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Plant seeds as source of nutrients and phytochemicals for the Indian population

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Summary Plant seeds are major sources of nutrients and bioactive compounds for human beings and vary across different locations. In addition, they are under used foods that could be a good complement for the daily nutrition of people. Therefore, the aim of this study was the analysis of different physical parameters, nutrients and bioactive compounds of 60 plant seeds belonging to 48 species and 9 families. The seeds were collected in 2016–2017 in the Raipur area, India (21.25°N 81.63°E), from three different locations. Fat, protein, starch, total polyphenols and mineral contents ranged from 0.7 to 44.2, 1.6 to 68.5, 11.3 to 84.0, 0.01 to 3.85 and 0.67 to 4.91 g/100 g (dry weight) respectively. Regarding physical properties, the heavier seeds were covered with thick testa over the range of 3.0 to 40% of the seed mass. Higher moisture and ash fractions for the starchy (cereal and pulses) and weed seeds were also found. The most abundant mineral elements in the seeds were P, S, K, Mg, Ca, Fe and Zn. Finally, it was calculated the contribution of the consumption of seeds to the daily macronutrients and micronutrients intake for Indian population, reaching up to 38, 13 and 25% for proteins, fat and carbohydrates respectively.

Keywords composition, fat, minerals, polyphenols, protein, seeds, starch.

Introduction

The largest concentration of people with micronutrient deficiencies (mainly of iron and zinc) lives in low-income South Asian countries, including India (Mark *et al.*, 2016; Rao *et al.*, 2018). Due to most Indians have predominantly vegetarian diets (Devi *et al.*, 2014), with high consumption in wheat and rice (Khatkar *et al.*, 2016), a possible solution for this problem is the diversification of diets, particularly by stimulating the use of seeds other than rice and wheat such as coarse cereals and pulses (Rao *et al.*, 2018). The Indian seed industry is the fifth largest seed market in the world, and it is majorly contributed by non-vegetable seeds (Kumar *et al.*, 2018).

Seeds from cereals, pulses, beans and herbal plants are used for food and medicinal purposes all over the world (Venkidasamy *et al.*, 2019), and the analysis of macronutrients content is regarded as essential for assessing their quality (Singh *et al.*, 2017). Nonetheless, other seed components are also receiving increasing attention. In this sense, polyphenols are strong antioxidant compounds used against various diseases such as cancer, diabetes or osteoporosis, among others (Pandey & Rizvi, 2009; Pérez-Burillo *et al.*, 2018). On the other hand, mineral elements are needed in small amounts for metabolic and developmental processes (Huskisson *et al.*, 2007). Hence, minerals and polyphenols contents have been reported in the literature for

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different seeds. Specifically, Venkidasamy *et al*. (2019) found that pulses are rich in potassium, calcium, magnesium, phosphorous and iron. This kind of seeds also contains bioactive compounds such as phenolic compounds (Sharma *et al*., 2021). Ramírez-Ojeda *et al*. (2018) reported that according to the contributions to Dietary Reference Intakes, legumes were proper sources of iron, calcium, manganese and zinc. Cereals are also an important source of mineral elements, contributing more than 50% of total dietary iron intake (Aslam *et al*., 2018). More specifically, high amounts of macro- (calcium, potassium and sodium) and microelements (iron and zinc) have been reported in Indian rice (Verma & Srivastav, 2017). The growing demand for minerals and antioxidants in the food and cosmetic industries promotes the search for new sources of these compounds.

No detailed study has been carried out to investigate the phytochemical and mineral composition of seeds belonging to cereals, pulses, beans and weeds cultivated in India, especially those from Raipur area. This work is aimed at providing a basic database of fat, protein, starch, total polyphenols, flavonoid and mineral contents in 60 seeds commonly grown in Central India. In addition, comprehensive analysis of weight, colour, moisture content and ash residue are also discussed along with the contribution of seeds consumption to nutrients intake of the usual daily Indian diet.

