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Pigeonpea is Significantly more than just a Delicious Pulse

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ABSTRACT

Pigeonpea (*Cajanus cajan* (L.) Millsp.), a popular pulse crop of rainfed tropics and sub-tropics, is predominantly grown for its high protein grains under mixed or pure stands. In India, where pigeonpea is grown on over 5.0 m ha, the entire produce is transformed into decorticated splits (dal) for marketing and consumption. Besides this, different parts of the plants are also used in several other ways which directly or indirectly contribute positively towards sustainable rural agricultural system. These include fresh vegetable, animal fodder and feed, soil conservation, folk medicine, lac and fuelwood production, thatch roofing, basket making, and the like. The authors in this paper have attempted to bring all such scattered information together for the benefit of those concerned with the overall pigeonpea research, development, production, and utilization.

KEYWORDS

Cajanus cajan, fodder, folk medicine, green vegetable, lac production, soil conservation

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INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.), also popularly known as red gram, *tur* or *arhar*, is a key crop of subsistence agriculture. According to global estimates (FAOSTAT, 2018), globally pigeonpea was cultivated on about 7.0 m ha with a total production of about 5.1 m t; India with 5.06 m ha of annual pigeonpea cultivation is the major contributor to the global production. It is grown under subsistence agriculture in parts of Asia, Africa, Southern America and the Caribbean islands (Choudhary and Nadarajan, 2012). Pigeonpea is considered a good health food with sufficient quantities of protein, important mineral nutrients (Saxena *et al*, 2010) and vitamin B, carotene, and ascorbic acid (Miller *et al*, 1956). Pigeonpea is known for its high adaptation in different soil types and production systems at varying latitudes and altitudes; it is attributed to (i) genetic tolerance to various biotic and abiotic stresses, particularly unpredicted spells of drought and insect attacks (Choudhary *et al*, 2011) and (Choudhary *et al*, 2013) (ii) produce reasonable amounts of high-protein grains with minimum inputs (Choudhary and Nadarajan, 2011), (iii) fit well in different cropping systems and crop rotations (Saxena *et al*, 2010), and (iv) generate additional income by utilizing its different plant parts (Choudhary and Nadarajan, 2011). These positives make it an ideal crop for under-privileged farming communities. Over a long period of its cultivation, the rural folks realized the multiple utility of this plant species in various domestic, community and on-farm applications. The literature pertaining to its diverse usage is scanty and scattered in different countries and languages. In this article, the authors have made efforts to compile this information from different sources to understand its full potential in the lives of rural masses.

ALTERNATE USES WITH COMMERCIAL PERSPECTIVES

Nutritive vegetable

In Asia, pigeonpea is predominantly grown for its dry seeds, and its de-hulled splits are cooked as a thick spicy soup popularly known as dal that is eaten with bread and rice (Choudhary and Nadarajan, 2011). In Africa, the whole dry grains of pigeonpea are cooked after overnight soaking (Saxena *et al*, 2010). In contrast, pigeonpea is predominantly grown for its fresh peas in parts of India, the Caribbean and South American countries (Faris *et al*, 1987). Like other vegetables, pigeonpea is a good source of carbohydrates, proteins, vitamins, minerals and dietary fibre (Table 1). Nutritionally, the vegetable pigeonpea has multiple edges over garden peas (*Pisum sativum*) with respect to β-carotene, thiamine (vitamin B_1), Riboflavin (Vitamin B_2), Niacin, ascorbic acid and calcium (Faris *et al*, 1987). In green pigeonpea, the normal sugar level is 5.10% (Gowda *et al*, 2011); but at ICRISAT a landrace (ICP 7035) with sugar content as high as 8.8% has been identified. According to Upadhyaya *et al* (2010), ICRISAT maintains vegetable pigeonpea lines containing soluble sugars as

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high as 9.7%.

Table 1: A comparison of immature seeds of pigeonpea and pea.

Quality attributes	Pigeonpea	Pea
Edible portion (g/100g)	72	53
Protein (%)	9.8	7.2
Protein digestibility (%)	66.8	64.0
Total soluble sugar (%)	5.1	9.7
Ca (mg/100g)	57	20
Mg (mg/100g)	58	34
Fe (mg/100g)	4.6	–
Zn (mg/100g)	2.5	1.09
Carotene (mg/100g)	469	83
Ascorbic acid (mg/100g)	25	9
Fibre content (%)	8.2	6.3
Starch content (%)	48.4	69.2
Fat (%)	2.3	–

Source: Upadhyaya *et al* (2010) and Gowda *et al* (2011)

