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An updated review on *Physalis peruviana* fruit: Cultivational, nutraceutical and pharmaceutical aspects

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Plants have always been rich sources of medicinally active constituents in the quest for curing numerous diseases. Among those, *Physalis peruviana* has been utilized traditionally as a therapeutic (antispasmodic, diuretic, antiseptic, sedative, and analgesic) and nutraceutical herb. It contains numerous active components like essential minerals, α-linolenic acid, iron, vitamins, carbohydrates, phytosterols etc. Its potential as a multifunctional agent in beverages, foods and nutraceutical industries makes it an important crop for consideration. From the agricultural point of view, this fruit is a profitable commercial crop for arid regions also and does not require much effort and investment for cultivation. It easily grows in wild and arid regions. Despite being a nutraceutical and a medicinally important crop, its utilization is not up to the mark. Thus the objective of the present review was to explore and emphasize the nutraceutical and therapeutic potential of *Physalis peruviana*. It provides exhaustive insight into the origin, distribution, cultivation, harvesting, active constituents and its prospective utility in food, nutrition and pharmaceutical industries.

Keywords: Antioxidant, Goldenberry, *P. peruviana*, Therapeutic.

IPC Code; Int. cl. (2015.01) - A23B 7/00, A23L 2/00, A23L 3/00, A61K 36/00, A61K 36/81

Introduction

Plants have been a rich treasure trove of prophylactic and therapeutically active constituents in the treatment of numerous diseases. The use of herbal medicines is on a steady increase with times. According to the World Health Organization, 70-80 % of the world population uses plant-derived traditional methods for the treatment of various health problems[1,2]. Fruits comprise of known health benefits since times immemorial, the minor fruit crops viz. wood apple *(Aegle marmelos)*, Chinese date *(Ziziphus mauritiana)*, phalsa fruit (*Grewia asiatica)*, Indian gooseberry *(Phyllanthus emblica)* and breadfruit *(Artocarpus communis)* are examples of fruits with immense therapeutic benefits[3-5].

Physalis peruviana var. latifolia (*P. peruviana*) known as cape gooseberry or golden berry, belongs to Solanaceae family and is grown in Egypt, Colombia, South Africa, India, New Zealand, Australia, Zimbabwe, Kenya and Great Britain. Colombia is one of its largest producer, consumer and exporter[6]. The genus *Physalis* includes around 100 species characterized via fruits bearing an inflated calyx[7,8]. It is a tropical plant with hairy, fuzzy, heart-shaped, slender-pointed leaves bearing yellow flowers and orange edible fruits. They bear a thin defensive covering which resembles a Chinese lantern to guard them form birds and bugs[9].

Present review deals in detail with cultivational, therapeutic and nutraceutical aspects of *P. peruviana* fruit. It also briefly discusses its culinary advantages and few nutraceutical formulations that have been tried either through extract or juice.

Horticultural aspects

Botanical Classification

Linnaeus first described *Physalis* as a genus, in 1753. United States Department of Agriculture (USDA) classified *P. peruviana* in Solanaceae family, Genus *Physalis*. (Groundcherry plant) and species *peruviana* (Peruvian groundcherry plant).

The name *Physalis* is derived from the Greek '*Physa*' (bladder or bulb), for having a fruit wrapped in a characteristic capsule. The flowers are hermaphroditic, with a yellow tubular corolla, which facilitates pollination through insects and wind[10].

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Origin

The *P. peruviana* is native to the Andes[11] but was naturalized long ago and soon got recognized by this geographical region. It was being cultivated in England around 1774, and in 1807 early settlers of Cape of Good Hope started its cultivation. Soon after, the plant was brought to Australia where it rapidly extended to the wild. Seeds were introduced to Hawaii before 1825, the plant naturalized on the entire island at medium as well as high altitudes (1,000 to 8,000 feet). Only in relatively small time, the fruit received attention in the continents of U. S. as well[12].

P. peruviana originated and diversified from the Andean zone, chiefly in Peru, Colombia, and Ecuador. There it was grown in diverse climatic conditions of tropical, subtropical as well as temperate regions[11,13].

Distribution and importance

Physalis fruits are eaten casually and occasionally sold in markets of South America, but not considered as an important crop. It was naturalized and cultivated on a small scale in Gabon and parts of Central Africa. In China, India, and Malaya, *P. peruviana* is a common fruit but is cultivated on a smaller scale. It is assumed to flourish in areas where tomatoes can be raised. South Africa commercialized its cultivation and used it frequently for jam, jellies and as canned fruit.

Cultivation in Europe started during the 1700s in the United Kingdom[14] and later out-stretched to Australia, New Zealand and South Africa by their earliest immigrants[15-18]. *P. peruviana* has also been grown widely all through the United States, Africa, Asia, and the Caribbean[7,19-25]. Due to favourable ecotype, Colombia became the largest exporter of *P. peruviana*. It took precedence in the international market for its distinct aroma, flavour and bright colour of berries grown there[26,27].

In appearance and flavour, it simulates a tomato though its sweet and sour taste is rich with a hint of tropical lavishness. The plant is quite compliant to a diversity of well-drained soils, and exceptional crops are obtained on poor sandy ground. A single plant of *P. peruviana* may produce 300 fruits and plants with care can yield 20-30 tons/hectare[28].

