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Review

Potential of *Celosia* species in alleviating micronutrient deficiencies and prevention of diet-related chronic diseases: a review

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Abstract: Dietary deficiencies have become significant in public health challenge globally. This is attributed in part to the pitiable quality of customary diets and the absence of variety in meals. Nutrition and health are closely related, and micronutrient deficiencies are one of the major culprits responsible for the positive correlation between diet and various diseases. Green leafy vegetables are important sources of micronutrients in most African rural communities where they have been used as an accompaniment for staple cereals and root-based diets for many years. Green leafy vegetables from *Celosia* species are good examples that could contribute to the prevention and management of micronutrient deficiencies and also provide food security. The main objective of this review is to highlight and bring to fore, the suitability of *Celosia* vegetables in preventing malnutrition and chronic diseases. Various electronic search databases including PubMed, ISI, Web of Science and CNKI were used to review existing literatures. Findings showed that *Celosia* species are good sources of nutrients that could prevent dietary deficiencies and chronic diseases. Also, the possible use of *Celosia* spp. in the development of functional foods has the potential to reduce malnutrition and foster complementary plans for the prevention and management of diseases. Therefore, further studies on formulations of food products using vegetables from *Celosia* species could contribute to the prevention and management of micronutrient deficiencies, chronic diseases and also provide food security.

Keywords: malnutrition; micronutrients; green leafy vegetables; deficiencies; diet; chronic diseases

1. Introduction

Overview of human dietary deficiencies

Dietary deficiency is a challenge that has plagued public health globally. Contrary to the general belief that malnutrition is restricted to low income or impoverished nations, the impact poses a threat to public health in some industrialized countries [1]. Malnourished populations have been reported to be those dependent on low quality, monotonous staple foods for their sustenance [2]. The pitiable quality of customary diets and the shortage of dietary diversity have also been reported to contribute to micronutrient deficiencies [3,4]. Bailey et al. [5], state that iron, iodine, zinc and vitamin A deficiencies are among the world's most serious health risk factors. The United Nations Administrative Committee on Coordination—Subcommittee on Nutrition estimated that about 40% of the world population could be affected by micronutrient malnutrition [6,7]. Similarly, FAO [8] reported that nutritional deficiencies account for almost two-third of childhood deaths worldwide. Research findings have also shown that approximately 795 million people do not have access to the nutrients essential for proper development and health [9–11]. In 2016, UNICEF [12], estimated that at least 150 million children were undernourished globally, among which 32 million live in Africa.

In Africa, 32 million children have been reported to be suffering from severe under nutrition, while 38% of African households often or sometimes go to sleep on empty stomachs [13–15]. In general, nutritional status variables, markers and data provided from epidemiological surveys have shown that on a population level, the nutritional status of adults is far from optimal [4,16].

Studies have shown that micronutrient deficiency results in huge societal costs, including learning disabilities among children, increased morbidity and mortality rates and reduced work productivity. As a result, dietary deficiencies have a significant impact on human well-being and on the economic development of poorer countries [17]. Hence, it has become imperative to provide a more balanced nutrient and calorie intake from high-grade foods.

2. Micronutrients

The term micronutrient from a broader perspective encompasses essential vitamins, minerals, phytochemicals, antioxidants and trace elements that are vital for all normal cellular and molecular functions. Although required in small amounts, deficiencies in any micronutrient could have significant effects on human health, which might eventually result in death if not addressed promptly.

Micronutrients such as iron, zinc, selenium and some vitamins (e.g., riboflavin, vitamins A, C and vitamin B12) are not substantially present in the diets of many people in many regions of the world, although the actual extent of these deficiencies is yet to be quantified [18,19]. These mineral elements and vitamins have been identified as distinct role players in human health; they act as antioxidants (vitamins C, E and beta-carotene), aids clearer vision, absorb calcium and promote bone development [20]. Vitamin-specific studies have reported various types of chronic diseases associated with certain deficiencies in different vitamins.

Improving the micronutrient status in a deficient population may prevent most chronic diseases and reduce mortality by up to 23% in infants and children [21]. A mineral element, such as copper is important in the regulation of oxidative free radicals and its deficiency increases the susceptibility to lipoprotein peroxidation and increase in plasma cholesterol concentrations [22,23]. Occurrence of non-alcoholic fatty liver diseases (NAFLD) has been linked to an alteration in the homeostasis of metals like copper [24]. This occurs in individuals with low copper levels as a consequence of copper deficient diets and sedentary life style [25]. Copper deficiency affects the antioxidant defense system resulting in increased ROS levels and the related oxidative damage of lipid, DNA, and proteins. A growing body of evidence has shown that the oxidative stress involved in the pathophysiology of NAFLD can be neutralized by increasing copper levels; hence copper increases the antioxidant defense to several liver diseases [26–28]. Thus, a highly-orchestrated regulation of copper pools is required to prevent oxidative stress and free radical damage events. Imbalances in physiological copper levels or tissue pathogenic compartmentalization, arising from genetic and/or dietary factors, are correlated with metabolic disorders, neurodegenerative diseases, and cancer.

Essential dietary mineral elements like sodium and potassium present in interstitial fluids are also very essential in the prevention of chronic diseases. An abnormally low plasma potassium concentration results in hypokalaemia and osteoporosis [28]. Several epidemiological studies have opined that increase in potassium intake is directly proportional to reduced risk of stroke and abnormally low sodium concentrations in the blood can cause hyponatremia [29–31]. This situation is common among individuals with hypertension, kidney disease, and heart disease. Acute hyponatremia may lead to brain edema with neurologic consequences, while iodine deficiency disorders can result in irreversible mental retardation, goiter, reproductive failure and increased child mortality [32]. A reduced risk of developing these chronic diseases has been recognized among people who consume diets rich in these mineral elements which are abundant in fruits and vegetables [33].

Reports have shown that in regions where there is significant reliance on millet-based diets, and where the nixtamalization process is not essential during seed processing, micronutrient deficiencies may occur at consumption [34,35].

With the deficiencies in one or more micronutrients leading to severe chronic diseases, it is therefore evident that suitable strategies are required for the delivery of more micronutrients in commonly consumed foods in order to address these deficits.