In Americas and the Caribbean, the first vegetable pigeonpea variety released was Prensado. In Dominican Republic, the popular varieties are Kaki, Pinto Villalba and Saragateado. In Puerto Rico and Venezuela, the commonly grown varieties are Kaki, Panameno and Saragateado (Mansfield, 1980). In India, mostly dual purpose (vegetable plus dry grains) varieties such as T 15-15, HY 3C and TTB 6 were used to be cultivated for vegetable purpose (Choudhary and Nadarajan, 2011). However, a few varieties bred specifically for vegetable purpose are also available for general cultivation (Table 2). These types are grown in the backyards, paddy field bunds or as regular field crop near large towns. Such plants are maintained for 3-5 years (Saxena *et al*, 2010). Generally, the immature pods are picked after three weeks from flowering. According to Faris *et al* (1987) and Mansfield (1980), the harvested pods are either marketed locally or exported as processed products in the form of shelled, frozen or canned peas (Figure 1).

Table 2: A list of vegetable pigeonpea varieties released for cultivation in India.

Variety	Pedigree/Parentage	Year	Salient features
T 15-15	Selection from a land race	1985	Non-determinate, white seeds, medium maturity, suitable for vegetable purpose, released for cultivation in Gujarat
BRG 1	Selection from Hosakote Local	2006	Non-determinate, semi-spreading vegetable type; large seeds (14-16 g/100 seeds); 2-3 pickings.
BRG 2	Local selection 'Nelamangala'	2009	Non-determinate, semi-spreading vegetable type with medium maturity; large seeds (14-16 g/100 seeds); 3-4 pickings.
BRG 3	ICP 8863 × BRG 1	2018	Non-determinate, semi-spreading, dark red standard petal, vegetable type released for the state of Karnataka; medium maturity, seed slightly larger than BRG 2; green pod yield/plant (484) significantly more than BRG 2; 3-4 pickings.

Source: Choudhary and Nadarajan (2011) and AICRPP (2019)

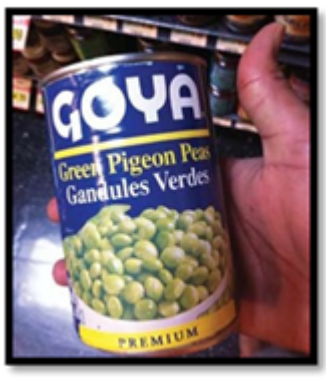

Fig. 1: Canned vegetable pigeonpea (photo source: RV Kumar)

Quality fodder resource

Empirical observations suggest that pigeonpea grows well under harsh environment, producing new flush of foliage once such stresses are over. Moreover, it can provide good quality forage when other fodder crops disappear from the production plots. According to Phatak *et al* (1993), pigeonpea fodder is a good partial replacement of alfalfa (*Medicago sativa*) for ruminant diets as a good source of protein. It can be used both for grazing and stall feeding. As per NDDB (2012), protein content of fresh forage ranges between 10-25%. The younger green leaves contain higher protein, and older dry leaves have less protein. In pigeonpea foliage, acid fibre fraction (ADF) and lignin vary between 16-37% and 7-

21%, respectively. The hay contains 9.3 % crude protein (CP), 9.3% ash, 78.6% neutral detergent fibre (NDF), 60.2 % ADF and 2.2 M cal/kg metabolizable energy (Table 3). Speedy and Pugliese (1992), reported that pigeonpea fodder chaff mixed with cereal roughage and oil cake formed excellent ration and fulfilled most nutrient requirements of growing calves. Fresh pigeonpea leaves and hay digestibility and degradability of dry matter are 50-60% (Silva *et al*, 2009). In vivo dry matter (DM) or organic matter (OM) digestibility of pigeonpea hay is usually similar to that of cowpea hay (55-56%), but slightly lower to that of annual or perennial peanut and soybean (Foster *et al*, 2009). Pigeonpea when fed as haylage is less digestible than other warm-season legumes (Foster *et al*, 2009).

Table 3: Chemical composition (% DM) of different plant parts of pigeonpea.

Plant parts	CP	OM	EE	NDF	ADF	Lignin	Ca	P	GE
Green leaves	10.1-26.7	91.2-96.0	2.4-6.1	37.2-62.9	15.7-38.7	7.3-21.4	0.46-1.08	0.1-0.26	19.7-25.5
Dry leaves	19.3	91.2	5.5	–	–	–	1.24	0.25	–
Hay	14.1	95.4	1.9	78.6	60.2	17.1	-	-	19.2
Seed	23.2	94.7	2.5	15.5	10.5	–	0.38	0.32	
Pods	20.3	96.7	1.7	–	–	–	–	–	19.7
Pod husk	6.7	95.0	0.3	–	–	–	0.97	0.18	18.4

Source: Feedipedia (2016) DM: dry matter, CP: crude protein, OM: organic matter, NDF: neutral detergent fibre, ADF: acid detergent fibre, EE: ether extract, Ca: calcium, P: phosphorus, GE: grass energy (MJ/KG DM).

