Soorya, V. “Studies on variability, character association and improvement of Curcuma aeruginosa roxb. (Travancore starch plant)”, Thesis, Department of Botany, University of Calicut, 2017.
2.1. The family Zingiberaceae

Zingiberaceae or the ginger family is a family of advanced monocot plants with very high ethno-medicinal potentials (Choudhury et al., 2013). The family forms the largest among the order Zingiberales with about 53 genera and 1200 species distributed mostly in tropical and subtropical regions with South East Asia being the major centre of distribution (Srirurgsa, 1997; Kress et al., 2002; Sabu, 2006). Malaysian region is characterized by both species and genus abundance. They form the ground flora of tropical forests and most of them grow in damp and humid shady places. India is occupied by 18 genera and 120 species as per Sirirugsa (1997). Sabu (2006) has reported 21 genera and 200 species from India and among them 10 genera and 65 species are present in South India.

Zingiberacean members are annual or perennial rhizomatous herbs. The plants perennate by means of the sympodial, fleshy, elongated or tuberous rhizomes. Most of them are terrestrial, but rare occurrence of epiphytic species has also been noticed (Sabu, 2006).

In Zingiberaceae, the rhizomes may be small, medium or large in size which is usually fleshy or rarely hard. The rhizomes show wide range of colour variation which may be shades of yellow, orange, orange yellow, deep blue, grey, blue, pink or white. The young rhizome and axillary buds are covered and protected by scale leaves. Sessile tubers if present are branched, condensed or elongated and the tips ending in an erect leaf bearing shoot or in a flower bearing shoot. Roots may be fleshy or fibrous sometimes ending in root tubers. These root tubers are
small, ovoid or elliptic, rarely long with watery pearl white inside (Sabu, 2006; Jayasree and Sabu, 2013).

True aerial stems with nodes and internodes are present in *Alpinia, Amomum, Elettaria, Globba, Hedychium and Zingiber*. It is very short or absent in *Alpinia* and fleshy in *Zingiber*. Aerial stem with hard and woody nature is seen in some genera like *Alpinia, Amomum, Elettaria, Hedychium*, etc. In the genus *Curcuma*, clasping of the leaf sheaths results in pseudostem (Jayasree and Sabu, 2013).

Members of Zingiberaceae show wide range of morphological variations with regard to the structure, shape, size, texture and venation pattern of leaves. Leaves are usually distichous and the leaves possess short stalks and sheathing bases. The sheaths are either encircling the stem or they themselves form a pseudostem. Lamina is elliptic to oblongate-lanceolate or circular, variegated sometimes, glabrous or pubescent and it remains convoluted in the bud. Short or long ligules are seen and in *Zingiber* and *Amomum* the ligules are up to 5cm in length (Pandey, 1997; Sabu, 2006).

Inflorescence is terminal or lateral in this family. In some species both terminal and lateral inflorescences can be observed in different seasons. The erect or pendulous inflorescences have short or long peduncles covered by sheaths. Condensed or elongated spikes could be coloured or white. Sterile bracts called comma bracts are seen at the tip of the spikes. Fertile bracts are spirally or distichously arranged, free to the base or adnate with each other laterally. They are green or coloured, deciduous or persistent or may be absent. Bracts bear single flower or many flowered cincinni. Bracteoles are present or sometimes absent (Sabu, 2006).
Flowers are bisexual; rarely unisexual flowers are seen on the upper part of the inflorescence. They are zygomorphic, trimerous, large and showy or small, which are less than, equal to or longer than the bracts. Flowers usually open in the morning, but opening during afternoon and in the night has also been reported. It is noticed that in India majority of the species flower during monsoon and rarely during summer. Some species flower throughout the year (Sabu, 2006; Sabu et al., 2011).

Calyx is formed with three sepals united to form a calyx tube which is shorter than the corolla tube or equal to the corolla tube. It may be persistent or deciduous. Corolla is made of three petals; they are fused at the base to form a corolla tube which may be short or long, tubular or funnel shaped and variously coloured which varies from white to yellow, orange, pink or purple. The dorsal lobe is longer and broader than the laterals and is always overlapping the others in the bud and usually with a hood. Lateral lobes are narrower with rounded tip (Sabu, 2006).

Androecium consists of six stamens arranged in two whorls of three each inserted to the throat of the corolla tube. The plants possess only one functional stamen which is the posterior one of the inner whorl, while the other two lateral stamens unite to form the labellum. Of the three stamens of the outer whole anterior one is always suppressed and the others are represented by two lateral staminodes. Labellum or the lip forms the large and most conspicuous attractive part of the flower which is variously coloured- white, pale yellow to deep yellow, purple or violet with strips or spots (Sabu, 2006). Length of the filament varies in different genera. Anthers are dithecous with longitudinal dehiscence. In
most cases anthers are provided with appendages. Some species are
provided with basal extensions of thecae called spur (Sabu, 2006).

Two epigynous glands are seen just above the ovary, which are
rarely absent. The ovary is always inferior, usually trilocular with axile
placentation, unilocular with parietal placentation, or with basal or free
columnar placentation. Style is long and filiform usually as long as the
filament and held within the filament below and between anther thecae
and appendages above. The stigma is usually swollen, bilipped and
fringed with hairs (Sabu, 2006).

Fruit is a dry or fleshy capsule or berry. These are oval, spherical
or rarely cylindrical and most of them are dehiscent. Fruit setting is very
rare in some species. Rare occurrence of fleshy and indehiscent fruits
has also been observed. Dehiscence of the capsule is mostly loculicidal.
Seeds are small and arillate with starchy perisperm and endosperm
(Sabu, 2006; Jayasree and Sabu, 2013).

2.2. Economic importance of the family Zingiberaceae

Zingiberacean members are important natural resources
providing many useful products for food, spices, medicines, dyes,
dyes, perfumes and aesthetics (Sirirugsa, 1997). Many of them are integral
part of our day to day life. The family yields major spices like
cardamom, ginger and turmeric. Many of the species are medicinal and
are used both in ethnomedicine and advanced systems of indigenous
medicine (Kumar et al., 2013).

The rhizome of Alpinia galanga (L.) Wild commonly called as
galangal, greater galangal, Java galangal and siamese ginger has various
medicinal properties. It is thermogenic, nerve tonic, stimulant,
repulsive, carminative, stomachic, bronchodilatory, anti-inflammatory
and disinfectant. It is also used as a spice and the volatile oil extracted has high medicinal potential. Galangal forms the source plant of *rasna*, an ayurvedic drug which is a popular remedy for rheumatism and respiratory ailments. Galangal is also used in cattle medicine (Alice and Asha, 2007). According to Warrier *et al.* (1994a), this plant is useful in the treatment of rheumatic arthritis, cough, bronchitis, asthma, cough, stomachalgia, obesity, diabetes, intermittent fevers, etc. *Alpinia galanga* finds varying uses in ayurvedic preparations such as *Rāsnādi powder* (Kumar *et al*., 2013).

Dried rhizome of *Alpinia officinarum* (Hance.) commonly known as lesser galangal, China root, India root or East India Catarrh root is used as stimulant and carminative. It is also effective in flatulence, dyspepsia, vomiting and stomach sickness and is recommended as a remedy for seasickness. It is sometimes prescribed in fever. In Homoeopathy it is used as a stimulant (Grieve, 1931). The plant contains high concentrations of the flavonol galangin, which is effective to slow down the increase and growth of breast tumor cells (So *et al*., 1996; So *et al*., 1997; Ciolino and Yeh, 1999).

*Amomum subulatum* Roxb., commonly known as large cardamom or Nepal cardamom is widely cultivated in the sub-Himalayan state of Sikkim and adjoining areas. It is used as a spice and it has got medicinal properties also. Dried leathery fruits form the useful part and it resembles cardamom in aroma, flavour and other characters and is a cheap and efficient substitute for small cardamom. It is used for the extraction of volatile oil and spice powder (Sabu, 2006; Nybe, *et al*., 2007).

The rhizome of *Curcuma aeruginosa* Roxb. is used for the extraction of East Indian arrowroot or Travancore starch (Sabu, 2006).
The starch extracted is an efficacious remedy for infantile diarrhoea and is also recommended for children and invalids (Ranjini and Vijayan, 2005).

*Curcuma amada* Roxb. is another member of the ginger family, endemic to South East Asia and commonly known as mango ginger. The rhizome is edible and has the flavour of green mango (Ravindran *et al.*, 2007). The rhizome shows cooling, appetizing, carminative, digestive, stomachic, demulcent, aphrodisiac, laxative, diuretic, expectorant, anti-inflammatory, antipyretic, antirheumatic and astringent activities. It is used in the treatment of vitiated conditions of pitta and in anorexia, dyspepsia, flatulence, diarrhea, colic bruises, wounds, chronic ulcers, skin diseases, fever, constipation, pruritus, cough, bronchitis, sprains, gout, etc. It promotes digestive power and cleans the throat and tongue. It shows specific action in rheumatism and inflammation of liver. Also used for bruises and skin diseases (Warrier *et al.*, 1994b; Joshi, 2000).

*Curcuma angustifolia* Roxb., commonly known as East Indian arrowroot, Bombay arrowroot and narrow leaved turmeric is a member of the family with high medicinal potential. The rhizomes have got nutritive and medicinal properties and hence it is used as an agreeable nonirritating diet in some chronic diseases, in convalescence from fevers and in irritations of alimentary canal, pulmonary system and the urinary apparatus. The starch extracted is suitable as a food for infants (Anonymous, 2012a). It is used to heal peptic ulcers, for the treatment of dysentery and also used as herbal tonic for patients suffering from tuberculosis (Doble *et al.*, 2011).

*Curcuma aromatica* Salisb. popularly known as wild turmeric is widely cultivated in South India. The rhizome is the medicinal part and the medicinal properties are similar to that of *Curcuma longa* and is
used as tonic, appetizer and carminative and is applied externally for scabies and the eruption of small pox. Along with benzoin it is used for headache. Also in combination with astringents and aromatics it is used for bruises, sprains, hiccough, bronchitis, cough, leucoderma and skin eruptions (Joshi, 2000; Parrotta, 2001; Sabu, 2006).

*Curcuma caesia* Roxb., commonly known as black turmeric or black zedoary is a perennial herb with bluish-black rhizome. Rhizomes are used for the treatment of pneumonia, cough and cold in children, and for fever and asthma in adults. It acts as rubefacient (Anonymous, 2015a). The paste prepared from the rhizome is applied in snake and scorpion bite, and a mixture prepared from the dried powder of *Curcuma caesia* rhizome and powdered seeds of *Andrographis paniculata* is used for insect and snake bite by the Khamti tribes of Lohi district of Arunachal Pradesh (Tag et al., 2007). The use of fresh rhizomes in leprosy, cancer, gonorrheal discharge and epilepsy and as anthelmintic, aphrodisiac, etc. has been reported by Arulmozhi *et al.* (2006). The paste made from the rhizome is applied on the injured region to control bleeding and for quick healing (Trivedi, 2003).

