2.1. Origin of *Jatropha*

*Jatropha* is believed to have been spread by Portuguese seafarers from its centre of origin in Central America and Mexico via Cape Verde and Guinea Bissau to other countries in Africa and Asia. It is now widespread throughout the tropics and sub-tropics. Until recently, *Jatropha* had economic importance in Cape Verde. Since the first half of the nineteenth century, with its ability to grow on poor soils with low rainfall, it could be exploited for oilseed production. Cape Verde exported about 35000 tones of *Jatropha* seeds per year to Lisbon. Along with Madagascar, Benin and Guinea, it also exported *Jatropha* seeds to Marseille where oil was extracted for soap production. However, this trade declined in the 1950s with the development of cheaper synthetic detergents and by the 1970s, the trade in *Jatropha* oil had disappeared (Wiesenhutter, 2003; Henning, 2004).

In the past, *Jatropha* oil was used for lighting lamps (Gubitz et al., 1999). Today, rural communities continue to use it for its medicinal value and for local soap production. India and many countries in Africa use *Jatropha* plant as a living hedge to keep out grazing livestock. *Jatropha* is planted in Madagascar and Uganda to provide physical support for vanilla plants. *Jatropha*’s potential as a petroleum fuel substitute has long been recognized. It was used during the Second World War as a diesel substitute in Madagascar, Benin and Cape Verde,
while its glycerine byproduct was valuable for the manufacture of nitroglycerine.

2.2. Taxonomy of Jatropha

**Kingdom:** Plantae

**Plant Subkingdom:** Tracheobionta

**Vascular plants Super division:** Spermatophyta

**Seed plant Division:** Magnoliophyta

**Flowering plants Class:** Magnoliopsida

**Dicotyledons Subclass:** Rosidae

**Order:** Euphorbiales

**Family:** Euphorbiaceae

**Genus:** Jatropha

**Species:** curcas L.

*Jatropha curcas* was first described by Swedish botanist Carl Linnaeus in 1753. It is one of many species of the genus *Jatropha*, a member of the large and diverse Euphorbiaceae family. Many of the *Euphorbias* are known for their production of phytotoxins and milky white sap. The common name “spurge” refers to the purgative properties of many of these Euphorbias. There are some 170 known species of *Jatropha*, mostly native to the New World, although 66
species have been identified as originating in the Old World (Heller, 1996). A number of *Jatropha* species are well known and widely cultivated throughout the tropics as ornamental plants. Accordingly, three varieties: Nicaraguan (with larger but fewer fruits), Mexican (distinguished by its less-toxic or non-toxic seed) and Cape Verde. The Cape Verde variety is the one commonly found throughout Africa and Asia. *Jatropha curcas* L. has many vernacular names including: physic nut or purging nut (English), *pinhão manso* or *mundubi-assu* (Brazil), *pourghère* (French), *purgeernoot* (Dutch), *Purgiernuss* (German), *purgeira* (Portuguese), *fagiola d’India* (Italian), *galamaluca* (Mozambique), *habel meluk* (Arab), *safed arand* (Hindi), *sabudam* (Thai), *bagani* (Ivory Coast), *butuje* (Nigeria), *makaen* (Tanzania), *piñoncillo* (Mexico), *tempate* (Costa Rica) and *piñon* (Guatemala). The genus *Jatropha* belonging to Euphorbiaceae family of plant kingdom, is a diploid with chromosome number (2n) 22, consisting of about 175 species in the world. In India, the following 18 species are found scattered in various states of the country.

- *Jatropha curcas*
- *Jatropha gossypifolia*
- *Jatropha glandulifera*
- *Jatropha heynei*
- *Jatropha integerrima*
- *Jatropha maheshwarii*
- *Jatropha multifida*
2.3. Description of *Jatropha*

*Jatropha* develops into a shrub or tree of 6 meter with spreading branches and stubby twigs and with a milky or yellowish rufescent exudate. Leaves are deciduous, alternate but apically crowded, ovate, acute to acuminate, basally cordate, 3 to 5-lobed in outline, 6–40 cm long, 6–35 cm broad, the petioles 2.5–7.5 cm long. The flowers are several to many in greenish cymes, yellowish, bell-shaped; sepals 5, broadly deltoid. Male flowers many with 10 stamens, 5 united at the base only, 5 united into a column. Female flower borne singly, with elliptic 3-celled, triovulate ovary with 3 spread bifurcate stigma. Capsules are 2.5–4 cm long, finally drying and splitting into 3 valves, all or two of which commonly
have an oblong black seed, these seeds are of 2 x 1 cm long (Morton, 1977; Little et al., 1974).

