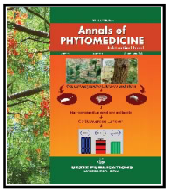
Annals of Phytomedicine 11(1): 236-246, 2022

DOI: http://dx.doi.org/10.54085/ap.2022.11.1.23

Annals of Phytomedicine: An International Journal

http://www.ukaazpublications.com/publications/index.php

Print ISSN : 2278-9839 Online ISSN : 2393-9885



Review Article : Open Access

Nutritional value, phytochemistry, pharmacological and *in vitro* regeneration of turmeric (*Curcuma longa* L.): An updated review

P. Sivakumar◆, S. Monisha, K.S. Vijai Selvaraj, M. Chitra, T. Prabha*, M. Santhakumar, A. Bharathi, and A.Velayutham

Agricultural College and Research Institute, Tamil Nadu Agricultural University, Eachangkottai, Thanjavur-614902, Tamilnadu, India

**Department of Pharmaceutical Chemistry, Nandha College of Pharmacy, The Tamilnadu Dr. MGR Medical University-Chennai, Erode-638052, Tamilnadu, India*

Article Info

Article history

Received 3 April 2022

Revised 19 June 2022

Accepted 20 June 2022

Published Online 30 June 2022

Keywords

Curcumin

Phytoconstituents

Pharmacological properties

In vitro propagation

Plant growth regulators

Abstract

Curcuma longa L. is a perennial herb known as Golden spice used for culinary, natural food coloring, and healing many medicinal ailments. It is also called Indian Saffron since 80% of global production is from India. The chemical constituents present in turmeric like curcumin and other alkaloids have so many medicinal properties. It contains about 200 chemical constituents and has all important pharmacological properties. Conventional methods of turmeric propagation are done through underground rhizomes which pave vulnerable to many pathogens since they persist below the soil surface and require a large number of mother rhizomes as seed materials. To overcome this, a micropropagation tool is vital to produce multiple numbers of plantlets from a single rhizome. These multiple plantlets produced will be free of contagious diseases since explants are being selected from healthy rhizomes. This article reviews the botanical characters, nutritional values, chemical constituents, pharmacological properties, and *in vitro* propagation methods for the multiplication of a high number of healthy disease-free plant materials.

1. Introduction

The holistic medicine system of India is Ayurveda, which uses plant-based products to treat various ailments (Sri Bhuvaneswari *et al*., 2021; Duraisami *et al*., 2021). Of the totally used medicines, 61% were traced to natural products. Ayurveda explains turmeric as Dashemani Lekhaniya (emaciating), Kusthagna (anti-dermatosis), and Visaghna (anti-poisonous). The great Ayurvedic medical textbooks like Charaka Samhita, Susrutha Samhita, Vaagbhada Samhita, and Haritha Samhithas explained that turmeric is used for medical preparations. Due to its yellow color, turmeric is known as a Golden spice and is used for culinary, food coloring, and medicinal purposes (Rathaur *et al*., 2012). Rhizomes are commonly used in Ayurveda and Chinese medicine (Sharifi-Rad *et al*., 2020). In India, 4000 years back during Vedic culture, turmeric was used as a spice for culinary purposes and has religious significance (Betancor-Fernández *et al*., 2003). In 1280, Marco Polo gives a name to turmeric as Indian saffron (Sayantani Chanda and Ramachandra, 2019). Turmeric is helpful in many pathological conditions as a preventive and curative crop (Shrishail *et al*., 2013).). The global annual production of turmeric is 11 lakh metric tons. India is the largest producer, consumer, and exporter of turmeric powder. India contributes 80% of world production and, China contributes only 8% of the total production. Erode, a city in South India is known as Turmeric city or Yellow city because it is the largest producer and trading center for turmeric in the globe. In North India, turmeric is called “Haldi,” derived from the Sanskrit word “Haridra”, and in South India, it is called “Manjal,” which is frequently used in ancient Tamil literature (Prasad and Aggarwal, 2011). Conventional propagation of turmeric is done by underground rhizomes. This is the very slow process of multiplication in which only 7-8 plants are produced from a single rhizome. To overcome this, micropropagation can be done using rhizome bud explants. *In vitro* propagation methods enable rapid multiplication to produce, quality disease-free tissue culture seedlings in large numbers. These regenerated plantlets can be successfully grown in field conditions (Seran, 2013).

Corresponding author: Dr. P. Sivakumar,

Assistant Professor (Biotech.), Department of Crop Improvement, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Eachangkottai, Thanjavur-614902, Tamilnadu, India.

E-mail: sivakumar.p@tnau.ac.in

Tel.: +91-9585871780

2. Botany

Turmeric (*Curcuma longa* L.) is an erect perennial plant. It belongs to the Zingiberaceae family and the origin of turmeric is tropical South Asia. It contains more than 130 species of *Curcuma* world wide. Most of them have common local names and are highly used because of their various medicinal properties. It is well grown at 20°C to 30°C with a rainfall of 1500 mm (Prasad and Aggarwal, 2011). Turmeric is grown in different types of soils, but loamy soils are the most preferred type of soil for cultivation. It cannot withstand prolonged water stagnation and alkalinity conditions.

3. Taxonomy

Many taxonomists (Linnaeus 1753; Hooker 1894; Rendle 1904; Valeton 1918; Hutchinson 1934) were involved in the taxonomic classification and nomenclature of the genus *Curcuma* (Table 1; Prasath *et al*., 2018).

Table 1: Taxonomy of turmeric

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
superdivision	Embroyophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Lilianae
Order	Zingiberales
Family	Zingiberaceae
Genus	*Curcuma* L.
Species	*Curcuma longa* L.

4. Morphological characters

Turmeric is a vegetative propagated crop. It is propagated through an underground stem (Rhizome). The rhizomes are curved thick and fleshy, ovoid (or) ellipsoid structures found underneath the ground. In that, older rhizomes are brown in colour and young rhizomes are pale yellow to brown orange. Rhizomes are, yellow to orange in colour and it measures about 2.5-7.0 cm in length and width of nearly 2.5 cm in diameter (Prasad and Aggarwal, 2011). Central rhizomes are pear-shaped known as "bulbs" while secondary rhizomes are cylindrical in shape (Ahmad *et al*., 2010). The height of the plant is about 60 cm to 1m (3.3 feet). The average number of leaves is 7-12. Total leaf length ranges from 30 to 45 cm and breadth is 14 to 16 cm (Prasath *et al.*, 2018). A group of leaves with long petioles was surrounded by bladeless sheaths, those leaf sheaths are forming a pseudostem. The inflorescence is cylindrical in shape, the central spike is 10-15 cm that was arising through the pseudostem. They are having laterally green and united bracts with reddish spots. Turmeric flowers are pale yellow in colour, a dense spike-like structure (Kumar *et al*., 2017). They are zygomorphic and hermaphrodite flowers.

Turmeric root is fleshy oblong, which is 5-10 cm in length. It is pointed at the distal end, and its exterior can be yellow or olive green in color (Schonbeck *et al*., 2022). The interior root is hard and orange-brown colored with transverse resinous parallel wings. The roots are hard, when broken into a powder, it is lemon yellow in color. The root of turmeric contains bitter volatile oil, brown coloring matter, gum, starch, calcium chloride, woody fiber, and curcumin. The dried and crushed turmeric powder was used for the various purposes (Prasad and Aggarwal, 2011).

5. Floral biology

The flowers are long with a central spike, enveloped by the leaf sheath, composed of an acute bract, imbricates, and greenish and or brownish on the edges (Udomdee *et al*., 2007). Corolla and calyx have three division which is tubular in form. It has three stamens two stamens are reduced into bifid staminodes and the third one is fertile that forms the androecium. The anther and ovary have two and three lobules, respectively. Fruit is globular in shape contains lot of arilate seeds (Thaisa Muriel Mioranza *et al*., 2017).

Rao *et al*. (2006) have described the floral biology of turmeric. A thesis was taken after 7 to 10 days after inflorescence emergences (Pathak *et al*., 1960). The number of flowers per inflorescence ranged from 26 to 35. The total number of days taken for flowering is 118 to 143 days. Flowers have greenish-white bracts, the upper part is white in color while the lower part is green in color (Nadkarni, 1976). Flowers are open from 7 to 9 am and maximum and thesis occurred around 8 am. Mode of pollination is by insects. The flowering period is between June-October. Another dehiscence starts from 10.15 -11.00 am (Nair *et al.*, 2004). *C. longa* is a triploid with a chromosome number of ($2n = 3 \times 63$) (Prasath *et al*., 2018). Some of the high-yielding varieties are long-duration types that take 8-9 months to mature.

