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Review Article

Below ground food producing plants and their contribution to the world food kitty – A review

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ABSTRACT

Below ground crops in general are regarded as the Treasures in the soil in view of their very high-yield potential which in turn is hidden inside the soil. Taking into account the potentialities of below ground crops under the present scenario of global environmental change, these crops can be regarded as the Future crops for the millennium. Below ground crops are the most important land-grown food crops after cereals and grain legumes. They are either the staple or subsidiary food for large share of the human population, mostly in the developing countries of the tropics or sub-tropics and even in the temperate climatic conditions. In spite of the fact that below ground foods contribute substantially to the world food needs but it is not well recognized. Potato is the fourth major supplier of carbohydrates after wheat, rice, and maize and in many countries; cassava is a major food for the poor households especially in African countries. Groundnut is a major oilseed in India. What is not recognized is its contribution to meeting the protein needs of the people. Below-ground root crops meet about 30% energy needs of people in some African countries. Hence, below ground food-producing crops contribute significantly to the world food and energy requirements and need to be promoted for further their share through basic and applied research.

Keywords: Carrots, Cassava, Elephant foot yam, Groundnut, Peanut, Potato, Taro

Root and tuber crops, including cassava, sweet potato, potato and yam are the most important food crops for direct human consumption in Africa (Sanginga 2015, Susan John *et al.* 2016, Gregory and Wojciechowski 2020). These four crops are grown in varied agro-ecologies and production systems and some countries meet more than one-third of food energy needs. Besides, there are numerous desirable nutrition and health benefits such as antioxidative, hypoglycemic, hypocholesterolemic, antimicrobial, and immunomodulatory activities (Chandrasekara and Kumar 2016). Groundnut is generally not included in a below ground crop which contributes largely to fat and protein requirements of the people in warmer regions. However, crops other than potato and groundnut have not received the attention due to them from scientists and therefore we are presenting a brief review on their contribution to the world-food basket.

Potato

Potato (*Solanum tuberosum* spp. *tuberosum*, family *Solanaceae*) is the world's number one below-ground produced food. According to United Nations Agriculture Organization—FAO it is the fourth important food crop in the world after wheat, rice and maize. Potato is a stem and not a root. The major species grown worldwide is *Solanum tuberosum* spp. *tuberosum* (a tetraploid with 48 chromosomes), and modern varieties of this species are the most widely cultivated. Potato is a crop of temperate ecosystems with temperatures below 20°C and acid soils of *p*H 4.0-5.0. In India, such conditions are obtained in the hill states of Himachal Pradesh and Uttarakhand although it also grows well in the plains of Punjab, Uttar Pradesh and Bihar in the fall-winter season when temperatures vary from 20 to 30 degrees and soils have *p*H values of 6.5-7.6 or above. Loam soils are the best. Clayey soils prevent tuber growth and also create problem in digging.

Potato was domesticated in the Peru-northwestern region of Bolivia of South America between 8000 and 5000 BC. The Spanish conquistadors took it to their country in the late 16th century from where it spread all over mainland Europe. Sir Walter Scott is said to have introduced it in Ireland and that is why the name Irish potatoes. Portuguese sailors took it to the Western Ghats in India, from where the British took it to Calcutta in West Bengal. Portuguese called it *batatta;* a name is still popular in the Maharashtra state of India. In Bengal, they called it '*alu or aloo*', its name all over India. In 2018, the world production of potatoes was 368.2 million tonnes (1 tonne = 1000 kg) tubers, which led by China (98.3 million tonnes tubers) with 26.7%, followed

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by India (48.5 million tonnes tubers) with 13.1%, followed by Russia (22.5 million tonnes tubers) with 6.1%, followed by Ukraine (22.5 million tonnes tubers) with 6.1% and followed by United States (20.6 million tonnes tubers) with 5.6% of the total. In India during 2018–19, Uttar Pradesh was the top producer of potato with 15.3 million tonnes tubers, followed by West Bengal with 13.7 million tonnes tubers, followed by Bihar with 8.1 million tonnes tubers, followed by Gujarat with 3.7 million tonnes tubers and followed by Madhya Pradesh with 3.2 million tonnes tubers.