*Jatropha* sheds its leaves during the dry season. It can withstand only a very light frost that causes it to lose all of its leaves, and the seed yield will probably decline sharply. Benge (2006), states that the current distribution shows that introduction has been most successful in drier regions of the tropics with an average annual rainfall between 300 and 1000mm, and seems to thrive well mainly at lower altitudes. *Jatropha* is warm loving and is not expected to perform well in areas with low temperatures or even frost.

2.4. Importance of *Jatropha*

2.4.1. Medicinal Importance of *Jatropha*

According to Ochse (1980), "the young leaves may be safely eaten, steamed or stewed." They are favored for cooking with goat meat, said to counteract the peculiar smell. Though purgative, the nuts are sometimes roasted and dangerously eaten. In India, pounded leaves are applied near horses' eyes to repel flies. The oil is used for illumination, making soap and candles, adulterate of olive oil, and making Turkey red oil. Nuts can be strung on grass and burned like candlenuts (Watt and Breyer-Brandwijk, 1962). Ashe of the burned roots is used as a salt substitute (Morton, 1981). Agaceta et al.; (1981) concluded that it has strong molluscicidal activity. Duke and Wain (1981) list it as homicide, piscicide, and raticide as well. The latex was strongly inhibitory to watermelon
mosaic virus (Tewari and Shukla, 1982). Bark is used as a fish poison (Watt and Breyer-Brandwijk, 1962). In South Sudan, the seed as well as the fruit is used as a contraceptive (List and Horhammer, 1969–1979). The sap stains linen and can be used for marking (Mitchell and Rook, 1979). Little, Woodbury and Wadsworth (1974) list the species as a honey plant.

According to Hartwell (1967-1971), the extract is used in folk remedies for cancer. Reported to be abortifacient, anodyne, antiseptic, cicatrizant, depurative, diuretic, emetic, hemostat, lactagogue, narcotic, purgative, rubefacient, styptic, vermifuge, and vulnerary physic nut is a folk remedy for alopecia, anasarca, ascites, burns, carbuncles, convulsions, cough, dermatitis, diarrhea, dropsy, dysentery, dyspepsia, eczema, erysipelas, fever, gonorrhea, hernia, incontinence, inflammation, jaundice, neuralgia, paralysis, parturition, pleurisy, pneumonia, rash, rheumatism, scabies, sciatica, sores, stomachache, syphilis, tetanus, thrush, tumors, ulcers, uterosis, whitlows, yaws, and yellow fever (Duke and Wain, 1981; List and Horhammer, 1969–1979). Latex is applied topically to bee and wasp stings. Mauritians massage ascitic limbs with the oil. Cameroon natives apply the leaf decoction in arthritis (Watt and Breyer-Brandwijk, 1962). Colombians drink the leaf decoction for venereal disease. Bahamans drink the decoction for heartburn. Costa Ricans poultice leaves onto erysipelas and splenosis. Guatemalans place heated leaves on the breast as a lactagogue. Cubans apply the latex to toothache. Colombians and Costa Ricans apply the latex to burns, hemorrhoids, ringworm, and ulcers. Barbadians use the
leaf tea for marasmus and Panamanians for jaundice. Venezuelans take the root
decoction for dysentery (Morton, 1981). Seeds are used also for dropsy, gout,
paralysis, and skin ailments (Watt and Breyer-Brandwijk, 1962). Leaves are
regarded as antiparasitic, applied to scabies; rubefacient for paralysis,
rheumatism; also applied to hard tumors (Hartwell, 1967–1971). Latex is used to
dress sores and ulcers and inflamed tongues (Perry, 1980).

2.5. Biochemistry of *Jatropha*

Per 100 g, the seed is reported to contain 6.6 g H₂O, 18.2 g protein, 38.0 g fat,
33.5 g total carbohydrate, 15.5 g fiber, and 4.5 g ash (Duke, 1983). Leaves,
which show antileukemic activity, contain □-amyrin, □-sitosterol, stigmasterol,
and campesterol, 7-keto-□-sitosterol, stigmast-5-ene-3-□, 7-□-diol, and
stigmast-5-ene-3 □, 7 □-diol (Morton, 1981). Leaves contain isovitexin and
vitexin. In the drug (nut) saccharose, raffinose, stachyose, glucose, fructose,
galactose, protein, and an oil, largely of oleic- and linoleic-acids (List and
Horhammer, 1969–1979), curcasin, arachidic-, linoleic-, myristic-, oleic-,
palmitic-, and stearic-acids are also reported (Perry, 1980).