*Curcuma longa* L. or the turmeric of commerce is regarded as the “golden spice” as well as the “spice of life”. India has considered the plant as medicinal and sacred from time immemorial. The rhizomes are orange yellow in colour and the plant is considered as the “herb of the sun” by the people of Vedic period. Ancient people praised it as oushadhi, the healing herb which possess a higher rank with respect to its medicinal values (Jagar, 1997). In English it is known as yellow root and Indian saffron (Ravindran, 2007). The rhizomes are strongly aromatic, pungent, bitter, laxative, carminative, anthelmintic and diuretic. Rhizome is a rich source of curcumin, widely used in Indian
cuisine as well as in traditional medicine. It has strong antiseptic properties and is used to treat poisonous affections, ulcers and wounds. It is a blood purifier. Ayurveda regards it as an alternative antiperiodic, germicidal, carminative, stimulant, tonic and vermifuge. Rhizome is used to cure cold, cough, purulent ophthalmia and conjunctivitis, bronchitis and liver affections. Paste prepared from the flowers is used externally to treat ring worm and other parasitic skin diseases and also for gonorrhea. Oral administration of rhizome powder gives relief from asthma and cough. Turmeric has got anti-inflammatory, hypocholesteremic, choleric, antimicrobial, insect repellent, anti-rheumatic, anti-fibrotic, anti-venomous, anti-diabetic, anti-viral, anti-hepatotoxic as well as anti-cancerous properties and the oil from turmeric is used in aroma therapy and perfume industry. It is used in the treatment of small pox, chicken pox, ring worm and other parasitic skin diseases, piles, common cold, catarrh, coryza and hysterical fits. It relieves pain in scorpion sting, chronic otorrhoea, reduces indolent swelling, and is used in the treatment of urinary diseases, leucoderma, diseases of blood, bad taste in mouth, elephantiasis, diarrhoea, bronchitis, vertigo and gonorrhoea (Sopher 1964; Kritikar and Basu 1984; Joshi, 2000; Parrotta, 2001; Nadkarni, 2005; Jankasem et al., 2013).

*Curcuma zanthorrhiza* Roxb., commonly known as Temulawak, Java ginger and Javanese ginger is used as a stomachic in ayurveda. The rhizome is applied to bruises and sprains. A decoction of the rhizome with long pepper, cinnamon and honey is effective for cold (Sabu, 2006).

*Curcuma zedoaria* Rosc., known as zedoary, white turmeric or kentju is stimulant, diuretic, carminative, expectorant and rubefacient. The roots are cooling and diuretic. A decoction of the
rhizome prepared along with pepper, cinnamon and honey is used in cold (Joshi, 2000; Anonymous, 2015b). Fresh roots of zedoary are used for blood purification. Rhizome is a source of “Shoti starch” which is used as a baby food and also used by convalescents recovering from chronic stomatitis. The powdered zedoary has antiallergant activity. The effect of zedoary is similar to ginger but milder (Khare, 2007).

*Elettaria cardamomum* (L.) Maton., Trans. (small cardamom) is popularly known as “Queen of Spices”. The dried capsule of this tall perennial herbaceous shade loving plant forms the cardamom of commerce. It is indigenous to the Western Ghats of South India. It is used in bakery and confectionary and also is medicinally important. It is used as an aromatic stimulant, carminative and antioxidant. It forms an essential ingredient of digestive stimulants and is used in medicinal preparations employed for indigestion and flatulence (Nybe *et al.*, 2007).

*Hedychium spicatum* Ham. ex Smith, commonly known as spiked ginger lily is also medicinally important. The root stock is acrid, bitter and pungent and is effective in inflammations, asthma, pains, foul breath, bronchitis, hiccough, vomiting and diseases of blood. It forms a laxative tonic to brain and is good in liver complaints. Rhizome acts as stomachic, carminative, stimulant and tonic and is used in dyspepsia and also has antimicrobial, anthelmintic and insect repellent properties (Joshi, 2000; Khare, 2007).

The rhizome of *Hedychium coronarium* Koenig, also called ginger lilly, is used as a febrifuge and a decoction from rhizome is regarded as anti-rheumatic, tonic and excitant. A paste of rhizome and leaf is applied on the forehead to relieve headache and to the body to treat swellings. It also has anti-inflammatory, anti-rheumatic and
tranquilizing properties. The juice obtained from the crushed roots is used as an eye wash to relieve redness, swollen eye, pain and excessive excretion by the Baigas of North Eastern Madhya Pradesh (Parrotta, 2001; Khare, 2007).

*Kaempferia galanga* Linn. is known as black thorn in English. The rhizome is medicinal and has stomachic, anti-inflammatory, stimulating, expectorant, carminative and diuretic properties. The paste or powder prepared from it is applied to wounds and bruises to reduce swellings. It also improves complexion and cures burning sensation, mental disorders and insomnia and the decoction is used for dyspepsia, headache and malaria. Roasted rhizomes are useful in rheumatism. It is also used for dandruff and for relieving irritation produced by caterpillars. Leaves are also used in lotions and poultices made for curing sore eyes, sore throat, swellings, rheumatism and fevers (Joshi, 2000).

*Kaempferia rotunda* Linn. known as Indian crocus is an erect herb with tuberous rhizome and all parts of the plant are medicinal. The tubers are useful for tumors, swellings and wounds. Because of its stomachic property it is given in gastric complaints. The juice from tubers is useful in dropsical affections of hands and feet and also in effusions in joints. The toxin benzyl benzoate in its flowers is used to prepare ointments for the treatment of scabies and the oil extracted from the plant is used to treat itches (Joshi, 2000; Anonymous, 2012b). Imam et al. (2013) have reported the wound healing activity of the leaves of this plant.

The rhizome of *Zingiber officinale* Rosc. forms the ginger of commerce and it is perhaps the most widely used spice both for flavouring and medicinal purposes (Nybe et al., 2007). Both dry and
fresh rhizomes are medicinally potent. Rhizome has stimulant and carminative properties when chewed internally and it acts as a sialagogue when chewed. It is applied externally as a rubefacient. Ginger oil is used as a flavourant in pharmaceuticals and also in perfumery (Joshi, 2000; Nybe et al., 2007). It is used as a natural pain reliever in rheumatoid arthritis and osteoarthritis. It is useful in curing ulcers, in preventing heart attack and stroke, in nausea and vomiting and in pregnancy related morning sickness. It is also used as an anti-inflammatory agent (Malhotra and Singh, 2003).

In traditional Indian ayurvedic system of medicine it plays a major role in curing various diseases. Indian traditional remedies for cough and asthma consist of juice of fresh ginger with a little juice of fresh garlic mixed with honey. Ginger is very commonly used to cure various illnesses such as indigestion, loss of appetite, flatulence, nausea, vomiting, allergic reactions, acute and chronic cough, common cold, fever, allergic rhinitis, sinusitis, acute chronic bronchitis, respiratory troubles, pain, headache, backache or any kind of muscular catch, painful tooth and swelled gum (Kumar et al., 2011).

*Zingiber montanum* (K.D. Koenig) Link ex Dietr., known as Cassumunar ginger is native to India. The rhizomes are medicinal and are also used for food flavoring. In tropical Asia the rhizomes are used primarily as a carminative and stimulant for the stomach and against diarrhea and colic. The rhizomes are consumed in Thai traditional medicine to relieve asthma and muscle and joint pain (Bua-in and Paisookantsivatana, 2009). Rhizome is useful in diabetes and it is used as a substitute for *Curcuma longa* by tribals (Sabu, 2006). It also shows anti-ulcer properties (Al-amin et al., 2012).
Many of the members of Zingiberaceae are ornamental and are employed for horticulture purposes. More than 250 species are used widely for various gardening activities including landscaping, private gardening, and commercial production of flowers and as potted plants. Species with high ornamental value include *Alpinia malaccensis* (Burm.f.) Roscoe, *Alpinia purpurata* (Vieill.) K. Schum., *Boesenbergia siphonantha* (Baker) M. Sabu *et al.*, *Curcuma aurantiaca* Zijp., *Curcuma inodora* Blatter J., *Curcuma petiolata* Wall., *Curcuma roscoeana* Roxb., *Etingera elatior* (Jack) R.M.Sm., *Globba schomburgkii* Hook.f., *Larsenianthus careyanus* (Benth.) W.J. Kress & Mood, *Kaempferia elegans* Wall. and *Zingiber zerumbet* (L.) Smith (Sabu *et al*., 2011).

### 2.3. The genus *Curcuma* L.

The genus *Curcuma* L. comprises of around 120 species distributed mostly in tropical Asia, while a few species extend to Australia and South Pacific (Skornickova *et al*., 2004). The genus is believed to have originated from the Indo-Malayan region (Purseglove, 1968) and about 40 species are of Indian origin (Velayudhan *et al*., 1999).

The members of this genus occur in the tropical and subtropical regions, especially in mixed deciduous tropical forests and tropical broad leaved evergreen forests. Geographically it is distributed from India to Thailand, Indochina, Malaysia, Indonesia and Northern Australia (Apavatjrut *et al*., 1999). According to Skornickova *et al.* (2007) and Skornickova *et al.* (2008) the genus is taxonomically very difficult and natural distribution is noticed throughout the southern and South East Asia with limited occurrence in China, Australia and the South Pacific. The highest diversity is observed in India and Thailand,
with about 40 species in each of these regions, followed by Burma, Bangladesh, Indonesia and Vietnam.

The genus name originates from the Arabic word “kurkum” meaning yellow, which refers to the colour of the rhizome or flower (Skornickova and Sabu, 2002). North East India occupies the vast majority of *Curcuma* species and most of them are endemic to this area (Sarma and Kalita, 2005). Many of the species in these regions are facing fear of being endangered because of the ruthless exploitation by the tribes because of its immense medicinal properties and food value (Das et al., 2011).

*Curcuma* exhibits significant morphological variations at both intra-specific and inter-specific levels, but the similarities of some species create problems during their identification. Members could be easily identified from other genera by their inflorescence which is a compound spike with prominent spiral bracts and the adnation of the adjacent bracts laterally or to the peduncle resulting in the formation of a pouch, each bearing a circinnus of 2-10 flowers. The terminal cluster of variously coloured, longest sterile bracts is often called “coma bracts” (Apavatjrut et al., 1999; Sabu, 2006).

The members of the genus are widely used for medicinal purposes, arrowroot production and as colouring agents. Species such as *Curcuma amada, Curcuma zedoaria, Curcuma xanthorrhiza, Curcuma aeruginosa* and *Curcuma petiolata* are cultivated in different regions because of their multipurpose uses (Velayudhan et al., 1999).

**2.4. Curcuma aeruginosa Roxb.**

*Curcuma aeruginosa* Roxb. is an underutilized species with various medicinal properties (Srivastava et al., 2006). It is popularly
known as pink and blue ginger (Anonymous, 2011a). In South India, the rhizomes are widely used for the extraction of East Indian arrowroot or Travancore starch (Sabu, 2006) and therefore the plant gains the name Travancore starch plant, arrowroot wild and East Indian arrowroot. The plant is recognized as temu hitam and temu ireng in Malaysia (Sukari et al., 2007; Lim, 2016) and in Thai as wan-ma-ha-mek and kha-min-dam (Srivilai et al., 2011). In Malayalam it is known as neela kuva (Sabu, 2006) and as mahamek in Hindi (Srivastava et al., 2006). In Bangladesh it has the local name kathali holud (Hossain et al., 2015).

It forms one of the oldest named spices of the genus Curcuma. The striking greenish blue colour of the rhizomes gives the specific epithet “aeruginosa” derived from the word aeruginous, which has a Latin origin meaning “bluish green” (Singh, 2011; Anonymous, 2015c). The plant is one of the most eminently used medicinal plant in Bangladesh, India, Myanmar, Indonesia, Malaysia and Thailand (Hossain et al., 2015). According to Singh (2011) the plant forms one of the esteemed species for extracting arrowroot since it is believed that species with blue coloured rhizomes are of the best value.