Grazing: Pigeonpea provides good grazing materials for livestock including cattle, goat, sheep and swine. Henke *et al* (1940) demonstrated that pigeonpea forage was very useful when grazed by beef cattle and swine. He further reported that grazing cattle for six months in pure pigeonpea stands recorded the average weight gain of 280 kg as compared with 181 kg in mixed grass pastures. Herrera and Croder (1953) reported that cumulative crude protein yield from defoliated stands of pigeonpea over 3 years totalled 4850 kg/ha. A well established pigeonpea crop either as the sole or pasture can be grazed, and it can withstand only light and rotational grazing (FAO, 2016). A properly managed pigeonpea crop, however, could be grazed up to five years (Cook *et al*, 2005). Rao and Northup (2012) studied the effects of grazing pigeonpea using stocker cattle (Bos taurus) and reported an average weight gain of one kilogram per day.

In Africa, domestic animals are released in the pigeonpea – maize intercropped fields soon after the harvest of maize for eagerly browsing pigeonpea (Omanga and Matata, 1987). In India, the animals are released in pigeonpea fields after the final cutting of pigeonpea plants. The left over pigeonpea stumps regenerate with new flush of tender branches and leaves, which form the best fodder during the difficult months of summer. In China, where pigeonpea is promoted for soil conservation on slopping hills, the controlled grazing of goats is undertaken (Saxena and Kumar, 2020).

Stall feeding: Stall feeding of domestic animals is a common practice in most countries and providing them quality fodder round-the-year is a challenging task. According to the information published by IGFRI (2015), there is a deficit of green and dry fodder to the tune of 35.6% and 10.95%, respectively in India. Further, the land and water resources are limited to grow the conventions fodders, and therefore, to reduce this deficit there is a need to exploit some non-conventional fodder resources to feed the large livestock population. Among these, pigeonpea appears to be an ideal crop that could provide high protein fodder. In the post rainy season, the use of pigeonpea fodder gives considerable relief to farmers (IGFRI, 2015).

For stall feeding of cattle in dairy farms, pigeonpea plants with leaves, flowers, young pods and branches are finely chopped and mixed with grasses in a proportion of 20-25%. Benezara and Barroeta (1953) reported that the protein content of the meal from pigeonpea cut after 60 days was higher and the crude fibre content lower than that of good alfalfa leaf meal. This fodder portion was found to meet the partial protein requirements of cattle in dairies located in dry Chinese hills. Shiying *et al* (2001) reported the production of 54 t /ha of green fodder in five cuttings from a sole pigeonpea forage crop in Guangxi province. In the dairy farms of this province, pigeonpea fodder is also preserved by preparing silos and salted fodder-bricks for future use in the dry season.

Useful feed resources

The threshing wastes (dry leaves, under-developed seeds, immature pods, pod shells) and milling by-products (broken grains, husk and splitting and polishing waste) have good nutritive value. These by-products are rich in protein, antioxidants and fibres which form quality cattle feed. The polishing waste that contains the outer layer of the cotyledons has high protein concentrate. These components together amounting to 25-30% of the total grain weight is considered an important feed material. It has also been observed that healthy cattle population can be raised economically by feeding pigeonpea straw and concentrate in the ratio of 30: 70. This would also reduce the daily feed cost by 14.39% and feed cost gain by 40.72% when compared with a control diet of 55% wheat straw and 45% concentrate (Singh *et al*, 2017).

Feeding pigeonpea up to 20% in the rations of goats as a protein source enhanced various carcass characteristics (Omer and Omer, 2016) . Corriher *et al* (2010) observed that pigeonpea seeds can be incorporated @ 20% in a maize silage-based diet without any detrimental effect on milk production (42 kg/day) in early lactation of Holstein cows. They also revealed that pigeonpea can be incorporated up to 20-30% in the diet of lactating cows, goats, growing pigs and poultry (Corriher *et al*, 2010). According to Wallis *et al* (1986),

pigeonpea seed, pods and milling trash can be used as an alternate to soybean and maize in pig and poultry feeding. In growing rabbits, feeding pigeonpea forage up to 25% of commercial diet has no adverse effect on growth and slaughter performance (Gonzalez *et al*, 1990). Dry pigeonpea leaves were found to be a useful replacement for alfalfa as a source of carotene and other essential nutrients in chicken rations (Squibb *et al*, 1950). The inclusions of pigeonpea in broiler diets may vary around 7.5%, amounting to about half of the soybean meal. The single limitation to this meal is the presence of some anti-nutritional factors, which can be overcome by boiling or fermenting the grains before using in the meal mixture (El-Hack *et al*, 2018). Thus, pigeonpea seeds could be used to reduce the cost of feeding broilers without any adverse effect on growth and development.