Materials and methods

Sample collection and preparation

The selected seeds (Figure S1) from 48 species were classified as cereals (seed no. 1–12), pulses (13–27), beans (28–36) and weeds (37–60). Among them, seeds no. 1–12, 13–48, 49–50, 51–55, 56, 57, 58, 59 and 60 belonged to the families Poaceae, Fabaceae, Boraginaceae, Convolvulaceae, Onagraceae, Cyperaceae, Acanthaceae, Brassicaceae and Capparidaceae respectively (Table S1).

The seeds were collected from November 2016 to March 2017 in the Raipur area, CG, India (21.25°N 81.63°E), from three different locations. The seeds were separated manually from the legume-fruit and sun dried for 1 week, stored in polyethylene bottles and refrigerated at 4 °C.

The mass of 20 seeds of each species was measured by using a Mettler Toledo (AG-245) electronic balance in triplicate. The testa was manually removed by weighting the kernel fraction. The mass of seed coat was determined by subtracting the kernel mass from the whole seed mass. At least 50 g seeds or kernels were crushed into powdered form with subsequent sieving out particles of ≤0.1 mm for the analysis.

Nutritional analyses

Reference protocols from AOAC were used for moisture, ash, fat, starch, protein and calorific analyses (see supplemental information). Polyphenols and flavonoids were measured with the spectrophotometric methods after extraction with organic solvents (see supplemental information). Finally, mineral content was determined by X-ray fluorescence spectrophotometry (see supplemental information for further details).

Statistical analysis

Analyses were performed in triplicate. Cluster analysis was used to classify the seeds from the 60 species as a function of nutritional contents using Statistica 10.0 (StatSoft, Tulsa, OK, USA) software. Principal component analysis (PCA) was used for clustering samples and relating them to the different parameters used in the study. This statistical treatment was performed in Origin Pro (OriginLab Corporation, Northampton, MA, USA). To study the contribution of the daily consumption of seeds to the nutritional requirements of the India population, the mean content of energy, macronutrients and micronutrients was used.

Results and discussion

Physical characteristics

The physical characteristics of the seeds are important data for the farming, harvesting, storage etc. The physical data of 60 cultivars under study are summarised in Table S1. All seeds were coloured, with differences in the thickness of the testa (Figure S1). Generally, the kernel of the examined seeds was yellowish in colour. The seed mass varied from 0.08 to 2034 mg per seed, with the largest mass corresponding to seeds from *C. arietinum, P. vulgaris, A. hypogaea* and *C. crista*. Twenty-seven examined seeds had measurable seed coats over the range of 4.7 to 814 mg, meaning a percentual fraction of 3.0 to 40%. Moisture and ash residue contents lied within the range of 1.8 to 10.5% and 1.2 to 5.5% respectively. Moisture contents (mean values) in the seeds followed the sequence: cereals (8.6%) > pulses (4.6%) ≈ weeds (4.6%) > beans (3.0%). No variations in the ash residue of the examined seeds were detected, and mean values for weeds, pulses, beans and cereals were 3.5, 2.7, 2.6 and 1.6% respectively.

Macronutrients content

The fat content of seeds ranged from 0.7 to 44.2, with a mean value of 6.4% (Table S2). Protein level was comprised between 1.6 and 68.5 g/100 g, with a mean content of 22.3%. Finally, the starchy fraction was prominent, with a mean percentage of 67.1, ranging from 11.3 to 84.0 g/100 g (Table S2). When seeds were grouped, the average macronutrient content followed the sequences: weeds (12.2%) > pulses (3.1%) ≈ cereals (2.7%) > beans (1.1%) for fat content, pulses (25.5%) ≈ beans (23.5%) ≈ weeds (21.9%) > cereals (18.0%) for protein content and beans (72.0%) ≈ cereals (70.7%) ≈ pulses (68.6%) > weeds (62.4%) for starch content. In general, comparable macronutrients levels were reported in the literature (McKevith, 2004; United States Department of Agriculture (USDA), 2009; Martino *et al*., 2012; Tacer-Caba *et al*., 2015; Venkidasamy *et al*., 2019).