Potato is planted/seeded on 20-25 cm high ridges made 30-40 cm apart with small seed tubers or cut pieces of large seed tubers with each piece with at least two eyes. Potato tuber is a stem with several eyes or vegetative growth buds (Kumar *et al.* 2013). Potato needs good fertilization, about 100-200 kg N + 50-60 kg P_2O_5 (21.8-26.2 kg P) + 150-180 kg K_2O (125-150 kg K) per ha (Singh and Raghav 2000; Allison *et al.* 2001). Nitrogen and phosphorus are limiting plant nutrients in Indian agriculture and mostly soils are low to medium in available nitrogen and phosphorus (Prasad and Shivay 2015; Prasad *et al.* 2018) and their recovery efficiencies are also low (Prasad *et al.* 2018). Potato crop favorably responds to phosphorus fertilization in Indian soils irrespective of the soils and climatic conditions. Phosphorus application significantly increased growth, yield parameters, yield and gross and net returns of potato (Shivay 2010). In an another study phosphorus application significantly increased productivity, protein yield and energy output of rice-potato-mungbean cropping system and resulted in an increase in 0.5 M sodium bicarbonate ($NaHCO_3$) extractable phosphorus (P) content in soil. The mussoorie rock phosphate (MRP) at 35 kg P/ha was at par with 17.5 kg P/ha as diammonium phosphate (DAP) in terms of productivity, protein yield, and energy output but significantly superior in terms of phosphate solubilizing bacteria (PSB) population in soil. Phosphorus balance (application–crop removal) was generally more positive for MRP than DAP and the highest with an application of 52.5 kg P/ha as MRP (Sharma *et al.* 2010). Potato crop requires frequent irrigation water and total water requirement of the potato varies from 350 to 550 mm, depending on crop duration, atmospheric conditions, soil type and variety under cultivation (Kumar *et al.* 2013).

Raw potato contains 79% water, 17% carbohydrates (of which 88% is starch), 2% protein, and negligible amounts of fat. A 100-gram raw potato provides 77 kcal of energy. It is a rich source of vitamin B6 (23% DV) and vitamin C (24% of DV, Daily Value). Potatoes also contain some toxic compounds known as glyco alkaloids, of which the most prevalent are solanine.

Potato is an important item in the diet everywhere. For poor people in India, it is a boon. It has replaced *dal* (split pulse or bean soup) because the availability of pulses has declined and they are expensive. So for the poor man it is no more *dal-roti* (unleavened wheat bread) or dal-rice but *alu-roti* or *alu-rice.* Boiled potato is a common food while fasting. For the rich people, it is the most common snack as potato *pakoras* (fritters) or potato *bonda* (little bolls or patties of potato battered with chickpea flour paste and deep-fried) or samosa (deep-fried mashed boiled and spiced potatoes in triangular wheat dough) or bread roles (potato mixed with bakery bread and deep-fried. Of course one can never forget the potato curry, frequently eaten by rich and poor in India. In the UK fish and chips are a popular food and in the US French fries are a side dish with a steak or hamburger. Chinese make pancakes with potatoes. There are a large number of dishes made with potato in every country. Besides, to use as a food, potato is rich in carbohydrates and is also used for making alcoholic beverages. Vodka is a world-famous drink.