Botanical species and cultivars

Genus *Physalis* contains numerous species which includes Tomatillo (*P. ixocarpa*), Clammy Ground Cherry (*Physalis heterophylla*), Strawberry Tomato (*P. pruinosa*), Purple Ground Cherry *(P. philadelphica)*, Ground Cherry, Sticky Ground Cherry (*P. viscosa*), Husk Tomato (*P. pubescens*). These *Physalis* species was intercrossed but incompatibility has been found[29,30]. *Physalis minima* is a closely related species to *P. peruviana* and is found growing as a delicate herbaceous, pubescent, erect annual[31].

In some parts of Asia, including India, *Physalis* has several species with inappropriate differences, which is firstly due to its introduction as a weed and cultivated species, and secondly due to the hybridization of a few species. Consequently, many *Physalis* species and their natural hybrids exist as a persistent weed that affects the landscape and other tropical crops.

According to Deb[31], six species of *Physalis* exist in India which include (a) *P. alkekengi* L., (b) *P. angulate* L., (c) *P. ixocarpa* Brot. ex DC., (d) *P. longifolia* Nutt., (e) *P. minima* L. and (f) *P. peruviana* L. While the identity of *P. longifolia* Nutt. (*P. virginiana* Mill.var.*sonorae* Torrey) of the Indian collections are doubtful, Singh *et al.*[32], included *P. maxima* Mill. in the list.

Cultivars

Standard cultivars are in their infancy for the cultivation of *Physalis* in India. Farmers are still dependent on seedlings or on direct sowing of seeds which are prepared from open pollination from the previous year's crop. However, a few cultivars continue to be grown in several parts of the world such as Giallo Grosso, Giant, Giant Poha Berry, Golden Berry, Golden Berry, Long Ashton etc.[33].

Growth,development and morphology

P. peruviana grows perennially in the tropics and is an annual fruit in temperate regions. It grows as wild between 2,500 and 10,000 feet in the Andean regions, South America. The plants get affected with frost and even perish at a temperature of about 30°F. California cultivators grow sapling in glass houses during the winters and put them out in early spring to have the advantage of a long growing season. The *P. peruviana* belonging to family *Solanaceae* with 2n = 24 can be simply raised in pots and acclimatize to greenhouse culture conditions[34].

Leaves of *P. peruviana* are slightly velvety. They are simple, heart-shaped, alternate, 5 to 15 cm in length and 4 to 10 cm in width[35]. The reticular system is branched, fibrous and deep with the main root between 50 to 80 cm[36]. The main stem of the plant is green, herbaceous and contain 8 to 12 nodes, from

where productive ramifications originate through dichotomy. Each node of the stem gives origin to two buds out of which one is vegetative and the other is flowering[37]. The plant bears hermaphrodite and pedunculate flowers which originate from the axillary bud with five yellow petals. The calyx is green, formed by five sepals (5 cm long) and covers the fruit completely during its development phase. Calyx turns brown on fruit ripening and indicates the time of harvest[38] (Fig. 1).

The fruit is berry-shaped, like a small globe, from green to yellowish, with a diameter around 12.5 to 25.0 mm and a weight from 4 to 10 g[35]. The fruit is sweet when ripe; making it ideal to eat in its natural form or in pies and jams. Seeds are numerous and germinate easily in alien soils justifying its growth away from the cultivation areas[39].

Cultivation

Conventionally, *P. peruviana* is indeterminate as meristems (vegetative and reproductive) remain active throughout the life cycle of the plant. Thus vegetative, floral as well as fruit growth take place concurrently[40]. *P. peruviana* fruit is somewhat unusual as it continues to increase in weight throughout development and ripening when still attached to the plant. Fruit colour turns green to orange owing to carotenoid accumulation and chlorophyll breakdown, a continuous softening take place and the ratio of soluble solids (S.S) and titratable acidity (T.A) augments linearly[41].

P. peruviana flourishes well in arid regions, protected land, well-drained soil, full sun or light shade[6]. A study was conducted to consider the effect of coloured-shade nets on physiochemical characteristics of *P. peruviana* in subtropical areas. T.A., S.S., S.S./T.A. relation, pH, Vitamin C, total phenolics and antioxidant capability were examined and it was found to have a better quality when grown in white, blue or black shade net[42]. A rich loam is favourable to it but can even bear poor soils and a rich soil promotes its leaf production with fruiting. The plants can tolerate a soil pH of 4.5 to 8.2. Several cultivars would tolerate temperatures down to about -10 ^{o}C when grown in this way. It would be wise to apply some defensive moisture condition to roots, especially in the late autumn following the peak growth incised back through frosts (Fig. 2).