2.6. Multipurpose use of *Jatropha* seed oil

2.6.1 Potential as an oil crop

*Jatropha curcas* seeds show the presence of, 6.62 moisture, 18.2 protein,
38.0 fat, 17.30 carbohydrates, 15.50 fibers, and 4.5% ash. The oil content is 35 to
40% in the seeds and 50 to 60% in the kernel. The oil contains 21% saturated
fatty acids and 79% unsaturated fatty acids. It has also been found that there are some chemical elements in the seeds which possess poisonous and purgative properties and render the oil non edible for human consumption. It is also been stated that technologies are now available whereby it could be possible to convert *Jatropha* oil into an edible oil which could prove to be a boon for developing countries. The oil is obtained from decorticates seeds by expression or solvent extraction and is known in trade as *Jatropha*. In general, the oil is reported to be mixed with groundnut oil for adulteration. This indicates the possibilities of obtaining edible oil from *Jatropha* oil base (Gubitz et al., 1999).

### 2.6.2. Potential for industrial use

In China, a varnish is prepared by boiling the oil with iron oxide. *Jatropha* oil has very high saponification value and being extensively used for making soap in India and other countries. At present, *Jatropha curcas* oil is being imported to meet the demand of cosmetic industry. In villages it is used as an illuminant as it burns bricant and candles as in case of castor oil. It is used for wool spinning in England. The protein content *Jatropha* oil cake may be used as raw material for plastics and synthetic fibers. It would also be advantageous to make use of *Jatropha* oil as hydraulic oil (Gubitz et al., 1999).

### 2.6.3. Potential as raw material for dye

The dye may be extracted from leaves and tender stems and concentrated to yellowish syrup or dried to blackish brown lumpy mass. The bark of *Jatropha curcas* yields a dark blue dye which is reported to be used in Philippines for
coloring cloth, finishing nets and lines. The dye imparts to cotton different shades of tan and brown which are fairly fast. Further research in this field can open up great possibilities (Gubitz et al., 1999).

2.6.4. Potential for enrichment of soil

*Jatropha curcas* leaves provide abundant organic matter and increase the microbial activity including earthworms which is an indication of ecological improvement of site (Gubitz et al., 1999). Tender branches and leaves are also used as manure for coconut trees. *Jatropha* oil cake is rich in nitrogen, phosphorous and potassium and can be used as organic manure. This indicates that this property of the plant can lead to the reduction of keeping large number of livestock by the rural folk in India mainly for the purpose of obtaining cow-dung as manure. *Jatropha* oil cakes can, hopefully, replace synthetic fertilizers by undertaking plantations of *Jatropha curcas* on wastelands,

2.6.5. Potential as a feedstock

*Jatropha* leaves are used as feed for the tusser silk worm. The oil cake is rich in protein but contains some toxic principle and as such it is considered unfit for use as cattle feed. But it is reported that the poisonous principle appears to exist in the alcohol soluble fraction of the oil. With suitable research it could be possible to convert the nonedible oil-cake into protein rich cattle and poultry feed on a massive scale (Gubitz et al., 1999).
2.7. Potential as non-conventional energy crop

*Jatropha* oil is an environmentally safe, cost effective and renewable source of non-conventional energy as a promising substitute to hydelpower, diesel, kerosene, LPG, coal, firewood etc. The fuel properties of the *Jatropha* oil closely resembles with the diesel oil. It was found that the specific gravity of *Jatropha* oil is 0.9180 (gr/ml) compared to diesel oil which is 0.8410 (gr/ml). Calorific value of the *Jatropha* oil is 41 MJ/kg and diesel oil is 45 MJ/kg (Rosenblum, 2000; Gubitz, 1999). Similarly, it has been reported that the flash point of *Jatropha* oil and diesel are 240 and 500°C respectively. In addition to this, cetane number of Bio-oil and Diesel is 51 and 50 respectively. Likewise, the Sulphur weight (%) of *Jatropha* oil and Diesel are 0.13 and 1.2 respectively.

