of concentrated $H_2O_2$ were added drop by drop, in order to destroy all the organic matter of the sample (this process is also called total mineralization of the sample). The samples did not require further addition of $HNO_3$ and/or $H_2O_2$. Finally, the samples were gauged to 25 mL in class A volumetric flasks with batch certificate.

### Determination of mineral elements in ICP-MS

The mineral content was determined with the inductively coupled plasma mass spectrometry (ICP-MS) procedure, using the iCAP™ RQ equipment, in KED (Kinetic Energy Discrimination) mode and with a collision cell [12].

### Data analysis

An analysis of variance and a comparison of means (Tukey $\alpha = 0.05$) were carried out for each element found in the different organs of the plant. Each species was studied separately, under a completely randomized design. The analysis was carried out in r-project® 4.2.2, using the RStudio® 2023.06.2 interface, both of free distribution.

## RESULTS AND DISCUSSION

### Distribution of dry matter in the organs of plants

According to their weight, the leaves (395.5 g) of the Pinto-Saltillo bean plant account for 39.55% of the total weight (1 kg). Meanwhile, the weight of the leaves of the pea plant accounts for 30.46% of the total weight of the plant. in both cases this distribution is comparable to the proportion of the weight of the fruits: 33.67% (bean) and 38.44% (plant) (Table 1).

### Macromineral composition of the different organs of the snap bean and green pea plants

According to the results, the leaves of pea plants have an outstandingly high concentration of calcium (6.59 mg $g^{-1}$), magnesium (4.81 mg $g^{-1}$), and potassium (64.70 mg $g^{-1}$); the highest concentration of sodium (11.61 mg $g^{-1}$) and phosphorus (7.52 mg $g^{-1}$) were found in the root and the fruit, respectively (Table 2). Meanwhile, the leaves of the Pinto-Saltillo bean plant had outstandingly high concentrations of calcium (3.16 mg $g^{-1}$), magnesium (2.39 mg $g^{-1}$), and phosphorus (4.66 mg $g^{-1}$); the highest concentration of sodium (0.15 mg $g^{-1}$) and potassium (17.09 mg $g^{-1}$) was recorded in the root and the stem, respectively.

**Table 1**. Distribution of dry matter in the different organs of snap bean (*Phaseolus vulgaris*) and green pea (*Pisum sativum*) plants.

| Specie | Organ | (%) | g kg$^{-1}$ |
|---|---|---|---|
| *Phaseolus vulgaris* | Root | 9.12 | 91.20 |
| | Stem | 17.66 | 176.60 |
| | Leaves | 39.55 | 395.50 |
| | Fruit | 33.67 | 336.70 |
| *Pisum sativum* | Root | 8.68 | 86.80 |
| | Stem | 22.42 | 224.20 |
| | Leaves | 30.46 | 304.60 |
| | Fruit | 38.44 | 384.40 |

Source: Table developed by the authors.

**Table 2**. Macromineral concentration in different organs of snap bean (*P. vulgaris*) and green pea (*P. sativum*) plants.

| Specie | Organ | Mineral content (mg g$^{-1}$) | | | | |
|---|---|---|---|---|---|---|
| | | Calcium (Ca) | Magnesium (Mg) | Potassium (K) | Sodium (Na) | Phosphorus (P) |
| *Phaseolus vulgaris* | Root | 2.16±0.212 | 0.77±0.001 | 9.93±0.234 | 0.15±0.001 | 2.95±0.056 |
| | Stem | 1.15±0.003 | 1.00±0.001 | 17.09±0.001 | 0.09±0.001 | 4.26±0.001 |
| | Leaves | 3.16±0.003 | 2.39±0.012 | 11.23±0.001 | 0.13±0.001 | 4.66±0.001 |
| | Fruit | 0.23±0.003 | 1.42±0.074 | 10.62±0.001 | 0.06±0.001 | 4.53±0.001 |
| *Pisum sativum* | Root | 2.01±0.003 | 1.82±0.002 | 38.02±0.001 | 11.61±0.010 | 5.18±0.001 |
| | Stem | 5.67±0.003 | 4.14±0.002 | 53.10±0.001 | 5.07±0.005 | 4.17±0.001 |
| | Leaves | 6.59±0.003 | 4.81±0.003 | 64.70±0.001 | 5.95±0.029 | 4.82±0.001 |
| | Fruit | 0.35±0.003 | 1.52±0.001 | 10.07±0.001 | 0.11±0.001 | 7.52±0.001 |