2.1. Overcoming micronutrient deficiencies

Some authors have reported various strategies to overcome micronutrient deficiencies. Such deficiencies include: food based strategies, vitamin and mineral supplementation and global public health and disease control measures [36,37]. Although vitamins and mineral supplementation can be used to address specific deficient nutrients, it may however not solve the problem because food, in all its complexity, is a more fundamental unit than any individual nutrient. Therefore, food synergy-a concept linking foods and dietary patterns to health because the food constituents have huge physiological effects [38] is also another strategy that could be considered.

This review focuses on the food-based strategies to encourage the consumption of micronutrient-rich foods. Many researchers have supported this strategy because it provides several essential micronutrients and at the same time, address a combination of deficiency problems [39–41].

2.2. Green leafy vegetables and micronutrient deficiencies

Several studies have documented the potential role of green leafy vegetables as the cheapest and most readily available natural source of nutrients for human nutrition [42,43]. Food plants contain considerable amounts of vitamins and minerals; as well as moisture, fibre and ash essential for good health [44,45].

Mensah et al. [46] compiled a comprehensive report on the nutritional and therapeutic properties of some leafy vegetables consumed in Nigeria. *Celosia argentea* L. in particular, was found to contain essential nutrients required by humans and animals such as calcium, iron and magnesium. In the same vein, Gupta et al. [47] analyzed the nutrient and anti-nutrient properties of some underutilized green leafy vegetables. Moisture and ash contents were in the range of 73–95 g/100 g and 0.77–3.54 g/100 g respectively. Among all thirteen green leafy vegetables selected for the study, *Celosia argentea* L. was one of the few that had exceptionally high iron (13.5 mg/100g), calcium (188 mg/100g), sodium (240.6 mg/100 g) ascorbic acid (26 mg/100g) and β-carotene (4.42 mg/100g) content. The edible portion of *Celosia argentea* L. was found to be 55 g/100g fresh weight which was one of the highest, while its moisture and protein content was found to be 87.6 g/100g and 3.2 g/100g respectively.

Unlike many other barriers to social and economic development, micronutrient deficiencies can be curtailed by introducing food plants like *Celosia* species to the diet of the population, thereby becoming essential components of an otherwise monotonous and nutritionally poor diet [48,49].

Several studies by numerous authors have shown that plants of this genus are used traditionally as food and medicine [50–52]. Also, phytochemical assessment of green leafy vegetables has confirmed their ability to prevent a large number of nutritional deficiencies and chronic diseases. However, there is a paucity of information on the nutritional, chemical constituents and pharmacological activities of most members of the genus *Celosia* as a potential means to alleviate micronutrient deficiencies and chronic diseases.

3. Materials and methods

The main objective of this review was to highlight and bring to fore, the suitability of *Celosia* vegetables in preventing malnutrition and chronic diseases. Related literatures published within 2000–2018 were retrieved from various electronic databases including PubMed, ISI, Web of Science, Google Scholar and CNKI. Scientific and general words such as *Celosia*, green leafy vegetables, micronutrients, dietary deficiencies, chronic diseases, functional foods and pharmacological applications were searched alone and in combination in these electronic databases. All literature that reported the use of *Celosia* species in various ways, especially as sources of micronutrients and their pharmacological potentials were selected for this review.

3.1. Celosia species

Species of *Celosia* are edible and ornamental plants which belong to the family Amaranthaceae [53]. The name *Celosia* is obtained from a Greek word which means ‘burned’, because of their flower heads which looks like a flame. Other names for the flowers include flame heads, velvet flowers, flamingo, cocks comb, wool-flowers and brain combs [54]. The genus comprises about 60 species which are popular as ornamental and food crops and is found in all continents of the world, but majorly in Asia, North America and Africa. Amongst the various plants in this genus, *C. argentea*, *C. cristata*, *C. isertii* and *C. spicata* are the most important leafy vegetable crops of dietary and economic value and were selected for this review [52]. The scientific classification of the four selected *Celosia* species is presented in Figure 1.

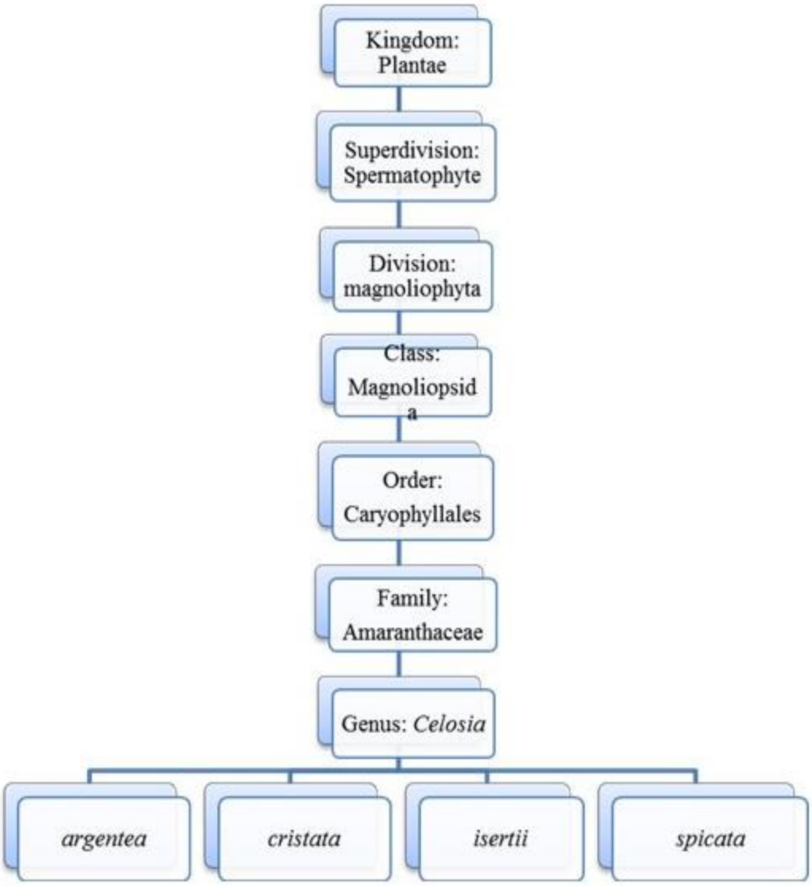

Figure 1. Scientific classification of *Celosia* species.

3.1.1. *Celosia argentea* L.