2.8. Plantation of *Jatropha curcas*

2.8.1. Soil requirement

*Jatropha curcas* can be grown potentially over wastelands which require re-vegetations. *Jatropha curcas* is a wild growing hardy plant well adapted to acid and moisture demand and can come up in stony, gravelly or sallo and even calcareous soils. It can be conveniently propagated from seeds as well as branch cuttings. It is, therefore, possible to plant large areas with *Jatropha curcas*, without requiring nursery plants raised in polythene bags, which can save foreign exchange as the raw material for polythene bags has to be imported. However, it can also be grown as a profitable non-edible oil crop on irrigated and partially irrigated lands as a perennial crop (Radich, 2004)
2.8.2. Spacing and seeds rate

For planting one hectare, around 5 to 6 kg of seeds is enough. The distance between the two rows should be 2 meters and the distance between two plants should also be 2 meters. This spacing will accommodate 2500 plants/ha under irrigated or partially irrigated conditions. On rainfed wastelands, high-density plantations at 2m x 1m. or 1.5 x 1.5 meter accommodating 5000 or 4444 plants per hectare respectively, was desirable (Radich, 2004; Gubitz et al., 1999).

2.8.3. Climate requirements

*Jatropha* can be grown over a wide range of arid or semi-arid climate conditions. For the emergence of seeds, hot and humid climate is preferred. Therefore, fairly warm summers with rains are beneficial for proper germination of seeds. Flowering is induced in rainy season with reduction in temperature and plants bear fruits in winter. *Jatropha* can be cultivated with successfully in areas with scanty to heavy rainfall (Gubitz et al., 1999). *Jatropha* can be grown in habitat of tropic/subtropical areas, with a suitable rainfall of 200-1500 mm/year.

2.8.4. Propagation

*Jatropha* can be propagated from seeds as well as from cuttings. Seeds or cutting twigs can be directly planted in the main field. Otherwise, seedlings grown in polybags are transplanted in the main field.

**Direct Planting:** The lands should be ploughed once or twice, depending on the nature of soil. In the case of heavy soils, deep ploughing is needed whereas in light soils, shallow ploughing is enough. The seed/cutting should be
planted in the main field with the onset of monsoon. Two seeds should be
dibbled at each spot at a spacing indicated above. When the seedlings are 4
weeks old, the weaker seedlings should be removed to retain one healthy seeding
on each spot and the seedlings so removed could be used for gap filling (Gubitz
et al., 1999).

**Transplanting:** Main field is prepared by digging small pits of 30 x 30 x
30 x 30 cm. The pits are filled with soil and compost or organic manure at the
rate of 400 g per pit. One Kilogram capacity, filled with soil and organic manure
mixture is 7:10:05 at the rate of 100 g per poly bag plus 400 g soil. Two seeds
should be sown around 6 cm deep in each poly bag and watering should be done
regularly. When the seedlings are around 4 weeks the weaker of the two
seedlings should be removed and used for gap filling (Gubitz et al., 1999).

**2.8.5. Irrigation**

In case of proper and well distributed monsoon, additional irrigation
during rainy season is not required. During dry period, the crop should be
irrigated as and when required.

**2.9. Potential of Jatropha cultivation in India**

The country has 168 million ha. arable land out of its 328.73 million ha.
geographical area. There is about 63 million ha. wastelands in the country, out of
which about 40 million ha. area can be developed by undertaking plantations of
*Jatropha*. 
2.9.1. Intercropping

The inter-cropping during initial years of plantation, i.e. up to gestation period, is suggested to increase income per unit area. The crops being utilized for inter-cropping should have the following characteristics:

- Annual crops having no competition in nutrient uptake, height, shade etc.
- Leguminous in nature to increase soil fertility
- Require less spacing, irrigation etc.
- Shade loving
- Having high economic value

Keeping in view of the above, the following crops need be selected for intercropping by Ministry of Agriculture, Government of India.

- **Pulse & oilseed crops**: Moong, Urd, Gram, Pea, Lentil, Cowpea, Sesamum, Soybean, Rapeseed, Mustard, Linseed etc.

- **Vegetable crops**: Ginger, Potato, Sweet potato, Carrot, Bitter guard, Tomato, Cucumber, Chilly, Cucurbits etc.