6. Nutritional value of turmeric

Turmeric has many nutritional constituents such as fat, carbohydrates protein (6.3%), minerals, and moisture It contains essential oils such as sabinene (0.6%), borneol (0.5%), α-phellandrene (1%), cineol (1%), sesquiterpenes (53%), zingiberene (25%) and curcumin (diferuloyl methane) (3-4%) obtained from turmeric rhizomes (Chattopadhyay *et al*., 2004). And also contains riboflavin, thiamine, niacin, calcium, phosphorus, potassium, and iron (Nwankwo, 2014). Leaves, it has vitamins and minerals (Chattopadhya *et al*., 2004). It is an excellent natural source of carotenoids with a maximum amount present in the middle leaves followed by lower and upper leaves (Table 2) (Niranjan *et al*., 2003).

Table 2: Nutritional composition of turmeric (Leela *et al*., 2002)

Entry	Constituents	Quantity per 100 g
1	Ascorbic acid (mg)	50
2	Ash	6.8
3	Calcium (g)	0.2
4	Carbohydrate (g)	69.9
5	Fat (g)	8.9
6	Food (K Cal)	390
7	Iron (g)	47.5
8	Niacin (mg)	4.8
9	Potassium (mg)	200
10	Phosphorus (mg)	260
11	Protein (g)	8.5
12	Riboflavin (mg)	0.19
13	Sodium (mg)	30
14	Thiamine (mg)	0.09
15	Water (g)	6.0

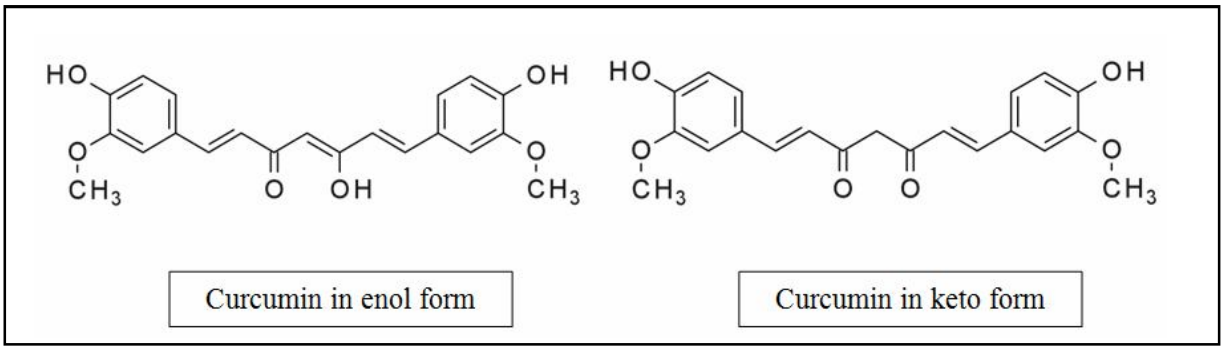


Figure 1: Important forms of curcumins.

Table 3: Chemical composition of turmeric powder

Sl. No.	Constituents	Quantity (%)
1.	Moisture	10.86
2.	Crude fat	37.39
3.	Crude Protein	2.78
4.	Crude fiber	3.11
5.	Crude ash	6.26
6.	Carbohydrate	42.71
7.	Starch	36.91
8.	Neutral detrget fiber (NDF)	12.11
9.	Acid deterget fiber (ADF)	9.68
10.	Soluble dietary fiber (SDF)	2.24
11.	Insoluble dietary fiber (ISDF)	17.37
12.	Cellulose	8.77
13.	α-Glucans	13.04
14	Lignin	0.91
15.	Hemicellulose	2.43

Nutritional analysis showed that 100 g of turmeric contains, 10 g total fat, 3 g saturated fat, 0.2 g calcium, 0.26 g phosphorous, 10 mg sodium, 2500 mg potassium, 47.5 mg iron, 0.9 mg thiamine, 0.19 mg riboflavin, 4.8 mg niacin, 50 mg ascorbic acid, 69.9 g total carbohydrates, 21 g dietary fiber, 3 g sugars, 8 g protein and there is no cholesterol (Balakrishnan, 2007). Turmeric is also a good source of omega-3 fatty acid and α-linolenic acid (Goud *et al*., 1993).

7. Phytochemistry

All the parts (roots, stems, leaves, flowers, and seeds) of turmeric contains phytochemicals (Saxena *et al*., 2013). There are varieties of phytochemicals present in turmeric. Some of those are curcumin, bisdemethoxycurcumin, curcumenol, curcumol, demethoxy curcumin, eugenol and zingiberene. The curcumin compound gives a yellow color to the turmeric rhizome (Adinew, 2012). Curcumin was isolated in 1815 (Vogel and Pelletier, 1815). Curcumin called diferuloylmethane is a flavonoid compound possess a chemical formula of 1,7-bis (4-hydroxy-3 methoxyphenyl)-1,6-heptadiene-3,5-dione present in ground rhizomes (Sahu, 2016). There are three different curcumin components presents which are Curcumin I (94%), Curcumin II (6%) (demethoxy- curcumin) and Curcumin III (0.3%) (bis-demethoxycurcumin) (Chin *et al*., 2014). Figure 1 shows the enol and keto forms of curcumins. In Figure 2 shows the molecular structures of some important curcumins.

Turmeric consists of sesquiterpenes like curcumenone, dehydrocurdione, and (4 S, 5 S)-germacrone 4,5-epoxide (Roth *et al*., 1998). Turmeric possesses various volatile and nonvolatile properties. The volatile property is due to the presence of the compounds turmerone (25%), curlone (11.58%), and zingibereneandar-turmerone (8.5%). Then the nonvolatile property is due to curcuminoids (Arutselvi *et al*., 2012). Oleoresin is a compound present in turmeric which contains mainly 79-85% curcumin, a yellow bioactive pigment. Other compounds which are also responsible for the yellow color present in smaller quantities are demethoxy curcumin and bisdemethoxycurcumin. Oleoresin contains various curcuminoids, monoterpenoids, and sesquiterpenoids (Menon *et al*., 2007).

Turmeric contains a mixture of curcumin, dimethoxy curcumin, and (Khanna, 1999). Acidic polysaccharides such as utonan A, B, C and D are present. Other chemical compounds such as campesterol, stigmasterol, beta-sitosterol, cholesterol, fatty acids, and metallic elements are present in *C. longa* (Srimal and Dhawan, 1973). Turmeric contains a very active component cyclocurcumin (Rajagopal *et al*., 2020).Turmeric contains 200 chemical molecules. Out of which 16 molecules are non-mutagenic, non-carcinogenic, and non-hepatotoxic. They are 1,3,5,11- bisabolatetraene, 3-hydroxy-1, 10- bisaboladien-9-one, ar-turmerone, bisacurone, bisacurone (A, B and C), and zedoarondiol. Among the remaining 184 compounds, 64 were hepatotoxic, 136 were mutagenic and 153 were carcinogenic (Balaji and Chempakam, 2010). Essential oils present in *C. longa* are α-bisabolene, 1,8-cineole, p-cymene, p-cymen-8-ol, tr-curcumin, curlone, dehydrocur-cumin, myrcene, α-phellandrene, α-phellandrene, α-pinene, α-pinene, terpinolene, tr-turmerone and turmerone **(**Leela *et al*., 2002). It has 0.76 % alkaloid, 0.08 % phenol ,1.08 % tannin, 0.40 % flavonoid, 0.03 % sterol, 0.82 % phytic acid and 0.45 % saponin and (Okwu and Josiah, 2006).

8. Chemical compositions of turmeric powder

The chemical composition of turmeric powder contains nearly 60-70% carbohydrates, 6-13% water, 6-8% protein, 5-10% fat, 3-7% dietary minerals, 3-7% essential oils, 2-7% dietary fiber, and 1-6% curcuminoids.(Table 3). The turmeric oil contains d-α-

phellandrene, d-sabinene, cinol, borneol, zingiberene, and sesquiterpenes. The flavor of turmeric is pungent and slightly bitter in taste.

9. Pharmacological properties

Under *in vitro* conditions, it exhibits antiparasitic, antispasmodic, anticarcinogenic, and gastrointestinal effects whereas it shows antiparasitic and anti-inflammatory activity through the oral application (Araujo and Leon 2001; Davis *et al.*, 2007). It also has antidiabetic, antimutagenic, anticoagulant, antioxidant, antiviral, antiprotozoal, antiulcer, antifungal, and hypercholesteremic properties (Figure 3).