Source: Table developed by the authors. In all cases, a significant difference was found ($p<0.001$), but no clustering was recorded (Tukey, 0.05).

The leaves and fruits of *P. vulgaris* recorded the following concentrations: 10.9 to 16.4 mg g$^{-1}$ of calcium, 2.4 to 3.3 mg g$^{-1}$ of magnesium, and 3.1 to 3.8 mg g$^{-1}$ of potassium. Meanwhile, the snap bean pod recorded values of 0.00018 mg g$^{-1}$, 0.00142 mg g$^{-1}$, 0.00033 mg g$^{-1}$, and 0.00053 mg g$^{-1}$ of phosphorus, potassium, magnesium, and calcium, respectively [14]. These results are different from those found in this research for the fruit of *P. vulgaris*: 4.53 mg g$^{-1}$ of phosphorus, 1.42 mg g$^{-1}$ of magnesium, and 0.23 mg g$^{-1}$ of calcium.

Other researchers [15] determined that pea (*P. sativum*) pods had magnesium values of 2.10 mg g$^{-1}$. Although this research obtained similar values (1.52 mg g$^{-1}$), calcium values (7.70 mg g$^{-1}$) were different (0.35 mg g$^{-1}$). Likewise, other authors reported 1.03 mg g$^{-1}$ of magnesium, 11.35 mg g$^{-1}$ of calcium, and 10.44 mg g$^{-1}$ of potassium in green peas [16].

Meanwhile, 1.62 mg g$^{-1}$ magnesium concentrations were recorded in pea seeds from various populations, these results are similar to the values recorded in this research (1.52 mg g$^{-1}$). Meanwhile, Hacisalihoglu, Beiselm, and Settles (2021) [12] reported similar magnesium (0.90 to 1.40 mg $g^{-1}$) and calcium (0.56 to 0.90 mg $g^{-1}$) values in pea seeds than those recorded in this research (0.34 mg $g^{-1}$ of calcium and 1.52 mg $g^{-1}$ of magnesium. The difference between the values of this research and the findings of previous research works may be due to several factors, including: variety, techniques, equipment and solvents used to determine the content of these minerals, climatic and cultivation conditions, and postharvest storage.

**Composition of essential trace elements of the different organs of the snap bean and green pea plants**

Snap bean leaves had a higher content of iron (437.14 mg $g^{-1}$), manganese (237.77 mg $g^{-1}$), copper (14.04 mg $g^{-1}$), and selenium (160.45 ng $g^{-1}$) than pea leaves. Meanwhile the root of the pea plant recorded the highest concentration of chromium (25.35 mg $g^{-1}$) and cobalt (0.30 mg $g^{-1}$). Finally, the stem presented the highest concentration of zinc (20.03 mg $g^{-1}$).

Pea leaves had a higher content of manganese (275.84 mg $g^{-1}$), iron (653.51 mg $g^{-1}$), copper (18.25 mg $g^{-1}$), zinc (74.49 mg $g^{-1}$), and selenium (312.42 ng $g^{-1}$) than snap bean leaves. Meanwhile the fruit of the green pea plant had the highest concentration of chromium (48.20 mg $g^{-1}$) and cobalt (0.59 mg $g^{-1}$) (Table 3).

On the one hand, the element with the highest concentration in the 8 samples evaluated was iron, particularly in the stem of the green pea plant (664.74 mg $g^{-1}$), followed by manganese, especially in the leaves of the snap bean plant (275.84 mg $g^{-1}$).