Celosia argentea L. is an annual herbaceous plant, having a height between 0.5 to 1.5 m; with ridged stem, glabrous and branches up to 25 leaves per plant. Its alternate leaves are linear to lanceolate, entirely simple and without stipules. The petioles are indistinctly demarcated, about 4–14 cm in length, tapering at the base and pinnately veined [54]. The inflorescence is conical at first, then becomes cylindrical as it elongates with numerous spiky flowers. The feathery spike inflorescence is continuous and the basal end of the inflorescence dies as the flower extends. The flowers are small in size and are dense erect spikes (8 to 12 mm in length), borne on solitary, erect, stout, dense, white, purple, or pink, glistening spikes and 1.5 to 2 cm thick, without petals. Sepals are longer than the bracts with membranaceous and shiny black seeds 1.5 mm in diameter [55].

Figure 2. *Celosia argentea* L. Source: grown in Botany department greenhouse, University of Fort Hare, South Africa.

3.1.2. Description and distribution

Celosia argentea L. is commonly found in West Africa, Ethiopia, Kenya, Somalia and other parts of East and Central Africa, as well as Mexico. The plant is cultivated in Nigeria, Cameroon, Togo, and Republic of Benin, where it is consumed as vegetable. It grows as a weed during the rainy season throughout India and other tropical regions of the world mainly Sri Lanka, Yemen, Indonesia, America and West indies [52].

Common names: (English) *Celosia*, cock's comb, quail grass, wool flower, Célosie (French) Sokoyokoto among Yorubas of Nigeria, Bambit (Sudan), (Kaphikaulesi) Malawi, gewone misbredie, isheke (Swati), poea (Sotho), Thepe (Tswana), Umtyutu (Xhosa), Umbuya (Zulu), Hanekam (Afrikans) Kalkoenslurp, misbredie, rooibossie, sprinkaan-bossie, cresta de gallo, rabo de conejo (Spanish) and qing xiang (Chinese).

3.2. Celosia cristata L.

Celosia cristata L. is a non-woody plant that reaches a height of 0.6 to 1.5 m. Veination on the leaf is pinnate and marginal. Leaves are arranged in alternate, simple and saggitate or arrow shaped. It grows up to 5 cm to 10 cm in length with greenish purple or red colour; with mostly red flower. It has the capability of producing purplish or reddish pigment in tissue culture systems [56]. This plant is reported to be a very useful herb traditionally and was first found in North America in the 18th century, but now widely grown in Africa, South America, India and some parts of Asia [57]. Common names include English: Cockscomb, red spinach, katifaorfeldeek in Arabic, Crete de coq, Célosie in French, silberhahenkamm in German, Chi Kuan in China, lalmurghka, kokan and pilemurghka in Hindi.

Figure 3. *Celosia cristata* L. Source: [57].

3.3. *Celosia isertii L.*

Celosia isertii L. is a straggling herb which reaches up to 3.0 to 3.2 m in length. It usually grows at damp sites, stream-banks, clearings and rarely in the savannah. The plant is well-known in Sierra Leone [58]. *C. isertii* L. is widely used traditionally in Congo and is regularly eaten as a vegetable or prepared in soups and sauces in West Africa [58].

C. isertii L. is found in Senegal, Cameroun across central Africa to Tanganyika, Southern part of Nigeria, Fernando Po, Angola and Zambia. Common names are *Celosia* laxa, Fula-Fulfulde, bukan gida in Nigeria (Adamawa), *Manding-Mandinka* furaynamo in Gambia, *Mende* gimbui in Sierra Leone.

Figure 4. *Celosia isertii* L. Source: grown in Botany department greenhouse, University of Fort Hare, South Africa.

3.4. Celosia spicata L.

This specie is a tall, upright plant with reddish purple foliage and eye-catching dark-pink, soft-pink terminal flower spikes that turn to white as they mature. It grows up to 81.3 cm in height and is considered a weed in some regions of the world, but eaten as a vegetable in Africa. *C. spicata* L. is known as a leafy vegetable in south western part of Nigeria [59], and is one of the most popular cut flowers for dried, everlasting floral arrangements. It occurs in tropical Africa and humid areas. Its common names include wheat straw, Flamingo feather in English, Sufaid murghu in Hindi.

Figure 5. *Celosia spicata* L. Source: [60].

4. Potentials of *Celosia* in alleviating micronutrient deficiencies

Like its cousins in the Amaranthaceae family, *Celosia* species are recognized as one of the major vegetables rich in both macro and micronutrients particularly iron, zinc, iodine, vitamins A, C and E [61,62]. It has been reported that this genus is an excellent source of various vitamins, mineral elements and macronutrients (Table 1). According to Ayodele and Olajide [63], the high ash content of *Celosia* leaves is an indicator of its richness in mineral contents.

4.1. Vitamin A

In vegetables, vitamin A occurs in the form of provitamin A carotenoids such as lutein, β-carotene, violaxanthin and neoxanthin. β-carotene plays an important role in human health by acting as biological antioxidants protecting cells and tissues [67]. Vitamin A is an important nutrient required in small amounts by humans for growth and development, good vision, preservation of epithelial tissues, immune function, normal functioning of the visual system and reproduction. β-carotene has been reported to be extremely high in the leaves of *Celosia*. Olaiya and Adebisi [68], using column chromatographic separation method analyzed ten leafy vegetables for basic nutrients in the diet and found *C. argentea* to be richer in vitamin A than the others with a value of 40 IU. The level of vitamin A content in *Celosia* leaves as reported by Yarger [61] was found to be 15.03 IU. This means that *Celosia* vegetables could be used as a supplement to meet the daily recommended intake (DRI) for vitamin A, since the daily requirement for the vitamin is 9.1333 IU [69]. Diemeleou and Niamke [70] found that even the seeds from *Celosia* contains appreciable amount of vitamin A (1 mg/g) which is enough to meet the required daily intake for infant (0 to 6 months) estimated at 0.375mg per day.

Table 1. Comparison of nutrient profiles of *Celosia* leaves to some selected green leafy vegetables per 100g of edible portion.