2.4.1. Origin and distribution

Curcuma aeruginosa is a native of Myanmar and is widely cultivated in Malaysia (Sabu, 2006). Common occurrence is found throughout South East Asia. In India it grows in West Bengal, Bihar, Coromandel coast and South Karnataka and is fairly common in Kerala (Srivastava et al., 2006). It grows wild in South India and is very common throughout the coastal areas and riverine alluvial soils extending up to the midlands in Kerala and South Karnataka. The plant is seen as common undergrowth in coconut and arecanut groves and as a weed in waste lands in monsoon (Sabu, 2006). It is also found in grassy
places and teak forest at 400m – 740m altitude (Wardini and Prakaso, 2016). According to Sirirugsa et al. (2007), the plant is distributed in India, Indochina, Malaysia, Indonesia, Sri Lanka and Thailand.

2.4.2. Taxonomic hierarchy of *Curcuma aeruginosa* Roxb.


2.4.3. Agronomy

There is not much of published information on the agronomical aspects of *Curcuma aeruginosa*. Cultivation practices of *Curcuma aeruginosa* are almost similar to that of *Curcuma longa*. According to Sabu (2006) *Curcuma aeruginosa* grows well in coastal areas and riverine alluvial soils and in the monsoon the plant occurs as a common undergrowth in coconut and arecanut groves and also as a weed in waste lands.

Recently Lim (2016) documented the agroecology of *Curcuma aeruginosa* and accordingly the plant flourishes best in warm, humid environment of partial or no shade. Though growth is seen in different soil types, it prefers mainly loose, well textured and well drained fertile soils.

2.4.4. Morphology

*Curcuma aeruginosa* is a perennial, semi erect rhizomatous herb. The whole plant is about 70-100cm tall and has weak aromatic odour. Rhizome is large, strongly aromatic, 5-10cm in size, has pink tips and greyish blue or blue centres. The rhizome possesses camphoraceous aroma and bitter taste. Depending on the nature of the soil and age of
the rhizome, it shows variation in blue colour. Pseudostem is 30-35cm tall with green sheaths. Leaves are distichous, 30-40cm x 10-12cm with oblong to lanceolate lamina. Leaves are characterized by purple or reddish brown patches along the sides on the distal half of the midrib on upper side which fades at maturity. Inflorescence is lateral, 25-30cm long, peduncle 12-18cm with large coma bracts, pink to violet, lower ones streaked green. Fertile bracts are 18-20 in number; each bract subtends a circinnus of 8-10 flowers. Flowers are 4.5-5cm long, equal to or slightly shorter than the bracts. Calyx is 3 lobed at the apex and split on one side. Corolla tubes are pink in colour and its lobes are unequal. Labellum is yellow with a deep yellow median band. Anther is 7mm long and yellowish green in colour. Ovary is trilocular with many ovules but fruiting is not common (Sabu, 2006; Sujatha and Renuga, 2013; Anonymous, 2015d). The plant resembles *Curcuma caesia*, black turmeric, except for the rhizome, which has bluish black rhizome (Anonymous, 2011a).

Rajeshkumar (2013) studied the morphological characters of some species of Zingiberaceae including *Curcuma aeruginosa* and also prepared a taxonomic key based on these features. As per the study, in this species the leaf sheath is green and leaf midrib is purple in colour; inflorescence is lateral in position; colour of calyx and corolla is light purple and the rhizomes are blue in the centre and grey towards periphery with camphoraceous aroma and bitter taste.

George and Britto (2015b) have documented morphological characters such as colour, shape, texture, size, taste and odour of the leaf, rhizome, root and flowers of *Curcuma aeruginosa* and *Curcuma amada*. Accordingly *Curcuma aeruginosa* has got thick green leaves which are lanceolate, smooth, 79-100cm in length, bitter and aromatic.
The rhizome is brown, oblong-irregular, rough, 9-10cm, slightly bitter and aromatic. Roots are light brown, long and cylindrical, smooth, 11-12cm, slightly bitter and slightly aromatic. Flowers are yellow, funnel shaped, smooth, 5-6cm, bitter and slightly aromatic.

According to Skornickova et al. (2003), *Curcuma aeruginosa* forms the closest species of *Curcuma codonantha*. They made comparative analysis of these two species. The identification of these species is difficult in the field since both are having similar habit and colouration of flower parts; both have deep yellow labellum and lateral staminodes with pink corolla lobes; both have lateral spikes and both flower at the same time. But they differ in their flowers which in *Curcuma codonantha* are bell shaped and well exerted from fertile bracts but those in *Curcuma aeruginosa* have same size as the fertile bracts and do not extend beyond it; in the rhizome which in *Curcuma codonantha* is inwardly creamy yellowish and inwardly aeruginous in *Curcuma aeruginosa*. A deep purple colour is present along both the sides of the midrib at the distal half of the upper side of the lamina in *Curcuma aeruginosa* which is absent in *Curcuma codonantha*. *Curcuma codonantha* has coma bracts of bright pink colour with darker brownish violet patch at the tips while *Curcuma aeruginosa* has pink or light pink coma bracts without obvious patches at the tips.

### 2.4.5. Anatomy

Jayasree and Sabu (2013) conducted anatomical studies of South Indian Zingiberaceae and also formulated keys based on both anatomical and morphological characters for easy identification. About 51 species and 2 varieties belonging to 9 genera of Zingiberaceae were subjected to anatomical studies and in *Curcuma aeruginosa* they studied transverse sections and epidermal peelings of aerial parts. The adaxial epidermal
cells of inter coastal region were polygonal, longer than broad and those of coastal epidermal region were broader than long. Abaxial coastal epidermal cells are bigger than adaxial coastal cells. Rare occurrence of oil glands was also seen on abaxial epidermis. Trichomes were completely absent on leaf lamina while very minute hairs were present on the abaxial surface of sheath. Stomata were mainly distributed on the abaxial epidermis while very few were seen on the adaxial epidermis. The adaxial and abaxial surfaces of leaf sheaths were U-shaped, bundle arcs I, II and III were present and silica deposits were also seen in some cells surrounding the bundle. Petiole was winged and had U-shaped abaxial and slightly concave adaxial surfaces. It also had bundle arcs I, II and III and showed the presence of oil cells in the ground tissue and silica in cells near to the bundle sheath. The abaxial and adaxial surfaces of the midrib were V-shaped. Midrib showed the presence of bundle arcs I, II and III. Crystals were also present in the ground tissue of the midrib. Leaf lamina of *Curcuma aeruginosa* was found to be of 352μm in thickness. Both the adaxial and abaxial epidermal cells were broader than high but the cells were much smaller in the abaxial epidermis. Both abaxial hypodermis and adaxial hypodermis were also present, of which the cells on the adaxial side were bigger than the epidermal cells while those on the abaxial side were much smaller. The mesophyll was found to be made of 1 or 2 layered palisade tissue and 4-6 layered spongy tissue. Oil cells and single crystal bearing mesophyll cells were also present. A two layered bundle cap connected with the adaxial epidermis was also seen. Leaf margin had broader adaxial epidermis which was as high as broad towards the tip. Both the adaxial hypodermis and abaxial hypodermis were also present in the margin. Mesophyll in this area was represented by one layered palisade tissue and 2 or 3 layered spongy tissue. The sclerenchymatous bundle cap was
not showing any connection with the epidermis. The portion beyond the last bundle was filled by mesophyll and parenchyma cells.

Anatomical studies of *Curcuma aeruginosa* rhizomes were done by Srivastava *et al.* (2006) also. According to them transverse section of the rhizome showed circular outline. Rectangular shaped epidermal cells were provided with thick cuticle and long unicellular trichomes. It was followed by 4-7 layered suberized cork cells interrupted by lysigenous oil glands. A wide cortex with irregularly scattered vascular bundles was present. The vascular bundles were enclosed within prominent fibrous sheaths. Cortex was followed by endodermis and pericycle, which followed the vascular bundles devoid of bundle sheath, arranged in a ring. Schizogenous canals and abundant tannin containing cells with suberized walls were also seen in the central region of cortex. Most of the parenchymatous cells were filled with starch grains, which were oval-ellipsoidal or sometimes polygonal in shape and 10-65µm. Vascular bundles in the central cylinder were similar to those present in the cortex, scattered, closed and collateral.

The presence of paracytic stomata and trichomes with oil cavities in the leaves of *Curcuma aeruginosa* has been shown in the studies of George *et al.* (2014). In their pharmacognostic studies they detected starch grains and spiral, pitted and scalariform xylary elements in the rhizome and also identified phytoconstituents like mucilage, lignin, starch, alkaloids, tannins, calcium oxalate crystals and saponins in the rhizome. Root powder showed the presence of root hairs and starch grains.

2.4.6. Pollination biology

Fruiting is rare in *Curcuma aeruginosa* (Sabu, 2006). According to Skornickova *et al.* (2004) seed setting is absent in many *Curcuma*
species including *Curcuma aeruginosa* and these are propagated vegetatively by rhizome. Aswani and Sabu (2017) investigated the floral biology of *Curcuma aeruginosa* in different locations of Kerala state of India. According to them in this species the inflorescence appears prior to premonsoon showers and flowering commences by the first week of May, attains the peak between the last week of April and the first week of May and decreases in the last week of May. Flowering is followed by vegetative growth which progresses till the end of September. Inflorescence has longevity of 30 days and flowers last for 24 hours. The plant is nectariferous, producing 30.2±2.94µl of nectar per flower from the base of the ovary after anthesis and it gets accumulated at the base of the corolla. Nectar shows a sugar content of 68.1±1.05% dominated by sucrose (77%) and followed by glucose (16%) and fructose (7%). Pollen grains are oval to round in shape and psilate or unsculptured type with a size of 68.16±1.42µm. They have reported that significantly poor pollen viability is the cause of fruitlessness in *Curcuma aeruginosa* and they failed to produce fruits in this species through artificial pollination. The most frequent and efficient pollinator of *Curcuma aeruginosa* is *Amegilla* sp. (Apiceae) and the other effective pollinators include *Apis* spp., *Ceratina* sp. and *Halictus* sp.

### 2.4.7. Cytology

Cytological studies by Ramachandran (1961) have shown that the members of the genus *Curcuma* possess diploid, triploid and tetraploid genomes with a basic set of 21 chromosomes. This high basic chromosome number in *Curcuma* might have been due to dibasic amphidiploidy or by secondary polyploidy (Ramachandran, 1968).

Joseph *et al.* (1999) reported the karyotypes of six *Curcuma* species including *Curcuma aeruginosa* and opined that all of them
possessed very small sized chromosomes with symmetric karyotypes. *Curcuma aeruginosa* was reported to be a triploid with 2n= 63 with a basic set of 21 chromosomes. In *Curcuma aeruginosa* the chromosome length ranged from 0.76-0.30\(\mu\)m and a total chromatin length of 31.7\(\mu\)m was observed (Ramachandran, 1961; Ramachandran, 1968; Joseph *et al.*, 1999).

### 2.4.8. Phytochemistry

The medicinal properties of *Curcuma aeruginosa* have been correlated with various phytochemical constituents contained in it. The rhizome shows a yield of 1.25-1.5kg per plant and the dry matter of the tuber has been reported to be 29.3%. Rhizome contains starch 14.1%, sugar 1.41% and lipids 0.47% (Sujatha and Renuga, 2013; Angel *et al.*, 2013). Physico-chemical analysis of the rhizome revealed that it contains total ash 5.8%, acid insoluble ash 0.56% and water soluble ash 3.96% (George *et al.*, 2014).