Cassava

Cassava (*Manihot esculenta*, family: *Euphorbiaceae*), Tapioca, manioc, or yuca Cassava is a crop of tropical ecosystems having temperatures above 25°C and good precipitation. It is a crop of South America, Africa and Asia (Hershey *et al.* 2000, Pope *et al.* 2001, Nweke 2005). It grows well even on poor soils of *p*H varying from 4.5 to 8.0 and is highly resistant to drought, but susceptible to water saturation of soils. Cassava is well adapted within latitudes 30° north and south of the equator and grows well between sea level and elevations up to 2000 m above sea levels. Tapioca is an important crop in the tropical region. In tropical region countries, it comes only after rice. Cassava is a highly productive crop when considering food calories produced per unit land area per day (250 Kcal/ha/day, as compared with 200 Kcal for maize 150 Kcal for rice. Cassava is the 'king of tropical tuber crops' and has a significant position in the global agricultural economy and trade. The productivity of cassava in Asia could attain a phenomenal increase of 22% through soil fertility management alone. In acid laterite soils of Kerala, the recommended N: P_2O_5: K_2O rate is 100:100:100 kg/ha. However, Nair *et al.* (1988) suggested the optimum dose of P as 50 kg P_2O_5/ha. Susan John *et al*. (2005) reported ground rock phosphate as a better choice of P fertilizer than super phosphate which can reduce the cost of P fertilization in low *p*H soils. Imas and Susan John (2013) stated that K is the key nutrient for tuber productivity and quality and the first K-efficient cassava variety Sree Pavithra performed well under low levels of K and was released in 2015. An N: P ratio of 3: 2 (Prema *et al*. 1975) and N: K ratio of 1:1 (Rajendran *et al*. 1976) was found best for tuber yield, dry-matter production, protein and starch content in cassava in acid laterite soils. The general lime recommendation for cassava is 2 t/ha (Mohan Kumar and Nair 1985).

Tapioca was domesticated in the western-central region of Brazil about 8000 years BC (Olsen and Schaal 1999; Pope *et al.* 2001). Portuguese sailors and traders introduced it to Africa and Asia. In the late 16th century, cassava was introduced in 1880-1885 CE to the South Indian state of Kerala by the King of Travancore Vishakham Thirunal Maharaja after a great famine hit the kingdom, as a substitute for rice. Cooked cassava is called kappa or *maricheeni* in Malayalam (Nagarajan 2019). World production of cassava

Table 1 Top 5 cassava producing countries of the world

Country	Production (million tonnes)	Percentage of world production (%)
Nigeria	59.5	21.4
Thailand	31.7	11.4
DR Congo	30.0	10.8
Brazil	17.6	6.3
Indonesia	16.1	5.7
World	278.0	100.0

is estimated at 278 million tonnes, Nigeria producing the most. The top 5 cassava producing countries are listed in Table 1. India produces about 5.5 million tonnes of cassava, mostly in the states of Kerala and Tamil Nadu.

Cassava is propagated by about 20 cm long stem cutting from the central part of the stem; top soft and bottom hard stem cuttings are not good. These cuttings are planted in a well-pulverized soil nursery about 5 cm deep for 2 weeks to initiate rooting. Seedlings are then transplanted vertically or slanting at 20 cm spacing about 15–20 cm deep in a plain seedbed. The field is then irrigated at 15–20 days interval if there are no rains. The crop is ready for harvesting after 8–12 months depending upon the variety. Roots at harvest are 8–10 cm thick at the start and taper to 3–4 cm. About 30 cm cuttings are made from the roots. These are tied in bundles and marketed.

Raw cassava contains 60% water, 38% carbohydrates, 1% protein, negligible fat and 25% of the DV for vitamin C. The 100 g of raw cassava provide 160 K calories. It also has some toxic cyanogenic glucosides (linamarin and lotaustralin), which on hydrolysis, release hydrocyanic acid (HCN). Cassava can be sweet or bitter. Bitter cassava has more toxins. Most newly developed varieties are sweet and less toxic. The presence of cyanide in cassava is of concern for human/animal consumption (Dhas *et al.* 2011). Once harvested, bitter cassava must be treated and prepared properly before human or even animal consumption, while sweet cassava can be used only after boiling. Cassava root cuttings are boiled after peeling the outer skin and boiled as rice and eaten. Dried and peeled cassava is also used for extracting starch, known as tapioca. Tapioca is used in bakeries for making many dishes and pudding. Cassava is also used for making alcoholic beverages.