Ideal host plant for lac production

Kerria lacca (Kerr.) is a tiny scale insect of high economic importance. The long duration perennial pigeonpea is one of its favourable hosts because its plants display fast growth habit and long branches (Choudhary *et al*, 2020). The lac insects thrive on their host plants by taking nutrition from the phloem sap. Sharma and Kumar (2006) opined that the lac insect-host association also contributes to the conservation of biodiversity of soil flora, fauna and other microorganisms.

The major component of lac is resin (65%) followed by two important by-products, lac dye (1%) and lac wax (5–6%). The lac resin, which is bio-degradable, non-toxic and environment-friendly, may be processed into various value-added industrial products (Prasad, 2014; Sharma *et al*, 2020). The "lac" is marketed as "shell lac", "seed lac" or "button lac", and commands high market value. The multiple uses of lac include production of the products like paints, inks, pharmaceuticals, cosmetics; besides these, lac is also important in other uses in the fields of textiles, electrical items, automobiles, defence, railways, marine, posts and surface coating of certain food items (Goswami and Sarkar, 2010).

For lac production, the four months old pigeonpea plants offer the best results. The rangeeni brood lac is tightly bound on the main stem below the first branch in the month of October-November. Soon the crowler of lac insect from the broodlac migrate upwards and sideways to settle down on the well-developed stem and branches, and they secrete resinous substances for their protection (Ghosh *et al*, 2014). Their secretes are deposited around these parts (Figure 2). The crop of lac from pigeonpea plants is harvested in about eight months (in the month of June-July). Plant should be grown each year to get tender shoots for settlement and survival of lac insect. According to Derrong and Wenliang (1985), each year 310 g lac can be harvested from each plant. Pigeonpea as a host crop produces about 750 kg of lac ha^{-1} (Yunzheng *et al*, 1980; Lisa and Kaigui, 1980).

In India also, pigeonpea is a popular host for lac production (Roonwal, 1962), and the product is exported to more than 70 different countries. The major markets are Indonesia, Germany, United States of America, Spain, Italy, Switzerland, United Arab Emirates and United Kingdom. India is the largest producer of lac with a share of 62% of the global production of 44,000 metric tons, with a total forex earning of Rs. 766.8 m ((Yogi *et al*, 2016). Recently, the commercial cultivation of lac has also been taken up in Myanmar, Thailand, Taiwan and Indonesia.

Fig. 2: Lac production on pigeonpea stem and branches in China (photo source: Li Zenghong, China)

Research conducted at the Indian Institute of Natural Resins and Gums (IINRG) showed that pigeonpea has distinct advantages over other lac-rearing hosts such as Indian plum (*Ziziphus mauritiana*), palas (*Butea monosperma*) and kusum (*Schleichera oleosa*) as these hosts have a gestation period of 5 to 10 years. Kumar (1988), reported significant varietal differences with respect to lac-pigeonpea system lac and grain yield. Using pigeonpea as a host for lac insect caused 32% reduction in grain yield of pigeonpea, but the total profit earned from this production system was 25% more as compared to non-inoculated pigeonpea Shrama and Ramani (2013). These observations suggest that the lac producing-farmers can use pigeonpea as an alternate host to generate extra income.

Healthy culture medium for mushroom production

Mushrooms are fleshy spore-bearing fruiting bodies of a number of epigeous macrofungi. Out of 100 cultivated species, only ten including *Agaricus bisporus* and *Pleurotus ostreatus* have industrial importance. The most popular white mushroom (*Agaricus bisporus*) is rich in protein, carbohydrates, Vitamin B_3 and minerals (Saritha *et al*, 2016). The formal cultivation of mushrooms was launched in China during 1000-1100 A.D. on wood logs (Chang and Chang, 2008). Later, its cultivation commenced on saw wood, compost and crop waste.