9.1 Curcumin

9.1.1 Anti-inflammatory

The effects of curcumin on phospholipases in a cell-free system inhibit 12-otetradeconoylphorbel-13 (Yamamoto *et al.*, 1997). Chronic inflammation affects the normal tissue that leads to the production of inflammation mediators through inducible gene products like inducible nitric acid (iNOS) and cyclo-oxygenase-2 (COX-2) and the derivatives of 4 diarylheptanoids and a series of new diarylheptalamine analogs from curcumin is evaluated anti-inflammatory activity by using LPS-stimulated macrophages (Lee *et al.*, 2005). Oral administration of curcumin in acute inflammation effectively reduces inflammatory swelling as cortisone or phenylbutazone and also inhibits both biosyntheses of inflammatory prostaglandins from arachidonic acid, and neutrophil function during inflammatory states (Cronin, 2003). Curcuminoids also inhibit phospholipases, leukotrienes, prostaglandins, thromboxane, nitric oxide elastase, hyaluronidase, collagenase, monocyte chemo-attractant protein-1, interferon-inducible protein, TNF and interleukin-12. They also decrease prostaglandin formation and inhibit leukotriene biosynthesis through the lipoxygenase pathway (Bundy *et al.*, 2004).

9.1.2 Antioxidant properties

Turmeric preparations and its curcumin ingredient have antioxidant properties equivalent to vitamins C and E (Dikshit *et al.*, 1995). Curcumin treatment improved cellular tolerance to oxidative stress (Mortellini *et al.*, 2000). It protects against micro and macrovascular illnesses, as well as hyperglycemia and excessive urination that are the symptoms of diabetes mellitus (Chinenye and Young, 2011). The beta cell of the islet of langerhans is damaged by oxygen radicals such as superoxide and hydroxyl anions, which are accountable for the facile accessibility of glucose into cellular membrane, which leads to cell death. Curcumin is an antioxidant that scavenges superoxide anion radicals in the system (Chuengsamarn *et al.*, 2012).

Curcumin lowers the testicular damage induced by di-n-butyl phthalate (DBP) exposure by increasing glutathione (GSH), levels of testosterone, and glucose-6-phosphate dehydrogenase (G6PD) function, as well as lowering malondialdehyde (MDA) levels. These characteristics might be attributed to curcumin's natural antioxidative capabilities (Okamoto *et al.*, 2002). Curcumin inhibits the mutagenicity of smoke distillate, cigarettes condensate and masheri (a pyrolysed tobacco product). The mitigative activities of curcumin and kolaviron (a biflavonoid from the seeds of Garcinia kola) on the DBP cause testicular injury in rats (Farombi *et al.*, 2007).

9.1.3 Anticancer properties

In a multidimensional pathway, more than 500 genes result in cancer which could be in form of the breast, colon, or prostate depending on where the virus-cell is signaling (Gupta *et al.*, 2010). This certain drug is used as monotargeted which can suppress the effect of replication of cancerous cells, but it has an adverse effect and is also costly in nature (Himangshu *et al.*, 2021). To overcome this, encapsulated curcumin extract nanoparticles have been used in the human clinic (Yallapu *et al.*, 2015). Curcumin inhibited the transforming activities of both cell lines, as demonstrated by the lowered colony-forming capacity in soft agar, and decreased the system of transcriptional activation and expression of AR, activator protein-1 (AP-1), nuclear factor-B (NF-B), and CREB (cAMP reaction element-binding protein). As a result of the downregulation of AR and AR-related cofactors (AP-1, NF-B, and CBP), it may have a therapeutic impact on prostate cancer cells.

9.1.4 Antimicrobial properties

Turmeric extract and the essential oil of *C. longa* inhibit the growth of a variety of bacteria, parasites, and pathogenic fungi. A study of chicks infected with the caecal parasite *Eimera maxima* demonstrated that diets supplemented with turmeric resulted in a reduction in small intestinal lesion scores and improved weight gain (Yadav *et al.*, 2013). Curcumin has moderate activity against *Plasmodium falciparum* and *Leishmania major* organisms (Rasmussen *et al.*, 2000). Ethanolic extract of turmeric also has antifungal, antibacterial, phytotoxic, cytotoxic, and insecticidal properties. The antifungal activity against *Trichophyton longifusus* and *Micro sporumcanis*, antibacterial activity against *Staphylococcus aureus*, and toxic activity against *Lemna minor* was also reported by Khattak *et al.* (2005). In chicks, infection with the caecal parasite *Eimera maximais* mitigated by diets supplemented with turmeric and also reduction in small intestinal lesion scores and improved weight gain (Allen *et al.*, 1998).

9.1.5 Antidiabetic properties

Turmeric extract on glucose is effective in the medications which are used in the treatment of diabetes. It also decreases the body's resistance to insulin which can prevent type-2 diabetes. Turmeric also decreases difficulties in diabetes mellitus (Nasri *et al.*, 2014). Turmeric is used to decrease cholesterol uptake in the intestines and increase the conversion of cholesterol to bile acids in the liver to control diabetes. The turmeric ethanolic extract contains both curcuminoids and sesquiterpenoids which is more effective hypoglycemic than either curcuminoids or sesquiterpenoids (Nishiyama *et al.*, 2005).

9.1.6 Gastrointestinal effects

Turmeric has a significant impact on the digestive system. Curcumin's anti-inflammatory effects and therapeutic advantages have been established with gastritis, *Helicobacter pylori* disease, stomach ulcers, inflammatory bowel disease, crohn's disease, and ulcerative colitis (Louay, 2014). In rats exposed to various gastrointestinal shocks, it reduces ulcer development induced by anxiety, alcohol, indomethacin, reserpine, pyloric ligation, and increased stomach wall mucus. It also reduces gastrointestinal contractions and boosts the release of bicarbonate, gastrin, secretin, and pancreatic enzymes (Khattak *et al.*, 2005).

9.1.7 Neuroprotective properties

Systemic inflammation is a kind of persistent inflammation that causes alterations in neuronal physiology and degeneration. Microglia accelerate neuronal death, whereas neuro-inflammatory causes astrocyte stimulation. Inflammatory markers like TNF-α and IL-1 are produced by astrocyte stimulation. Curcumin has a neuroprotective impact, inhibiting the effects of amyloid protein, which induces loss of memory by causing the death of cholinergic neurons (Ringman *et al*., 2005). Curcumin has numerous activities in the brain and might be used to treat a wide variety of neurological illnesses such as severe depression, dyskinesia, and peripheral neuropathy (Kulkarni and Dhir, 2010).

9.1.8 Cardio protective property

Curcumin is an effective treatment for cardiac illnesses, notably atherosclerotic, which is defined as the accumulation of fatty deposits in the capillary liner of the artery walls, causing rigidity and reducing the delivery of oxygen-rich blood flow to the heart (Kinouchi *et al*., 2014). Curcumin generates a protective effect on the cardiovascular system which includes decreasing susceptibility of low-density lipoprotein (LDL) to lipid peroxidation, lowering cholesterol and triglyceride levels, and inhibiting platelet aggregation due to the antioxidant property of turmeric (Akram, 2010). Turmeric extract has its potential effect on cholesterol levels due to decreased cholesterol uptake in the intestines and increased conversion of cholesterol to bile acids in the liver (Pawar *et al.*, 2015).

9.1.9 Hepatoprotective effects

Turmeric has hepatoprotective properties for a variety of hepatotoxic injuries, including carbon tetrachloride (CCl_4) (Ruby *et al*., 1995) galactosamine, and acetaminophen (paracetamol) (Chattopadhyay *et al*., 2004) and *Aspergillus* aflatoxin. In rats, CCl_4 induced acute and subacute liver injury studied by Rao *et al*. (2016). The hepatotoxicity in alcoholic rats was induced by the curcumin effect on alcohol (Rajakrishnan *et al*., 1998). This effect is mainly due to antioxidant properties as well as its ability to decrease the formation of proinflammatory cytokines (Park *et al*., 2000). Turmeric reduced 90% of infection of *Aspergillus parasiticus* and inhibited fungal aflatoxin production.

10. *In vitro* propagation response of *C. longa*

10.1 Explant selection

Micropropagation or *in vitro* propagation means that any part of the plant is used for producing multiple plantlets under *in vitro* conditions. Excise part of the plant known as explant. Regeneration of plantlets mainly depends on the selection of explants. For turmeric, the rhizome is used as vegetative propagation material. The explant is selected based on availability, age, size, and genotypes. Rhizome bud is the best explant and it can be used for micropropagation efficiently (Rahman *et al*., 2004; Nasirujjaman *et al*., 2005; Hazare *et al*., 2005; Naz *et al*., 2009; Roopadharshini, 2010; Sharma *et al*., 2012; Arghya *et al*., 2013; Shahinozzaman *et al*., 2013). Though, rhizome bud is a good explant, various explants were tried in turmeric like immature inflorescence (Salvi *et al*., 2000), sprouted shoots (Nayak, 2000), bud (Salvi *et al*., 2002), basal part of stem (Zapata *et al*., 2003), terminal bud (Prathanturarug *et al*., 2003), leaf sheath (Prakash *et al*.,2004), rhizome (Prakash *et al*., 2004; Das *et al*., 2010), axillary bud from unsprouted rhizome (Singh *et al*., 2011; Taghavi *et al*., 2021), bud (Prathanturarug *et al*., 2005; Goyal *et al*., 2010; Raihana *et al*., 2011), sprouted rhizome bud (Shirgurkar *et al*.,2001; Behera *et al*.,2010; Sinchana *et al*., 2020; Bandara *et al*., 2021), shoot tip (Bharalee *et al*.,2005), emerging buds (Ali *et al*., 2004), vertically excised two halves of the aerial stem (0.5 cm) (Upendriand Seran, 2020) and rhizomatous explants of two months old buds (Arghya *et al*., 2013).