Colocasia

Colocasia esculenta, family *Arecaceae*, Taro *or Arvi, or Ghuiyan* is a tropical crop and prefers regions with good rainfall. It prefers moist soil conditions and grows well in acid as well as near alkaline soils (*p*H 5-8). It grows well on loams as well as heavy soils. It is very popular in Asia and Africa. It is not as important globally as cassava. It is a perennial, tropical plant but is also grown annually primarily as a root vegetable for its edible, starchy corm. The plant has rhizomes of different shapes and sizes. Leaves are up to 40 cm × 25 cm and sprout from the rhizome. They are dark green above and light green beneath. They are triangular-ovate with the tip of the basal lobes being sub-rounded. Taro is an under-utilized and under-exploited tuberous vegetable of the tropics, grown by small and marginal farmers. Taro responds very well for balanced nutrient management options. Cattle manure or compost at the rate of 3–4 t/ha along with N, P_2O_5 and K_2O @ 80, 60 and 80 kg/ha is recommended for most parts of India. The Package of Practices (PoP) recommendation for taro followed in Kerala is N, P_2O_5 and K_2O at the rate of 80, 25 and 80 kg/ha along with FYM at the rate of 10 t/ha. The organic production technology developed for taro is FYM at the rate of 15 t/ha along with neem-cake 1 t/ha, *in-situ* green manuring with cowpea to get a green biomass of 15–20 t/ha, ash at the rate of 2 t/ha, bio-fertilizers (*Azospirillum)* at the rate of 3 kg/ha, mycorrhiza 5 kg/ha and phosphobacteria 3 kg/ha (Suja *et al.* 2015).

Domestication and region: Colocasia was domesticated in the south Asia-India region (Bevacqua 1994) and has been growing there for the ages. From there it moved to Africa where it is widely grown. Five top taro producing countries in 2014 were from Africa. Although it is widely grown in India, the country does not figure in the top 5 (Table 2).

It is cultivated by sowing the rhizomes about 20 cm apart in rows and 30 cm apart on a plane bed. It can also be grown in big earthen pots in the garden. Generally, mostly organic manures are used but mild fertilization can increase yield. A 100 g portion of colocasia gives about 135 Kcals. On a dry matter basis, taro rhizome contains about 85% starch and 11% protein. Raw rhizomes also have some anti-nutrition chemicals, which irritate the tongue and rhizomes can be consumed only after boiling. Taro rhizomes are generally boiled, sometimes with potatoes, peeled and salted and eaten as such. This is the most common food while fasting in India. In India rhizomes or young leaves are also battered in rice flour, spiced and deep-fried.

Zimikand or elephant ear yam or purple yam or suran

Zimikand (*Dioscorea alata,* family *Diascoraceae*) is a tropical plant and grows well on loamy soils of *p*H 5-7 in well rainfall areas. It was domesticated in Southeast Asia-India-New Guinea region (Bevacqua 1994). Zimikand has a large corm on or just below the ground surface. The leaves are large to very large, 20-150 cm (7.9-59.1 inch) long, with a sagittate shape. The elephant's-ear plant gets

Table 2 Top five taro producing countries of the world

Rank	Country	Taro production (million metric tonnes), 2014
1	Nigeria	3.3
2	China	1.8
3	Cameroon	1.6
4	Ghana	1.3
5	Papua New Guinea	0.3

Source: World Atlas via the internet accessed on 4 July 2020.

its name from the leaves, which are shaped like an elephant ear. Zimikand is a tropical plant and grows well on loamy soils of *p*H 5-7 in well rainfall areas. The plant contains an irritant which causes intense discomfort to the lips, mouth and throat. This acridity is caused in part by microscopic needle-like raphides of calcium oxalate monohydrate. It must be processed by cooking, soaking or fermenting – sometimes along with an acid (lime or tamarind) – before being eaten.