Figure 1a shows the macronutrient content of seeds grouped by botanical families. The seeds from the Acanthaceae family were characterised by their high content in oil (up to 30%). Phytochemical investigations of *H. auriculata* (Acanthaceae family) reported major classes of fatty acids and essential oils (Sethiya *et al*., 2018). The starch content ranged between 53 g/100 g (Acanthaceae) and 75.5 g/100 g (Onagraceae). The highest protein content corresponded to the Fabaceae family (25 g/100 g). This protein content is in accordance with that reported by Venkidasamy *et al*. (2019), establishing the protein content of the Fabaceae in 27–32%.

Energy content

Calorific value is a unit of energy used to measure the chemical energy preserved in a seed. The estimated gross calorific value (GCV) of the seeds varied from 365 to 594 Kcal/100 g (Table S2). The highest GCV corresponded to the seeds from *A. hypogaea, T. indicum*, *H. auriculata, C. viscosa* and *R. palustris,* in agreement with their higher fat contents (ranging from 20.9 to 44.2%). Comparatively, higher GCV weasobtained for weeds (447 Kcal/100 g) than those from cereals, pulses and beans (379 to 397 Kcal/100 g). Similar energy content was reported in the literature (Tacer-Caba *et al*., 2015; Venkidasamy *et al*., 2019; Sharma *et al*., 2021).

Phenolic compounds

Polyphenols are one of the most common groups of secondary metabolites in plants, synthesised for the environmental and microbial protection (Terence *et al*., 1985). The TPh and Fla contents ranged from 12 to 3851 mg/100 g and from 4.0 to 3330 mg/100 g respectively (Table S2). Remarkable higher TPh values (>3200 mg/100 g) were recorded for seeds from *A. hypogaea* and *I. tinctoria*. Syed *et al*. (2021) reported that peanuts (*A. hypogaea*) have a high content of bioactive compounds, which have positive effects on noncommunicable diseases. Higher TPh content was noticed in weeds (1366 mg/100 g) than in pulses, beans and cereals (155, 170 and 369 mg/100 g respectively). The same order was found for Fla contents: weeds (844 mg/100 g) > cereals (226 mg/100 g) > pulses (22 mg/100 g) ≈ beans (17 mg/100 g). The Fla/TPh ratio varied from 0.05 to 1.05, with a mean Fla/TPh ratio of 0.12, 0.29, 0.62 and 0.64 for the seeds from beans, pulses, cereals and weeds respectively.

Figure 1b depicts the content of total phenols and flavonoids of seeds grouped by botanical families. The seeds from the Onagraceae family had the highest content in flavonoids, and the seeds from Cyperaceae family had the higher content in polyphenols, although it was a content lower than that reported by Sahu *et al*. (2019). Gobalakrishnan *et al*. (2020) identified ten bioactive compounds, including flavonoids, in *L. parviflora* (Onagraceae), also from India, which makes them candidates for the treatment of various diseases.