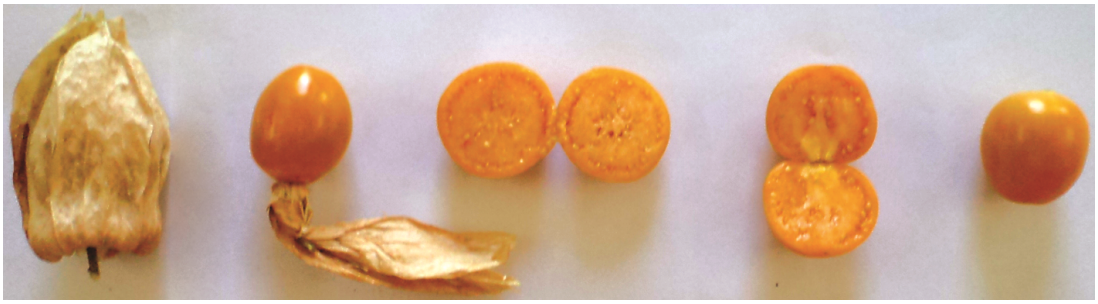

Fig. 1 — Fruits of *Physalis peruviana* with husk, open, lateral section and vertical section (fruit)

Fig. 2 — Cultivation of *Physalis peruviana* in central Uttar Pradesh (India)

Pests and disease

Several diseases infest *P. peruviana* including powdery mildew and *Alternaria*. When grown on poorly drained soil, the plants become prone to the attack of viruses and root rots. A host of bugs also infest the plants, namely cut worm, *Heliotissuflixa* (Stem borer), *Epiatrix* species (Leaf borer), *Phthorimaea* (Fruit moth), *Phyllotreta vittula* (Flea beetle), *Leptinotarsa decemlineata* (Colorado potato beetle), and *Acalymma vittata* (Striped cucumber beetle). Plants grown in the greenhouse are usually attacked by aphids and white fly. The stored fruit is adversely infested by *Penicillium* and *Botrytis* molds[43,44].

Harvesting yield and production season

In several parts of India, the fruit ripening season is of February and in the Southern region, crop season is from January to May. In southern as well as the central part of Africa, the crop season ranged from the early April to late June. In England, plants are sown from seeds in spring, begin to bear fruit from August and it continued till strong frosting[33].

P. peruviana fruits are harvested when the calyx turns to a pale tan colour and the berry is bright orange or gold. Green fruits should not be harvested as these often fail to ripen properly with good sweetness and may be toxic. At full ripeness, the fruit falls from the plant. Fruit for processing can be shaken from the plant or picked from the ground, but fruit for fresh sale should be harvested from the plant. The fruits are either twisted off gently or cut with secateurs. Whatsoever technique is applied calyx is critical and should remain intact/ undamaged. The fruits should be harvested in dry weather when the plants are quite dry and morning dew has evaporated[45].

Microscopical identification of the fruit

The fruit powder (dried form) is brown in colour. Presence of the following is the diagnostic feature of this fruit:

i) Oil globules on the epidermal cell surface and in the mesocarp region.

ii) Simple, rounded or oval starch grains and prominent hilum being present at the centre of starch grains.

iii) Group of stone cells (elongated).

iv) Reticulated xylem vessels and

v) Tannin in the parenchymatous tissue[46]

Storage of fruit

P. peruviana fruits are long-lasting, therefore the freshly obtained fruits can be stored in sealed containers and can be kept in the dry atmosphere for several months. When fresh fruits are shipped then it is best to leave the husk for protection. *P. peruviana* can be stored under refrigeration upto 2 weeks, depending on their ripeness and presence of husk. Most fruits sold in the Indian market are without the husk[31].

If one is harvesting the fruits for long-term storage, semi-ripe fruit should be picked and the husk should be kept intact, though the fruit will by no means remain as sweet as it would have been if picked fully ripe. The key to preserving the fruits is dryness, even a small amount of moisture present on the husks may lead to fungal infections or rot. In cool storage of 2-12 °C, the fruits last for four to five months and when stored in freezer bag they would last for up to a year[47,48].

Packaging

Fruits with open or burst calyx should be discarded together with under-ripe fruits and those damaged through handling or disease. Calyx should be dried completely before packing. The fruits should be dried gently undercover on sheets of card or slatted wood; fans can be used if required. Once the fruits are dry, they may be given a final grading and sorting for size before packing into lidded punnets. It is mandatory to mention the name, address or mark of dispatcher, nature and origin of produce and specifications related to size, class and quantity. Package specifications also include the net weight of the product, storage temperature and handling instructions[45].

Quality-wise grading of *P. peruviana*

As per CODEX STAN- 226-2001 (Standard for *P. peruviana*), *P. peruviana* can be classified as

- Extra class: which is superior in quality and is usually free from defects
- Class-I: good quality but maybe with a slight defect in shape, colour and skin which does not affect the pulp of the fruit
- Class-II: does not get included in a higher class and may be with defects in shape, colour and skin, the defect does not cover more than 5% of the total surface area of the fruit, moreover, it does not affect the pulp of the fruit.

Nutraceutical/ pharmaceutical aspects

Constituents in the fruit

The fruit contains about 80.97% water content, 3.16% total lipids, 1.85% proteins and 13.22% carbohydrates. The fruit contains three major sugars: sucrose, glucose and fructose. The composition may

vary as per cultivation at different altitudes[11,49]. The tribute for the nutraceutical importance of the fruit goes to the various constituents present within. In addition, the fruit contains several micronutrients and phytocomponents that are mentioned below in detail.