On the other hand, the values of the snap bean plants are similar to the snap bean pod: 5.61 mg $g^{-1}$ of copper, 25.21 mg $g^{-1}$ of manganese, 73.45 mg $g^{-1}$ of iron, and 19.28 mg $g^{-1}$ of zinc [14]. Likewise, the following concentrations were found in *P. vulgaris* fruits: 6,004 to 1,474 mg $g^{-1}$ of iron , 312 to 557 mg $g^{-1}$ of manganese, 30.4 to 43.7 mg $g^{-1}$ of zinc, 5.7 to 30.5 mg $g^{-1}$ of copper, 2.7 to 4.69 mg $g^{-1}$ of chromium, 1.9 to 3.1 mg $g^{-1}$ of nickel, and 915 to 2,152 mg $g^{-1}$ of aluminum [13]. The following concentrations were found in various green pea seeds: iron (67.49 mg $g^{-1}$), zinc (49.70 mg $g^{-1}$), and copper (6.60 mg $g^{-1}$) [12]. These results are also similar to the findings of this research: iron (91.58

**Table 3**. Concentration of essential trace elements in different organs of snap bean (*P. vulgaris*) and green pea (*P. sativum*) plants.

| Specie | Organ | Trace elements (mg $g^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Cr | Mn | Fe | Co | Cu | Zn | *Se (ng $g^{-1}$) |
| *P. vulgaris* | Root | 25.35±0.64[a] | 39.96±0.08[c] | 169.95±0.96[b] | 0.30±0.01[a] | 4.40±0.39[b] | 14.86±0.89[c] | 33.67±0.64[b] |
| | Stem | 8.73±0.02[c] | 37.20±1.16[c] | 91.58±0.04[c] | 0.16±0.01[b] | 4.16±0.07[b] | 16.21±0.01[b] | 16.59±0.18[b] |
| | Leaves | 19.90±0.13[b] | 237.77±0.01[a] | 437.14±0.10[a] | 0.29±0.05[a] | 14.04±0.04[a] | 14.95±0.02[c] | 160.45±0.32[a] |
| | Fruit | 4.99±0.03[d] | 47.71±0.22[b] | 64.60±0.16[d] | 0.08±0.01[c] | 4.62±0.02[b] | 20.03±0.02[a] | 19.21±0.14[c] |
| *P. sativum* | Root | 0.73±0.01[d] | 72.75±0.18[c] | 304.33±0.03[b] | 0.30±0.04[d] | 14.75±0.06[c] | 33.89±0.03[c] | 200.85±1.29[c] |
| | Stem | 48.20±0.17[a] | 63.23±0.02[d] | 157.53±0.04[c] | 0.59±0.01[a] | 6.93±0.02[d] | 26.80±0.24[d] | 21.34±0.63[d] |
| | Leaves | 1.81±0.01[c] | 275.84±0.08[a] | 653.51±0.18[a] | 0.34±0.08[c] | 18.25±0.07[a] | 74.49±0.24[a] | 312.42±2.70[a] |
| | Fruit | 9.84±0.03[b] | 242.72±0.23[b] | 664.74±45.87[a] | 0.38±0.01[b] | 17.77±0.16[b] | 46.33±0.21[b] | 237.69±2.37[b] |

*Expressed in nanograms per gram. Source: Table developed by the authors. In all cases a significant difference was found ($p<0.001$). Means with the same letter in each column for each species do not record a significant difference (Tukey, 0.05).