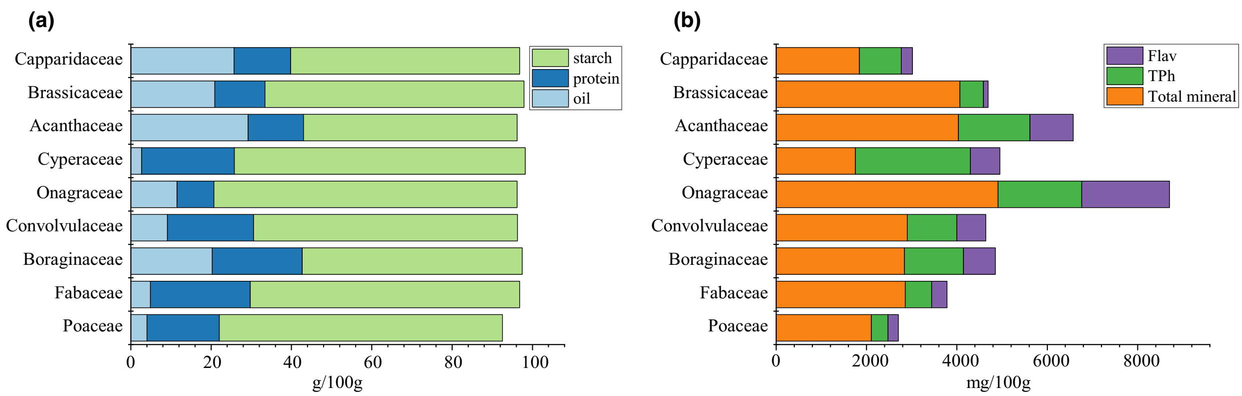

Figure 1 Macronutrients content (a) and phenolic compounds-total mineral content (b) of seeds grouped by botanical families.

Mineral composition

Plant seeds are rich resources of essential minerals. The mineral contents are detailed in Table S3. Total mineral contents varied from 668 to 4913 mg/100 g in the following trend: weeds (3174 mg/100 g) > pulses (2657 mg/100 g) > beans (2622 mg/100 g) > cereals (2109 mg/100 g). More specifically, in Fig. 2, the distribution of macro- and microelements by types of seeds, and in Fig. 3 by families, was observed. The Onagraceae family is the one with the highest degree of mineralisation, for reasons discussed later. The seeds from Cyperaceae had the lower mineral content.

Regarding macronutrients, K was the major element in weeds, beans and pulses (ranging from 112 to 2191 mg/100 g) while Na was the main element in cereals (Fig. 2a). Specifically, high Na accumulation was detected in the seeds from *E. corocana*, *O. sativa*, *S. italica* and *Z. mays*. All these cereals belong to the Poaceae family and their high Na content is justified because this family grows in saline soils, secreting salts to regulate the ion balance, contributing to salinity tolerance (Céccoli *et al*., 2015).

Phosphorous, which is an important macronutrient required for normal growth and maturity of plants (Pandey, 2015), ranged from 130 to 932 mg/100 g (Table S3). Noticeable variations in P content were observed as a function of the type of plant (Fig. 2a), having weeds the highest P content (537 mg/100 g). Sulphur is another essential micronutrient for the synthesis of proteins and chlorophyll (Pandey, 2015) and ranged from 78 to 915 mg/100 g. S followed the same pattern distribution as P. The family with the highest content of S was Brassicaceae. Similar S contents have been reported by Sahu *et al*. (2019). The S/P mass ratios lied in the 0.23–2.19 range. High S/P ratios (>1.0) for the seeds from *C. albida*, *R. palustris* and *C. viscosa* were recorded.

Magnesium is the main component of chlorophyll (Pandey, 2015) and was found at concentrations between 41 (*Hordeum vulgare*) and 548 mg/100 g (*Setaria italic*) (Table S1). No large variations between the different types of seeds were found (Fig. 2a). The low contents of *H. vulgare* (barley) and the high contents of *S. italica* (millet) are characteristic of these seeds (Liang *et al*., 2018; Obadi *et al*., 2021). Remarkable high Mg contents (>400 mg/100 g) were observed in the seeds from *P. sumatrense*, *S. italica*, *C. tetragonoloba*, *S. alata* and *S. obtusifolia*. On the other hand, Ca was accumulated (>800 mg/100 g) in weeds (Fig. 2a) such as *P. sumatrense*, *S. italica*, *S. tora*, *H. indicum*, *R. palustris* and *L. parviflora*. The Ca content in *L. parviflora* (3038 mg/100 g) was particularly high; since no bibliography has been found regarding the mineral composition of this seed, this is the first paper describing it. Regarding Ca/Mg mass ratios, they followed the sequence: beans (0.4) > pulses (1.0) > cereals (1.25) > weeds (2). According to Costello *et al*. (2021), the optimal values for this relationship are between 1.7 and 2.6; therefore, weeds have the best Ca/Mg ratio.