Minerals

The cape gooseberry fruit contains about 0.0347% magnesium, 0.00147% iron, 0.009% calcium, 0.00049% zinc, 0.0011% sodium, 0.3470% potassium, 0.00028% copper, 0.00026% manganese, 0.00033% aluminum, 0.00006% barium, 0.00001% cobalt and 0.00001% chromium, 0.00004% strontium and 0.00042% rubidium.

Fatty acids

P. peruviana fruit contains an elevated concentration of linoleic acid (about 72.42%). It also contains 10.03% oleic acid, 2.67% stearic acid, 9.38% palmitic acid, 0.71% palmitoleic acid, 0.32% α-linolenic acid, 1.36% arachidic acid, 0.26% behenic acid and 0.24% lignoceric acid. Thus constituting, 12.87% saturated, 10.71% monounsaturated and 73.78% polyunsaturated fatty acids[49].

Vitamins

Different vitamins present in this fruit include:Vitamin C 0.0322%[50], Vitamin $B_1$0.0001%, Vitamin B_3 0.0008 to 0.0017% and Vitamin E. Vitamin E will obviously be inhigher concentrations in the oil extracted out from the fruit. The amount of α-tocopherol is higher than β-tocopherol in the oil[51]. High level of Vitamin K was also found to be present in its oil[52]. In a study, researchers tried to extract out ascorbic acid through high hydrostatic pressure assisted extraction and they could extract it upto 0.02631%[53].

Provitamins

P. Peruviana fruits are also a rich source of provitamins. Ripe fruits do contain provitamin A carotenoids such as α and β-carotene and β-cryptoxanthin. Among different provitamin A carotenoids being analyzed, β-carotene was found to be the most abundant. It was 147 times higher than α-carotene content and 20 times higher than β-cryptoxanthin content. When compared among different altitudes, these contents were found to be increased with the decreasing altitude[50].

Organic acids

Citric acid, malic acid and tartaric acid were found to be present in the ripe fruit out of which citric acid is the major organic acid present. Its concentration was found to be 5.3 times higher and 7.5 times higher than malic acid and tartaric acid respectively[50].

Phenolic acids

The major phenolic acids identified in this fruit include Caffeic, gallic, chlorogenic, ferulic and p-coumaric acids[54].

Flavonoids and polyphenols

Flavonoids are well-known anti-oxidants present in the *P. Peruviana* fruit[55]. The phenolic contents of fruit decrease from zero to three maturation stages while maturation stage four to six shows no significant change. The various isolated flavonoids present in the fruit are Myricetin, quercetin, kaempferol and rutin[56]. It is one of these flavonoid/phenolic compounds which is responsible for the competitive inhibition of α amylase and moderate inhibition of α glucosidase[57]. Rutin and myricetin, both the components are predominant in the mature samples[58].

Withanolides

Withanolides are a group of steroidal lactones. It exhibits a broad biological properties[6]. Concentration of 4β- hydroxywithanolide E is higher than Withanolide E concentration. The overall decrease in withanolide content takes place during the development of the fruit. So, when young, berry exhibits a strong chemical defence because of the presence of this intrinsic withanolides[59]. Several withanolides have been identified from the fruits of *P. peruviana* so far. Few of the withanolides that showed a greater significance for their potential nutraceutical value are given below:

1. Withanolide E and Physapruin A (the components that have shown selective toxicity towards renal carcinoma)[60,61].

2. 4β- hydroxywithanolide E obtained from the fruit has also shown potential anticancer/anti-hepatoma activity and anti-inflammatory activity. It can be assumed that this compound can be a promising ingredient as a liver cancer-preventive agent[62].

There are many other withanolides present within the species but in other parts (eg. in aerial part), but as per our knowledge, 'fruit' is restricted to the above-mentioned withanolides[63].

Phytosterols

The fruit also contains certain phytosterols, such as campesterol, lanosterol, stigmasterol, β-sitosterol,

avenasterols, and ergosterol. Campesterol is the most abundant phytosterol found. The phytosterols present in the fruit could be responsible for reducing the cholesterol level[52]. The highest level of phytosterols being found in oil (extracted out from fruit), contained the highest number of unsaponifiable substances.

Saponins

Warming the extract with warm distilled water gives frothing which indicates the presence of saponins. Further test revealed the presence of steroidal saponin. Saponin is one of the major compounds of fruit[64].

Tannins and Lactones

Tannins and lactones are demonstrated in the etherial fractions of the fruit[65].

Terpenes

Terpene possesses the anti-oxidant activity and is also a volatile component among berries. *P. Peruviana* contains the highest amount of terpenes among other berries (like cranberry, blueberry) due to which it possesses the highest pro-health value. The anti-oxidant activity was estimated by ABTS and CUPRAC assays and the highest activity was found due to the presence of γ-terpinene.γ-terpinene also shows high binding property with human serum albumin which is significant for its pro-health value[66].