The use of pigeonpea stalks and leaves as the agro-waste for cultivation of selected species of mushroom (*Pleurotus spp.*) is documented (Mane *et al*, 2007). Recently in China, pigeonpea by-products were tried to grow mushrooms. For this purpose, the culture media was prepared by grinding pigeonpea stems, branches, leaves, pod shells and unutilized seeds. These were mixed well and inoculated with fungus under humid conditions. According to Bao Shiying (pers. comm.),

the mushrooms produced on pigeonpea culture medium (Figure 3) were larger, heavier, attractive and nutritionally superior to those grown on saw dust or paddy straw medium.

Fig. 3: Mushroom production using pigeonpea trash (photo source: Bao Shiying, China)

RENAISSANCE OF SOIL FERTILITY

The exposure of farming lands to continuous radiation, undulated topography, wind, faulty crop husbandry and excessive rains often leads to loss of valuable organic matter, nutrients and top soil. Over a period of time, such agricultural lands become unfit for the cultivation of high value crops. To meet the increasing food demand, it is necessary that such areas are rejuvenated and brought again under cultivation. During the process of land restoration, crops like pigeonpea can be grown, which will not only produce high value grains but also help in rejuvenating the fertility and structure of soils. A series of the on-farm trials conducted in Malawi have shown that the long duration intercropped pigeonpea fixes 50 kg N ha^{-1} (Snapp *et al*, 2002), while the medium maturing cultivars fix 40 kg N ha^{-1} (KumarRao *et al*, 1983). Some examples of the role of pigeonpea in the renaissance of soil fertility are discussed in the following text.

Arresting soil erosion

The problem of soil erosion in the hilly areas is extremely serious and despite implementation of various corrective measures, huge losses of top soil and fertility are observed during every rainy season or soon after. This problem may be reduced to some extent if plant roots could hold the soil together and the dense canopy helps in reducing the impact of heavy rains on the ground. Interestingly, under these situations the long duration perennial pigeonpea cultivars fit well since it produces rapid canopy cover; has deep root system with strong laterals (Choudhary *et al*, 2020). Besides the pigeonpea plants grow well under eroded soils and barren lands with least inputs (Figure 4). The field trials conducted in the hills of southern China demonstrated that pigeonpea is the best option for arresting the soil erosion and to provide valuable fodder for livestock (Figure 5). In these areas, various ecological conditions are prevailing, and pigeonpea can be grown in all the situations as the crop has shown wide adaptation (Choudhary *et al*, 2011; Saxena and Kumar, 2020).

Fig. 4: Pigeonpea on steep slopes of waste lands (photo source: Gu Young, China)

Fig. 5: Pigeonpea on eroded hill (photo source: Yang Shiying, China)

Fig. 6: Pigeonpea on eroded road side (photo source: Zong XuXiao, China)

Fig. 7: Pigeonpea on riverside (photo source: Gu Yong, China)

Pigeonpea has been shown to be a very good option to prevent soil erosion from sloping land and preserving highly eroded hills, road side berms (Figure 6) and river banks (Figure 7) (Saxena and Kumar, 2020).

Improving soil structure and fertility

In the long-term agriculture systems particularly in heavy soils, a sub-soil hard pan is formed due to the base of the plough sliding along the furrows or by repeated use of heavy machines. Such 'plough pan' is harmful to the crops because it prevents surplus water draining away and restricts root growth. Growing a cover crop of long duration pigeonpea with zero tillage is ideal for this purpose (Nene, 1990). The strong tap roots of pigeonpea that grows down to 3-4 meters even in heavy dry soils can break the plough pan easily and improve the structure and other physical attributes of soil. Pigeonpea is also known to improve its fertility by fixing atmospheric nitrogen, releasing the soil-bound phosphorus, recycling the nutrients and adding organic matter through huge leaf fall at maturity (Snapp *et al*, 2002; Ae *et al*, 1990) .

OTHER ALTERNATE USES

Folk medicines

From the time immemorial, plants and herbs have been used for treating illnesses of different types. Not only had this, even now the extracts of some specific plant species form the basis of various highly valued pharmaceutical compounds. According to Pal *et al* (2011), plants produce a range of secondary metabolites to defend themselves against various biotic and abiotic stresses and physical injuries. In the same context, different plant parts of pigeonpea are also used for treating various illnesses of human beings and livestock. Chinese scientists have taken lead in this area of medicine, using pigeonpea as an important constituent of the traditional Chinese system of medicine. Excellent reviews on various technical aspects pigeonpea usage in treating various illnesses including the development of different pharmacy products has been published (Pal *et al*, 2011; Shaomei *et al*, 1995).