10.2 Sterilization techniques

Sterilization methods are used to make the explant get rid of microorganisms for producing disease-free plants. It plays a major role in turmeric because rhizome bud is mostly used as an explant in many experiments and it acts as an inoculum for soil-borne diseases. Rhizomes were dipped in soap solution for surface sterilization for 20 min then rinsed with sterile distilled water 4 times. Zapata *et al*., (2003) reported surface sterilization of rhizomes with the mixture of mercurial chloride (0.07%, w/v) and Tween 80 (0.05%, v/v) for 10 min, followed by washing with sterile distilled water 5 times. Rahman *et al*. (2004) used antiseptic solution salvon 5% as a surface sterilant for 10 mins. Before using mercuric chloride,70% ethanol was used as a disinfectant for 30-40 sec (Islam *et al*., 2004).

10.3 Shoot regeneration

Explants need nutrients for their growth and it can be supplemented through the nutrient medium. Shoot multiplication is obtained by balancing the ratio of Auxin and Cytokinin in the medium in various forms. Sprouted rhizome bud is elongated by culturing under the medium containing MS basal medium with 0.88 µM benzyl aminopurine (BAP) and 0.92 µM Kinetin after bud elongation. It is cultured under the medium consisting of MS basal medium with 2.2 µM BAP and 0.92 µM Kinetin for multiple shoot formation (Shirgurkar *et al*., 2001). Immature inflorescence of *C. longa* is taken as explant and cultured in the medium of MS medium with BA (5 or 10 mg/l) and 2,4-D (0.2 mg/l) or NAA (0.1 mg/l) and thidiazuron (TDZ) (1 or 2 mg/l) +IAA (0.1 mg/l) for shoot formation with 95% regeneration (Salvi *et al*., 2000). Nayak (2000) has experimented with a medium containing BA (1-7mg/l) and a medium provided with both BA (1-5 mg/l) and Kinetin (0.5-1 mg/l). The optimum concentration for the multiplication of shoots is 5 mg/l BA. Shoot multiplication is produced from vegetative bud through the medium containing 10 µM of BA and 1 µM of NAA 1 µM with 95% regeneration. Carbon sources such as sucrose, glucose, maltose, and table sugar were found to provide the best results for shoot multiplication (Salvi *et al*., 2002). The terminal bud is divided into pieces and each part acts as an explant, it was cultured under MS medium contains18.17µM TDZ after 4 weeks, then transferred to MS medium without plant growth regulators which resulted in 18 shoots/explants (Prathanturarug *et al*., 2003). Prathanturarug *et al*. (2005) had done the same experiment with another concentration of 72.64 µM TDZ. Rahman *et al*. (2004) cultured rhizome bud in a shoot multiplication medium containing 2.0 mg/l BA and 0.1-1.0 mg/l of IBA with 70% regeneration. Plants were regenerated from emerging buds when it was cultured under a multiple shoot medium of MS +1 mg/l BAP + 0.25 mg/l Kinetin (Ali *et al*., 2004). Even shoot tip was cultured under the medium MS +4 mg/l BAP + 1.5 mg/l IAA for shoot multiplication (Bharalee *et al*., 2005) (Table 4).

Many researchers used rhizome bud as an explant, but it was cultured under different mediums. Different composition of the media are

woody plant medium (WPM + 4 mg/l BAP +1 mg/l NAA (Nasirujjaman *et al*., 2005); MS + 2 mg/l BAP + 2 mg/l Kinetin (Hazare *et al*., 2005); MS + BAP 2 mg/l + NAA 1 mg/l with 75% of shoot induction (Naz *et al*., 2009); MS + 2.5 mg/l BAP and + 0.5 mg/l NAA with shoot multiplication rate of 5.6 shoots/explant (Sharma *et al*., 2012); MS +2.5 mg/l BAP + 1.5 mg/l NAA with 86% regeneration (Arghya *et al*., 2013); MS + 3 µM BAP + 0.5 µM NAA with 99.97% regeneration (Shahinozzaman *et al*., 2013). Arghya *et al.* (2013) specifically used rhizomatous explant of two months old bud and cultured in the medium consisting of MS + 2.5 mg/l BAP + 1.5 mg/l NAA for shootlet production. After sprouting, sprouted rhizome buds were cultured in MS with 2 mg/l BAP and + 0.5 mg/l NAA with length of 1.5-2 cm (Behera *et al*., 2010); MS + 2mg/l BAP + 0.2mg/l IAA with 94.4% regeneration (Sinchana *et al*., 2020); MS + 2 mg/l BAP with 100% regeneration (Bandara *et al*.,2021). Rhizome pieces were cultured for shoot multiplication under the medium of MS + 2.5 mg/l BAP + 0.1 mg/L NAA with 97% survival (Taghavi *et al*., 2021); MS +4.44 µM BA +1.08 µM NAA (Prakash *et al*., 2004). MS + 3mg/l BAP + 1 mg/l NAA (Raihana *et al*., 2011) and MS + 2 mg/l BAP +3 mg/l Kinetin (Goyal *et al*., 2010) were used for plant regeneration from the bud as explant with regeneration capacity of 75% and 93% respectively. Specifically, axillary bud from an un-sprouted rhizome was cultured under the medium of MS with 3 mg/l BAP and 1 mg/l IAA (Singh *et al*., 2011). On a whole, BAP is very much needed for multiple shoot production sometimes auxin is also needed as a minimum based on explants (Table 4).

Table 4: Types of explants used and their media composition, and regeneration frequency of turmeric

S.No	Explant	Media composition	Regeneration (%)	References
1	Immature infloroscence	MS + 5 or 10 mg/l BA + 0.2 mg/l 2,4-D or 0.1 mg/l NAA + 1 or 2 mg/l TDZ	95%	Salvi *et al*., 2000
2	Sprouted shoots	MS + 1-5 mg/l BA + 0.5-1 mg/l KN	_	Nayak,2000
3	Sprouted rhizome bud	MS + 0.88 µM BAP + 0.92 µM Kinetin + 5% Coconut	-	Shirgurkar *et al*., 2001
4	Vegetative bud	MS + 10 µM BA + 1 µM NAA	95%	Salvi *et al*., 2002
5	Basal part of stem	MS + 1.5 mg/l 2,4-D + 0.2 mg/l BAP	_	Zapata *et al*., 2003
6	Terminal bud	MS +18.17 µM TDZ	_	Prathanturarug *et al*., 2003
7	Rhizome bud	MS + BA 2.0 mg/l + IBA 0.1-1.0 mg/l	70%	Rahman *et al*., 2004
8	Emerging buds	MS + 1 mg/l BAP + 0.25 mg/l kinetin	-	Ali *et al*., 2004
9	Leaf sheath	MS + 8.88 µM BA + 2.7µM NAA.	-	Prakash *et al*., 2004
10.	Sprouted axillary bud	MS + 12.0 µM BA + 0.3 µM NAA	-	Islam *et al*., 2004
11	Shoot tip	MS + 4mg/l BAP + 1.5 mg/l IAA	-	Bharalee *et al*., 2005
12	Bud	MS + 72.64µM TDZ	-	Prathanturarug *et al*., 2005
13	Rhizome bud (1 cm)	WPM + 4mg/l BAP + 1 mg/l NAA	-	Nasirujjaman *et al*., 2005
14	Rhizome bud	MS + 2 mg/l BAP + 2 mg/l kinetin	-	Hazare *et al*., 2005
15	Rhizome bud	MS + 2mg/l BAP + 1 mg/l NAA	75%	Naz *et al*., 2009
16	Rhizome bud	LSBM + 3.5 mg/l BAP	95%	Roopadharshini, 2010
17	Rhizome	MS + 13.31µM BAP + 2.68µM NAA	80%	Das *et al*., 2010
18	Bud	MS + 2mg/l BAP + 3 mg/l Kinetin	93%	Goyal *et al*., 2010
19	Sprouted rhizome bud	MS + 2mg/l BAP + 0.5 mg/l NAA	-	Behera *et al*., 2010
20	Axillary bud	MS + 3mg/l BAP + 1 mg/l IAA	-	Singh *et al*., 2011
21	Bud	MS + 3mg/l BAP + 1 mg/l NAA	75%	Raihana *et al*., 2011
22	Rhizome bud	MS + 2.5mg/l BAP + 0.5 mg/l NAA	-	Sharma *et al*., 2012
23	Rhizome bud	MS + 2.5mg/l BAP + 1.5 mg/l NAA	86%	Arghya *et al*., 2013
24	Rhizome bud	MS + 3 µM BAP + 0.5 µM NAA	99.97%	Shahinozzaman *et al*., 2013
25	Rhizomatous	MS + 2.5 mg/l BAP + 1.5 mg/l NAA	86%	Arghya *et al*., 2013
26	Leaf base	MS + 2.64 µM BA	91.1%	SoundarRaju *et al*., 2015
27	Sprouted rhizome bud	MS + 2 mg/l BAP + 0.2 mg/l IAA	94.44%	Sinchana *et al*., 2020
28	Vertically excised two halves of aerial stem	MS + 2 mg/l BAP	-	Upendri and Seran, 2020
29	Rhizome pieces (1-2 cm)	MS + 2.5 mg/l BAP + 0.1 mg/l NAA	97%	Taghavi *et al*., 2021
30	Rhizome buds sprouted	MS + 2 mg/l BAP	100%	Bandara *et al*., 2021