Flavour compounds

As per the studies, 83 volatile compounds were recognized and quantified in fruit pulp, including 8 acids, 21 alcohols, 23 esters, 8 ketones, 6 lactones, 11 terpenes, and 4 aldehydes. The major aromatic constituents of *P. peruviana* are benzyl alcohol (17.22 %), 1-butanol (5.71%), cuminol (3.98%), dimethyl vinyl carbinol (6.54%), γ- hexalactone (17.66%), 2 methyl-1-butanol (5.22%), benzyl alcohol, 1 butanolcitronellol, ethyl decanoate, ethyl octanoate, γ hexalactone, 2-heptanone, 1 heptanol, hexanal, 2 methyl-1-butanol, nonanal, γ-octalactone, and phenethyl alcohol[67]. Around 40 bound volatile compounds were also identified in the *P. peruviana* fruit. (1S, 2S)-1-phenylpropane-1,2-diol2-*O*-β-D-glucopyranoside and *p*-menth-4(8)-ene-1,2-diol1-*O*-α-L-arabinopyranosyl-(1-6)-β-D-glucopyranoside are the two of them. The volatile compounds exhibit aromatic structure (34.5%), acids (31.5%), aliphatic alcohols (19%), hydroxyesters (6.5%) and terpenoids (3.2%)[68]. A few examples of volatile flavour include Methyl-2-methylbutyrate, 2.5-dimethyl-4-hydroxy-(2H)-furarone and its 4-methoxy derivative, 4- and 5-octanolide, β-ionone, and β-damascenone. The non-volatile flavour compounds include glucose, fructose, citric acid, sucrose, and smaller amounts of organic and benzoic acids[69].

Forms obtained from the fruit

Juice

The juice constitutes about 72.6% of the berry weight. The pH of the juice was found to be acidic (3.79-3.86). The fruit juice is a rich source of provitamin A, vitamin B complex, vitamin C and minerals. The juice is rich in water as well as fat-soluble bioactive components. The sugar content in the juice is generally 4.9% and the fructose and sucrose are the major sugar components. Quercetin is the chief phenolic component followed by myricetin and kaempferol. Thus, the juice from this fruit can be a great source of functional drinks[70]. Minerals are known to play several vital roles in physiology and biochemistry of body as enzyme co-factors and affect fertility, mental stability and immunity[52,71]. The juice has shown remarkably valuable effects in numerous experimental studies[72,73].

Pomace

The left out pulpy part of the fruit is called pomace which is generally discarded after juice extraction. Moreover, pomaceis a good source of bioactive compounds and nutrients. So, this waste material is not really a waste. It contains 17.8% protein, 28.7% fiber, 24.5% carbohydrates and 19.3% oil[6].

Seed

Seeds of this fruit are majorly utilized for the purpose of cultivation. The oil extracted out of seed is also rich in many components[74,75].

Oil

Oil can be obtained using pomace/ seed/ whole berries as the starting material. Below are a few methods to extract out oil from the fruit.

Extraction using a solvent: Soxhletion was employed using petroleum ether as a solvent and the temperature during the extraction process was 40-60 °C. Raw material being air-dried, the fruit yielded 7.3% and seed yielded 18% of the oil. The specific gravity of the fruit oil was found to be 0.9235 g/m^3 whereas that of seed oil was 0.9264 g/m^3. The acid number of fruit oil was 4.3 mg whereas that of seed oil was 2.9 mg potassium hydroxide per gram. Similarly, iodine number for fruit oil was 88.2 whereas that of seed oil was 116.3. Unsaponifiable contents of fruit and seed oil include tocopherols,

carotenoids and sterols. Overall saturated and unsaturated fatty acid contents were 18.4 and 81.6% by weight respectively in fruit oil whereas those in seed oil were 11.3% by weight of saturated and 89.7% of unsaturated fatty acids[74].

Treatment with enzymes: Enzymes include pectinase, cellulose etc. Before the process, it was treated so as to inactivate the native enzymes. Fruit pomace was freeze-dried (juice being discarded), ground (0.125-0.500 mm) and an enzyme-assisted-aqueous extraction were carried out (pH 4.3; temperature 50 ^{o}C). It was then centrifuged at 3,000 rpm (25 ^{o}C and 20 minutes) and three layers were obtained after centrifugation: top, middle and bottom layer. The top layer was the lipid phase. Total saturates were 11.6, monoenes 11.2, dienes 76.5, trienes were 0.06. S/U ratio was found to be 13.1%. The comparison was also made with the solvent-extracted phase where the solvent used was n-hexane and S/U ratio, in this case,was found to be 12.8%[76]. Different nutritional constituents, i.e. total protein, total carbohydrates, crude fibre, ash, iron, calcium, manganese, copper, potassium and magnesium were highest in the case of enzyme-solvent extraction followed by solvent extraction and then enzyme–assisted aqueous extraction. The enzyme-assisted aqueous extraction yielded the highest amount of oil upto 20.9%[77].

Components in oil

P. peruviana oil comprises of carbohydrate, pectin, fibre, lipids (linoleic acid, oleic acid, palmitic and stearic acid). Neutral lipids comprise more than 95% of the total lipids, glycolipids comprise more than 5% and phospholipids comprise more than 3.9% which may be upto 6% of total lipids in seed oil and whole berry oil[75,77]. Few more components include sterols (ergosterol, campesterol, stigmasterol, lanosterol, β-sitasterol, Δ5-avenasterol, Δ7-avenasterol), fat-soluble vitamins (α, β, γ and δ- tocopherol, and vitamin K1) and β-carotene[75].