mg $g^{-1}$), zinc (16.21 mg $g^{-1}$), and copper (4.16 mg $g^{-1}$). The values reported in another research work [16] for zinc (38.80 mg $g^{-1}$) and iron (33.10 mg $g^{-1}$) in green peas are similar to the results of this research for both minerals (49.70 mg $g^{-1}$ of zinc and 67.49 mg $g^{-1}$ of iron). Other publications [17] have reported similar values for copper (7.00 mg $g^{-1}$), iron (70.00 mg $g^{-1}$), and zinc (30.03 mg $g^{-1}$) in green pea seeds than those reported in this research for copper (4.16 mg $g^{-1}$), iron (91.58 mg $g^{-1}$), and zinc (16.21 mg $g^{-1}$). Likewise, other researchers [18] report the following concentrations in green pea seeds: copper (10.7 mg $g^{-1}$), zinc (39.6 mg $g^{-1}$), iron (53.8 mg $g^{-1}$), and manganese (16.6 mg $g^{-1}$). Those results are also similar to the findings of this research for copper (4.16 mg $g^{-1}$), zinc (16.21 mg $g^{-1}$), iron (91.58 mg $g^{-1}$), and manganese (37.20 mg $g^{-1}$).

**Composition of toxic trace elements of the different organs of the snap bean and green pea plants**

On the one hand, according to the results, the leaves of the snap bean plant are the product with the highest amount of toxic trace elements, particularly aluminum (708.52 mg $g^{-1}$), titanium (93.08 mg $g^{-1}$), barium (15.53 mg $g^{-1}$), and boron (10.40 mg $g^{-1}$). Meanwhile, the root has high concentrations of strontium (122.70 mg $g^{-1}$), nickel (14.44 mg $g^{-1}$), and lithium (7.20 mg $g^{-1}$). The fruit has high concentrations of tin (56.10 mg $g^{-1}$) (Table 4).

On the other hand, green pea leaves have a higher concentration of aluminum (806.33 mg $g^{-1}$), strontium (263.47 mg $g^{-1}$), boron (69.00 mg $g^{-1}$), barium (43.52 mg $g^{-1}$), and lithium (5.39 mg $g^{-1}$). Meanwhile, the fruit has a higher concentration of tin (44.87 mg $g^{-1}$), nickel (32.18 mg $g^{-1}$), and titanium (8.80 mg $g^{-1}$).

The toxic trace elements with the highest concentration in the two varieties were aluminum, strontium, boron, tin, titanium, nickel, and barium. The toxic trace elements with $<$10 mg $g^{-1}$ concentrations were lithium, gallium, lead, bismuth, arsenic, antimony, vanadium, cadmium, zirconium, niobium, silver, tantalum, tungsten, mercury, thorium, and uranium.

**Table 4**. Concentration of toxic trace elements in different organs of snap bean (*P. vulgaris*) and green pea (*P. sativum*) plants.

| Specie | Organ | Mineral content (mg $g^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lithium (Li) | Boron (B) | Aluminum (Al) | Nickel (Ni) | Strontium (Sr) | Tin (Sn) | Barium (Ba) | titanium (Ti) |
| *Phaseolus vulgaris* | Root | 7.20±0.20$^{a}$ | 2.58±0.21$^{d}$ | 111.19±0.20$^{b}$ | 14.44±0.60$^{a}$ | 122.70±0.30$^{a}$ | 37.49±1.47$^{b}$ | 4.32±0.10$^{c}$ | 51.39±0.98$^{b}$ |
| | Stem | 0.10±0.01$^{c}$ | 5.61±0.02$^{b}$ | 35.06±0.29$^{d}$ | 6.83±0.04$^{c}$ | 14.56±0.18$^{d}$ | 56.10±0.02$^{a}$ | 2.86±0.01$^{d}$ | 5.89±0.09$^{d}$ |
| | Leaves | 0.86±0.01$^{b}$ | 10.40±0.01$^{a}$ | 708.52±0.29$^{a}$ | 11.19±0.08$^{b}$ | 118.06±0.01$^{b}$ | 36.54±0.04$^{b}$ | 15.53±0.03$^{a}$ | 93.08±0.30$^{a}$ |
| | Fruit | 0.87±0.01$^{b}$ | 4.15±0.03$^{c}$ | 72.49±0.29$^{c}$ | 3.49±0.04$^{d}$ | 67.12±0.02$^{c}$ | 28.17±0.07$^{c}$ | 7.04±0.02$^{b}$ | 27.48±0.25$^{c}$ |
| *Pisum sativum* | Root | 2.87±0.01$^{c}$ | 28.40±0.02$^{c}$ | 453.91±0.29$^{c}$ | 0.74±0.01$^{d}$ | 115.92±0.02$^{c}$ | --------- | 16.99±0.03$^{b}$ | --------- |
| | Stem | 0.44±0.01$^{d}$ | 3.98±0.01$^{d}$ | 48.18±0.29$^{d}$ | 32.18±0.01$^{a}$ | 19.85±0.03$^{d}$ | 44.87±0.05 | 2.43±0.01$^{d}$ | 8.80±0.35 |
| | Leaves | 5.39±0.01$^{a}$ | 69.00±0.01$^{a}$ | 806.33±0.29$^{a}$ | 1.60±0.01$^{c}$ | 263.47±0.01$^{a}$ | --------- | 43.52±0.1$^{c}$ | --------- |
| | Fruit | 4.35±0.02$^{b}$ | 61.18±0.01$^{b}$ | 657.73±0.29$^{b}$ | 1.92±0.02$^{b}$ | 216.44±124.9$^{b}$ | --------- | 33.82±0.09$^{a}$ | --------- |