George and Britto (2015b) conducted comparative studies regarding the pharmacognostic and phytochemical aspects of *Curcuma aeruginosa* and *Curcuma amada* with the objective of providing an efficient protocol to detect drug adulteration. Aqueous, alcohol and chloroform extracts of rhizome of *Curcuma aeruginosa* showed extractive values of 8.5, 6.2 and 2.5mg respectively. Physico-chemical analysis revealed a total ash of 5.8%, acid insoluble ash of 0.56% and 3.69% water soluble ash. *Curcuma aeruginosa* predominated over *Curcuma amada* with regard to the extractive values and physicochemical properties. Powders of leaf, rhizome and roots of *Curcuma aeruginosa* showed blackish green, yellow and yellow respectively at day light; green, pale green and pale green respectively at
250-270nm; thick ash, light green and light green respectively at 360-390nm during fluorescence analysis.

Pfoze et al. (2013) carried out phytochemical screening of 21 locally used ethnomedicinal plants collected from the Senapati district of Manipur, India including *Curcuma aeruginosa*. The screening tests for alkaloids, saponins, flavonoids and tannins in the methanol extracts of the rhizome showed only the presence of flavonoids.

Starch extracted from the rhizomes of *Curcuma aeruginosa* is used as a substitute for arrowroot (Ranjini and Vijayan, 2006; Sabu, 2006). The starch extracted is an efficacious remedy for infantile diarrhoea and is also recommended for children and invalids (Ranjini and Vijayan, 2005) and is used as an alternative food source to replace cassava and corn (Anonymous, 2012c). It is believed that the medicinal value of the starch increases, as the powder becomes aged (Sabu and Skornickova, 2003). According to Wardini and Prakaso (2016) during the periods of famine, the starch is being used as a substitute for cassava and maize. X-ray diffraction studies indicate that the starch granules of the plant have crystalline properties; they are only partly crystalline and vary in their degree of crystallinity. This is because of the fact that starch from *Curcuma aeruginosa* is a highly amylose starch with lesser amount of amyllopectin (Ranjini and Vijayan, 2006). The polysaccharide from *Curcuma aeruginosa* has shown the same spectral appearance as that of high amylose starch; the Iodine binding measurements being high blue in colour than that of potato starch support the presence of high amylose starch. Starch granules are 6.66-33.3μm in size (Peng and Perlin 1987; Ranjini and Vijayan, 2006; Sujatha and Renuga, 2013).
Phytochemical screening of the methanol extracts of *Curcuma aeruginosa* rhizomes showed the presence of alkaloids, carbohydrates, proteins, amino acids, flavonoids, phenols, steroids, glycosides and tannins as major constituents. These bioactive substances might be responsible for the medicinal properties of the plant (Jose and Thomas, 2014). Rhizome of *Curcuma aeruginosa* contains curcumin which acts as antioxidant and it has cytotoxic and tumour reducing properties also (Dey, 1980; Soudamini and Kuttan, 1988; Choudhury et al., 2013).

It was Takano et al. (1995) who at the first time identified two new Guaiane sesquiterpene lactones such as zedoalactone A and zedoalactone B from n-butanol extract of *Curcuma aeruginosa* rhizome. Along with this they also isolated an already known guaianolide, *i.e.*, zedoarondiol. According to Zwaving and Bos (1992), the essential oil of *Curcuma aeruginosa* rhizome is characterized by the presence of isocurcumenol (8.5%), β- eudesmol (6.5%), curdione (3.6%) curcumol (9.9%), curcuminolides A, B (11.4%), dehydrocurdione (9.4%) and curcumene (1.9%).

Jarikasem et al. (2005) investigated the chemical constituents of the essential oils of three *Curcuma* species of Thailand including *Curcuma aeruginosa*, through capillary GC and GC-MS analysis. *Curcuma aeruginosa* rhizome showed an essential oil yield of 0.19% and from this 35 compounds were identified and the curzerenone (41.63%) was found in higher amount which was followed by 1,8-cineol (9.64%) and β-pinene (7.71%). The other detected compounds include α-pinene (1.46%), camphene (0.34%), sabinene (0.22%), myrcene (0.13%), limonene (0.65%), 2-heptanol (0.2%), 2-nonenone (1.10%), 2-decanone (0.21%), 2-nonanol (2.04%), β-elemene (1.68%), β-caryophyllene (0.32%), 2-undecanone (0.76%), myrtenol (0.43%), γ-
elemene (0.21%), trans-pinocarveol (0.19%), humulene (0.28%), isoborneol (0.58%), δ-terpineol (0.29%), α-terpineol (1.31%), borneol (0.48%), germacrene-D (0.50%), β-bisabolene (0.22%), δ-cadinene (0.42%), β-sesquiphellandrene (0.57%), ar-curcumene (1.01%), germacrene B (0.51%), curzerene (1.08%), caryophyllene oxide (0.32%), germacrone (0.99%), T-cardinol (0.86%), T-muurolol (1.15%) and cardinol (0.83%).

Sukari et al. (2007) isolated and characterized three sesquiterpenes from the rhizome of *Curcuma aeruginosa* which include zedoarol, curcumenol and isocurcumenol and it was the first time they isolated isocurcumenol from this species.

Nasrullah et al. (2010a) isolated and characterized zederone as *Curcuma aeruginosa* rhizome marker compound using n-hexane fraction of ethanol extract of the rhizome. The compound has a melting point of 149.2°C-155.3°C and according to them zederone can be used as a marker to control the quality of traditional medicinal products containing *Curcuma aeruginosa* rhizome extract.

According to Aromdee et al. (2011) steam distillation of *Curcuma aeruginosa* rhizome resulted in the production of 0.44% volatile oil and GC-MS analysis of volatile oil revealed the presence of 16.85% camphor, 16.81% curzerenone, and 3.5% epicurzerenone and the TLC chromatogram showed very lesser amount of curcumin in the case of *Curcuma aeruginosa* rhizome. By using these results along with DNA fingerprint of the rhizome they outlined a standard for the identification of the rhizome of *Curcuma aeruginosa* from its closely related species.

According to Maiyani et al. (2012), water distillation of *Curcuma aeruginosa* rhizome yielded 0.47% essential oil and GC-MS revealed 66
compounds which included 1,8- cineole (20.28%), camphor (6.5%), borneol L. (1.72%), β- pinene (1.03%), terpenyl (15.56%), curcumol (12.34%) and α- terpineol (1.17%).

Kamazeri et al. (2012) conducted phytochemical screening of the essential oils of three ginger species rhizomes viz., Curcuma aeruginosa, Curcuma mangga and Zingiber cassumunnar and according to them sesquiterpenes are found as common chemical constituents of the essential oils of Curcuma aeruginosa. It comes to 94.08% of the essential oil content and oxygenated monoterpenes (5.92%) constitute the remaining portion. The major sesquiterpenes isolated from the rhizomes of this plant include cycloisongifolene, 8,9-dehydro-9-formyl (35.29%) and dihydrocostunolide (22.51%) in higher amounts and velleral (10%), germacrone (6.50%), β-elemene (4.76%), alloaromadendrene oxide-(2) (4.07%), aromadendrene oxide-(2) (2.4%), β-farnesene (2.65%), α-bulnesene (2.14%) and eudesma(14),11-diene (1.13%) as in remaining percentages. Major oxygenated monoterpenes detected include eucalyptol (3.98%), L-camphor (1.32%), isoborneol (0.62%), caryophyllene (1.01%), β-cubebene (0.92%) and xanthin (0.69%). A new sesquiterpene lactone, aeruginon and a known compound curcuminone were isolated from the chloroform fraction of Curcuma aeruginosa rhizome by Atun et al. (2016).

Curcuma aeruginosa leaves showed the presence of furanogermenone, (2)-3-hexanol, furanodienone, curcumeno1, isocurcumeno, b-elemene, curzerenone, germacrone, 1,8-cineole and camphor (Dung et al., 1995; Jirovetz et al., 2000).

Rajeshkumar (2013) studied the variations of some Zingiberacean members at biochemical level including Curcuma aeruginosa by GC-MS based metabolic profiling of the essential oil.
from the rhizomes. Accordingly *Curcuma aeruginosa* rhizome showed the occurrence of 2-pyridinamine, 4,6-dimethyl (28.84%), eucalyptol (10.27%), 1,6,10-dodecatriene, 7,11-dimethyl-3-methylene (6.24%), camphor (6.15%), 2-(benzothiazol-2-ylamino)-3H-imidazol-4-ol (4.55%), thiazole, 5-methyl-4-phenyl (3.95%), cyclohexanone, 2-methyl-5-(1-methylethenyl) (3.78%), beta pinene (2.76%), camphene (2.06%), isoborneol (2.19%), caryophyllene (2.15%), Ar-tumerone (1.99%) and carbone (1.54%) as the major compounds.

Recently Simoh and Zainal (2015) carried out phytochemical profiling of *Curcuma aeruginosa* rhizome using two different techniques of direct solvent extraction such as methyl tetra-butyl ether (MTBE) extraction method and two phase methanol or chloroform (M/C) system, of which the extraction using M/C method showed higher metabolite coverage. MTBE extraction method revealed the occurrence of 27 compounds while M/C system allowed the extraction of 54 compounds. The major compounds detected by MTBE extraction method were cycloisolongifolene, 8,9-dehydro-9-formyl (15.93%), methenolone (16.64%), propiolic acid, 3-(1-hydroxy)-2 isopropyl-1,5-methyl cyclohexyl (7.84%), labd-13-en-15-oicacid, 8,12-epoxy-12-hydroxy-γ-lactone(10.77%), 4-oxo-β-isodamascol (5.17%), velleral (3.11%) and z-α-farnesene (2%). The major compounds identified in the polar fraction of M/C extraction method included α-D glucopyranoside,1,3,4,6-tetrakis-O-(TMS) (trimethylsilyl)-β-D-ructofuranosyl2,3,4,6-tetrakis-O-(TMS) (38.08%), D-glucose,2,3,4,5,6-pentakis-O-(TMS)-,O-methylloxime (14.61%), D-fructose,1,3,4,5,6-pentakis-O-(TMS)-,O-methylloxime (5.28%), isocitric acid (TMS) (3.06%), oxalic acid, bis (TMS) ester (2.96%), hexa decanoic acid, TMS ester (2.16%), citric acid, ethyl ester, tri-TMS (1.91%) and butanedioic acid, [TMS oxy]-, bis (TMS) ester (1.14%) while those in
the nonpolar extraction included cycloisolongifolene, 8,9-dehydro-9-formyl (15.7%), propiolic acid, 3-(1-hydroxy-2-isopropyl-1,5-methyl cyclohexyl) (11.09%), stearic acid, TMS ester (2.78%), hexadecanoic acid, TMS (2.33%), oleic acid, TMS ester (1.62%), curzerene (1.56%), z-α-farnesene (1.52%), germacrone (1.41%) and β-elemene (1.33%). They also concluded that the plant was a potential source of various phytochemicals.