	Nutrient compositions (%)				
	C. argentea	*C. spicata*	*Amaranth*	*Brassica oleracae*	*Basella alba*
Starch/Carbohydrate	45.50	47.6	7.67	4.52	3.4
Fiber	3.53	12.3	1.93	3.77	0.6
Ash	22.43	15.3	1.85	1.05	1.4
Protein	5.17	10.2	2.11	1.94	47.1
Fat	1.10	1.15	0.47	0.31	0.3
Dry matter	15	15.3	9.0	9.3	7
Moisture	8.84	8.61	87.90	87.93	93.4
energy (Kcal)/100g	234.45	341.9	78.73	59.77	207.6
	Elemental composition (mg/100g)				
Potassium	128.33	659	3460	678	7800
Sodium	71.32	25.3	108	71	660
Calcium	178.08	242	330	28.9	109
Iron	15.25	4.90	18.2	13.00	5.5
Copper	3.75	0.40	300	0.05	0.10
Zinc	7.25	4.20	10	2.11	41.00
Manganese	1.73	1.70	8	0.67	-
Magnesium	39.64	463	1842	6.69	350
Phosphorus	38.01	102	52	26.92	52
	Mineral and Vitamins (mg/100g)				
Thiamin	0.09	-	0.08	0.1	0.05
Vitamin A (IU)	48.20	9.02	6100	7.14	8000
Vitamin C (mg)	59	56.00	17	56.37	15
Vitamin E	28.3	23.1	18.2	2.15	5.5

Energy (kcal) was calculated by summing the multiplied values for protein, lipid and carbohydrate respectively, using the factors (4kcal, 9kcal and 4kcal). References: [61–66].

4.2. Vitamin C

Ascorbic acid is a water soluble vitamin that is very important for growth and repair of bones, teeth, skin and other tissues. Vitamin C is not stored in large amount in the body but it helps to prevent cell damage and acts as immune booster against cold and other infections [71]. It appears that variations in vitamin C content exist among *Celosia* vegetables. Olaiyia and Adebisi [68], reported 410 mg/100 g for vitamin C content of *Celosia argentea,* while Adediran et al., [72] reported 38.10 ± 1.80 (g/100 g) for the same species. For *C. spicata*, the ascorbic acid content was reported to be 56.00 mg/ mg [59]. In a study carried out in India, *C. argentea* was reported to contain 59 mg of vitamin C, 28.3 mg of iron and 8.3% of protein [73]. This implies that the daily requirements for these nutrients could be met by the consumption of vegetables of the species since USDA recommends 60 mg vitamin C per adult per day [74].The burden of micronutrient deficiencies could thus be reduced by the inclusion of the vegetables of these species in the diet.

4.3. Vitamin E (α-tocopherol)

Vitamin E is a fat soluble antioxidant vitamin that prevents the degradation of polyunsaturated fatty acids and other compounds by oxygen thereby preventing oxidative stress. *Celosia* vegetable is part of the array of healthy vegetables and fruits that can serve as a good source of vitamin E. The nutritive characterization of *Celosia* seeds revealed the presence of vitamin E [70]. Ogungbenle and Otemuyiwa [59] also reported the presence of vitamin E in the leaves of *C. spicata* with a value of 23.1 mg/100 g. *Celosia* contains sufficient vitamin E that can meet the recommended dietary allowance (15 mg/day) for an adult per day.

4.4. Minerals

Illodibia et al. [63] analyzed the mineral content of *C. argentea* and found that the leaves of the species contain zinc (0.82 ± 0.01 mg/100 g), phosphorus (39.77 ± 5.06 mg/100 g) and iron (8.19 ± 1.02 mg/100 g). Similarly, Awang et al. [75] reported that the mineral composition of *C. cristata* leaves contained 3.24% of nitrogen, 0.42% of phosphorus, 2.25% of potassium and 2.60% of magnesium. The iron value (4.90 ± 0.04) recorded for *C. spicata* was found to be higher than that of African nutmeg (3.0 mg/100 g) but comparable with that of cowpea (4.9 mg/100 g) [76,77]. The zinc content in the leaves of *C. spicata* (4.20 ± 0.09) was also found to be higher than those of *Luffa cylindrica* (1.0 mg/100 g), guinea corn (1.8 mg/100 g), and maize (1.48 mg/100 g) [78]. The potassium, magnesium and calcium levels of *Celosia* species were also reported to fall within the daily requirement range as set by USDA (Table 2). Therefore, intake of *Celosia* vegetables could increase the amount of vitamins and minerals required by the body.

4.5. Macronutrients

Several studies have reported the carbohydrates, fat and protein contents of *Celosia* species [59,63]; some of these are summarized in Table 2.

4.6. Dietary fibre and moisture content

The genus *Celosia* is principally rich in dietary fibre. The crude fibre (12.3%) of *C. spicata* has been reported to be greater than those of *Arachis hypogea* (3.70%), *Amaranthus hybridus* (8.61%) and *Dioclea reflexa* (9.23%) [79]. Crude fibre is very essential for regulating bowel movement, reducing the danger of congenital heart failure, colon cancer, constipation and facilitation of nutrient absorption in the body [80]. Akinnibosun and Adeola [81], reported that *C. argentea* had the highest moisture (62.98 ± 0.38%), fat (1.44 ± 0.28%) and ash contents (9.58 ± 0.05%) compared to

Amaranthus hybridus (moisture, 62.38 ± 4.05%, fat, 0.23 ± 0.13 and ash content, 5.10 ± 0.14%) and *Talinum triangulare* (moisture, 65.00 ± 0.56%, fat, 1.06 ± 0.28% and ash content, 0.70 ± 0.12%). Ogungbenle and Otemuyiwa [59] also reported that the leaves of *C. spicata* possess oil absorption capacity of 303% and water absorption capacity of 440%.

Table 2. Essential amino acids with FAO reference (g/16 g N).

Amino acids (g/100 g)	Spinach	*Celosia*	Amaranth	*Basella alba*
Arginine	4.85	6.69	1.06	3.97
Histidine	2.25	6.68	0.389	2.14
Isoleucine	3.30	4.43	0.582	3.01
Leucine	6.31	5.53	0.879	7.75
Lysine	4.68	6.42	0.747	2.92
Methionine	1.52	1.50	0.226	0.89
Phenylalanine	3.94	5.18	0.542	3.88
Threonine	3.47	4.60	0.558	2.84
Valine	4.37	6.77	0.679	3.13

Essential amino acids of *Celosia* species in comparison with other vegetables. References: [54,76,77].