It is cultivated in 45 cm × 45 cm × 45 cm pits about 1 m apart in rows. Seeding is done of rhizome cuttings of 200-500 g each having a piece of central bud for germination. After seeding the pit is filled with a 1:1 mixture of soil and manure. It takes 10-12 months to mature. Nutrient management is the key for realization of the yield potential of this crop. Yams are highly efficient in the utilization of native and applied nutrients. The magnitude of response to fertilizers was found to vary with the species (Kabeerathumma and Mohankumar 1994). Continuous cropping of yams may lead to severe depletion of soil essential nutrients. Suja (2005) reported that application of coir-pith compost @ 5 t/ha along with N, P_2O_5 and K_2O @ 80, 60 and 80 kg/ha could maintain high yield (24.6 t/ha), net income (₹ 36187/ha) and benefit: cost ratio (1.42) when white yam was intercropped in coconut garden. The rate of application of NPK for different species of yams was standardized as N, P_2O_5 and K_2O @ 80, 60 and 80 kg/ha along with 12.5 t/ha farmyard manure (FYM). Organic production technology for yams was standardized as application of FYM @ 15 t/ha, *in-situ* green manuring to get 15–20 t/ha green biomass, neem-cake @ 1 t/ha, ash @ 1.5 t/ha, *Azospirillum* @ 3 kg/ha, mycorrhiza @ 5 kg/ha and phosphobacteria @ 3 kg/ha over the conventional practice of applying FYM @10 t/ha and N, P_2O_5 and K_2O @ 80, 60 and 80 kg/ha (Suja *et al*. 2015). It is cut into pieces and boiled and mashed or used as a vegetable or for making curry. It is also pickled. In folk medicine, it is used as a moderate laxative and vermifuge, and for fever, gonorrhea, leprosy, tumors, and inflamed hemorrhoids (Wanasundera and Ravindran 1994). *Dioscorea alata* has relatively high levels of oxalates 486–781 mg/100 g dry matter. The plant contains an irritant which causes intense discomfort to the lips, mouth and throat. This acridity is caused in part by microscopic needle-like raphides of calcium oxalate monohydrate. It must be processed by cooking, soaking or fermenting – sometimes along with an acid (lime or tamarind) – before being eaten.

Sweet potato

Sweet potato (*Ipomea batatas*, family *Convolvulaceae*) grows in warmer regions of the world in Asia, Africa and the southern US. It is an important sweet tuber crop rich in Vitamin A. Tubers are 10-15 cm long with a maximum diameter of 5-7 cm at the center and are tapered at both the edges. The colour of the skin could be white, beige, pink or purple, while the colour of the flesh varies from white to orange. The domestication of sweet potato occurred about 5000 years ago, with the origin of *Ipomea batatas* possibly between the Yucatán Peninsula of Mexico and the mouth of the Orinoco River in Venezuela (Austin 1988; Zhang *et al.* 1999). It was most likely spread by local people to the Caribbean and South America by 2500 BCE. It was introduced to the Philippines during the Spanish colonial period (1521-1598) (Loebenstein 2009). It was introduced to the Fujian province of China in about 1594 in response to major crop failure. The growing of sweet potatoes was encouraged by the Governor Chin Hsüeh-Tseng (Jin Xuezeng) (Spence 1993). However, according to Schuster (2018), 57 million years old fossil plants found in Meghalaya in India seem ancestral to the sweet potato.

Sweet potato deserves special attention both nationally and internationally owing to its β-carotene content, especially in the orange fleshed varieties. China is the largest producer of sweet potato globally, where the average yield is 20-25 t/ha. In India, it is grown mostly in Odisha, Uttar Pradesh, Bihar, West Bengal and NEH states. Nutrients play a significant role in the productivity and quality of tubers. From the nutraceutical point of view, the reasonably high content of antioxidants like anthocyanins and carotenoids and the storage protein sporamin in sweet potato tubers make this crop nutritionally significant for infants, invalids and tribals. Sweet potato is cultivated by 20-25 cm long cuttings of its vines having 2-3 nodes. These cuttings are planted in 15-20 cm high ridges about 45-50 cm apart. The fertilizer recommendations are 30-40 kg N + 20-30 kg P_2O_5 (8.7-13.1 kg P) + 30-40 kg K_2O (25-33.3 kg K) per ha are generally applied, which can be modified as per soil test recommendations. The crop matures in 3-4 months when the sweet potatoes are harvested.

Sweet potato contains about 20% carbohydrates (13% starch, 4% sugar and 3% fiber), 1% protein and very little fat. A 100 g serving supplies about 86 Kcal of energy and 89% DV of vitamin A, 3% DV of vitamin C and about 20% (3-5% of its different components) DV of vitamin B complex and some amounts of most essential minerals. Its richness in vitamin A has made it popular even in the US. Considering its richness in Vitamin A and view of the spread of night blindness in Asia and Africa, scientists have developed, a richer vitamin A containing genetically modified (GM) golden sweet potato. Mostly sweet potato is boiled, peeled and eaten, sometimes with the milk.