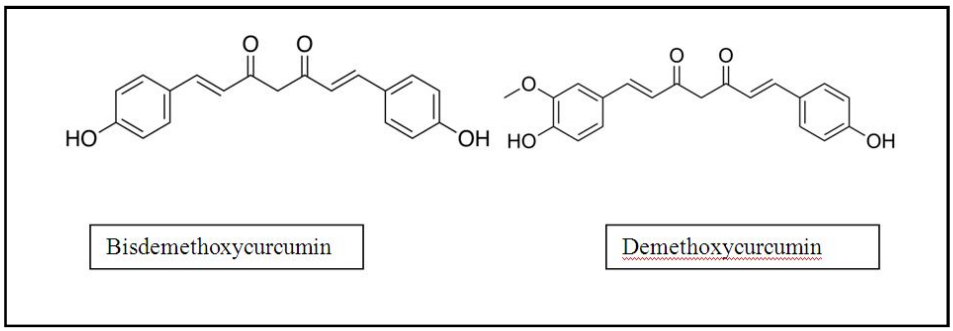


Figure 2: Chemical structures of bisdemethoxycurcumin and demethoxycurcumin.

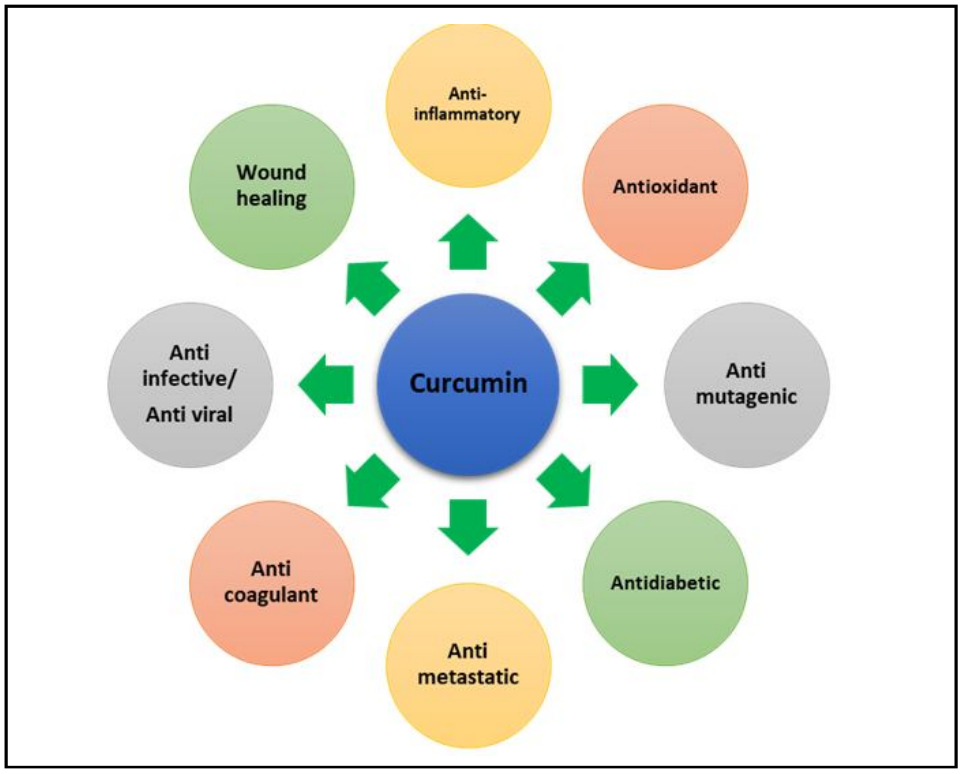


Figure 3: Pharmacological properties of curcumins.

10.4 Root regeneration

Roots are formed after shoot multiplication. It needs different nutrient requirements in the medium. Researchers used different cultural mediums for root formation. The root is inducted from sprouted rhizome bud in the medium containing 0.1 mg/l NAA with 95% regeneration (Salvi *et al*., 2000). Nayak (2000) used 5 mg/l as optimum for rooting. Rooted shoots were produced from the rhizome bud under the rooting medium of MS with 0.5 mg/l IAA (Hazare *et al*., 2005); ½ MS + 2 mg/l IBA with 86% regeneration (Arghya *et al*., 2013), and MS + 3 µM IBA with 89.76% regeneration (Shahinozzaman *et al*., 2013). The medium with 1/2 MS and 2 mg/l IBA (Sinchana *et al*., 2020) and 1/2 MS with 2 mg/l NAA (Behera *et al*., 2010) were used as rooting medium with a survival capacity of 91.17% for rooting from sprouted rhizome bud (Sinchana *et al*., 2020). Even roots can be produced from the rhizome as an explant and the culturing medium was MS with 0.1 mg/l BAP and 0.1 mg /l NAA (Taghavi *et al*., 2021) and ½ MS with 2.68 µM NAA (Das *et al*., 2010) with regeneration capacity of 97% and 80% respectively. Mostly auxin plays a major role in rooting and it is available in various forms mainly used ones are NAA and IBA. The highest survival capacity was observed when the medium contains both auxin and cytokinin (Table 4).

10.5 Indirect organogenesis

Indirect organogenesis is the pathway of complete plant regeneration after callus induction from the explant. A callus is an unorganized mass of proliferating parenchymatous cells. Callus induction was done from the rhizome bud explant in the medium of Linsemaier skoog basal medium (LSBM) contains 3 mg/l of 2,4-D 3 mg/l with a survival capacity of 95% (Roopadharshini, 2010). Zapata *et al*. (2003) used the basal part of the stem as an explant for callus induction and the culturing medium was 1.5 mg/l of 2,4-D 1 and 0.2 mg/l BAP. Even leaf sheath was used as an explant because rhizome acts as an inoculum for soil-borne pathogens. For callus formation, medium with MS + 9 µM 2,4-D and MS + 8.88 µM BA + 2.7 µM NAA

were utilized for multiple shoot formation (Prakash *et al*., 2004). Here 2,4-D is important for callus induction and the availability of explants is more because any part can be used as explants (Table 4).

10.6 Somatic embryogenesis

Somatic embryos are formed from the explant under *in vitro* conditions. Soundar Raju *et al*. (2015) have done direct somatic embryogenesis. Primary embryos were produced from the leaf base explant under the medium containing MS + 1.32 µM BA with 91.1% survival. Secondary somatic embryos were formed with the addition of 2.64 µM BA. When, the medium was added with gibberellic acid under dark conditions produced maximum plantlet with 87% regeneration capacity. The aerial stem was cut into two halves vertically in 0.5 cm size then it was cultured in the medium MS +2 mg/l BAP for direct somatic embryogenesis (Upendri and Seran., 2020). BA and BAP are important for the production of somatic embryos. Cytokinin plays a major role in somatic embryogenesis (Table 4).