4.7. Essential amino acids

Celosia species have been reported to possess substantial amounts of amino acids. The *in-vitro* protein digestibility reported by Ogungbenle and Otemuyiwa [59] showed that the major amino acids which were found in the leaves of the species were Glutamic acid (12.8 g/100 g crude protein) and aspartic acid (8.96 g/100 g crude protein). The nutrient and amino acid compositions of two *Celosia* species, compared with some commonly consumed green leafy vegetables are summarized in Table 3. Glutamic acid, histidine and arginine were the major amino acids present in *Celosia*. These species are richer in leucine, lysine, phenylalanine and threonine; while valine, histidine, methione and isoleucine are in moderate amounts and compare favourably with the FAO reference for essential amino acids required for infants, pre-school-, school children and adults [61]. This, therefore, indicates that *Celosia* species are a good source of quality protein and essential amino acids.

5. Anti-nutrients

The presence of some anti-nutritive compounds such as oxalates, alkaloids, phytates and saponins have been reported in minimal amounts in *Celosia* species [47]. These antinutrients can impede the absorption of some nutrient elements like iron, zinc, magnesium, calcium and potassium; thereby making them less available in the body. However, the harmful effects of anti-nutrients depend on the dosage. The methods of preparing green leafy vegetables which involves soaking, blanching, boiling and cooking with or without other condiments for few minutes, have been known to remove or reduce the anti-nutrient content thereby releasing the nutrients and rendering them bioavailable [85]. Kunyanga et al. [86], has reported that boiling causes a decrease in total phenolic content of leafy vegetables; this is similar to the findings of Medoua and Oldewage-Theron [87] and Moyo et al. [88] for Amaranthus hybridus leaves. The authors [87,88] reported reductions of 25.44% and 51.97% for kaempferol and myricetin respectively, after boiling. The decrease was attributed to the leaching of compounds into the boiling water. Heating is believed to cause an increase in membrane permeability, destruction/breakdown of the plant cell wall components, a process that allows the release of cell components to the cooking water. Dolinsky et al. [89] advised the use of steam as the most suitable cooking technique for maintaining higher concentrations of soluble phenols. This may possibly lead to increase in phenols or total flavonoid content and antioxidant activity of the vegetable as a whole.

6. Possible toxicity of *Celosia* species

Studies in phytoremediation have reported that some species of *Celosia* possess great potential in the remediation of heavy metals- a characteristic trait of a plant to maintain growth and biomass on heavy metal contaminated soils [90,91]. Heavy metal uptake, translocation, speciation and distribution have been reported for *Celosia* species. *C. argentea* and *C. cristata* in particular are manganese (Mn) and lead (Pb) hyper accumulators [90,92]. Lead is one of the most wide-spread and hazardous heavy metal in the soil while excess Mn causes toxicity to biotas. For heavy metals to be hyper accumulated by plants, it has to be excessively present in the soil [93]. Therefore, to prevent toxicity as a result of heavy-metal accumulation, soil analysis of the field should be carried out before cultivating *Celosia*.

7. Pharmacological potential of *Celosia* species for the management of chronic diseases

Chronic diseases, many of which are related to poor quality of diet, eating patterns and physical exercise can be prevented by eating food plants rich in micronutrients and polyphenols. *Celosia* species contains a high content of diverse polyphenolic compounds. Long term consumption of polyphenolic rich diet confers some protective activities, by acting as strong antioxidants and preventing oxidative damages to biomolecules such as lipids, DNA and protein [94]. Tang et al. [55] reported that the anti-oxidants present in *Celosia* species endow them with a broad-spectrum of medicinal and pharmacological activities. Medicinal potentials of *Celosia* species are subjects of increasing interest because of their beneficial effects on human diet and health. Table 4 shows the different bioactive components present in *Celosia* species, and their associated pharmacological importance.

Table 3. Phytochemical constituents of *Celosia* species.

Metabolite	Phytochemical constituents	Part of the plant
	C. argentea	
Carbohydrate	Sucrose, disaccharide	Seed
Lipids	Fatty acids, waxes, glycerides, phospholipids, sterols, vitamin A, D, E and K, β- sitosterol 1, palmitic acid and stigmastrol, daucosterol and oleanolic acid	Whole plant
Amino acids, peptides and protein	Bicylic peptides: celogenamide A, B, C, D, E, F, G, H and J, mordin Cyclic peptides: celogenamide A, celogntin K	Seed

Continued on next page

Metabolite	Phytochemical constituents	Part of the plant
	C. argentea	
Betalain	Betacyanins, amaranthin, isoamaranthin, betalamic acid, miraxanthin V (dopaamine-BX), (S)-tryptophan, (S)-tryptophan-BX, 3-methoxytyramine-BX and yellow betaxanthins	Flower, inflorescence
Phenols and phenolic acid	1-(4-O-β-glucopyranosyl-3- methoxyphenyl) propan-2-ene (citrusin C), 3-O-β-glucopyranosyl-1H-indole (indican), (7E)-6,9-dihydromegastigma-7-ene-3-one-9-O-b-glucopyranoside, (3Z)-hexenyl-1-O-β-(6-O- ß-rhamnopyranosyl-β-glucopyranoside), (3Z)-hexenyl-1-O-β-dglucopyranoside and trans-ferulic acid	Leaves
Phenolic glycosides	4-*O*-β-D-glucopyranosyl-2-hydroxy-6-methoxyacetophenone, 4-*O*-β-D-apifuranosyl-(1ﬁ 2)-β-dglucopyranosyl-2-hydroxy-6-methoxyacetophenone, eugenyl-*O*-β-D-glucopyranoside, sucrose, quercetin-3-*O*-β-D-glucopyranoside, isorhamnetin-3-*O*-β-D-glucopyranoside, hamnatin-3-*O*-β-D-glucopyranoside, isorhamnetin-3-*O*- ß-L-rhamnopyranosyl-(1ﬁ 2)-β-D-glucopyranoside, b-sitosterol, stigmasterol, stigmasterol-3-*O*-β-D-glucopyranoside	Whole plant
Flavonoids	Isoflavones: 5-Methoxy-6,7-methylenedioxy-2'-hydroxyisoflavone and 2'-methoxy derivative: tlatlancuayin	Aerial parts
Diterpenes steroids	Gibberellic acid	Seed
Seroids	Cristatain, saponins, celosin A, B, C, D and celosin E, celosin F, celosin G	Seed
	C. cristata	
Flavonoids	Isoflavone, cristatein and cochliophilin, celosin A, B, C	Leaves
Phenols	2-hydrox-yoctadecanoic-acid, 4-hydroxphenethylalcohol, kaempferol, quercetin, stigmasterol and β-sitosterol	Leaves
Protein	CCP-25, CCP-27, glycoproteins,	Leaves
Alkaloids	Celosianin I, celosianin II	
	Celosia isertii	
Alkaloids, saponins, tannins, flavonoids, phenol	Anthraquinones, cardiac glycosides, steroids, terpenoids, phytosterol, triterpenoids and phlobatannins	Leaves
	Celosia spicata	
Flavonoids, tannins and alkaloids		Leaves
Phenols	Phytosterols	Leaves
Proteins, amino and fatty acids		Leaves

Essential amino acids of *Celosia* species compared with other green leafy vegetables. References: [58,59,95–100].