It was George and Britto (2015a) who identified and also elucidated the structures of 18 chemical compounds from the essential oil GC-MS analysis of *Curcuma aeruginosa* rhizome. The detected compounds include camphene (1.26%), eucalyptol (6.44%), (+)-2-bornanone (3.10%), santolinatriene (7.28%), caryophyllene (1.65%), (E)-β-famesene (3.99%), naphthalene,1,2,3,4,4a,5,6,8a-octahydro-4a,8-dimethyl-2-(1-methylethenyl) (3.36%), naphthalene,1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1-methyl ethenyl) (1.42%), benzoferan, 6-ethenyl-4,5,6,7-tetrahydro-3,6-dimethyl-5-isopropenyl-,trans (7.15%), 10s,11s-himachala-3(12),4-diene (1.29%), ethoxybenzene (33.44%), isolongifolene,4,5-dehydro (3.34%), elemene (4.02%), 4,6-dimethyldibenzothiophene (5.27%), phenol,3-phenoxy (1.58%), cyclohexanone,2-methyl-5-(1-methylethenyl)- (2.3%), bicyclo[3.1.0] hexan-3-one,4-methyl-1-(1-methylethyl) (4.46%) and 4-amino-N- (2-phenylethyl)-1, 2,5-oxadiazole-3-carboxamide (8.62%). They identified that components such as (+)-2-bornanone and santolinatriene possessed anticancer activities; eucalyptol showed antibacterial, anti-inflammatory and analgesic properties; β-famesene showed antifungal properties; benzoferan,6-ethenyl-4,5,6,7-tetrahydro-3,6-dimethyl-5-isopropenyl-,trans had immune enhancement activities; elemene had anti lung cancer activity and bicyclo[3.1.0]hexan-3-one,4-methyl-1-(1-methylethyl) and phenol, 3-phenoxy showed antimicrobial properties. These compounds
have been reported to be responsible for the various pharmacological activities exhibited by this plant.

Theanphong et al. (2015) described the chemical composition and biological activities of the essential oil of *Curcuma aeruginosa* rhizome. They extracted the essential oil with percent yields of 0.23 which was clear and pale yellow in colour, and identified 22 chemical constituents. The essential oil was dominated by oxygenated sesquiterpenes (42.85%) followed by sesquiterpene hydrocarbons (30.80%), oxygenated monoterpenes (10.92%) and monoterpenes hydrocarbons (10.82%). Among them the oxygenated sesquiterpene germacrone (23.49%) was found in higher concentration which was followed by curzerenone (11.78%) and 1,8-cineole (10.92%). Hastuti et al. (2016) for the first time isolated and elucidated the structure of a flavonoid compound flavone from the rhizome of *Curcuma aeruginosa* and according to them the isolated compound has a melting point of 98°C-100°C.

Prastyo and Laily (2015) tested the concentration of leaf chlorophyll content in *Curcuma mangga*, *Curcuma aeruginosa* and *Curcuma xanthorrhiza* using different grades of Whatman type filter papers such as 1, 40 and 42. *Curcuma aeruginosa* showed the highest chlorophyll concentration than the other two species; its highest chlorophyll content was observed on Whatman type 1 filter paper and the lowest on Whatman type 40.

Bos et al. 2007 conducted analysis of curcuminoid content of four underutilized medicinal plants of Indonesia including *Curcuma aeruginosa* using the HPLC-photodiode array detection method. The rhizomes of all the three accessions of *Curcuma aeruginosa* studied showed lesser amounts of curcuminoids ranging from 0.02% to 0.03%
in which demethoxycurcumin occupied 0.01-0.02%, curcuminin 0.01% though bis-demethoxycurcumin was not detected. All the other species possessed all these three in significantly higher concentration.

According to Nasrulla et al. (2010b) the specific retention time of n-hexane and ethyl acetate extracts of *Curcuma aeruginosa* obtained during the thin layer chromatography (TLC) could be used as fingerprint for standardizing its traditional medicinal extract.

The flowers of *Curcuma aeruginosa* possess significant nutritional values. The nutrient composition per 100g of edible portion includes moisture 90.4g, energy 34Kcal, fat 0.6g, protein 1.3g, carbohydrate 5.8g, vitamin A, RE 8.7μg, vitamin A, RAE 4.3μg, Beta-carotene 52μg, thiamine 0.07mg, Calcium 43mg, iron 1.9mg (CINE, 2008).

Zanariah et al. (1997) analysed the nutritional composition of nine zingiberaceous members utilized in traditional medicines and cooking including the rhizome of *Curcuma aeruginosa*. 100g of the rhizome showed a coloric value of 86cal, 76.8g moisture, 2.4 g protein, 0.4g fat, 18.3g of carbohydrate, 1.1g fibre, 1g ash, 0.02mg thiamine, 0.09mg riboflavin and 4.22mg ascorbic acid.

### 2.4.9. Pharmacognostic activity and medicinal properties

The rhizomes of this plant have been used in traditional medicine as gastrointestinal and uterine remedies. Various biological activities of *Curcuma aeruginosa* have been reported such as postcoital contraceptive, anti HIV, hepatoprotective, antimicrobial, antioxidant, antiplatelet activating and antinociceptive by different workers (Otike et al., 1995; Jantan et al., 2005; Reanmongkol et al., 2006; Chan et al., 2008; Thaina et al., 2009; Kamazari et al., 2012). It is commonly used as a treatment for asthma (Ibrahim and Abd Rahman, 1988).
The rhizome is being used as a medicine for asthma, cough, scurvy and mendal derangement in peninsular Malaysia and for colic in Indo China. The rhizome forms a major ingredient of a decoction given to women after child birth to accelerate lochia. Due to the depurative activity of the rhizome, it has been used both internally and externally for the treatment of exanthema and also as poultice for treating itch. It has wild applications against obesity, rheumatism, etc. (Wardini and Prakaso, 2016).

Angel et al. (2012a) have reported that *Curcuma aeruginosa* is a promising source of potential antioxidants. The antioxidants include volatile oils, terpenes, phenolics and flavonoids. A study using methanolic extracts of *Curcuma aeruginosa* rhizome showed very high phenolic content, DPPH free radical scavenging activity and iron reducing power. The methanolic extracts of the leaves possessed higher total phenolic content and iron reducing power when compared to those of the rhizome.

*Curcuma aeruginosa* extracts showed nitric oxide radical scavenging activity and the scavenging potential or the antioxidant activity was enhanced towards maturity of the rhizome. It was noticed that the free radical scavenging activities were highly correlated with total phenol content, suggesting that the antioxidant activities were due to the presence of polyphenolic compounds in the plant (Choudhury *et al*., 2013). Superoxide dismutase, an antioxidant enzyme, was purified from the rhizome of *Curcuma aeruginosa*. It catalyses the disproportionation of harmful superoxide anion radicals to hydrogen peroxide and molecular oxygen and it has long been used in medical, cosmetic and other chemical industries (Moon-ai *et al*., 2012).
Similar observations have also been made by Chan et al. (2008) during their studies on the antioxidant and tyrosinase inhibition potentialities of leaves and rhizomes of 26 ginger species. In their study the leaves and rhizomes of Curcuma aeruginosa showed considerable total phenol content (TPC) and ascorbic acid equivalent antioxidant capacity (AEAC) in which the leaves possessed much higher TPC and AEAC than those of the rhizomes.

According to Liu et al. (2013) the methanolic extract of Curcuma aeruginosa rhizome showed good activity in MTT antioxidant assay and at 100μg ml\(^{-1}\) the activity was similar to those of Vitamin C and tert-butylhydroquinone (TBHQ) at 25μg ml\(^{-1}\) whereas the hexane extract does not show any significant activity. Also these extracts did not exhibit any inhibition towards lipid peroxidation during Lipid Peroxidation Inhibitory Assay and the inactive nature of hexane extracts was due to its scanty solubility in water or buffers of LPO and MTT assays.

George and Britto (2015a) evaluated the antioxidant potentiality of essential oil of Curcuma aeruginosa rhizome by comparing it with the activity of the natural antioxidant, ascorbic acid. The essential oil at a concentration of 50μg ml\(^{-1}\) showed the highest DPPH radical scavenging activity (77%) with an IC\(_{50}\) and EC\(_{50}\) values of 28μg ml\(^{-1}\) and 30μg ml\(^{-1}\) respectively; higher total antioxidant activity of 64.3% with an IC\(_{50}\) and EC\(_{50}\) values respectively of 45μg ml\(^{-1}\) and 30μg ml\(^{-1}\); good reducing power of 2.54% and higher Nitric oxide radical scavenging activity of 72.3%.

Chen et al. (2003) for the first time evaluated the occurrence of melatonin, a potent antioxidant in 108 Chinese medicinal herbs including Curcuma aeruginosa using advanced techniques and it was
noticed that this molecule was present in all these tested herbs in varying concentrations. Among them 49 herbs showed melatonin in excess of 100ng g\(^{-1}\) of dry weight and *Curcuma aeruginosa* possessed a concentration of 120ng g\(^{-1}\) of melatonin. Melatonin rich herbs are traditionally used to treat diseases related to free radicals and also to alter aging.

Waras *et al.* (2015) conducted comparative studies on the phytochemical screening and antioxidant and cytotoxic activities of different parts of *Curcuma aeruginosa* rhizome such as primary rhizome, secondary rhizome and tertiary rhizome using crude aqueous, 70% ethanol and 96% ethanol extracts of each. Preliminary phytochemical study revealed the occurrence of tannins and triterpenoids in all the three extracts from different parts of the rhizome. Saponins were identified from both the 70% ethanol and aqueous extracts of all the three parts of the rhizome while these were absent in 96% ethanol. Screening of alkaloids, flavonoids and steroids showed their absence in all the three extracts. Estimation of the antioxidant activity using the DPPH radicals showed the dose dependent increase in the DPPH radical scavenging activity by the crude aqueous, 70% ethanol and 96% ethanol extracts from all the three rhizome parts, with the 70% ethanol extract of the primary rhizome showing the highest DPPH radical scavenging and the aqueous extracts of primary rhizome showing the lowest scavenging activity. When compared with ascorbic acid which was used as the positive control, the rhizome of *Curcuma aeruginosa* showed negligible activity. Cytotoxic activity using Brine Shrimp Lethality Test (BSLT) showed an increase in the percentage of mortality of shrimp nauplii with increase in concentration of 96% ethanol and 70% ethanol extracts of *Curcuma aeruginosa* primary rhizomes with good cytotoxic activity.
According to Theanphong et al. (2015) the essential oil of Curcuma aeruginosa rhizome showed significant antioxidant activities in which the DPPH and OH radical scavenging activities were almost similar to that exhibited by the control L-ascorbic acid whereas lesser scavenging activity was observed in the case of \( \text{H}_2\text{O}_2 \) compared with those of L-ascorbic acid. The essential oil failed to show any reducing power.

Recently Nurcholis et al. (2016a) evaluated the variability in total phenolic and total flavonoid contents and antioxidant activities of 20 accessions of Curcuma aeruginosa collected from different parts of Indonesia. They observed significant variability in total phenolic content, total flavonoid content and DPPH scavenging activity. Correlation studies showed low positive correlation and low negative correlation of DPPH scavenging activity with phenolic content and flavonoid content respectively indicating that antioxidant activities of these accessions are not due to corresponding phenolic and flavonoid contents.

Maiyani et al. (2012) screened the antimicrobial activity of essential oils of six Curcuma species including Curcuma aeruginosa and found that the essential oil of the plant showed antibacterial activity against Staphylococcus epidermidis, Escherichia coli and Bacillus subtilis.

Kamazeri et al. (2012) has reported mild antimicrobial activity in the case of Curcuma aeruginosa. Its ethyl acetate extract showed inhibition against Pseudomonas aeruginosa, Staphylococcus aureus and Bacillus subtilis at a concentration of 500mg ml\(^{-1}\) while at 50mg ml\(^{-1}\) it inhibited only Bacillus subtilis. The methanol extract at 500mg ml\(^{-1}\) showed inhibition only on Pseudomonas aeruginosa whereas at 50mg
ml⁻¹ it had no inhibitory effects. At 50mg ml⁻¹ the hexane extract inhibited *Pseudomonas aeruginosa* while at 500mg ml⁻¹ it inhibited *Pseudomonas aeruginosa* and *Staphylococcus aureus* (Philip et al., 2009). *Curcuma aeruginosa* oil showed moderate activity against the fungus *Candida albicans* and weak inhibition against *Cryptococcus neoformans* (Kamazeri et al., 2012). Supercritical fluid extraction study of *Curcuma aeruginosa* has revealed that the extracts showed inhibitory activities against *Staphylococcus epidermidis, Staphylococcus aureus, Bacillus cereus, Bacillus subtilis* and *Propionibacterium acnes* (Pyo and Oo, 2007). The results of the studies suggest that essential oils of *Curcuma aeruginosa* with antimicrobial activities may be useful in many applications, such as food preservation, pharmaceuticals and natural therapies. Activity of the essential oils of the rhizomes of *Curcuma aeruginosa* against *Bacillus subtilis, Staphylococcus aureus* and *Escherichia coli* has also been reported by Angel et al. (2012b).