10.7 Microrhizome production

First, multiple shoots were produced from the sprouted buds as explant through a multiple shoot elongation medium. After that, it was cultured in ½ MS + 80 g/l sucrose under dark conditions at 25 ± 1°C for microrhizome production. Microrhizome is produced in the size of 0.1-2.0 g which produces more plantlets rapidly under *in vitro* conditions. Microrhizome production is inhibited by supplementation of BAP (Shirgurkar *et al*., 2001). Microrhizome was produced in the medium MS containing 5 mg/l BA (Nayak, 2000). Sprouted axillary bud produced multiple shoots in the shooting medium. Then, the shoots were cultured in the medium MS containing 12.0 µM BA and 0.3 µM NAA for microrhizome formation (Islam *et al*., 2004). Hashemy *et al*. (2009) used Kinetin in high concentration for the formation of microrhizome in the callus. In general, BA and sucrose gave good results for microrhizome production (Table 4).

11. Conclusion

In this review, we discussed about the botanical features, nutritional value, photochemistry, and pharmacological properties of turmeric extracts, essential oil, and its active chemical components. It also contains essential minerals, vitamins (Vit-B6), protein, dietary fiber, and carbohydrates. *C. longa* has been associated with a variety of biological activities since ancient periods. Turmeric rhizome contains several biologically active compounds that play an essential role in their medicinal and nutraceutical uses. Additionally, the plant has a variety of potential pharmacological activities against several diseases and disorders.

Conflicts of interest

The authors declare no conflicts of interest relevant to this article.

References

Adinew, B. (2012). Phytochemistry of turmeric: An overview. Chem., **21**:888-897.

Ahmad, W.; A. Hassan.; A. Ansari. and Tarannum, T. (2010). *Cucurma longa* L. a review. Hippocratic J. Unani Med., **5**:179-190.

Akram, M. (2010). *Curcuma longa* and curcumin: A review, Rom. J. Biol. Plant Biol. Bucharest., **55**(2):65-70.

Ali, A.; Munawar, A. and Siddiqui, F.A. (2004). *In vitro* propagation of turmeric (*Curcuma longa* L.). Int. J. Biol.Biotechnol., (Pakistan) **1**:511-518.

Allen, P.C.; Danforth, H.D.; Augustine, P.C. (1998). Dietary modulation of avian coccidiosis. Int. J. Parasitol., **28**:1131-1140.

Araujo, C.A.C. and Leon, L.L. (2001). Biological activities of *Curcuma longa* L. Mem. Inst .Oswaldo. Cruz. Rio de Janeiro, **96**:723-728

Arghya, G.; Padma, C. and Parthadeb, G. (2013). A protocol for rapid propagation of genetically true to type Indian turmeric (*Curcuma longa* L.) through *in vitro* culture technique. Adv. Appl. Sci. Res., **4**(3):39-45.

Arutselvi, R.; Balasaravanan, T.; Ponmurugan, P.; Saranji, N.M and Suresh, P. (2012). Phytochemical screening and comparative study of antimicrobial activity of leaves and rhizomes of turmeric varieties. Asian J. Plant Sci. Res., **2**:212-219.

Balaji, S. and Chempakam, B. (2010). Toxicity prediction of compounds from turmeric (*Curcuma longa* L). Food Chem. Toxicol., **48**:2951.

Balakrishnan, K.V. (2007). Postharvest technology and processing of turmeric. In: Ravindran P. N, Nirmal Babu K, Sivaraman K, editors. Turmeric: The Genus Curcuma. Boca Raton, FL: CRC Press; 193-256.

Bandara, M.M.N.T.; Dahanayake, N.; Subasinghe, S. and Perera, P.C.D. (2021). A review on *in vitro* propagation of turmeric (*Curcuma longa* Ln.). J. Uni. Ruhuna., **9**(1):39-46.

Behera, K.K.; Pani, D. and Sation, S. (2010). Effect of plant growth regulator on *in vitro* multiplication of turmeric (*Curcuma longa* L. cv. Ranga), Int. J. Biol. Technol., **1**(1):16-23.

Betancor-Fernández, A.; Pérez-Gálvez, A.; Sies, H. and Stahl, W. (2003). Screening pharmaceutical preparations containing extracts of turmeric rhizome, artichoke leaf, devil's claw root and garlic or salmon oil for antioxidant capacity. J. Pharm. Pharmacol., **55**(7):981-986.

Bharalee, R.; Das, A. and Kalita, M.C. (2005). *In vitro* clonal propagation of Curcuma caesia Roxb and *Curcuma zedoaria* Rosc. from rhizome bud explants. J. Plant Biochem, Biotechnol., **14**(1):61-63

Bundy, R.; Walker, A.F.; Middleton, R.W. and Booth, J. (2004). Turmeric extract may improve irritable bowel syndrome symptomology in otherwise healthy adults: A pilot study. J. Altern Complement Med., **1**:1015-1018.

Chattopadhyay, I.; Biswas, K.; Bandyopadhyay, U. and Banerjee R.K. (2004). Turmeric and curcumin: Biological actions and medicinal applications. Curr. Sci., **87**:44-53.

Chin, P.; Huebbe, J.; Frank, G.; Rimbach, H. and Pallauf, K. (2014). Curcumin may impair iron status when fed to mice for six months. Redox Biol., **2**:563-569.

Chinenye, S. and Young, E. (2011). Diabetes Care in Nigeria. Nigerian Health J., **11**(4):101-106.

Chuengsamarn, S.; Rattanamaongkolgul, S.; Luechapudiporn, R.; Phisalaphong, C. and Jirawatnotai, S. (2012). Curcumin extract for prevention of type 2 diabetes. Diabetes Care., **35**(11):2121-2127

Cronin, J.R. (2003). Curcumin: Old spice is a new medicine. J. Alt. Compl. Ther., **9**(1):34-8.

Das, A.; Kesari, V. and Rangan, L. (2010). Plant regeneration in Curcuma species and assessment of genetic stability of regenerated plants. Biol Plant., **54**(3):423-429.

Davis, J.M.; Murphy, E.A.; Carmichael, M.D.; Zielinski, M.R.; Groschwitz, C.M.; Brown, A.S; Gangemi, J.D.; Ghaffar, A. and Mayer, E.P. (2007). Curcumin effects on inflammation and performance recovery following

eccentric exercise-induced muscle damage. Am. J. Physiol. Regul. Integr. Comp. Physiol., **292**:2168-2173.

Dikshit, M.; Rastogi, L.; Shukla, R. and Srimal, R.C.(1995). Prevention of ischaemia induced biochemical changes by curcumin and quinidine in the cat heart. Indian J. Med. Res., **101**:31-35.

Duraisami, R.; Sengottuvelu, S.; Prabha, T.; Sabbani, S.; Divya Presenna, S. and Muralitharan, C.K. (2021). Evaluation of antidiabetic efficacy potency of polyherbal formulations in experimentally induced hyperglycemic rats. Ann. Phytomed., **10**(2):286-291.

Farombi, E.O.; Akanni, O.O. and Emerole, G.O. (2002). Antioxidative and scavenging activities of kolaviron *in vitro*. Pharm. Biol., **40**:107-116.

Goud, V. K.; Polasa, K. and Krishnaswamy K. (1993). Effect of turmeric on xenobiotic metabolising enzymes. Plant Foods Hum. Nutr., **44**:87-92.

Goyal, A.K.; Ganguly, K.; Mishra, T. and Sen, A. (2010). *In vitro* multiplication of *Curcuma longa* Linn.: An important medicinal zingiber. NBU J. Plant Sci., **4**:21-24.

Hashemy, T.; Maki, H.; Yamada, Y.; Kaneko, T.S. and Syono, K. (2009). Effects of light and cytokinin on *in vitro* micropropagation and microrhizome production in turmeric (*Curcuma longa* L.). Plant Biotechnol., **26**(2):237-242.

Hazare, S.T.; Karnewar, S.D.; Khedkar, C.D. and Pawar, V.N. (2005). *In vitro* micropropagation and regeneration of turmeric. J. Soils and Crops., **15**(2):304-307.

Hooker, J.D. (1894). The Flora of British India, Vol. VI. L. Reeve and Co., London, 792.

Himangshu, B.; Jadav, S.; Pritam, M.; Sanjib, K.; Probodh, B.; Pankaj, D.; Durlav, P.B.; Jakir, H. and Shantanu, T. (2021). Evaluation of cytotoxicity of *Azadirachta indica* A. Juss., *Curcuma longa* L. and *Ocimum sanctum* L. in BHK-21 cell line. Ann. Phytomed., **10**(2):182-186.

Hutchinson, J. (1934). Families of Flowering Plants II Monocotyledons. Oxford University Press, London, pp:243.

Islam, M.A.; Kloppstech, K. and Jacobsen, H.J. (2004). Efficient procedure for *in vitro* microrhizome induction in *Curcuma longa* L.(Zingiberaceae): A medicinal plant of tropical Asia. Plant Tissue Cult., **14**(2):123-134.