8. Some documented pharmacological applications of *Celosia* species

8.1. Anti-diabetic potentials

Diabetes mellitus is a disease of metabolic disorder caused by the impairment of glucose usage associated with underlying factors for both hypoglycemia and hyperglycemia. According to Harding et al. [101], adequate consumption of green leafy vegetables reduces the risk of diabetes. Ghule et al. [102] reported the anti-diabetic activity of *C. argentea* root extracts on streptozotocin-induced diabetic rats. The effect of extracts from *C. argentea* at 500 mg/kg dose on diabetic rats after 2 weeks of treatment showed a significant decrease in glycaemic levels from 397.83 $\pm$ 9.67 mg/dL to 99.33 $\pm$ 1.84 mg/dL, this translates to a reduction of 75%. The alcoholic extracts of *Celosia argentea* seeds have also been reported to reduce blood glucose in alloxan-induced diabetic rats after two weeks. A decrease of 27.8% and 38.8% in the blood glucose level was reported after 6 hours, at 250 and 500 mg/kg dose respectively [103]. Another study by Shan [104], revealed that both the aqueous and ethanolic fractions of *C. argentea* exhibited significant hypoglycemic activities on alloxan-induced diabetic rats after oral administration at 800 mg/kg dose.

8.2. Anti-obesity potentials

The low, crude fat content of the genus could be suitable in facilitating initial weight loss and subsequent weight stability. Fitoussi et al. [105] evaluated the impact of *C. cristata* extract on human adipogenesis $CD34^+/CD31^-$ cells, using immunoselection/depletion approaches. Results revealed that *C. cristata* extract reduces lipid content of progenitor cells undergoing adipogenic differentiation within 10 days at a dose of 0.5%; and a significant decrease in the expression of C/EBPα gene to a level of 56.0% was recorded. Hence the species could be explored for the treatment and management of obesity.

8.3. Hepatoprotective potentials

Liver health maintenance is one of the major therapeutic uses of *Celosia* species in traditional medicine [55]. This has been supported by various modern scientific pharmacological findings [57,58]. According to Xue et al. [106], a three-day intragastric administration of celosin A and B (bioactive compounds from the species) at different doses of 1.0, 2.0 and 4.0 mg/kg had a modulatory effect on hepatic enzymes in 0.10% CCl_4-induced liver damage in Kunming mice by lowering the levels of AST, ALT and ALP from 299 $\pm$ 77, 167 $\pm$ 26, 380 $\pm$ 72 to 293 $\pm$ 54, 162 $\pm$ 42, 360 $\pm$ 75, respectively, at the highest dose of 4.0 mg/kg. Another study [107] reported that celosins from *C. cristata* decreased the level of lipid peroxidation in a carbon tetrachloride (CCl_4)-induced hepatotoxic mice. The levels of antioxidant enzymes (SOD, CAT and GSH-Px) were reported to increase significantly with an oral dose of 0.1, 0.2 and 0.4 mg/kg.

Studies have shown that *Celosia cristata* flower extracts protect against tert-butyl hydroperoxide-induced oxidative hepatotoxicity. In vitro, the extracts prevented reactive oxygen species (ROS) generation and mitochondrial membrane depolarization in t-BHP-induced hepatotoxicity in Chang cells [108,109]. Also, in vivo administration of *Celosia cristata* flower extracts (100 and 500 mg/kg body weight) orally to rats consecutively for five days before a single dose of t-BHP (2 mmol/kg, i.p.) significantly ($p < 0.05$) protected the liver cells by lowering serum levels of glutamate oxaloacetate transaminase (GOT) and glutamate pyruvate transaminase (GPT); as well as decreased hepatic lipid peroxidation and serum triglyceride against t-BHP-induced oxidative stress [108,109].

8.4. Anti- cancer potentials

Several studies have shown that *Celosia* species are potent anti-tumor agents [48,110]. Rub et al. [111] reported that 28 µg/mL of methanolic extracts of *C. argentea* showed significant cytotoxic activity comparable to methotrexate, a standard anti-cancer drug; while Hayakawa et al. [112] reported the anti-metastatic effect of *C. cristata* extracts on liver metastasis of murine colon 26-L5 carcinoma cells and that *C. cristata* exerted mitogenic activity of on the spleen cells at concentration of 1000 µg/mL. Wu et al. [110] also reported the anti-tumour activities of four triterpenoid saponins from *Celosia* on five human cancer cell lines at concentrations less than 100 µg/mL. Inhibition of cancer cells at concentration range of 24–30 µg/mL was recorded for the entire cancer cells tested. Nirmal et al. [113] reported that aerial parts of *Celosia argentea* extracted with 70% ethanol and water, reduced myelosuppression and enhanced immune response against cyclophosphamide-induced myelosuppression in Swiss mice. Rub et al. [111] investigated the effect of ethanolic extract of *C. argentea* on the viability of two cancer cell lines (SiHa and MCF-7) using MTT assay. The outcome of the study showed that *C. argentea* exhibited a potent anti-cancer activity against both cell lines at concentration of 28 µg/mL, but does not have any toxicity effect towards normal cells investigated. Navarra [114] reported that plants from *Celosia* were consumed by prisoners of war in Thailand to prevent nutritionally related diseases and also as an anti- cancer agent.

8.5. Antimicrobial and anthelmintic potentials

Extracts from *Celosia species* has been reported to show inhibitory activities against *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Candida albicans* and *Aspergillus niger* at concentrations ranging from as low as 3.125 to 50 µg/mL [115]. Yun et al. [116] also investigated the antimicrobial activities of *C. cristata* and reported that methanolic and ethanolic extracts of the species inhibited the growth of *S. aureus, B. subtillus* and *C. albicans* at 0.125, 0.5 and 1 mg/mL respectively. Rubini et al. [117] reported that the aqueous extract of *C. cristata* showed significant anthelmintic activity on adult worms of *Pheretim posthuma* at 100–200 mg/mL.