With an objective of identifying natural food preservative, Rukayadi et al. (2013) tested the antimicrobial potentialities of 45 tropical edible medicinal plant extracts including the methanolic extracts of *Curcuma aeruginosa* against five microorganisms. Here the methanolic extracts of *Curcuma aeruginosa* showed inhibition towards *Staphylococcus aureus* only with a minimum inhibitory concentration (MIC) of 25.6mg ml⁻¹ and a higher minimum bactericidal concentration (MBC) of 51.2mg ml⁻¹, whereas no inhibition was observed against *Aspergillus niger, Candida albicans, Escherichia coli* and *Pseudomonas aeruginosa*.

Jose and Thomas (2014) tested the antibacterial properties of polar and non-polar extracts of the rhizome of *Curcuma caesia* and *Curcuma aeruginosa* against three gram positive (*Staphylococcus*
aureus, Streptococcus haemolyticus, Bacillus cereus) and five gram negative (Salmonella typhi, Enterobacter aerogenes, Vibrio cholerae, Pseudomonas aeruginosa and Serratia marcescens) strains of bacteria. In the case of the gram positive bacteria, the hexane extract of Curcuma aeruginosa at a concentration of 5mg ml$^{-1}$ disc$^{-1}$ showed the maximum activity against Bacillus cereus with a zone of inhibition higher than those of the reference antibiotic, streptomycin. The chloroform and acetone extracts inhibited all the gram positive strains tested. The ethyl acetate extract did not inhibit Streptococcus haemolyticus and Bacillus cereus. Methanol and hexane extracts did not show inhibition towards Bacillus cereus and Staphylococcus aureus respectively, while inhibited all other strains. In the case of gram negative bacteria, the methanol extracts exhibited maximum zone of inhibition against Salmonella typhi which was higher than those of streptomycin. The hexane, chloroform and methanolic extracts exhibited inhibition towards all the gram negative bacteria studied whereas the aqueous extracts failed to show any antibacterial activity on these. Ethyl acetate and acetone extracts showed no inhibition on Salmonella typhi and Vibrio cholerae and inhibited all other strains of gram negative bacteria tested. The antibacterial activity of Curcuma aeruginosa was found to be dose dependent and the activity was more predominant over gram negative strains.

Antibacterial studies conducted by Theanphong et al. (2015) have shown that the essential oil of Curcuma aeruginosa rhizome showed strong activity against Enterococcus faecalis and weak activity against Bacillus subtilis though no activity was observed in the case of Escherichia coli and Staphylococcus aureus. The essential oil also exhibited mild antimycobacterial activity against Mycobacterium tuberculosis.
Emantoko et al. (2011) detected the quorum sensing inhibition properties of ethyl acetate extracts of *Curcuma aeruginosa* on *Pseudomonas aeruginosa* during their exploration of quorum sensing inhibitors of seven Indonesian medicinal plants. Quorum sensing is a bacterial activity which regulates the expression of specific proteins in bacteria. The genes for virulence activities, antibiotic properties, flagella, etc. are under the control of quorum sensing. The inhibitors of quorum sensing could help to overcome multi-drug resistant bacterial pathogens.

Jantan et al. (2003) investigated the antifungal activities of the essential oils of nine Zingiberaceae species including *Curcuma aeruginosa* against five dermatophytes, three filamentous fungi and five strains of yeast and found that *Curcuma aeruginosa* failed to express antifungal activities.

Pujiyanto et al. (2012) isolated nine endophytic actinomycetes from the rhizome of *Curcuma aeruginosa* while isolating and selecting alpha glucosidase inhibitor producing endophytic actinomycetes from different antidiabetic medicinal plants. Alpha glucosidase is one of the compounds widely utilized for the treatment of diabetes. The isolate TIR-13 of *Curcuma aeruginosa* showed an inhibitory activity of 3.623%.

George and Britto (2014) synthesized stable copper oxide nanoparticles from the powdered rhizome extract of *Curcuma aeruginosa* and these nanoparticles exhibited efficient antimicrobial activity against gram negative *Escherichia coli* and gram positive *Staphylococcus aureus*, *Klebsiella pneumoniae* and *Bacillus cereus*, antifungal activity against *Aspergillus niger* and *Aspergillus fumigates* and antioxidant activity against DPPH radical.
Liu et al. (2013) have reported significant anti-tumor and cancer preventing activities of *Curcuma aeruginosa*. Tumor cell proliferation inhibitory assay revealed the inhibitory activities of hexane and methanolic extracts of *Curcuma aeruginosa* rhizome against different cancer cell lines. Experiments have shown that methanolic and hexane extracts inhibited the growth of the tumour cell lines of human colon (HCT-116), central nervous system (SF-268), breast (MCF-7), lung (NCI-H460), stomach (AGS), pancreas (MIA PaCa-2), and prostrate (LNCaP and DU145).

However, Kirana et al. (2003) found that the ethanolic extract of *Curcuma aeruginosa* rhizome was less active against human colon cancer HT-29 and breast cancer MCF-7 cells with an IC$_{50}$ value between 100-120µg ml$^{-1}$. In a study on the human colon cancer derived HCT-116 and HT29 cells, it was found that crude chloroform extract of *Curcuma aeruginosa* was active in inhibiting the proliferation of HT29 cell line (Abdullah, 2009). Atun et al. (2016) tested the cytotoxicity of methanol, n-hexane and chloroform extracts of the rhizome of *Curcuma aeruginosa* on breast carcinoma MCF-7 and T-47D cell lines, cervical carcinoma Ca Ski and Hela S$_3$ cell lines and on normal cells and found that the n-hexane and chloroform fraction exhibited low cytotoxic activity against MCF-7 and Ca Ski cells and no cytotoxic activity was observed against others.

The rhizome of *Curcuma aeruginosa* is one among the six ingredients of a Chinese herbal preparation, Weikang Keli (WK)-a traditional Chinese medicine which is used in the therapy of cancer. It has been reported that WK can possibly inhibit the growth of human gastric cancer cell line SGC-7901 in vitro and in vivo through autophagy and meanwhile improve the life quality of nude mice. It has also
showed outstanding efficacy in improving the immunity, the anticancer functions of chemotherapeutic drugs and the life quality of patients (Huo et al., 2013).

*Curcuma aeruginosa* forms one among the seven ingredients of a Chinese herbal decoction, Qianlie Xiaozheng Tang (QLXZT) which is used in treating cancers in the traditional Chinese medicine. Here *Curcuma aeruginosa* along with *Hedyotis diffusa*, *Rhizoma bolbostematis* and *Polyporus* act as assistants that remove the factors of pathogenesis via clearing heat, by detoxication and by removing blood stasis. This empirical formula causes the inhibition of tumor growth in nude mice and C57 mice model affected with hormone refractory prostate cancer (HRPC) (Zhang and Lin, 2005a; Zhang and Lin, 2005b). Studies of QLXZT on Castration Resistant Prostate Cancer (CRPC) have shown its effects in reducing prostate specific antigen (PSA) progression, enhancing the quality of life (QOL) and the alleviation of the prostate cancer anxiety in patients suffering from CRPC. QLXZT also improves the quality of life in patients with advanced prostate cancer. So this can be used as an alternative medicine in treating prostate cancer including CRPC (Pang et al., 2010; Pang et al., 2015). *Curcuma aeruginosa* along with 16 other medicinal herbs is used for the preparation of San Zhong Kui Jian Tang (SZKJT), a traditional Chinese medicine used in treating various types of cancers. The property of SZKJT as a promising agent for breast cancer treatment has been experimentally proven (Hsu et al., 2006).

Chew et al. (2012) has reported the outcome of an experiment carried out for studying the anti-proliferation and anti-migration activities of petroleum ether, methanol and chloroform extracts of the rhizomes of 10 Zingiberacean members including *Curcuma aeruginosa*
against the human breast cancer cell line MDA-MB-231. MTT assay of *Curcuma aeruginosa* revealed that the methanolic extract was inactive on the MDA-MB-231 cells whereas the petroleum ether extract was moderately active and that the chloroform extract was weakly active against the proliferation of breast cancer cells. Both the crude petroleum ether extract and chloroform extract except the methanol extract of *Curcuma aeruginosa* showed significant anti-migration activity on MDA-MB-231 cells during the scratch wound assay.

Moektiwardoyo et al. (2014) investigated the potential effect of *Curcuma aeruginosa* rhizome as prominent remedy in the treatment of dengue fever by studying its effects against the number of thrombocytes and erythrocytes and the hematocrits level on adult male wistar rats and it was observed that oral administration of *Curcuma aeruginosa* rhizome at a dosage of 500mg kg\(^{-1}\) BW and 250mg kg\(^{-1}\) BW showed better thrombocytopenia and anti-anemia activities. Treatment with *Curcuma aeruginosa* at a concentration of 500mg kg\(^{-1}\) BW and 250mg kg\(^{-1}\) BW increased the number of thrombocytes and erythrocytes. Thus the rhizome of *Curcuma aeruginosa* could be recommended as a promising medicinal herb in the alleviation of dengue symptoms.

Yingngam et al. (2011) evaluated the crude ethanolic extracts of 13 medicinal plants including *Curcuma aeruginosa* for their estrogen like and cytotoxic properties in order to identify the herbal medicine that can be used in anti-ageing preparations which favours good estrogenericity and has got lower cytotoxicity, and also compared the protective effects of these herbals against oxidative stress related with anti-ageing activities. Rhizome of *Curcuma aeruginosa* showed moderate estrogenericity and the estrogen like activity of this occurs through estrogen receptor pathway. *Curcuma aeruginosa* at its high
concentrations (50 & 100μg ml\(^{-1}\)) exerted cytotoxicity towards mice fibroblast cells whereas at low concentrations of 0.1 and 1μg ml\(^{-1}\) promoted cell growth. It also showed protective effect against cell death due to oxidative stress generated by H\(_2\)O\(_2\).

The antiandrogenic activity of *Curcuma aeruginosa* is attributed to the sesquiterpenes present in the rhizome. Six sesquiterpenes namely germacrone, zederone, dehydrocurdione, curcumenol, zedoarondiol and isocurcumenol were isolated from the rhizomes of *Curcuma aeruginosa*. They showed inhibition towards 5α-reductase which converts testosterone to dihydrotestosterone (DHT). Germacrone was found to be the most potent (Suphrom *et al*., 2012). This enzyme is involved in the development of benign prostatic hyperplasia, androgenic alopecia (common baldness), hirsutism, prostate cancer and acne skin. Inhibitors of 5α-reductase are useful for the treatment of these diseases. It is observed that furanodiene, another sesquiterpene present in the hexane extract of *Curcuma aeruginosa* rhizome, at the concentration of 1mg ml\(^{-1}\) showed 40% inhibition towards 5α-reductase. Thus the rhizome containing furanodiene can be used for the development of anti-androgenic drugs (Srivilai *et al*., 2011).