- **Medicinal & aromatic crops**: Mentha, Ashwagandha, Kalmegh, Sarpgandha, Isabgol, Satavar etc.

While intercropping during the first five years of a *Jatropha* plantation is a common practice, there have been few studies on intercrop yields, plant spacing or optimal management practices. The same applies to permanent intercropping systems and agroforestry. Plate 10 shows the intercropping of young *Jatropha* trees in India. Trials in Uttar Pradesh, India, found that
groundnuts could be grown successfully between lines of *Jatropha* trees spaced 3.0 meters apart and pruned down to 65 cm. Groundnuts were planted in the dry season with limited irrigation, when there was no leaf cover from the *Jatropha*. It was found that this system helped with weed control of the plantation and that the growth of intercropped *Jatropha* was better than the non intercropped control (Singh *et al.*, 2007).

2.10 *Jatropha* Impact on the Soil

Worldwide, an estimated 3.7 million acres (1.5 million hectares) of agricultural land is lost yearly to salinization and water logging. As the loss of topsoil continues, however, the decrease in productivity and increase in vulnerability to drought also continues (Wright, 2008). In Zambia, there have been fears that *Jatropha* cultivation could be detrimental to the soil. Unsubstantiated reports have been circulated around in both electronic and print media that *Jatropha* destroys the soil. However, such reports have not been backed up with scientific proof. Since *Jatropha* has a deep reaching tap root, it is able to “pump” minerals from the depth of the soil to the surface. This leads to a rehabilitation of degraded land or fields. The report further revealed that there was a slight increase in soil pH with *Jatropha* production.

2.11. Allelopathic Effect of *Jatropha curcas*

Secondary metabolites are phytochemicals produced as by-products of primary metabolism (Bako and Aguh, 2007) and are less widespread in plants. It is of course this restricted occurrence among plants that renders them valuable
and useful in taxonomic delimitation of species. The groups of compounds mostly utilized for this purpose include alkaloids, phenolics, glucosinolates, amino acids, terpenoids, oils and waxes, carbohydrates and crystals. Recent investigations and reports of the usefulness of these compounds either for medicinal/therapeutic purposes or taxonomic elucidation of species include Edeoga et al., (2005), Hassan et al., (2007), Ibrahim et al., (2007), Mallikharjunah et al., (2007), Irshad et al., (2010), Nyananyo et al., (2010), Rasool et al., (2010), Ganesh and Vennila (2011). The only phytochemical report known to the authors on Jatropha species occurring in the Niger Delta is that of Burkill (1994). This simply reported the occurrence of tannins in the leaves of J. gossypifolia and saponin in the leaf of J. multifida.

Aqueous extracts of Jatropha curcas leaves and roots inhibited the growth of corn (Zea mays) and tobacco (Nicotiana tabacum). Increased inhibition by increasing the concentration of extracts suggests that the extracts may have inhibitory substance which possesses allelopathic potential. Different extracts of leaves and roots of J. curcas were bio-assayed and analyzed. The main allelopathic substance was determined by gas chromatography-mass spectrometry (GC-MS) data as azelaic acid. This compound inhibited the germination of Z. mays seeds at concentrations greater than 500 µg ml-1, but the shoot and root growth were inhibited at concentrations greater than 100 µg ml-1. The root and shoot growth were inhibited by 50% at 270 and 654 µg ml-1, respectively. The percentage of azelaic acid in distilled water extracts of leaves
was at least 0.94%, which indicated that azelaic acid may provide a competitive advantage to *J. curcas* in the defense mechanism by inhibiting the growth of neighboring crops (Yuan Ma *et al.*, 2011)