Source: Table developed by the authors. In all cases a significant difference was found ($p<0.001$). Means with the same letter in each column for each species do not have a significant difference (Tukey, 0.05).

These results contribute to a more complete and accurate information about the mineral content. An optimal use of the different organs of the green pea and snap bean plants is achieved in the different chemical, biological, and technical processes.

There is little information about the toxic trace elements in the different organs of the green pea and snap bean plants. However, other researchers [14] have reported similar nickel values (4.00 mg $g^{-1}$) in snap bean pods to this research (6.83 mg $g^{-1}$). Meanwhile, different boron concentrations (9.69 mg $g^{-1}$) in various green pea seeds were found in other research works; these results differ from the findings of this research regarding the fruit (3.98 mg $g^{-1}$).

**Composition of the rare earth elements in the different organs of snap bean and green pea plants**

The snap bean leaves recorded significant concentrations of cerium (947.94 ng $g^{-1}$), yttrium (808.05 ng $g^{-1}$), neodymium (440.04 ng $g^{-1}$), and lanthanum (437.6 ng $g^{-1}$). The other elements are found in concentrations of $<$100 ng $g^{-1}$.

Meanwhile, the only organ of the green pea plant that has a concentration of rare earth elements is the fruit (pod). As in the previous case, cerium recorded the highest concentration (71.86 ng $g^{-1}$), followed by yttrium (48.63 ng $g^{-1}$), lanthanum (30.30 ng $g^{-1}$), and neodymium (28.52 ng $g^{-1}$). The other elements are found in concentrations of $<$7 ng $g^{-1}$ (Table 5).

**Table 5**. Concentration of rare earth elements in different organs of snap bean (*P. vulgaris*) and green pea (*P. sativum*) plants.