The stability of antiandrogenic components of *Curcuma aeruginosa* such as Germacrone and other sesquiterpenes was tested by Suphrom *et al.* (2014) in which they evaluated the influence of pH, temperature and light on these 5-alpha reductase antagonist compounds. It was observed that these principles were unstable at high temperature and in the solid form, and the stability of germacrone was independent of the pH (2.0-9.0) but it was degraded lightly when in the dried extract form by light. Hence it was suggested that it was better to store the extract as a solution or in a solid form under low temperature.
Jantan et al. (2005) have explained the platelet activating factor antagonistic activity of *Curcuma aeruginosa*. Among the 37 species studied, the methanol extracts of *Curcuma aeruginosa* rhizome showed significant PAF inhibition of 75.4% with an IC$_{50}$ value of 5.8μg ml$^{-1}$. According to them this property could be due to the presence of active compounds in these extracts which have the ability to strongly bind to PAF receptors. Vargaftig and Braquet (1987) have proposed these compounds as potential therapeutic agents for the treatment of immunological and inflammatory disorders.

*Curcuma aeruginosa* is an essential component of Jamu Cekok, a kind of traditional medicine widely used in Yogyakarta mainly for children without appetite (Limananti et al., 2003).

Evaluation of analgesic, antipyretic and anti-inflammatory activities of the rhizome extracts of *Curcuma aeruginosa* was done by Reanmongkol et al. (2006). According to them chloroform and methanol extracts of *Curcuma aeruginosa* possess antinociceptive activities and the antinociceptive activities of the active compounds in these extracts have been mediated through peripheral mechanisms. Significant antipyretic and anti-inflammatory activities were not observed by them.

Hossain et al. (2015) isolated and purified an antinociceptive principle Germacrone (1) from the rhizome methanolic extracts of *Curcuma aeruginosa* with possible anti-inflammatory potentiality.

Anti-inflammatory activity of *Curcuma aeruginosa* was noticed in the studies of Liu et al. (2013). The methanolic extract of the rhizome showed inhibition towards COX-2 enzyme by 84.4% while COX-1 enzyme inhibition was not observed. The inhibition profile was similar to that of Celebrex®, a non-steroidal anti-inflammatory drug.
The proteins isolated from the aqueous extract of the rhizome of *Curcuma aeruginosa* also exhibited significant anti-inflammatory activity (73% inhibition of paw oedema) at a dose level of 100mg kg\(^{-1}\) BW, when assayed by the carrageenan rat paw oedema model system and it was less than that of the standard drug Voveran (Angel *et al.*, 2013).

Triastuti *et al.* (2015) succeeded in observing potential anti-inflammatory properties of the ethanolic extract of *Curcuma aeruginosa* rhizome using two typical inflammatory models, such as Croton oil induced ear edema and Thioglycollate-induced peritonitis. Topical application of ethanolic extracts of *Curcuma aeruginosa* could cause significant reduction of edema in all the concentrations and the extract at a dose of 160mg ear\(^{-1}\) showed better inhibition than hydrocortisone 1%, the reference drug. Reduction of edema increases with respect to the increase in the concentration of the extract. Histological studies of ears treated with *Curcuma aeruginosa* ethanol extract at 40mg ear\(^{-1}\), 80mg ear\(^{-1}\) and 160mg ear\(^{-1}\) showed considerable reduction of edema and vasodilation. The extract at doses of 200mg kg\(^{-1}\) BW and 400mg kg\(^{-1}\) BW caused a decrease in leucocyte migration in balb/c mice with slight activity, lower than that of indomethacin during thioglycollate induced peritonitis assay.

The presence of sesquiterpenes imparts anthelmintic potency to *Curcuma aeruginosa*. Studies on the comparison of the anthelmintic potency of the root squeeze and root infusion of the plant against *Ascaridia galli* have shown that root squeeze was better than root infusion. The anthelmintic property of *Curcuma aeruginosa* root squeeze and root infusion was lower than Piperazine citrate (Tamara, 2008).
Curcuma aeruginosa rhizome is used along with papaya leaves, Phyllanthus niruri, turmeric, Languas galanga and Alstonia scholaris for the preparation of a recipe for the treatment of malaria. Along with Curcuma heynanea and garlic it is used for the preparation of another recipe used for round worm infestation (Anonymous, 2010).

The effectiveness of Curcuma aeruginosa as an anthelmintic on ascariasis was tested by Utami and Hermansyah (2015) during their in vitro experiments on adult worm and eggs of Ascaris suum. The results showed paralysis and death of the worms when immersed in Curcuma aeruginosa extracts, and the paralysis increased parallel with the increasing concentration and the duration of contact with the same extract, indicating the vermifuge properties of Curcuma aeruginosa. The extracts at a concentration of 2% with a duration of 3 hours showed paralysis of 20% of worms and this percentage increased in the subsequent concentration also. More than 50% of paralysis and 20%-40% death of the worms were noticed at an incubation of more than 24 hours. Curcuma aeruginosa extracts also showed ovicidal effect with an IC$_{50}$ value of 0.343%. It is described that the essential oils of these extracts act as vermifuge substances and the monoterpenes and the sesquiterpenes are provided with anthelmintic property which act as an antagonist of acetylcholine, a neurotransmitter, thus the rhizome of Curcuma aeruginosa is a potent vermifuge which could be utilized for the eradication of human ascariasis.

Another similar work on the anthelmintic activity of Curcuma aeruginosa done by Saputri (2015) in sheep affected with natural nematode infestation showed that the addition of Curcuma aeruginosa powder at the level of 750 and 1500mg per day for 5 days did not have
any significant effect on nematode infestation but it exerted a positive effect on animal weight gain in sheep.

Woelansari et al. (2013) conducted in vitro studies to investigate the effect of rhizome boiled water of *Curcuma aeruginosa* and *Curcuma heyneana* on the killing of *Fasciola hepatica* which caused fascioliasis. Both the species exerted significant influence on the mortality of the worm and it was observed that when the concentration of rhizome decoction increased there was a decrease in the time taken for killing all the *Fasciola hepatica* and vice versa.

Abd Razak et al. (2014) evaluated the antiplasmodial activities of 14 selected Malaysian medicinal plants including *Curcuma aeruginosa* against the asexual blood stage of chloroquine resistant *Plasmodium falciparum* using *Plasmodium falciparum* Histidine Rich Protein II ELISA technique. The experimental programme involved the determination of antiplasmodial activity using the dichloromethane, methanol and deionised water extracts of these selected plants and in vitro cytotoxicity assay of mammalian MDBK cell line using the different plant extracts showing significant antiplasmodial activity. It was noticed that *Curcuma aeruginosa* rhizome showed good to moderate antiplasmodial activity in all the three extracts with an EC$_{50}$ value less than 10μg ml$^{-1}$ with negligible cytotoxic effects on normal mammalian MDBK cell line with a selectivity index greater than 10.

Otake et al. (1995) reported that the aqueous extract of the rhizome of *Curcuma aeruginosa* effectively inhibited HIV-1 induced cyto-pathogenicity in MT-4 cells through inhibition of HIV protease and reverse transcriptase.

Rhizome extract of *Curcuma aeruginosa* at a concentration of 5μg ml$^{-1}$ was found to significantly exert potential inhibitory effects on
Matrix Metalloproteinase-9 (MMP-9) expression at secretion, protein and gene levels in LPS-induced vascular endothelial cells *in vitro*. Zingiberaceae rhizome extracts with potential anti-MMP activities could represent beneficial diet in terms of cardiovascular protection (Yanti, 2011).

Rhizome extract of *Curcuma aeruginosa* has potential anti-photoaging properties. Darmakusuma *et al.* (2013) have reported that the methanolic extracts of *Curcuma aeruginosa* rhizome inhibited UV-induced degeneration of type I procollagen by inhibition of the UV-induced intracellular ROS production or any antioxidant effect of the extract.

Thaina *et al.* (2009) have reported that the rhizome extract of *Curcuma aeruginosa* showed uterine relaxant activity on isolated uterus strips from estrogen primed rats. Based on the inhibitory effect of the extract on oxytocin induced contraction, it can be concluded that the extracts might be useful as tocolytic agents for the prevention of preterm labour. The uterine relaxant effect of the plant extract could be due to beta-pinene and some sesquiterpene lactones. The result of this study also justifies the use of the rhizome of this plant for prevention of dysmenorrhea.

Wimolwat *et al.* (2016) evaluated the efficacy and safety of 2% *Curcuma aeruginosa* extract containing cream in the treatment of mild to moderate seborrheic dermatitis and found that the application of the above cream resulted in significant improvement in patients suffering from this disease irrespective of its mild adverse effects.

Nurdin *et al.* (2011) examined the consequences of the supplementation of four herbs including *Curcuma aeruginosa* on milk yield and quality of milk in dairy cows distressed with mastitis.
Accordingly feeding of *Curcuma aeruginosa* showed highly significant effect in increasing the milk yield and milk lactose, decreasing the milk protein and milk fat and in reducing the mastitis status.

Hanafi (2015) conducted a study on the effect of *Curcuma aeruginosa* powder on Aspartate Amino Transferase (AST) and Alanine Amino Transferase (ALT) of sheep. The administration of rhizome powder at a dosage of 0.3g kg\(^{-1}\) BW and 0.6g kg\(^{-1}\) BW for five days showed no considerable effect on the activity of AST and ALT in sheep.

Darusman (2015) carried out an experiment to study the result of the supplementation of *Curcuma aeruginosa* powder at a dosage of 2% through the feed in Turi ducks (*Anas platyrhynchos*) and found that there was no negative effect on total plasma protein (TPP) concentrations. Neither the treatment nor the duration of the test influenced the TPP metabolism.

Rhizome extract of *Curcuma aeruginosa* at a concentration of 5g l\(^{-1}\) has been found to be equally effective as those of high concentrations such as 10, 15, 20 and 25g l\(^{-1}\) for the eradication of red spider mite which infests the foliage of *Livistona rotundifolia* (Svinningen et al., 2010). Herbal shampoo prepared from 10% (v/v) crude extract of *Curcuma aeruginosa* rhizomes showed pediculicidal effects (Watcharawit and Soonwera, 2013).

Pitasawat et al. (2003) investigated the mosquito repellent activity of 95% ethanol extracts of the rhizomes of three *Curcuma* species including *Curcuma aeruginosa* using *Aedes togoi* on human volunteers. *Curcuma aeruginosa* extracts failed in expressing significant repellent activity in laboratory repellent tests.
The rhizome of *Curcuma aeruginosa* Roxb. showed inhibition towards Dengue-2 virus NS2B/NS3 protease, of which the hexane fraction of the rhizome was more inhibitory than its methanol fraction. The study has further shown that the active components of *Curcuma aeruginosa* responsible for this activity were possibly more lipophilic (Tan *et al.*, 2006).

In spite of the reports on several beneficial properties, *Curcuma aeruginosa* possesses some toxic effects also. Only a few researches have been done on the toxic effects of this species. Cytotoxic studies done by Yuliawati and Hestianah (2010) revealed that *Curcuma aeruginosa* was not showing any cytotoxic effect on fibroblast cell lines but the percentage of viable cells was seen to be decreased significantly. Hestianah *et al.* (2014) reported the toxic effect of *Curcuma aeruginosa* rhizome on mice as it caused necrosis of mice hepatocytes. They identified three compounds with toxic effects from the rhizome of the plant, *i.e.*, 9-methyl tetracyclo tetradecane, epicurzerenone and cis-1,3-dimethyl-2-methylene cyclohexane. These compounds are correlated with mice hepatocyte apoptosis and PARP-1 expression. The highest PARP-1 expression was shown by the essential oil group at a dosage of 0.06g kg\(^{-1}\).