According to Abugre and Quashie-Sam (2010) the effect of aqueous extracts of *Jatropha curcas* on four traditional crops (*Phaseolus vulgaris*, *Zea mays*, *Lycopersicon lycopersicum* & *Hibiscus esculentus*) was examined. Aqueous extracts from leaves (L) and roots (R) of *Jatropha curcas* were prepared at different concentrations of 2%, 4%, 6%, 8%, 10% and applied to the test crops. All the crops were affected by the different concentrations of aqueous extracts. The most pronounced effect was on *H. esculentus*, where germination, radicle and plumule length were reduced by a range of 58.34%-97.92%, 35.84-94.33% and 1.65-87.55%, respectively. Extract at higher concentrations of *J. curcas* had a strong inhibitory effect on germination, radicle and plumule length of all the test crops. The highest inhibition of seed germination was by 5.26% in R8 for *Z. mays*, 24.28% in R10 for *L. lycopersicum*, 15.41% in R10 for *P. vulgaris* and 97.92% in L10 for *H. esculentus*. The highest reduction in radicle length of 65.34%, 91.03%, 65.95% and 94.33% was recorded at L8, L8, L10, L10 for *Z. mays*, *L. lycopersicum*, *P. vulgaris* and *H. esculentus*, respectively. The highest inhibitory effect in plumule length was 70.08%, 87.15%, 66.35% and 87.55% at L8, L10, L10 and L10 for *Z. mays*, *lycopersicum*, *P. vulgaris* and *H. esculentus*, respectively.
The allelopathic effects of leaf leachates and residues of *Jatropha curcas* amended into soil were determined on the growth, relative membrane permeability (RMP) and the proline content of marigold (*Tagetes erecta*) seedlings. The application of leaf leachates of *J. curcas* in the soil significantly inhibited the shoot and root length of marigold compared to unamended soils. The leaf leachates increased the RMP and proline content in the roots of marigold seedlings. The leachates concentrations did not influence the soil pH; however their 75 and 100% concentrations increased the soil electrical conductivity (EC) by 128 and 215%, respectively, over the control. Similarly the *J. curcas* residues incorporated into soil were more phytotoxic to the root than shoot growth of marigold seedlings. During the decomposition, RMP was increased from 37.11 to 56.72% and proline from 19.68 to 37.66 μmol^{-1}fw. In the soil incorporated with the residues, the phytotoxicity to growth, RMP and proline content in the seedlings increased with increasing amount of residues incorporated and decreased over time. During the decomposition, the electrical conductivity (EC) varied with magnitude of inhibition, whereas, pH was not correlated to inhibition (Wang J. C, et al., 2009).

The allelopathic effect of three accessions of *Jatropha curcas* on four field crops viz., *Triticum aestivum*, *Brassica juncea*, *Sesamum orientale* and *Vigna mungo*. The level of inhibition of the aqueous leaf extract of *J. curcas* varied with its accessions and type of tested field crops. The tolerance of the crops was in the order of *V. mungo>*T. aestivum>*B. juncea>*S. orientale.
Invariably, maximum inhibition was observed in the higher concentrations of aqueous extract. (Venkatesh, A, et al., 2011).

*Jatropha curcas* on mustard (*Brassica juncea*) cv RH-30, taramira (*Eruca sativa*) cv T-27, Chickpea (*Cicer arietinum*) cv HC-5 and Barley (*Hordeum vulgare*) cv-BH-393. Pot experiment was conducted. Pots were incorporated with dry senescent leaves with soil at 15, 20 and 25 q/ha. As the doses of *Jatropha* leaf litter increased, the growth, yield and yield attributes of test crops were also increased up to 20 q/ha, thereafter, it reduced at 25 q/ha but significantly higher than control (Singh, M. K. et al., 2010).

2.12. Allelochemicals

Allelochemicals include mainly the plant secondary metabolites (Levin, D.A., 1976). They exhibit allelopathic effect either on the growth and development of the same plant or nearby plant species. The term allelochemicals include, (a) plant biochemicals that exert their physiological/toxicological action on plants (allelopathy, autotoxicity or phytotoxicity), (b) plant biochemicals that exert their physiological/toxicological action on microorganisms (allelopathy or phytotoxicity) and (c) microbial biochemicals that exert their physiological/toxicological action on plants (allelopathy and phytotoxicity). About 125 natural allelopathic compounds were isolated by Macias et al., (2002) from different cultivars of sunflower, showing phytotoxic effects on growth of many weed species. Macias et al., (2000) investigated the effect of several
compounds isolated from *Helianthus annus* on different dicotyledon and monocotyledon species. Secondary compounds are metabolically active in plants and microorganisms, their biosynthesis and biodegradation play a key role in the ecophysiology of the organism in which they occur (Waller and Nowacki, 1978; Waller and Dermer, 1981). Some of them are accumulated at various stages of growth, while, accumulation of some compounds depends upon season.