Regarding micronutrients, pulses and weeds had a larger accumulation of these elements (Fig. 2b). Larger variations in Fe contents (2.8–896 mg/100 g) were observed; it has not been represented in Fig. 2 since its amounts are much lower than those of macronutrients and much higher than those of micronutrients. The seeds from six species showed noticeably high Fe concentrations (>100 mg/100 g): *H. auriculata*, *S. articulatus*, *H. vulgare*, *L. angulatus*, *R. palustris* and *T. purpurea*. Iron accumulation followed the trend: pulses (109 mg/100 g) > weeds (36 mg/100 g) > cereals (28 mg/100 g) > beans (9.4 mg/100 g). It is remarkable the high Fe content of Acanthaceae seeds (896 mg/100 g) and Cyperaceae (893 mg/100 g). This fact has been reported for other parts of these plants (Sethiya *et al*., 2018; Sahu *et al*., 2019).

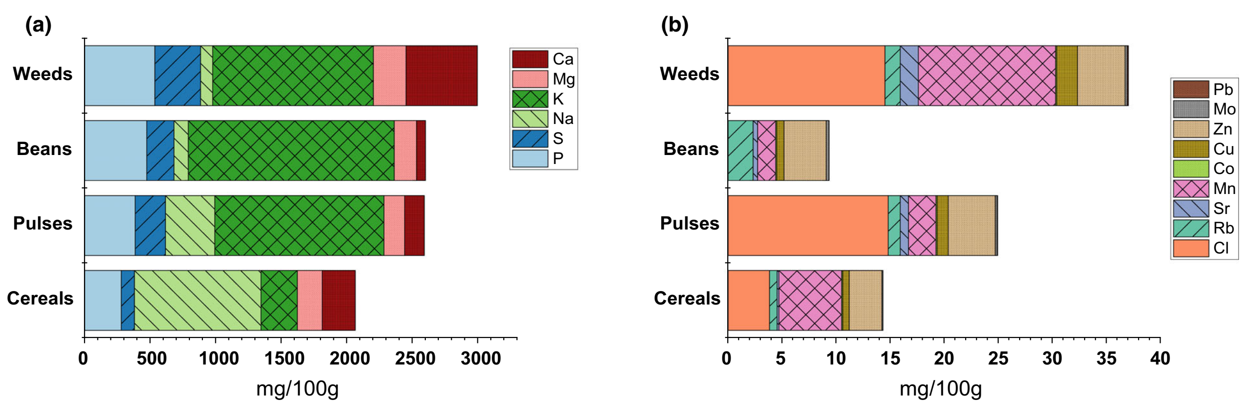

Figure 2 Mineral elements content grouped by group of seed: a) macroelements and b) microelements.

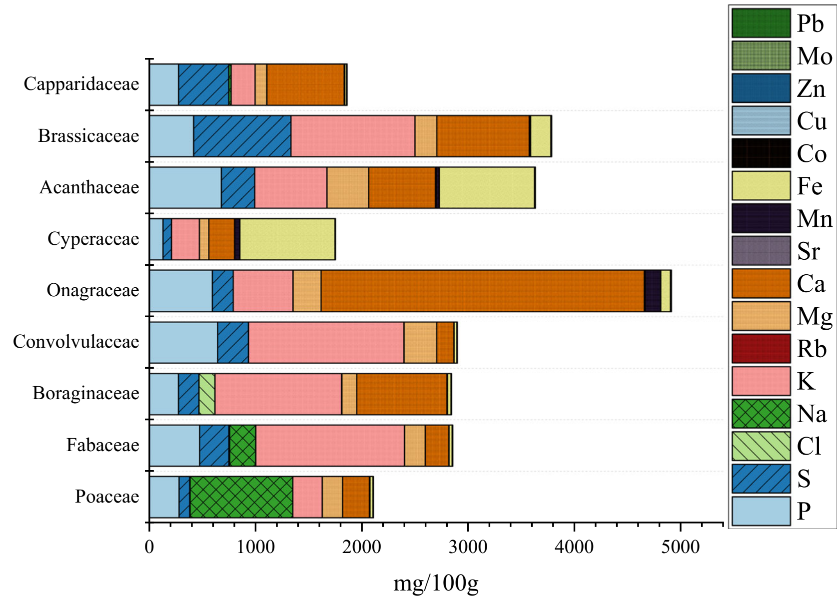

Figure 3 Mineral elements content grouped by families.