Chosdu (2008) has shown that gamma radiation processing as pasteurization method and as method of sprouting inhibition of *Curcuma aeruginosa* rhizome was beneficial and can be useful on a broad scale in pharmaceutical industries. Gamma radiation at irradiation doses of 0.06- 0.08kGy was sufficient to inhibit sprouting of fresh harvested rhizomes and it prolonged its storage life for 6- 8 weeks. Also 10kGy gamma radiation was sufficient to reduce the microbes which contaminated the dried rhizome by 2- 4 log cycles.
2.4.10. Propagation and micropropagation

The propagation of *Curcuma aeruginosa* is through the underground rhizome and natural propagation is very low. Propagation using rhizomes cannot be done in winter because of its dormancy in this period. *In vitro* plant tissue culture method has been developed to overcome this drawback. Micropropagation helps to maintain uniform and consistent production of true to type plants within a short period of time (Selvakumar *et al*., 2007; Dheeranupattana *et al*., 2008). All the available micropropagation protocols of this plant use rhizome buds as explants.

Balachandran *et al*. (1990) have reported that the rhizome explants of the plant cultured on MS medium supplemented with 3mg l⁻¹ BA showed the highest multiplication rate. Theanphong *et al*. (2010) have reported a new protocol for the micropropagation of *Curcuma aeruginosa* in which MS medium supplemented with cytokinin and auxin at low concentration gave the highest number of new roots and the highest length of shoot.

Yusuf *et al*. (2007) compared the field performance of *in vitro* and *in vivo* derived plants of six medicinal *Curcuma* species including *Curcuma aeruginosa*. Also they developed an efficient protocol for *in vitro* propagation of these species through shoot bud. According to them the frequency of plants with well formed shoots was BAP (Benzy laminopurine) dependent and was inhibited by NAA. The optimum concentration of BAP for *in vitro* multiplication was found to be 3mg l⁻¹ for all the six species and the tissue culture derived plants were better than those developed by conventional methods.

A study by Dheeranupattana *et al*. (2008) on the effect of bud size and benzyladenine (BA) on *in vitro* propagation of *Curcuma*
*aeruginosa* has shown that rhizome buds of 3-4 cm in MS medium supplemented with 1 mg l\(^{-1}\) BA produced better results.

According to Choudhury *et al.* (2013) the rhizome of *Curcuma aeruginosa* can be successfully propagated through single node cutting and apical tip culture. 100% germination was obtained from longitudinal single nodal cuttings and apical tip culture and 90% germination from transverse single node cutting of the rhizome and the techniques have been suggested as good methods for the conservation of the species.

### 2.4.11. Genetic variability

The genetic variability of *Curcuma aeruginosa* has not been studied very much. However, some efforts have been made to analyze the genetic variability of the genus *Curcuma*. Zaveska *et al.* (2011) investigated the intra-populational genetic variability in *Curcuma* species with the aid of AFLP. They found that the hexaploid species exhibit significantly higher genetic diversity than higher polyploids and it is largely influenced by the mode of reproduction since the higher polyploids reproduce vegetatively whereas the hexaploid species mainly reproduce sexually.

A study using isozymes for the first time for the identification of some early flowering *Curcuma* species was carried out by Apavatjrut *et al.* (1999) and they reported the relationship within the taxonomically still confusing groups. With the help of molecular markers, relationship within these groups was also evaluated. Out of the 21 isozymes used, 8 produced polymorphic patterns which were used for the study. Cluster analysis of isozyme data of the seven species studied showed that *Curcuma rubescence* Roxb. was separated from the other taxa while *Curcuma aeruginosa* Roxb. and *Curcuma zedoara* Rosc. were grouped
with two unidentified taxa at different degrees of similarity together with *Curcuma xanthorrhiza* Roxb. and *Curcuma elata* Roxb.

Srirugsa *et al.* (2007) grouped *Curcuma aeruginosa* along with *Curcuma amada*, *Curcuma angustifolia*, *Curcuma aromatic*, *Curcuma comosa*, *Curcuma latifolia*, *Curcuma leucorhiza*, *Curcuma longa*, *Curcuma mangga*, *Curcuma rubescens*, *Curcuma viridiflora*, *Curcuma zanthorrhiza* and *Curcuma zedoaria* in to ‘Longa’ group based on morphological characters during their taxonomic studies on the genus *Curcuma* in Thailand.

Syamkumar and Sasikumar (2007) characterized 15 species of the genus *Curcuma* using Inter Simple Sequence Repeats (ISSR) and Random Amplified Polymorphic DNA (RAPD) markers. 39 RAPD primers yielded 352 polymorphic bands and 8 ISSR primers yielded 87 polymorphic bands. Based on the molecular genetic fingerprints they elucidated the genetic variability/relatedness among these species. All the 15 species studied were placed into seven groups and these were bifurcated in to two major clusters. They paired *Curcuma aeruginosa* with *Curcuma caesia* into the fourth group in the second cluster, because of the overall similarity which was of 72% between them.

Aromdee *et al.* (2011) isolated DNA from the mature rhizome of *Curcuma aeruginosa* and its related species and conducted DNA fingerprinting via RAPD analysis with the help of six random decamers such as OPA02, OPA03, OPA13, OPA20, OPE4 and OPE7. All the primers except OPA02 produced clear reproducing polymorphic bands between *Curcuma aeruginosa* and other related species and the data were used for designing a standard for the identity of *Curcuma aeruginosa* rhizome.
Rajeshkumar (2013) investigated the variations among some species of *Curcuma* and *Zingiber* at molecular level through RAPD and ISSR analysis of the leaves using 42 RAPD and 8 ISSR primers. During the analysis 20 RAPD and 7 ISSR primers exhibited polymorphic bands in all *Curcuma* species selected which were used for further analysis. The number of polymorphic bands shown by *Curcuma aeruginosa* ranged from 2 to 9 in which primer OPC10 showed the highest polymorphic bands of 9 which was followed by OPA17, OPA12, OPA07, OPC08, OPC09, OPC12 and OPB16, and OPA 08 showed the lowest number which was 2. The ISSR primer ISSR7 showed the highest number of polymorphic bands and ISSR5 showed only a single band. UPGMA cluster analysis lead to the construction of dendrograms of relatedness and 19 species were grouped into two clusters of which *Curcuma aeruginosa* with other 17 species belonged to cluster II. Further division of cluster II into cluster IIA and II B with an overall Jaccard’s Similarity Coefficient of 25% placed *Curcuma aeruginosa* into cluster IIB. Finally he paired *Curcuma aeruginosa* along with *Curcuma zanthorrhiza* into a group because of their 34.7% Jaccard’s Similarity Coefficient.

Nurcholis *et al.* (2016b) evaluated the variability in curcuminoid content and cytotoxic activity of the ethanolic extracts of 20 *Curcuma aeruginosa* genotypes of different locations of Indonesia to identify superior accessions with good curcuminoid content and cytotoxic activity for use in industrial breeding programmes. Considerable variation was observed in curcuminoid content and cytotoxic activity. Total curcuminoid content, curcumin content, demethoxy curcumin content and bisdemethoxy curcumin content varied from 0.0.% to 1.95%, 0.01% to 1.45%, 0.01% to 0.47% and 0.01% to 0.03% respectively. All the accessions showed cytotoxicity. However, a low
positive correlation occurred between cytotoxicity and the percentages of curcumin, demethoxy curcumin, bisdemethoxy curcumin and curcuminoids.

2.4.12. Extraction and nature of starch

The traditional method for the extraction of starch from the rhizomes of *Curcuma aeruginosa* has been explained by Sabu and Skornickova (2003). In South India, the rhizomes are harvested during December-January soon after the drying of the aerial parts of the plant. The outer skin of the rhizomes is removed, the peeled rhizomes are washed thoroughly in cold water and then it is dipped in water for a few hours. The rhizomes are then rubbed on a specially made tin sheet grater to get the rhizomes into a paste form. Recently, grinder or mixer is used for this purpose. The paste is then mixed with water and this mixture is sieved through a fine cloth attached to the mouth of a vessel. This sieving allows the fine particles of starch grains to pass through it and settle at the bottom of the vessel. Addition of a drop of oil in the water will prevent coagulation of the powder. The settled powder also contains some brown dirt particles at the top of the powder which can be removed by mixing with water and decanting. It also removes the bitter taste. This mixing and decanting is repeated many times, until the water becomes clear and the powder is white. The powder is then taken out of water and sun dried in a cloth. This dehydrated powder can be stored for a long time without any change in colour or taste and it is believed that the medicinal value will increase as the powder becomes aged. From 1kg of rhizome, approximately 125g of pure starch can be extracted.
According to Vimala (2002), *Curcuma aeruginosa* starch showed 99.97% digestion at 24 hours, similar to that of cassava and higher than that of arrowroot.

**2.4.13. Traditional uses**

Rhizome of *Curcuma aeruginosa* is used for the treatment of various diseases in different systems of medicine as reported below:

- The rhizome is used to treat asthma and cough, scurvy and mental derangements and it is added in a beverage given to women in confinement to accelerate lochia and decrease pain and inflammation of uterus (Pongbunrod, 1979; Perry, 1980; Ibrahim and Abd. Rahman, 1988).
- The rhizome is used in Malaysia in the treatment of breathlessness, worm infestation, obesity and skin diseases (Arifin, 2005).
- The starch obtained from the rhizome of *Curcuma aeruginosa* is used as an effective remedy for infantile diarrhoea and is also recommended for children and invalids (Ranjini and Vijayan, 2005).
- Traditionally used to treat rheumatism, contusions and irregular menstruation (Hembing, 2007).
- Used as gastrointestinal remedy and spice in east and southern Asia and as medicine in child birth because of its purgative action (Sukari *et al*., 2007).
- Used in Indonesia to treat piles, gonorrhea, antidote, prolapsed uterus and to prevent spread of diseases in infants through mother’s milk (Hariana, 2008).
- Used to treat asthma and cough and as a paste with coconut oil for dandruff in Malaysia (Singh, 2011).
• Used as a natural herbal medicine to overcome appetite, skin diseases like scabies, rash and ulcers, stomach pains (colic), mouth sores, cough, shortness of breath and intestinal worms (Anonymous, 2011b).

• Used as a blood purifier after birth/menstruation and carminative and stimulant for appetite (Anonymous, 2012c).

• Helps to neutralize toxins and aids to fight scabies, ulcers, asthma and thrush (Anonymous, 2012c).

• Used for the treatment of stomach ache and fevers (Pfoze et al., 2013).

• Used for the treatment of pain and inflammation related with rheumatic diseases (Hossain et al., 2015).

The above review of the available literature gives a general idea on different aspects of Curcuma aeruginosa and also the major lacunae in the case of the information available. Exploring, collecting, documenting and analyzing the diversity of the genetic resources of this species have not been yet carried out on a significant scale. Such efforts to document, conserve and evaluate the genetic diversity of the species on a geographical basis are very important since all the marginalized crops of this type that grow neglected in the hamlets of native settlements of poor people are being devastated resulting in the erosion of their valuable genetic potential due to unplanned developmental activities without any care to the environment and ecology of such ecosystems. In the above state of affairs the present experiments have been designed and carried out so as to study the variability of the genotypes of Curcuma aeruginosa and the interrelationship and association of the growth and yield characters of it. An effort has also been made to optimize the nature of the rhizomes that could be used as planting materials.