| **Specie** | ***Phaseolus vulgaris*** | | | | ***Pisum sativum*** |
|---|---|---|---|---|---|
| **Rare-earth element (ng $g^{-1}$)** | **Root** | **Stem** | **Leaves** | **Fruit** | **Fruit** |
| Yttrium (Y) | 151.45±1.44 | 72.07±0.77 | 808.05±2.74 | 36.18±0.24 | 48.63±0.79 |
| Lanthanum (La) | 84.01±1.31 | 41.74±0.30 | 437.60±9.47 | 25.53±0.39 | 30.30±0.18 |
| Cerim (Ce) | 207.49±2.67 | 102.78±1.08 | 947.94±10.72 | 68.48±0.25 | 71.86±0.21 |
| Praseodymium (Pr) | 19.62±0.57 | 9.27±0.06 | 117.34±0.06 | 6.04±0.06 | 6.48±0.17 |
| Neodymium (Nd) | 79.17±2.23 | 38.48±0.40 | 440.31±0.2 | 27.51±0.16 | 28.52±0.45 |
| Samarium (Sm) | 17.27±1.77 | 7.45±0.20 | 96.33±0.21 | 5.38±0.16 | 5.26±0.16 |
| Europium (Eu) | 0.17±0.03 | --- | 4.62±0.35 | --- | --- |
| Gadolinium (Gd) | 16.58±0.63 | 7.27±0.22 | 92.56±0.18 | 5.05±0.05 | 5.12±0.15 |
| Terbium (Tb) | 0.90±0.13 | --- | 12.26±0.12 | --- | --- |
| Dysprosium (Dy) | 14.87±2.34 | 6.26±0.04 | 77.45±0.08 | 4.75±0.20 | 4.62±0.27 |
| Holmium (Ho) | 1.28±0.28 | --- | 13.76±0.23 | --- | --- |
| Erbium (Er) | 8.36±0.58 | 3.54±0.13 | 42.62±0.33 | 2.68±0.10 | 2.72±0.19 |
| Thulium (Tm) | --- | --- | 4.33±0.29 | --- | --- |
| Ytterbium (Yb) | 5.91±0.94 | 1.65±0.11 | 36.68±0.38 | 1.12±0.18 | 0.80±0.19 |
| Lutetium (Lu) | 0.06±0.03 | --- | 4.20±0.28 | --- | --- |

Source: Table developed by the authors.

## CONCLUSIONS

The weight ratio of the leaves of the green pea and snap bean plants is comparable to the weight of the fruit. Additionally, these leaves have the highest concentration of such minerals as calcium, magnesium, phosphorus, and potassium, as well as essential trace elements, including manganese, iron, selenium, and zinc. The toxic trace elements with the highest concentration in the leaves of both species are aluminum, strontium, boron, tin, and barium. Meanwhile the highest concentration of rare earth elements (cerium, yttrium, lanthanum, and neodymium) was found in the snap bean leaves and the green pea fruit.

The organs of green pea and snap bean plants are an alternative raw material for the food and biomaterial production enriched with minerals, essential trace elements, toxic trace elements, and rare earth elements, which accumulate and bioconcentrate in these organs. In conclusion, these plants can be used as indicators or as phytoextractors which can be selected as inputs in Industry 4.0 processes.