Carrots

Carrots (*Daucus carota*) although not a food crop (each 100 g supplies only about 40 Kcal of energy and has about 10% carbohydrates and very little protein and virtually no fat) is included here because it is a major source of Vitamin A (A 100 g serving meets most of the DV for Vitamin A). Carrots could be orange, yellow, red or purple. Orange ones are richer in Vitamin A. They are about 10-15 cm long, with 5-7 cm in diameter at the top and tapering to a few mm at the bottom. Carrots were domesticated in the Iran-Afghanistan region of West Asia (Zohary 2000). About 40 million tonnes of carrots are produced annually

in the world, out of which about 50% is produced in China (FAOSTAT 2019).

Groundnut

Groundnut or peanut (*Arachis hypogea*; family *Fabaceae* or *Leguminosae)* is an important crop grown worldwide in warmer regions on soils varying from *p*H 5.0-7.5. It is used mainly for edible oil production but apart from oil, many by-products contain proteins, fibers, polyphenols, antioxidants and vitamins. It is the only plant, where the fruit develops below the ground. The flowers are formed near the soil surface and after fertilization; the small ovary connected to the main plant with a filament that penetrates the soil and develops as a pod.

Groundnut was domesticated in the Peru-Bolivia-Brazil region of South America and spread to Africa and Asia by Spanish conquistadors and Portuguese sailors and traders to Africa and Asia. In 2017 about 47 million tonnes of nuts were produced in the world, China producing the most followed by India. Groundnut production in some countries is given in Table 3. In 2017, the world production of peanuts (reported as groundnuts in shells) was 47 million tonnes, with China producing the most followed by India (Table 3). In India Gujarat is the leading producer of groundnut followed by Rajasthan, Tamil Nadu, Andhra Pradesh, Maharashtra, West Bengal, Uttar Pradesh and Odisha in that order; the order may change from year to year.

Groundnut is a crop of tropical-subtropical regions with warm temperatures and soils of *p*H 5.0-8.0. It grows well on sandy loam soils. Heavy clayey soils are not good because of the problem in digging the nuts. Light sandy soils also help in pod development. As regards its cultivation kernels are seeded at about 5-10 cm depth at a distance of 15-20 cm on a plane seedbed in rows 30-40 cm apart. Since it is a legume, not much N is needed. About 20-25 kg N/ha as a starter dose is enough, but adequate P and K are needed. Generally, about 30-60 kg P_2O_5 (13.1-26.2 kg P) and 40-70 kg K_2O (33.3-58.3 kg K) per ha is required (Rana *et al.* 2013). Calcium nutrition of the groundnut is very important at pegging (about 30 days after seeding). Calcium is banded as gypsum or lime (on acid soils). Tracer studies have shown that when Ca is applied in the gynophore zone, 88% is absorbed by gynophore, while when it is applied in the root zone only 15% of it reaches gynophore (Chahal and Virmani 1973). On a *p*H of 5.1 soils, about 0.5 tonne of gypsum or 1.0 tonne of lime is needed (Raddar and Biradar 1973). The crop matures in about 4 months and 3-4 irrigations are needed.

Table 3 Six top groundnut producing countries in 2017

Country	Nuts (million tonnes)	Percentage of the world (%)
China	17.1	36.3
India	9.2	19.5
USA	3.3	7.0
Nigeria	2.4	5.0
Myanmar	1.6	3.4
Sudan	1.6	3.4
World	47.1	100.0

Peanuts being an oilseeds are full of energy and each 100 g of kernels provide 579 Kcal of energy, 48 g of fats (50% of it as mono-saturated), 25 g of proteins and 21 g of carbohydrates (dietary fiber 9 g). They are also a rich source of vitamin B complex and supply several dietary minerals, such as manganese (95% DV), magnesium (52% DV) and phosphorus (48% DV) (USDA 2014).

Conclusion

Below-ground food crops include roots (cassava, taro, elephant foot and other yams, sweet potato, carrot), a stem (potato) and a nut fruit (groundnut). Though potato, sweet potato and groundnut have been heavily investigated, however the researchers have not given enough attention to cassava and other root crops, which are a poor man's major food in many African and Asian countries. All these below-ground food crops need to be given priority for their increased productivity and nutritional quality through basic and applied research to meet out the future demand.

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