Khanna, N. M. (1999). Turmeric: Nature's Precious Gift." Current Sci., **76(**10):1351-56.

Khattak, S.; Saeed U.R. R.; Ullah Shah, H.; Ahmad, W. and Ahmad M. (2005). Biological effects of indigenous medicinal plants *Curcuma longa* and Alpinia galanga. Fitoterapia, **76**(2):254-7.

Kinouchi, M.; Aihara, F.; Fujinaka, Y.; Yoshida, S.; Ooguro, Y.; Kurahashi, K.; Kondo, T.; Aki, N.; Kuroda, D.; Endo, I.; Matsushisa, M. and Matsumoto, T. (2014). Diabetic conditions differentially affect the endothelial function, arterial stiffness and carotid atherosclerosis. J. Atherosclerosis. Thrombosis., **21**(5): 486-500.

Kulkarni, S.K. and Dhir A.(2010). An overview of curcumin in neurological disorders. Indian J. Pharm. Sci., **72**(2):149-54

Kumar, A.; Singh, A.K.; Kaushik, M.S.; Mishra, S.K.; Raj, P.; Singh, P.K. and Pandey, K.D. (2017). Interaction of turmeric (*Curcuma longa* L.) with beneficial microbes: A review. Biotech., **7**(6):1-8.

Lee, S.L., Huang. W.J, Lin, W.W, Lee, S.S and Chen, C.H. (2005). Preparation and anti-inflammatory activities of diarylheptanoid and diarylheptylamineanalogs. Bioorganic. Med. Chem., 13:6175-6181.

Leela, N.K.; Tava, A.; Shaf, P.M.; John, S.P. and Chempakam, B. (2002). Chemical composition of essential oils of turmeric (*Curcuma longa* L.). Acta Pharma., **52**:137-141.

Linnaeus, C. (1753). Species Plantarum. Ray Society Facsimile, London, pp:523.

Louay, L. (2014). Medicinal and pharmacological properties of Turmeric (Curcuma longa)., Pharm Biomed Sci., **5**(1):17-23.

Menon V.P. and Sudheer A.R. (2007). Antioxidant and anti-inflammatory properties of curcumin, Adv. Eep. Med. Biol., **595**:105-125.

Mortellini, R.; Foresti, R.; Bassi, R. and Green C.J. (2000). An antioxidant and anti-inflammatory agent, induces heme oxygenase-1 and protects endothelial cells against oxidative stress. Free Radic. Biol. Med., **28:**1303-12

Nasirujjaman, K..; Uddin, M.S.; Zaman, S. and Reza, M.A. (2005). Micropropagation of turmeric (*Curcuma longa* Linn.) through *in vitro* rhizome bud culture. J. Biol. Sci., **5**(4):490-492.

Nasri H.; Shinfard N.; Rafieian M.; Rafieian S. and Shirzad M. (2014). Turmeric-A spice with multifunctional medicinal properties, J. Herb. Med. Pharmacol., **3**(1):5-8

Nayak, S., (2000). *In vitro* multiplication and microrhizomeinduction in Curcuma aromatica Salisb. Plant Growth Regul., **32**(1):41-47.

Naz, S.; Ilyas, S.; Javad, S. and Ali, A. (2009). *In vitro* clonal multiplication and acclimatization of different varieties of turmeric (*Curcuma longa* L.). Pak. J. Bot., **41(**6):2807-2816.

Niranjan, A.; Prakash, D.; Tewari, S.K.; Pande, A.; Pushpangadan, P. (2003). Chemistry of species of Curcuma cultivated on sodic soil. J. Med. Aromatic Plant Sci., **25**:69-75.

Nishiyama, T.; Mae, T.; Kishida, H.; Tsukagawa, M,; Mimaki, Y.; Kuroda M. (2005). Curcuminoids and sesquiterpenoids in turmeric (*Curcuma longa* L.) suppress an increase in blood glucose level in type 2 diabetic KK-Ay mice. J. Agric. Food Chem. **53**(4):959-63.

Nwankwo, C. (2014). Nutritional composition of turmeric (*Curcuma longa*) and its antimicrobial properties. Int. J. Sci. Eng. Res., **5**:1085-1089.

Okamoto, T.; Yamagishi, S.; Inagaki, Y.; Amano, S.; Koga, K. and Abe R. (2002). Angiogenesis induced by advanced glycation end products and its prevention by cerivastatin. Faseb J. **16**(14):1928-1930.

Okwu, D.E. and Josiah, C (2006). Evaluation of the chemical composition of two Nigeria medicinal plants. African J. Biotechnol., **5**(4):357 -361.

Park, E.J.; Jeon, C.H.; Ko, G.; Kim, J. and D.H. Sohn. (200). Protective effect of curcumin in rat liver injury induced by carbon tetrachloride. J Pharm. Pharmacol, **52**:437-40.

Pathak,S.; Patra,B.C. and Mahapatra, K.C.(1960). Flowering behavior and anthesis in *Curcuma longa*. Curr.Sci., **29:**402.

Pawar, M.A.; Patil, S.S. and Nagrik, D.M. (2015). Phytochemical and physicochemical investigation of *Curcuma longa* Linn. rhizome. Int. J. Chem. Phys. Sci., **4**:458-463.

Prakash, S.; Elangomathavan, R.; Seshadri, S.; Kathiravan, K. and Ignacimuthu, S. (2004). Efficient regeneration of *Curcuma amada* Roxb. plantlets from rhizome and leaf sheath explants. Plant Cell, Tiss. Organ Cult., **78**(2):159-165.

Prasad, S. and Aggarwal, B. (2011). Turmeric, the golden spice from traditional medicine to modern medicine. In: Benzie, I.F.F. and Wachtel-Galor, S., Eds., Herbal Medicine, Biomolecular and Clinical Aspects, 2nd Edition, CRC Press, Boca Raton, pp:1-26.

Prasath, D.; Kandiannan, K.; Leela, N.K.; Aarthi, S.; Sasikumar, B. and Babu, K.N. (2018). Turmeric: Botany and production practices. Hort. Rev., **46**:99-184.

Prathanturarug, S.; Soonthornchareonnon, N.; Chuakul, W.; Phaidee, Y. and Saralamp, P. (2003). High-frequency shoot multiplication in *Curcuma longa* L. using thidiazuron. Plant Cell Rep., **21**(11):1054-1059.

Prathanturarug, S.; Soonthornchareonnon, N.; Chuakul, W.; Phaidee, Y. and Saralamp, P. (2005). Rapid micropropagation of *Curcuma longa* using bud explants pre-cultured in thidiazuron-supplemented liquid medium. Plant Cell, Tiss. Organ Cult., **80**(3):347-351.

Rahman, M.M.; Amin, M.N.; Jahan, H.S. and Ahmed, R. (2004). *In vitro* regeneration of plantlets of *Curcuma longa* Linn. A valuable spice plant in Bangladesh. Asian J. Plant Sci., **3**(3):306-309.

Raihana, R.; Faridah, Q.Z.; Julia, A.A.; Abdelmageed, A.H.A. and Kadir, M.A. (2011). *In vitro* culture of *Curcuma mangga* from rhizome bud. J Med. Plants Res., **5**(28):6418-6422.

Rajagopal, K.; .Varakumar, A.; Baliwada, G. and Byran, A. (2020). Activity of phytochemical constituents of *Curcuma longa* (turmeric) and *Andrographis paniculata* against coronavirus (COVID-19): An *in silico* approach. Fut. J. Pharm Sci., **6**(1):104.

Rajakrishnan, V.; Menon ,V.P. and Rajashekaran, K.N. (1998). Protective role of curcumin in ethanol toxicity. Phyto. Res., **12**:55-56.

Rao, A.M.; Jagadeeshwar, R. and Sivaraman, K. (2006). Turmeric. In: Ravindran, P.NNirmal Babu,K.,Shiva, K.N.,Johny,A.K.(Eds.). Adv. Spices Res., **12**:433-492.

Rao, C.V.; Desai, D.; Rivenson, A.; Simi, B.; Amin, S. and Reddy, B.S.(2016). Chemoprevention of colon carcinogenesis by phytochemical evaluation *Curcuma Longa* and Curcumin. Int. J. Pharm. Chem Sci., **5**(4):234-236

Rasmussen, H.B.; Christensen, S.B.; Kvist, L.P and Karazami A. (2000). A simple and efficient separation of the curcumins, the antiprotozoal constituents of *Curcuma longa*. Planta Med., **66**:396-8.

Rathaur, P., Raja, W.; Ramteke, P.W. and John, S.A. (2012). Turmeric: The golden spice of life. Int. J. pharm. Sci. Res., **3**(7):19-87.

Rendle, A.B. (1904). The Classification of Flowering Plants I. Gymnosperms and Monocotyledons. Cambridge University Press, Cambridge, 403.