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## REFERENCES

1. ONU, 2022. Organización de las naciones unidas. Población mundial | Fondo de Población de las Naciones Unidas. Recuperado 13 de mayo de 2022 (https://www.unfpa.org/es/data/world-population-dashboard).
2. Diamond, J. 2006. Colapso. Por qué unas sociedades perduran y otras desaparecen. Barcelona, Debate. ISBN: 84-8306-648-3. 747 p.
3. Sheldon, R. A. (2000). Atom efficiency and catalysis in organic synthesis. *Pure and Applied Chemistry, 72*(7):1233-1246. https://doi.org/10.1351/pac200072071233
4. Saval, S. (2012). Aprovechamiento de residuos agroindustriales: pasado, presente y futuro. *Revista de la Sociedad Mexicana de Biotecnología y Bioingeniería A. C, 16*(2), 14-46. https://www.academia.edu/23775116/Aprovechamiento_de_Residuos_Agroindustriales_Pasado_Presente_y_Futuro
5. Pachón, H.2010. El impacto nutricional de cultivos biofortificados o cultivos con mayor calidad nutricional [WorkingPaper]. AgroSalud; Centro Internacional de Agricultura Tropical (CIAT). https://cgspace.cgiar.org/handle/10568/70022
6. Özcan, M., Ünver, A., Uçar, T., & Arslan, D.2008. Mineral content of some herbs and herbal teas by infusion and decoction. *FoodChemistry*, 106, 1120-1127. https://doi.org/10.1016/j.foodchem.2007.07.042
7. Tyler, G. 2004. Rare earth elements in soil and plant systems – A review. *Plant and Soil. 267*(1):191-206. (https://link.springer.com/article/10.1007/s11104-005-4888-2)
8. Prego Reboredo, R. M. (2019). Las tierras raras: CSIC, Consejo Superior de Investigaciones Científicas, 2019 - 141 p. - ¿Qué sabemos de...?; 99 - ISBN: 9788400104634 - Permalink: http://digital.casalini.it/9788400104634 - Casalini id: 4452076
9. Sánchez-Castillo C.P., Dewey P.J.S., Aguirre A., Lara J.J., Vaca R., León de la Barra P., Ortiz M., Escamilla I. & James, W.P.T. (1998). The mineral content of Mexican fruits and vegetables. *Journal of Food Composition and Analysis.11*(4): 340-56. https://doi.org/10.1006/jfca.1998.0598
10. de Oliveira, MW, Bhatt, R., Lessa, JB, Santos, D. de F., de Assis, WO y Tenório, TM (2023). Eliminación de nutrientes y calidad bromatológica del maíz en cultivos de alta productividad. *DELOS: DESARROLLO LOCAL SOSTENIBLE , 16* (43), 525–543. https://doi.org/10.55905/rdelosv16.n43-004
11. Jakubowska, M., Zembrzuski, W., and Lukaszewski, Z. (2006). Oxidative extraction versus total decomposition of soil in the determination of thallium. *Talanta, 68*(5), 1736-1739. https://doi.org/10.1016/j.talanta.2005.08.035
12. Hacisalihoglu G, Beisel N.S.& Settles A.M. (2021). Characterization of pea seed nutritional value within a diverse population of *Pisum sativum*. *PLoSOne. 16*(11): e0259565. https://doi.org/10.1371/journal.pone.0259565

13. Hernández A. J.; Alexis, S.; Fernández-Pascual, M.; Pastor, J. 2006. Estudio de la nutrición mineral de Phaseolus vulgaris L. en suelos de cultivo que contienen metales pesados. En: Nutrición Mineral. Aspectos fisiológicos, agronómicos y ambientales. C. Lamsfus, (EditoraCoordinadora): 573-580 Ed. Universidad Pública de Navarra, Pamplona. ISBN: 84-9769-165-2. https://digital.csic.es/bitstream/10261/52096/1/Pamplona.pdf
14. Fernández Valenciano, A. F., y Sánchez Chávez, E. (2017). Estudio de las propiedades fisicoquímicas y calidad nutricional en distintas variedades de frijol consumidas en México. *Nova scientia, 9*(18), 133-148. https://doi.org/10.21640/ns.v9i18.763
15. Mateos-Aparicio, I., Redondo-Cuenca, A., Villanueva-Suárez, M. J., Zapata-Revilla, M. A., and Tenorio-Sanz, M. D. (2010). Pea pod, broad bean pod and okara, potential sources of functional compounds. *LWT - Food Science and Technology, 43*(9), 1467-1470. https://doi.org/10.1016/j.lwt.2010.05.008
16. Millar, K. A., Gallagher, E., Burke, R., McCarthy, S., and Barry-Ryan, C. (2019). Proximate composition and anti-nutritional factors of fava-bean (*Vicia faba*), green-pea and yellow-pea (*Pisum sativum*) flour. Subtropical Plant Science. https://10.1016/j.jfca.2019.103233
17. Woźniak, A., Makarski, B., Stepniowska, A. & Soroka, M. (2012). Chemical composition of pea (*Pisum sativum* L.) seeds depending on tillage systems. *Journal of Elemntology*. 19. DOI: 10.5601/jelem.2014.19.3.484
18. Ton, A., Mart, D., Karaköy, T., Türkeri, M., Torun, A. A. & Anlarsal, A. E. (2022) "Characterization of some local pea (*Pisum sativum* L.) genotypes for agro-morphologicaltraits and mineral concentrations," *Turkish Journal of Agriculture and Forestry*: 46: 2, 11. https://doi.org/10.55730/1300-011X.2975