8.6. Antinociceptive and Antiurolithiatic potentials

Islam et al. [118], reported a strong antinociceptive effect of the methanolic extract of *C. cristata* in mice at a dose of 400 mg/kg, providing a rationale for its traditional use for the treatment of painful conditions. Joshi et al. [119] evaluated the antiurolithiatic activity of ethanolic extract of *C. argentea* seeds in rats. The authors found that *C. argentea* seed extracts prevented the formation of kidney stones at doses of 250 and 500 mg/kg, thus preventing impairment of renal function. Kachchhi et al. [120] also reported that extracts of *C. argentea* roots exhibited significant prophylactic effect on renal stone of ethylene glycol induced rats at both high and low doses of 250 and 500 mg/mL p.o, comparable to the effect of the standard drug used in the study.

9. Potential for integrating *Celosia* species into the diet

Research communities, government and development agencies have made significant progress in outlining strategies to provide long-term alleviation of specific dietary deficiencies especially through food based strategies. Thompson and Amoroso [121], affirmed that this approach promotes nutritional well-being, community and national health and wealth as a whole. Dietary diversification and modification, bio-fortification and food production are some strategies used for sustainably improving nutrition [122].

Dietary diversification and modification is the alterations in food production and food selection patterns, as well as traditional household methods for preparing and processing indigenous foods. Dietary diversification and modification and fortification methods could be suitable for the integration of *Celosia* into diets because these two methods aims at promoting availability, access and sustainable use of nutrient-rich foods. These methods will also increase the production and consumption of *Celosia* [15,123]. Gibson and Anderson [124] reported that dietary diversification and modification has the potential to prevent coexisting micronutrient deficiencies simultaneously for the entire household and across generations without risk of antagonistic interactions (Figure 6).

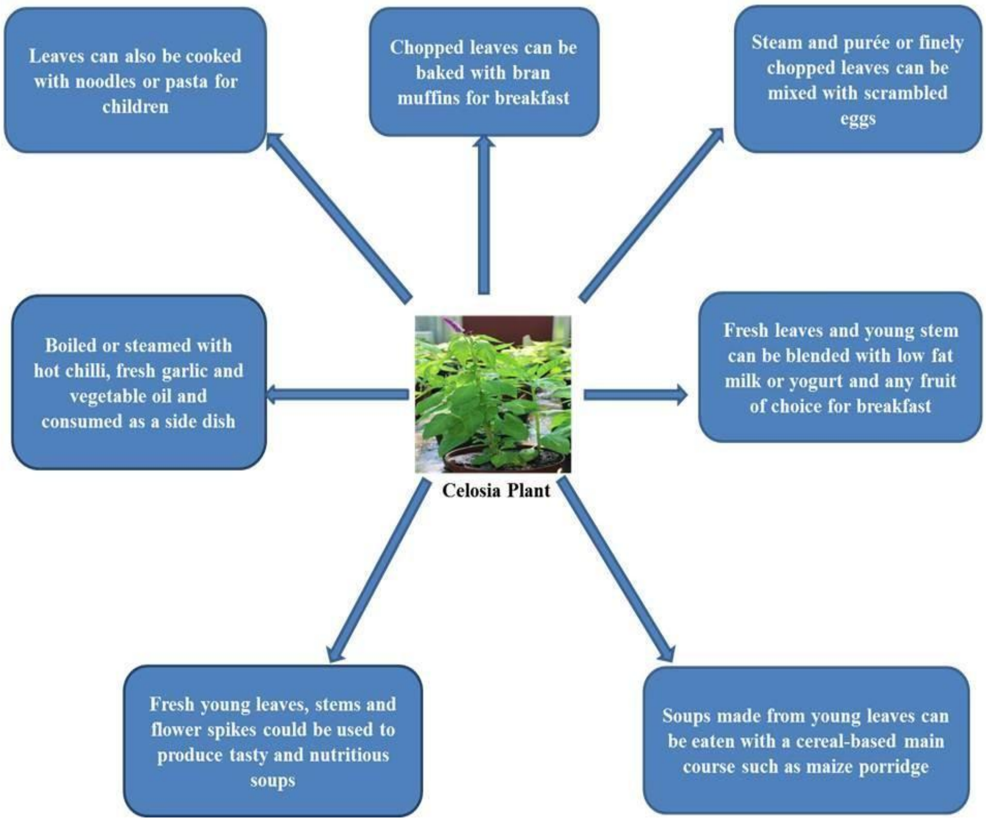

Figure 6. A schematic representation of the integration of *Celosia* into the diet using the DDM strategy.

Dietary diversification and modification is designed to supply micronutrients without any changes in feeding practices, irrespective of the amount of food consumed. Food fortification on the other hand, is the process of adding micronutrients (essential trace elements and vitamins) and bioactives to processed foods. Whole grain or refined whole grains have been used severally for food fortification [125]. Mixed flour snacks like biscuits are commonly used as vehicles for fortificants because of their many nutritional advantages of being able to retain the nutrients of most fortificants [126,127]. The use of *Celosia* species as fortificants in such vehicles could thus be an avenue for adding botanical varieties to the diet. It may be a purely commercial choice to provide extra nutrients in food, or as a public health policy which aims to reduce the number of people with dietary deficiencies within a population. Some researchers have also supported the use of fortification as a food based approach in alleviating malnutrition [36,128]. Foods fortified with *Celosia* leaves can be used as a ready-to-use therapeutic food for treating malnourished children [121].

With fortification, species of *Celosia* could be integrated into the diet through the following

- *Celosia* can be used to fortify snacks like biscuits; Dhokla, a legume-based snack was fortified by replacing Bengal gram flour with dehydrated *Celosia argentea* at 4, 8 and 12% levels and also Mathri, a kind of flaky biscuit from north-west region of India [129].
- Gupta et al. [130] had also fortified biscuits with dehydrated *C. argentea* leaves; this was incorporated into 3 conventional recipes at 20% level of incorporation and administered to improve the anaemic status of 60 adolescent girls for six weeks. Results revealed a significant rise in the weight and haemoglobin levels of the experimental group by 14.3%. This is an indication that the supplementation of *C. argentea* based products such as 'mathri' can significantly improve the haemoglobin status of an adult.
- Fortification of weaning foods: *Celosia* can also be used to fortify infant cereals. Chutney powder, a legume-based high fiber cereal food that is very commonly used in Indian households was also fortified with dehydrated *Celosia* at 4, 8 and 12% levels. The most remarkable increase in micronutrient and mineral contents β- carotene (2078 μg), Fe (7.28%) and Ca (128%) and dietary fibre was observed at 12% level of inclusion when compared to the cereals without fortification. Fortification of chutney powder by *Celosia* can be used to develop a low cost nutritious product that can be used as a rich source of nutrients [130].