According to Chaohong *et al* (2001), different pigeonpea plant parts were found effective in curing various diseases. These include roots for treating internal fever and febrile diseases. The roots are also used to destroy internal worms and constriction of tissues to control bleeding. In China, pigeonpea leaves are used to treat jaundice, trauma, cough, inflammation, burns and bedsore, food poisoning, colic and constipation as an analgesic and to kill parasite, as pain reliever and sedative (Ahsan and Islam, 2009). In recent times, pigeonpea is also explored for treatment of diseases like ischemic necrosis of the caput femoris, aphtha, wound healing, diabetes, sores, skin irritation, hepatitis, measles, dysentery, expelling bladder stone and regularizing menstrual periods (Zu *et al*, 2010). In parts of Tamil Nadu (India), the pigeonpea leaves, seeds, and young stems are used to cure gingivitis and stomatitis (Ganeshan, 2008). In Rajasthan (India), fresh juice/boiled leaves are given orally to nullify the effect of intoxication, and are also used as a laxative. Leaf paste is applied in oral ulcers and inflammation. Leaves and seeds are applied as poultice over the breast to induce lactation (Upadhyay *et al*, 2010).

Green manure and cover crop

The value of legume green manure in enhancing various soil fertility parameters is well-established. This is achieved through direct fixing of atmospheric nitrogen or gradual decomposition of the incorporated foliage of the green manure crop. The use of pigeonpea as green manure crop is not very common, but the researchers have demonstrated the benefits of this rotation in harvesting greater yields of the subsequent food crops, particularly cereals. Bashir and Ahmad (2019) reported that the incorporation of pigeonpea as green manure 90 and 120 days from emergence significantly improved the growth and yield of following wheat crop. It was recorded that the treatment of 90 days old green manure plus application of 90 kg N produced highest biological as well as grain yield; and these values were significantly superior to the recommended treatment of 120 kg N ha^{-1}. The enhancement of biomass and grain yield of wheat was attributed to gradual decomposition and release of other essential nutrients necessary during the entire growth period (Tautges *et al*, 2018), and thus pigeonpea green manure can offset the requirements of N fertilizer for wheat. The use of pigeonpea green manure is also recommended in Thailand for dry land cultivation of cassava; and for this, a dwarf pigeonpea variety D1 has been recommended. Our observations indicate that this variety produces large amount of biomass with soft primary and secondary branches which decompose faster than other cultivars. It is thus evident that this crop has potential in sustainable agriculture.

Shade crop for vegetables and herbs

Quality of fruit and green vegetables is highly important from the perspective of marketing. In some vegetables, the exposure to sunlight is known to adversely affect the colour development, shine and general appearance (Woolf and Ferguson 2000 and CABI 2006). In this context, an experiment conducted at Maha Illupallamma (Sri Lanka) showed that the overall quality of chilli fruits improved considerably when a single row of pigeonpea variety ICP 7035 was sown after every four rows of chilli crop. It was found that the pigeonpea plants provided good shade over the chilli plants particularly during reproductive stage. The shade provided by fast growing erect pigeonpea plants helped in developing an attractive colour profile in the chilli fruits. The bright and glossy fruits fetched 10-15% higher price in the market, and thus benefited the growers (V. Arulnandhy, pers. comm.). Pigeonpea plants are also used to provide shade to young plants of vanilla, coffee and forest seedlings in nurseries (Valenzuela, 2011). In Punjab (India) where the summer months are very harsh with hot and desiccating winds, pigeonpea plants were used as green shelter in young mango graft nursery (Dhilioh *et al*, 1970).

Component crop in agro-forestry

Agro-forestry is micro-agricultural eco-system which integrates locally adapted farm, animal and forest tree species to make maximum use of a given piece of land. This ultimately helps in evolving a sustainable income generating production system that is compatible with local culture. Perennial pigeonpea genotypes fit in this concept amicably since they provide high protein food, fodder, fuelwood and organic fer-

tilizers (Van-Der-Maesen, 2006). Daniel and Ong (1990) conducted experiments using perennial and short-aged pigeonpea in agro-forestry systems, and based on their findings they called for harnessing the potential of perennial pigeonpea as an agro-forestry species. However, they emphasized the need to develop suitable management practices keeping in view of limitations nutrients requirements of annual vs. perennial types.

Forestry by -products

Fuelwood: A survey conducted by European Union Energy Initiative (EUEI., 2009) in Malawi revealed that virtually all energy consumption consisted of biomass, of which 97% is from fuel wood and 3% from crop residues. The fuel wood collection is time consuming with each woman spending about two hours every day for this job. In recent years the demand for fuel wood is increasing which imposes further de-forestation pressure on natural resources. This calls for searching new fuel sources which is likely to reduce the demand for forest-based energy and increase the energy supply from crop residues without compromising household food security.