Cl is required at small amounts for plant metabolism and photosynthesis (Pandey, 2015). However, high Cl accumulation was only found in the seeds from *H. indicum* (300 mg/100 g). This value cannot be compared with plants of the same species since there is no bibliography about it. Rubidium was accumulated in the seeds at concentrations of 0.1 to 10.9 mg/100 g (Table S3). The Rb contents were within the normal range in foods (Abdi *et al*., 2015).

Manganese was accumulated in all the examined seeds, with contents ranging from 0.3 to 147 mg/100 g. High Mn accumulation was recorded in the seeds from *H. auriculata*, *H. vulgare*, *L. parviflora* and *S. articulatus*. The highest value corresponds to *L. parviflora* (147 mg/100 g). These high amounts of Mn are also associated with high amounts of Ca (Table S3), since MG can replace CA in its functions (Alejandro *et al*., 2020).

Zn values are between 0.5 and 8.0 mg/100 g (Fig. 2b). Weeds had the highest Zn content (Fabaceae family, *Cassia* genus). The study of this element is very interesting since Zn deficiencies have been described in India (Rao *et al*., 2018). Cu ranged from 0.1 to 9.2 mg/100 g, with the highest values in weeds and pulses. The abnormally high contents of the *L. parviflora* stand out (9.2 mg/100 g). As stated for Ca, there are no previous studies of the mineral content of this seed.

Sr, Co and Mo had very low values, in some cases at the detection limit (Table S3). Sr was high (>2 mg/100 g) in *C. tetragonoloba*, *A. hypogaea*, *C. obtusifolia*, *C. tora*, *T. indicum* and *H. indicum*. Particularly, high Co values were found in *C. arietinum* (reddish brown) seed. High Mo concentrations (>0.8 mg/100 g) were detected in *C. pallida*, *V. unguiculata* and *C. tetragonoloba*.

Finally, as regards toxic as elements, Pb was found at low concentrations (0.1–0.4 mg/100 g) in the seeds from 19 species, with maximum value in the *R. palustris* seeds. Sahu *et al*. (2019) also detected significant amounts of Pb in this seed.

Statistical relationship among nutritional seeds parameters

Due to the large number of nutritional parameters studied (n = 23), a principal component analysis (PCA) was performed to obtain a low number of linear combinations of such parameters that explain data variability. As depicted in Figure S2, it was found that a combination of 2 components can explain a 69.73% of the variance. The total mineral content is fundamentally related to the contents of P, Mg, S and K. The PCA analysis grouped the seeds from the Poaceae family due to their high Na content (Fig. 3). In addition, seeds from the *Fabaceae* family were grouped according to their starch and total mineral levels, as well as the content of some elements like Zn, K, P and S. The Capparidaceae and Cyperacidae family are associated with phenol contents and oils (Fig. 1).