**2.12.1. Classes of Allelochemicals**

The allelochemicals are biosynthesized from the metabolism of carbohydrates, fats and amino acids and arise from acetate or the shikimic acid pathway (Robinson, 1983). Therefore, in a review of the potential use of allelochemicals as herbicides, the allelochemicals isolated from terrestrial and aquatic plants include: Alkaloids, benzoxazinones, cilmamic acid derivatives, cyanogenic compounds, ethylene and other seed germination stimulants and flavonoids.

**2.12.2. Occurrence of Allelochemicals**

The presence of allelochemicals in higher plant species and microbes has been documented by several researchers. These are originated in upper or lower plant parts or in both and posses allelopathic impacts on a broad range of plant species. The allelochemicals may be found in all parts of the plants such as seeds, flowers, pollen, leaves, stems, roots etc (Rice, 1974).
2.12.3. Leaves

They are the most important sources of allelochemicals. Specific inhibitors in leaves have been demonstrated by many researchers, root and stem exhibit allelochemicals usually of low potency and in lesser amounts.

2.12.4. Flowers/inflorescence and Pollen

There is increasing evidence that the pollen of corn and sunflower have allelopathic properties.

2.12.5. Fruits and Seeds

Fruits and seeds contain allelochemicals which have been found inhibitory to microbial growth and seed germination.

2.12.6. Modes of release of Allelochemicals

A major pre-requisite of allelopathy is that allelochemical be transferred from a donor plant to a recipient plant. Therefore, mode of transfer may play a great role in toxicity and persistence of 3 allelochemicals. Once these chemicals from the donor plants are released into the environment, they may be either degraded or transformed into other forms, which affect the receiver plants and may also be toxic to the host plant (autotoxicity).

2.12.7. Volatalization

Allelochemicals may volatilize from the plants to the atmosphere. The volatile vapours may be absorbed directly from the atmosphere by plants. The
absorbed vapours may condensate into dew and fall on the ground. These volatile compounds may be absorbed on the soil particles and subsequently taken by plants from the soil solution. The genera which release volatiles are in *Artemisia, Salvia, Parthenium* and *Eucalyptus*. The camphene, camphor, cineole, dipentene, \( \alpha \)-pinene and \( \beta \)-pinene are volatile inhibitors produced by several shrubs of the Southern California Chaparral (White *et al.*, 1989). From the plants rich in such compounds, these may be released continuously as vapours to the atmosphere. The pulverized leaves of cruciferae species (*Brassica juncea*, *B. nigra*, *B. napus*, *B. rapa* and *B. oleracea*) also release volatile substances. The volatiles of *B. juncea* and *B. nigra* were most harmful to germinating seeds of lettuce and wheat (Oleszek, 1987).

### 2.12.8. Leaching

Many allelopathic compounds both organic and inorganic are leached, such as phenolic acids, terpenoids and alkaloids. The leaching of mineral nutrients, carbohydrates and phytohormones, may be beneficial for the growth of associated species; however, mainly toxic effects have been studied. Although seed leachates may also be important but mainly foliage leachates have been investigated. Toxin-bearing leachates are important in weed-crop associations and in plant plant interactions in grasslands.

### 2.12.9. Decomposition of Plant Residues

The decomposition of plant residues adds the largest quantity of allelochemicals to the soil. On plant death, materials compartmentalized in cells
are released into the environment. The nature of the plant residues, the soil type are important pre-requisite for decomposition. As the roots grow through the soil, at some point they may get in touch with decaying plant residues and are impacted by allelochemicals. Some of the toxic effects of decomposition products on plants are: inhibition of seed germination, stunted growth, and inhibition of the primary root system and increase in secondary roots, inadequate nutrient absorption, chlorosis; slow maturation and delay or failure of reproduction.

2.12.10. Factors Affecting Production of Allelochemicals

Rice (1984) observed that the following factors which affect the amount of allelochemicals produced viz., (a) radiation, (b) mineral deficiencies, (c) water stress, (d) temperature, (e) allelopathic agents, (f) age of plant organs, (g) genetics, (h) pathogens and (i) predators.

2.12.11. Mode of Action of Allelochemicals

Allelopathic agents influence the plant growth (Rice, 1984) through the following physiological processes viz., (i) cell division and cell elongation, (ii) phytohormone induced growth, (iii) membrane permeability, (iv) mineral uptake, (v) availability of soil phosphorus and potash, (vi) gas exchange and process of photosynthesis, (vii) respiration, (viii) protein synthesis and (ix) changes in lipid and organic acid metabolism, (x) inhibition of porphyrin synthesis, (xi) stimulation or inhibition of certain specific enzymes, (xii) corking and clogging
of xylem elements, (xiii) conductance of water through stem, (xiv) interior water relationships and (xv) miscellaneous.