Ringman, J.M.; Frautschy, S.; Cole, G.M.; Masterman, D.L. and Cummings, J,L. (2005). A potential role of the curry spice curcumin in Alzheimer's disease. Curr. Alzheimer Res., **2**(2):131-6.

Roopadarshini, V. (2010). High frequency shoot multiplication and callus regeneration of turmeric. Int. J. Biotechnol. Biochem., **6**(5):723-734.

Roth, G.N.; Chandra, A. and Nair, M.G. (1998). Noval bioactivities of *Curcuma longa* constituents. J. Nat. Prod., **61**:542-545.

Ruby, J.; Kuttan, G.; Babu, K.D.; Rajashekharan, K.N. and Kuttan, R. (1995). Antitumor and oxidant activity of natural curcuminoids. Cancer Lett., **94:**79-83.

Sahdeo Prasad, B. and Bharat, A. (2011). Turmeric, the golden spice from traditional medicine to modern medicine In: Herbal Medicine: Biomolecular and Clinical Aspects. 2nd edition. Boca Raton (FL): CRC Press/Taylor and Francis. pp:15-23.

Sahu, P.K. (2016). Design, structure activity relationship, cytotoxicity and evaluation of antioxidant activity of curcumin derivatives/ analogues, Eur. J. Med. Chem, **121**:510-516.

Salvi, N.D.; George, L. and Eapen, S. (2000). Direct regeneration of shoots from immature inflorescence cultures of turmeric. Plant Cell, Tiss. Organ Cult., **62**(3):235-238.

Salvi, N.D.; George, L. and Eapen, S. (2002). Micropropagation and field evaluation of micropropagated plants of turmeric. Plant Cell, Tiss. Organ Cult., **68**(2):143-151.

Saxena, M.; Saxena, J.; Nema, R.; Singh, D. and Gupta, A. (2013). Phytochemistry of medicinal plants. J. Pharm. Phytochem., **1**(6):231-235

Sayantani Chanda, T.V. and Ramachandra, M. (2019). Phytochemical and Pharmacological Importance of Turmeric (*Curcuma longa*): A Review. Research and Reviews: A Journal of Pharmacol., **9**(1):16-23.

Schonbeck, Joan, Frey and Rebecca, (2022). "Turmeric." Gale Encyclopedia of Alternative Medicine. Encyclopedia.com. 2 Jun.

Seran, T.H. (2013). *In vitro* propagation of ginger (*Zingiber officinale* Rosc.) through direct organogenesis: A review. Pak. J. Biol. Sci., **16**:1826-1835.

Shahinozzaman, M.; Ferdous, M.; Faruq, M.; Azad, M. and Amin, M. (2013). Micropropagation of black turmeric (*Curcuma caesia* Roxb.) through *in vitro* culture of rhizome bud explants. J. Central Eur. Agricult., **14**(3)213-225.

Sharifi-Rad, J.; Rayess, Y.E.; Rizk, A.A.; Sadaka, C.; Zgheib, R.; Zam, W.; Sestito, S.; Rapposelli, S,; Neffe-Skociñska, K.; Zieliñska, D.; Salehi, B,; Setzer, W.N.; Dosoky, N.S.; Taheri, Y.; Beyrouthy, M.; Martorell, M.; Ostrander, E.A; Suleria, H.A.R.; Cho, W.C.; Maroyi, A. and Martins N. (2020). Turmeric and its major compound curcumin on health: Bioactive effects and safety profiles for food, pharmaceutical, biotechnological and medicinal applications. Front. Pharmacol., **11**:01021

Sharma, S.K.; Mamta, S.; Singh, A.K.; Vishal, R. and Lal, A.M. (2012). *In vitro* protocol standardization for turmeric multiplication in Jammu Division. Asian J Hort., **7**(1):151-153.

Shirgurkar, M.V.; John, C.K. and Nadgauda, R.S. (2001). Factors affecting *in vitro* microrhizome production in turmeric. Plant Cell, Tiss. Organ Cult., **64**(1);5-11.

Shrishail, D.; Ravichandra,H.K.H.; Tulsianand, G. and Shruthi, S.D. (2013). Turmeric: Nature's precious medicine, Asian J. Pharm. Clinical Res., **6**:11-16.

Sinchana, N.S.; Kattimani, K.N.; Prabhuling, G.; Sudesh, K. and Jagadeesha, N. (2020). Standardization of tissue culture protocol for turmeric (*Curcuma longa* L.) Cv. Salem. Int. J Chem Stu., **8**(1):2721-2726.

Singh, S.; Kuanar, A.; Mohanty, S.; Subudhi, E. and Nayak, S. (2011). Evaluation of phytomedicinal yield potential and molecular profiling of micropropagated and conventionally grown turmeric (*Curcuma longa* L.). Plant Cell, Tiss. Organ Cult., **104**(2):263-269.

Sotanaphun, U.; Phattanawasin, P. and L. Sriphong. (2009). Application of Scion image software to the simultaneous determination of curcuminoids in turmeric (*Curcuma longa*). Phytochem. Anal., **20**(1):19-23.

Soudamini, K.K. and Kuttan R. (1989). Inhibition of chemical carcinogenesis by curcumin, J. Ethnopharmacol., **27**(1):227-233.

Soundar Raju, C.; Aslam, A. and Shajahan, A. (2015). High-efficiency direct somatic embryogenesis and plant regeneration from leaf base explants of turmeric (*Curcuma longa* L.). Plant Cell, Tiss. Organ Cult., **122**(1):79-87.

Sri Bhuvaneswari, S.; Prabha, T.; Sameema Begum, S.; Sivakumar, T.; Saranraj, P.; Manivannan, V. and Ashok Kumar, B. (2021). Formulation and evaluation, comparison of herbal hair dye with marketed formulation. Ann. Phytomed., **10**(2):175-181.

Srimal, R.C. and Dhawan, B.N. (1973). Pharmacology of diferuloyl methane (curcumin), a non-steroidal anti-inflammatory agent. The J. Pharm. Pharmacol., **25**(6):447-452.

Taghavi, T.; Rahemi, A.; Rafie, R. and Kering, M.K. (2021). Optimizing turmeric tissue culture, testing different media and a plant growth regulator matrix. Hort. Technol., **31**(6):692-704.

Udomdee, W., Fukai, S. and da Sliva, L.A. (2007). Curcuma: Studies on tissue culture, pollen germination and viability, history and flow cytometry. propag. Ornam. Plants., **3**(1):34-41.

Upendri, H.F.L. and Seran, T.H. (2020). Effect of explants and low cost medium on morphogenic response of aerial stem and rhizome bud explants of turmeric (*Curcuma longa* L.) for plant regeneration. J. Hort. Plant Res., **1**: 15-24.

Valeton, T.H. (1918). New Notes on Zingiberaceae of Java and Malaya. Bulletin du Jardin Botanique de Buitenzorg., **2**:1-8.

Vogel, A. and Pelletier, J. (1815). Examen chimique de la racine de Curcuma. J. Pharm., **1**:289-300.

Yadav, D.; Yadav, S.K.; Khar, R.K.; Mujeeb, M. and Akhtar, M. (2013). Turmeric (*Curcuma longa* L.): A promising spice for phytochemical and pharmacological activities. Int. J. Green P., **7**:85-89.

Yallapu, M.M.; Nagesh, P.K.; Jaggi, M. and Chauhan SC. (2015). Therapeutic Applications of Curcumin Nanoformulations. AAPS J., **17**(6):1341-1356

Yamamoto, H.; Mizutami, T. and Nomura, H. (1997). Inhibitory effects of curcumin on mammalian phospholipase D activity. FEBS Lett. **417**:196-198

Ye, J. and Zhang, Y. (2012). Curcumin protects against intracellular amyloid toxicity in rat primary neurons. Int. J. Clin. Exp. Med., **5**:44-49

Zapata, E.V.; Morales, G.S.; Lauzardo, A.N.H.; Bonfil, B.M.; Tapia, G.T.; Sánchez, A.D.J.; Valle, M.V.D. and Aparicio, A.J. (2003). *In vitro* regeneration and acclimatization of plants of turmeric (*Curcuma longa* L.) in a hydroponic system. Biotecnol. Appl., **20**(1):25-31.

Citation **P. Sivakumar, S. Monisha, K.S. Vijai Selvaraj, M. Chitra, T. Prabha, M. Santhakumar, A. Bharathi, and A.Velayutham (2022). Nutritional value, phytochemistry, pharmacological, and in vitro regeneration of turmeric (*Curcuma longa* L.): an updated review. Ann. Phytomed., 11(1):236-246. http://dx.doi.org/10.54085/ap.2022.11.1.23.**