Nutritional implications of Indian seeds consumption

It is possible to calculate the contribution of seed consumption to the daily intake of calories and macronutrients to the Indian diet (Table S2). On one hand, the recommended pulse consumption in India is 80 g per day (National Institute of Nutrition, 2011), being such date used as a reference to estimate the daily contribution for three different population groups: urban population, pregnant women and geriatric population. Considering that the daily intake of calories of urban population is 2216 Kcal (Sendhil *et al.*, 2020), 1392 Kcal for pregnant women (Sharma *et al.*, 2020) and 1418 Kcal for geriatric population (Gupta *et al.*, 2017), the contribution of one serving of seeds could reach a 15, 24 and 24% respectively (Table 1); the main contributor could be *Arachis hypogaea* seeds (peanuts), due to their high fat content (44.2 g/100 g). In the case of proteins, the consumption of 80 g per day represents 30, 46 and 38% of the daily intake for these groups of the population. In this case, the *Glycine max* (soybean) seed stands out due to their high protein content (68.5 g/100 g). This energy and protein intake is especially important for women of reproductive age, especially from socially backward classes, which present energy and protein deficiencies in India, posing a public health problem (Sharma *et al.*, 2020). Finally, the contribution of seeds consumption to the carbohydrates' daily intake could be important for geriatric population, reaching a 25% of the total (Gupta *et al.*, 2017). The highest contribution of carbohydrates intake corresponds to the consumption of *Zea mays* seeds (corn) due to the high starch content (84 g/100 g).

It should also be highlighted the contribution of seeds consumption at the level of mineral elements in the Indian diet. Thus, taking the values of the daily intake of the Indian population of Tarwadi *et al.* (2008), the daily consumption of 80 g of seeds would contribute to the daily intake on minerals up to 89% for Zn, 108% for Cu, 686% for Fe and 72% for Ca. Regarding phenolic compounds, the consumption of a seeds portion could contribute up to 292% of the daily intake in pregnant women (Panwar & Punia, 2000).

Conclusions

In conclusion, this paper reinforces the role of seeds for human nutrition, due to the high content of important nutrients (starch, proteins, phenolic compounds and mineral elements). This could be especially important in countries like India, with a steadily expanding population and looking for new underused sources of nutrients. In this sense, it is especially important the high mineral content of some weed seeds, which could be a potential source of P, S, Mg, Ca and Zn. In turn, pulses and beans were also significantly enriched with Fe, K and Mn nutrients. Therefore, such seeds could be very important to avoid the development of hidden hunger because a daily consumption of these seeds could make an important contribution to the diet of the Indian population.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Ana Cervera-Mata: Formal analysis (equal); Investigation (equal); Methodology (supporting); Writing-original draft (equal). **Pravin Kumar Sahu:** Formal analysis; Supervision (equal). **Suryakant Chakradhari:** Data curation (equal); Formal analysis. **Yaman Kumar Sahu:** Formal analysis; Resources (equal). **Khageshwar Singh Patel:** Funding acquisition (equal); Resources (equal); Writing-original draft. **Samarendra Singh:** Formal analysis; Validation (equal). **Erick K Towett:** Data curation (equal); Formal analysis. **Pablo Martín-Ramos:** Formal analysis; Resources (equal). **J J Quesada-Granados:** Data curation (equal); Software (equal); Writing-review & editing (equal). **Jose A. Rufian-Henares:** Conceptualization (equal); Formal analysis (equal); Writing-review & editing (equal).

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Table 1 Contribution of seeds consumption to the daily nutrient intake in the Indian diet

		Daily mean nutrient intake			**% Daily mean of nutrient intake**		
	Daily intake[a]	**Urban population**	**Pregnant women**	**Geriatric population**	**Urban population**	**Pregnant women**	**Geriatric population**
Energy (Kcal)	332.2	2216	139	1418	15.0	23.9	23.4
Protein (g)	17.8	60.5	38.5	47	29.5	46.3	38.0
Fat (g)	5.1	56.7	28	44.8	9.0	18.3	11.4
Carbohydrates (g)	53.6	na	na	216.6	na	na	24.8

na, not available.

[a]Considering recommended daily pulse consumption (80 g/day) and the average energy, protein, fat and carbohydrates of all seeds.

Peer review

The peer review history for this article is available at https://publons.com/publon/10.1111/ijfs.15414.

Data availability statement

Further research data are shared as supplemental information.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Supplemental information describing analytical methods, seeds images, principal components analysis of nutritional seeds parameters, physical characteristics of seeds, nutritional and phytochemical composition of seeds, mineral content of seeds and supplemental references.