Therapeutic potential (also contributing to nutraceutical value)

P. peruviana fruit possesses a number of compounds which are responsible for various therapeutic and nutraceutical activities. Some of the pharmacological activities being reported to date (as per our knowledge) are mentioned below:

Antioxidant activity

The antioxidant activity of *P. peruviana* fruit is the result of high levels of polyphenols present in it. Antioxidant activity can be estimated by FRAP (Ferric Reducing/Antioxidant Power) assay, 2,2-diphenyl- 1-(2,4,6- trinitrophenyl)-hydrazinyl (DPPH) free radical scavenger and the concentration of total phenols (Folin–Ciocalteu method)[52]. Offline and online HPLC-DPPH methods were employed for antioxidant activity which was found to be 547.6±88.8 and 380.3±14.3 μg Trolox Equivalent/ 100 g FW[78]. The supercritical extract of *P. peruviana* (SCEPP-5), an extract of SFE-CO_2 (supercritical carbon dioxide), displays strong antioxidant and anti-inflammatory activities when compared with other extracts.The protective action of SCEPP on the lipopolysaccharide (LPS) stimulated inflammation might owe to the inhibition of induced enzymes, nitric oxide synthase (iNOS) and COX-2 (cyclooxygenase- 2) expression[79].

Anti-cancer activity

P. peruviana fruit shows preventive effect against certain carcinogens, such as nicotine derived nitrosamine. Nitrosamine leads to lung cell proliferation and inhibition of tumour suppressor gene based on ROS generation. *P. peruviana* fruit protects against this carcinogen because of its anti-oxidant and anti-proliferative properties[80]. The fruit extract has also shown to reduce the release of interleukin-6, interleukin-8 and monocyte chemoattachment protein-1 in a dose-dependent manner. Thus, it shows immunomodulatory and anti-cancer potential[81]. A component present in the fruit called 4β-Hydroxywithanolide E is a potential anti-cancer substance. Another study came up where this component inhibited the proliferation of cells in a dose-dependent manner. Thus, this component is a potential chemotherapeutic and DNA-damaging agent for lung cancer cells[62]. It also possesses anti-cancer activities towards other cancers such as colon and breast cancer. For a study, ethanolic extracts displayed high antioxidant and anticancer activity and it is concluded that the extract of this fruit is more effective towards colon cancer cell lines as compared to breast cancer cell lines[82].

Anti-hepatotoxic activity

In-vivo studies indicated that *P. peruviana* fruit extract can stabilize the hepatic cell membrane and act as a hepatoprotective substance against the toxic effect of certain toxicants such as cadmium[83] andcarbon tetrachloride[64]. Polyphenols are able to maintain the integrity of cell membranes, protecting the cells from death. This role is not related to

enhancing the antioxidant activity. However, the possible mechanism of the protective function of *P. peruviana* fruit, aqueous or ethanolic extract may be due to their ability to scavenge free radicals and enhanced antioxidant effect or inhibition of cytochrome P_{450}[84]. The underlying mechanism behind the hepatoprotective mechanism may also be attributed to a decrease in the expression of a fibrotic marker matrix metalloproteinases (MMP-9). In a study, *P. peruviana* fruit juice lowered the MMP-9 expression and thus inhibited fibrosis, the effect found was probably owed to the presence of quercetin (a strong antioxidant)[85].

Anti-neurotoxicactivity

Cadmium has a number of biological toxic effects, some of which affect the brain and induce diseases like Parkinson's, Alzheimer's disease etc. Humans can consume cadmium either via direct exposure or by food chain resulting in neurodegeneration. Exposure to cadmium generates free radicals which result in neuronal lipid peroxidation and reduction in the enzymatic and non-enzymatic components and causes many other effects. An experimental study conducted on rats concluded that *P. peruviana* fruit holds the potential to protect from cadmium-induced neurotoxic effect due to its free radical scavenging activity and its constituents (phenolics and flavanoid) and can act as a strong defence against cadmium neurotoxicity. Thus, it can be used as a supplementary extract and as a novel therapeutic dietary strategy against cadmium neurotoxicity[86]. Further, in 2017 via another experiment on rats, it was proved that the beneficial neuroprotective effects of its juice might be due to the antioxidant and anti-apoptotic activities[72].

Nephroprotective/ renoprotective activity

Nephroprotective activity is also the result of free radical scavenging. Increase in the antioxidant defence system and a larger susceptibility of the kidney to oxidant stress might be anticipated. Researchers by their *in-vivo* experiments confirmed its beneficial effects[83,87].

Europeans use *P. peruviana* for treatment of bladder and kidney stones, fluid retention, urinary tract disorders and gout. Researchers investigated the solubility of kidney and bladder stones in natural fresh juice and in acid hydrolyzed juice of *P. peruviana* fruit. The results of their study showed that the solubility in natural fresh juice is more than acid hydrolyzed juices at any time for urinary stones of different form and size[1,88].