Dry pigeonpea sticks form an excellent household fuel wood. After completing the harvesting and threshing jobs, the dry shoots are used for fuel and other odd jobs. Stick yields of 7-10 t ha^{-1} are routinely reported from rainfed and of >30 t ha^{-1} from irrigated crops (ICRISAT, 1986). Høgh-Jensen *et al* (2007) harvested pigeonpea fuel wood yield of 1977 kg ha^{-1} from a crop grown under rainfed low fertility conditions in Malawi. In China, about six tonnes of high-quality fuel wood was harvested from one hectare of pigeonpea crop (Yude *et al*, 1993).

Plywood bonding glue: In order to find a substitute for the expensive soybean glue in plywood bonding, Jianyun and Yun (1998) successfully developed a technology to prepare the glue from pigeonpea. This glue had a bonding strength of 1.28-1.92 MPa, and it was at par with the Chinese National Standards.

Pulp and paper making: In Sudan, Elzaki *et al* (2012) studied the suitability of pigeonpea stalks for making pulp and paper from its woody stem. The pulping in this case was carried out using soda, soda anthraquinone, alkaline sulphite, and alkaline anthraquinone with ethanol. From this pulp, they prepared paper hand sheets. In this experiment they observed that the average basic density for pigeonpea stalks (350 kg m^{-2}) and average bark to wood ratio (12.6%) were in the normal range for commercial pulp wood. These observations suggested that pigeonpea wood can also be used for producing papers. More research, however, is needed to take this technology at commercial level.

Honey production: Pigeonpea flowers have conspicuous nectar glands at the base of each flower. The nectar production in these glands commences with the opening of flowers and continues as long as the flowers remain opened. The nectar production is regulated by a phyto-hormone that is produced in floral nectaries endogenously (Radhika *et al* (2010). According to Yogesh *et al* (2009), the nectar production in pigeonpea flowers remains consistent throughout the day and across the entire flowering duration.

Large pigeonpea flowers with bright colours attract honey bees. Soon they start foraging on the flowers and start collecting nectar for converting it into honey. According to an on-line marketing agency (centralzay.com), which sells pigeonpea honey with brand name "Haven" (Figure 8), the texture of pigeonpea honey is silky and light on the tongue with a fragrance that is reminiscent of chamomiles or chrysanthemums. It has the aroma of tropical fruits and flowers. Primary taste of pigeonpea honey is sweet followed by a lightly bitter dry finish. The honey producing potential of pigeonpea is yet to be fully exploited.

Fig. 8: Sample of a commercial "Haven" brand pigeonpea honey (photo source: on-line marketing brochure at centralzay.com)

Non-traditional food items

The most popular way for the consumption of pigeonpea is its decorticated splits, commonly referred to as "dal" that is eaten with "chapati" (bread) or rice. The pigeonpea dal is prepared by hundreds of commercial mills located in different parts of India and Malawi. Besides dal, there are numerous other ways for consuming pigeonpea dry and green (vegetable) seeds (Choudhary and Nadarajan, 2011). Also, over the time, besides various new recipes, some innovative products have also been evolved by food technologists and these include cakes, biscuits, snacks, noodles, tempe and sprouts. Saxena *et al* (2010) have elegantly compiled the pigeonpea recipes produced and consumed in different Asian, Africa and American countries.

The milling by-products (obtained after milling) are rich in protein and polyphenols (Table 4) (Verma *et al*, 2020), exhibiting functional property of antioxidant activity to scavenge free radicals (Tiwari *et al*, 2013). Such by-products obtained after fine grinding can also be used as an additive to make value added edible products. Biscuits with different levels of pigeonpea milled by-product have been developed and evaluated for organoleptic assessments at IIPR, Kanpur (Figure 9). Organoleptic evaluation of biscuits showed the acceptability of pigeonpea milling by-product incorporated value added products (Table 5). Powder component of pigeonpea milled by-product was utilized for making dal analogs and chunks for direct consumption as cooked products (Verma *et al*, 2020). In order to take full advantages of nutritional benefits of pigeonpea, formulations and recipes need to be developed from pigeonpea.

Table 4: Biochemical parameters of milling by-product fractions

Fractions of milling by-product	Soluble protein (%)	Total phenols (%)
>1.00	15.13	3.38
>0.5	15.90	1.83
>0.25	18.62	0.86
>0.125	22.70	0.27
>0.063	23.31	0.23
<0.063	21.60	0.19

Source: Verma *et al* (2020)

Table 5: Organoleptic evaluation of biscuits madefrom pigeonpea by-products.