10. Cultivation and consumption of *Celosia* species globally

There is limited information on the early history of breeding and domestication of *Celosia*, but there are speculations that the genus *Celosia* is of Asian origin in the Nara period (A.D 710–794). Identification of the genus in the Materia Medica of the ancient Chinese and its popularity as a foodstuff in Indonesia and India also support this fact. In spite of the high nutritional and medicinal values of this genus, they are under-exploited as food crops in most parts of the world. Usually, *Celosia* species are grown as native or naturalized wildflower and as a nutritious leafy green vegetable across Mexico, Northern South America, Africa and West Indies [131]. Distribution of *Celosia* across all continents of the world is presented in Table 4. Cultivation of the species is done on small and scattered plots in home gardens, farmland and urban areas and very few field productions. Though its occurrence in tropical part of Africa is widespread, the distribution is high in parts of the world where it is considered as weeds. It appears to be particularly relished by the West Africans. In Accra, Ghana; it is known as Lagos spinach because it is eaten by Nigerian expatriates implying its exotic origin. *Celosia* is a leading vegetable of high economic value in the south western part of Nigeria where it serves as a source of living for most rural vegetable farmers during the dry season [132]. Consumption and cultivation of *Celosia* is highly practiced in this part of Africa as the genus is well known for its nutritional and medicinal purposes. In Benin and Nigeria, young *Celosia* plants are sold in small bunches (0.5–1.0 kg) in main and small street markets [133]. There are indications of its fairly recent introduction in the southern part of Africa and East Africa where the ornamental varieties are grown for decoration and medicinal purposes. There have also been reports on the production and consumption of *Celosia* in the tropical parts of America [134]. In fact the world's largest market for *Celosia* as flowers include the US, Western Europe and Japan [135]. There are possibilities that in the nearest future, *Celosia* might assume a higher and wider consumption status, most especially in the arid and malnourished regions of the equatorial zone because of its wide tolerance to both tropical and dry conditions.

Table 4. Current status of *Celosia* production and consumption globally.

Region	Status	Region	Status
Benin	Present	State of Kerala	Present
Congo Democratic Republic	Present	State of Madhya Pradesh	Present
Ivory Coast	Present	State of Maharashtra	Present
Ethiopia	Present	State of Odisha	Present
Ghana	Present	State of Tamil Nadu	Present
Guinea	Present	State of Uttar Pradesh	Present
Liberia	Present	Indonesia	Widespread
Malawi	Present	Laos	Present
Nigeria	Widespread	Malaysia	Widespread
Senegal	Present	Myanmar	Widespread
Sierra Leone	Present	Nepal	Present
Sudan	Present	Pakistan	Present
Uganda	Present	Philippines	Widespread
Zambia	Present	Sri Lanka	Present
Afghanistan	Present	Taiwan	Present
Bangladesh	Present	Thailand	Present
Cambodia	Present	Vietnam	Present
China	Present	Puerto Rico	Present
Jiangsu Sheng	Present	United States	Present
India	Widespread	Papua New Guinea	Present
State of Arunachal Pradesh	Present	Brazil	Present
State of Bihar	Present	Sao Paulo	Present
State of Gujarat	Present	Colombia	Present
State of Haryana	Present	Suriname	Present
State of Karnataka	Present		

Source: The center for agriculture and bioscience international, (2018) (revised 15 July, 2018) [136].

11. Challenges

The combined impact of climate change, environment pollutants, shifting global population demographics, food safety and growing disease pandemics to mention a few, place undue stress on the planet's food system. All these threats, either natural or man-made, pose a great challenge to the scientific community.

Another major challenge is the palatability of the food after preparation. Although *Celosia* is not hardy like other amaranths, the anthocyanin content of some of the species may change the color of foods during cooking; resulting in less attractive products, thereby decreasing the consumption level of poor households and reducing sustainable livelihoods [137].

Consumption of vegetables generally is perceived by some communities as foods for the weak, women and children. This could make its integration into the staple meals of such communities a little difficult [138].

Climatic change could also pose a challenge to the production, yield and utilization of *Celosia,* especially in countries where there is no adequate sunshine all year round; because the genus is not frost tolerant, therefore growth and yield of these vegetables in such regions will be affected negatively [137,139].

Finally, due to the influx and invasion of African rural/urban markets with exotic vegetables like cabbage, spinach, broccoli etc., local and indigenous vegetables have been treated with disdain as only a few now cultivate them while a vast majority consider them as weeds [140].

12. Conclusion

In many regions of the world, diet and human well-being are strongly related, with many plants been consumed both as food and for therapeutic purposes. The most common dietary deficiencies all over the world are iron, iodine, and vitamins A and C. The relationship among these micronutrients can also lead to serious health challenges. These deficiencies can be adequately addressed by introducing *Celosia* species into the diet, because of their high nutritional values, especially in vitamins A and C, iron and calcium.

Many researchers have found that phytochemicals in food plants or in green leafy vegetables have the potential to improve immune functions, hamper toxic substances in the diet from becoming malignant, reduce inflammation and prevent DNA damage. In addition, such bioactivities have been shown to reduce oxidative damage to cells, slow the growth rate of cancer cells, stimulate damaged cells to self-destroy (apoptosis) before they can reproduce, and control the intracellular signaling of hormones and gene expression.

This is an indication that nutritional security entails not only consumption of a balanced diet to meet the needs of macro and micronutrients, but also phytonutrients which may play a major role in promoting health and nutrition. This review has shown that plants of the genus *Celosia* are used traditionally as food and medicine; and have the potential to prevent malnutrition and a large number of chronic diseases. There is therefore, the need for further studies on incorporating vegetables from *Celosia species* into the diet as well as educating the populace on the nutritional and pharmacological applications of the genus.

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Conflict of interest

All authors declare no conflict of interest in this paper.

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