Hypoglycaemic/anti-diabetic activity

In 2009, the hypoglycaemic and antihypertensive ability of native *P. peruviana* fruits was evaluated by using *in-vitro* models. It was concluded that these can be effective food-based strategies for anti-diabetic and anti-hypertensive effect[89]. Later, in 2014, the anti-diabetic potential of *P. peruviana* fruit in high-fat diet rats was explored. It was reported that the fruit extract improved insulin sensitivity and possess significant anti-diabetic effect which probably was due to the active ingredients present within the extract[90]. Also, in Chinese folk medicine, *P. peruviana* fruits were consumed and have also been reported for diabetes mellitus treatment. A study suggested that one of the modes of action for the anti-hyperglycemic property of this fruit is its inhibition of intestinal carbohydrase enzyme[57]. Further, in 2016 Bernal came up with a dry powder formulation of *P. peruviana* fruit extract and concluded that this can prove to be a future phytotherapeutic agent and can be utilized for the treatment of diabetes[91]. Thus, *P. peruviana* fruit can also be a potential candidate for the development of new anti-diabetic formulations.

Anti-hypertensive activity

The fruit exhibits low Angiotensin-I converting enzyme (ACE) inhibiting potential compared to other fruits like water chestnut, sugar datepalm etc. ACE is a key component for blood pressure regulation via rennin angiotensin system. Subsequently, inhibition of ACE is a major target for controlling hypertension[92].

Anti-hypercholesteremiaactivity

The pomace of the fruit was utilized to check its effect on hypercholesterolemia. The lipid profile of high cholesterol diet rats was analyzed and it was observed that the pomace lowered the levels of total cholesterol, total triacylglycerol, total low-density lipoprotein cholesterol anda higher level of high-density lipoprotein cholesterol. Thus, the consumption of pomace provides an overall beneficial effect in suppressing high cholesterol diet-induced hypercholesteremia[93].

Anti-pterygia activity

Pterygium is a frequently occurring ophthalmic problem which is more common in tropical regions, characterized by wing-shaped fibrovascular growth of pink and fleshy tissue in the conjunctival region. While the pterygial body remains on the sclera, the head might advance into the cornea affecting vision in most cases and causing discomfort[94]. In more

advanced cases, it can cause reduction and even lead to blindness.

Traditional Colombian medicine utilized *P. peruviana* fruit juice in the treatment of pterygia by applying it directly to the eye. This was later proved by Pardo *et al.* in 2008. This anti-pterygial activity could possibly be supported by two other activities i.e. cytostatic and anti-inflammatory activity[73].

Anti-inflammatory activity

The anti-inflammatory activity of *P. peruviana* fruits is attributed to the presence of withanolides. Few of these withanolides inhibited TNF-α induced NF-κB activity[95]. It has also been reported that in comparison to prednisolone, its anti-inflammatory activity is mild[73].

Anti-microbial activity

The antimicrobial activity of *P. peruviana*is estimated against several species. Minimum inhibitory concentration values of active extracts were determined and were observed to be 128 µg/mL for *Pseudomonas aeruginosa*, 256 µg/mL for *Enterobacter aerogens*, 512 µg/mL for several species (*Bacillus megaterium, Candida albicans, C. globrata, C. tropicalis, Klebsiella pneumonia, Trichophyton* sp., and *Proteus vulgaris*) and 1054 µg/mL for *Epidermophyton* sp. and *Escherichia coli*[96]. Among different parts of this plant, fruit and seeds are the most effective parts for anti-microbial activity[97]. Besides this, *P. peruviana* fruits' both aqueous and alcoholic extract (from both fresh and lyophilized state) showed sufficient anti-listerial activity comparable to the synthetic antibiotics such as ampicillin and gentamicin[98]. The antibacterial activity has been proved by testing against Streptomyces 85E strain[99].

Toxicity

Unripe fruits are poisonous. Solanine, a bitter glycoalkaloid is supposed to be a toxin. The immature fruits contain sufficient solanine. If ingested, it can cause gastroenteritis and diarrhea[100]. Under an experimental study, lyophilized *P. peruviana* fruit juice showed cardiotoxicity only at higher doses[101].

Culinary preparations

It most centuries, *P. peruviana* used to be cultivated for direct consumption. Moreover, the fruits possess a good reputation in several international markets, such as Europe, where premium prices are paid for it. They have a distinct flavour and besides having great potential as fresh fruit. It can be consumed as fresh fruit, juices, salads, fruit cocktails, dipped in chocolate and other glazes, pricked and rolled in sugar or in cooked dishes, jams, natural snacks and fruit preserves. For desserts, it can be cooked with apples or ginger and stewed with honey. It has high pectin content, therefore can be canned as whole fruit, made into sauce and chutneys, ice-creams, pies and puddings. It can also be dried into flavoursome raisins or used as a garnish[102]. Here are some of the culinary preparations that are either studied scientifically or have been used traditionally for some purpose (Fig. 3).

Jellies

As compared to other species of *P. peruviana*, jellies obtained from Peruvian species was found to be more suitable for processing. Also, it was found to be sensory accepted jelly[103]. Influence of different sugars have also been checked out but it was found that though it may affect the physico-chemical and rheological properties (white refined, white crystal and demerara sugars being most suitable), it had no significant influence on sensory acceptability of jellies on consumers[104].

Wine

People use the fruit to make wine and the foremost factors which affect the sensory quality and alcohol content of wine are a level of saccharifying liquid and fermentation temperature.