By-product addition (%)	Dislike very much (%)	Dislike a little (%)	Not Sure (%)	Like a little (%)	Like very much (%)
10	—	5.26	—	26.32	68.42
30	—	—	—	55.26	44.74
50	5.26	10.53	18.42	34.21	31.58

Fig. 9: Biscuits with low, medium and high by-product incorporation

Other recognized uses of pigeonpea

Trap crop for pod borers: Among field crops, pigeonpea is the most preferred host of pod borers (*Helicoverpa armigera*) (Patil *et al*, 2017). The same insect species also causes severe damage to other high valued crops like cotton and different vegetables (Kakimoto *et al*, 2003; CABI, 2006). Professional entomologists suggest using pigeonpea as a trap crop to attract the pod boring insects for feeding and egg laying (GV Rangarao, pers. comm.). For this purpose, sowing a mixture of genotypes with varying maturity period is the best insect attractant since pods and flowers pigeonpea will be available for a relatively long period. This exercise is likely to reduce pod borer density on the main crop and may require fewer insecticide sprays for economic yields.

Windbreaks: The late maturing non-determinate photosensitive pigeonpea varieties such as ICPL 366, Bahar, NP 69, and the like (Choudhary and Nadarajan, 2011) are used as windbreaks on specific need basis. These genotypes are tall, compact and produce primary and secondary branches which originate at acute angle and grow upright. Such genotypes, when grown at close spacing before the longest day, form a strong vegetative screen. These live screens are stretchy or springy in nature which can sustain fairly strong wind strokes, and therefore, make a perfect windbreaker to provide protection to nursery seedlings and grafts (GA Siddiqui, pers. comm.).

Thatch and temporary fences: In villages, pigeonpea is recognized for its multiple uses. Since its wood is strong enough with secondary growth, this by-product is used to construct temporary fences around huts and to contain small animals such as goats and pigs. It involves no cost, and the fence can be repaired easily, if damaged. Similarly, the dried pigeonpea sticks are also used for preparing thatch roof and walls (Van-Der-Maesen, 2006). Dry grass bundles are densely sandwiched in between the two layers of pigeonpea stalks and then tied with rope. This type of roof is water proof and has cooling effect in the summer months.

Weaving baskets: The baskets made from pigeonpea are very popular in rural areas Choudhary and Nadarajan (2011) . We have observed that soft and straight stems and primary branches are used for weaving baskets of different sizes. The baskets are strong with load-carrying capacity of 8-10 kg and fetch good price (approx @ Rs 20-25 / piece) in the whole sale market. Besides, using pigeonpea baskets for various domestic purposes including transportation of freshly harvested vegetable and fruits from field to the market is common in rural India (Hari Mohan, Pers comm.).

CONCLUSIONS AND OUTLOOK

Pigeonpea originated about 3500 years age, but before this, its direct progenitor *Cajanus cajanifolius* was eaten as green and whole grains. Presently this wild species, still found growing in Central and Eastern Ghats, is eaten by some native tribes and they call it as "Ban Arhar" meaning wild tuar or pigeonpea. As the cultivated landraces evolved and diversified, the usage of pigeonpea also diversified. The growers found pigeonpea to be a highly adapted species and therefore continued growing the crop; and over a period besides food its use as fodder and feed also emerged. Since pigeonpea was adopted by the people of different culture over the globe, it new cuisines were also invented. Subsequently, as the pigeonpea cultivation extended to different directions and ecologies, its use in non-food subjects was also invented. Also, the local artisans successfully used pigeonpea by-products in various in-house items. At present all such pieces of information is scattered in different levels of journals, newsletters etc. of different languages and it has never been presented in a consolidated form. In this context, the authors have made serious efforts to bring together this diverse information in the form of a review article and

hope that it will help in educating those working on pigeonpea research and development.

AUTHOR CONTRIBUTION STATEMENT

Arbind K Choudhary and K B Saxena originated the idea. Arbind K Choudhary developed the initial draft with inputs received from Jyotirmay Ghosh, Sultan Singh and Prasoon Verma. K B Saxena substantially modified the initial draft based on further inputs from V A Dalvi and Rachit K Saxena. Arbind K Choudhary and Saurabh Kumar finalized the MS for submission.

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COMPLIANCE WITH ETHICS GUIDELINES

Kulbhushan Saxena, Arbind K. Choudhary, VA Dalvi, Rachit K. Saxena, Jyotirmay Ghosh, Sultan Singh, Prasoon Verma and Saurabh Kumar declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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