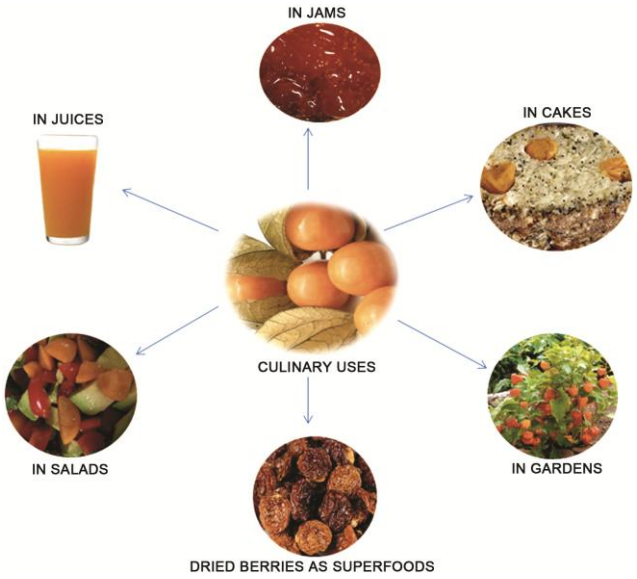

Fig. 3 — Culinary uses of *Physalis peruviana*

Effect of processing on the nutritional composition

Many fruits that are consumed today are usually processed, canned, frozen or dried. Processing can either lower or increase the fibre content of fruit. Higher consumption of this fruit whether consumed processed or un-processed is beneficial[105].

Blanching

It is also an important technique to inactivate enzymes and destroy micro-organisms which are utilized in food industries. This process is done for better shelf life. The fruit contains a considerable amount of nutrients in both blanched and unblanched fruits. However, there is a reduction in the number of nutrients after being blanched[106].

Drying

These fruits are externally covered with a waxy skin which limits the moisture permeability. Skin is made up of a heterogeneous mixture of lipids. Fruits were pretreated before drying. Higher shrinkage was observed for untreated gooseberries in comparison to those which were physically or chemically pretreated, showed lower shrinkage. Faster drying also increases moisture absorption property. Drying process resulted in ascorbic acid retention ranging from 23 to 46% (higher in pretreated ones; upto 46% in chemically treated due to shorter drying time needed). Exposure to light, oxygen and heat causes acceleration of the oxidation of the compounds[107]. Effect of drying was also evaluated where it was observed that the total polyphenol content increased on drying (gallic acid 0.0295% of dry mass; highest record with microwave drying with the power of 480W). This is probably attributed to the evaporation of water during drying which results in the densification of some active ingredients. In the case of microwave drying, lesser oxidation of polyphenols would take place. Similarly, microwave drying was also suitable for retention of other components such as carotenoid contents. There was a higher amount of α-carotene in comparison to fresh fruit or conventionally dried fruit. Also, 15-cis-β-carotene was detected after drying but not found in fresh fruit[108]. Thermal stability of numerous components of fruit was evaluated and they found β-carotene to be stable with some isomeric transitions and degradation of ascorbic acid. Catechin and epicatechin increased at 40 °C and degraded at 60 °C[78].

Pasteurization

As per a study, pasteurization of the *P. peruviana* juice at 90 ^{o}C for 2 minutes contributed to a significant improvement in its organoleptic characters and shelf life. It lowered the ascorbic acid amount during storage while in case of fresh juice it remains the same. Heated juice showed total DPPH and phenol loss of 28.51 and 20.88% respectively. In pasteurized juice, sucrose level decreased from 25 (fresh juice) to 16%. An increase in viscosity by 7% and a decrease in the cloud by 22% was observed after 21 days of storage of the juice[109].

Freeze drying

The process consisted of freezing of the fruit and then removing water by sublimation. This technique is helpful in retaining the quality of food and is better than other dehydration processes. However, the drawbacks may be high energy cost and long processing times[110].

Nutraceutical formulations of *P. peruviana* fruits

Dry powder formulation

Ethanolic extract of *P. peruviana* fruit showed high hygroscopicity, reduced flow properties and low compressibility. The hygroscopic nature affects uniformity while blending and also affects its stability. Dry powder formulations were prepared using *P. peruviana* extract as a drug for hypoglycaemic activity. The most compatible excipients were selected for this purpose. The formulation showed advantages in density, particle size, flowability, hygroscopicity in comparison to extract. The solid-state formulation was administered orally and showed hypoglycaemic activity. This lead to a conclusion that this formulation could be a promising tool for developing future pharmaco-therapeutic products[91].

Microencapsulated powder

P. peruviana juice was utilized for preparing microencapsulated powder in order to extend its shelf life by using maltodextrin mixed with other excipients. Prepared formulation retained >75% of phenolic content and showed a greater release of these compounds in simulated intestinal fluid. The authors suggested that this can be used as a functional food ingredient[111].

Conclusion

*P. peruviana*is a well-known plant with multiple medicinal uses. Its cultivation and utilization as a

potential nutraceutical and economical crop have just commenced. It can also be utilized for extracting out a number of potential phytocomponents. Adequate agro-techniques can make it a promising and profitable crop for arid regions. This natural crop and its phytochemicals may fetch potential functional and nutraceutical benefits to food/ beverage/ phytomedicine industries.

Conflict of interest

The authors have no conflict of interest to report.

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