2.12.12. Fate of Allelochemicals

The biological activity, persistence, movement and fate of natural products in the soil depend upon their interaction with the soil adsorption complex, soil microbial population and chemical environment of the soil. Absorbed allelochemicals may be biologically active or rendered inactive, depending on nature of the absorbing surface, but absorbed molecules are less available to soil microbes. Some natural products/allelochemicals may be irreversibly bound in soil humic substances. Thus, allelopathic effects in soil depend on the relative rates of allelochemicals, addition and fixation in the soil.

2.12.13. Crop-to-crop Interactions

Promising results were obtained by selecting allelopathic crop types, using allelopathic companion plants or crops (Weston and Duke, 2003). Usually the field crops put in phytotoxins or allelochemicals to the soils through crop residues and to a certain extent through root exudates, therefore, their allelopathic effects have been studied most.

2.12.14. Effect of Allelochemicals

Allelochemicals have mostly negative effects on crop plants such as: (a) delayed or complete inhibition of germination, (b) reduced plant population, (c)
stunted and deformed roots and shoots, (d) deranged nutrient absorption, (e) lack of seedling vigour, (f) reduced tillering, (g) chlorosis, (h) wilting, (i) increase susceptibility to disease (Walker and Jenkins, 1986; Waller et al., 1987; Oleszek and Jurzysta, 1987; Hicks et al., 1988). However, the main impacts of phytotoxins on crop plants are: (i) inhibition of nitrification and biological nitrogen fixation, (ii) predisposing the plants to diseases and (iii) inhibition or stimulation of germination, growth and yield.

2.12.15. Root exudates

Root exudates of crops influence the germination, development and yield of other crop plants. Therefore, root exudation plays a major role in crop mixtures or intercropping systems. The first report on harmful effects of root exudates of one plant on the growth of other plants was given by De Candolle (1832). Sorghum and maize root exudates inhibited the growth of sesame plants; therefore, the sesame could not be grown closer than 60 cm to live sorghum plants, which released natural toxins in the growing medium (Fletcher, 1912; Breazeale, 1924; Hawkins, 1925). Of the buckwheat, alfalfa, red clover, pea, soybean, rye, vetch and blue grass root exudates, only that of buckwheat reduced the yield of tomato (Alderman and Middleton, 1925). According to Overland (1966), Barley is an excellent smother crop due to its extensive root growth and root exudates, which inhibited the germination and growth of tobacco, chickpea etc. However, its root exudates had no inhibitory effect on wheat plants. The root
exudates from living plants contained the alkaloid 'gramine' and were more inhibitory effect than aqueous leachates of dead roots. This proved active metabolic secretion of allelopathic substances. Root exudates of rice varieties 'CB-1' and 'Rupsail' inhibited the root and shoot growth of test seedlings of both these varieties owing to presence of phenolic compounds and also abscisic acid. The maximum release of inhibitors in root exudates occurred under favourable climatic conditions for rice growth (Sadhu and Das 1971). Tobacco root exudates inhibited the germination of maize, mustard and foxtail seeds and subsequently their seedling growth (Haq and Hussain, 1979), while that of Chinese cabbage reduced radical growth and dry matter of Chinese cabbage and mustard (Akram and Hussain, 1987). The root exudates play significant role in living plants and may inhibit or stimulate the seed germination or seedling growth of associated weeds. The root exudates of rye (Borner, 1960), corn (Dzyubenko and Petrenko, 1971), oat (Fay and Duke, 1977), wheat and oat (Martin and Rademacher, 1960), sorghum (Forney et al., 1983; A1-Saadawi et al., 1985; Panasuik et al., 1986), alfalfa (Abdul-Rahman and Habib, 1989), lupine (Dzyubenko and Petrenko, 1971), soybean (Massantini et al., 1977; Rose et al., 1984), sunflower (Wilson and Rice, 1968) and buckwheat (Tszuki, 1980) inhibited the seed germination and stimulated the seed germination of red sorrel (Panasuik et al., 1986) and witchweed (Netzy et al., 1988). Sunflower (Leather, 1983) and sweet potato (Harrison and Peterson, 1986) decreased the seed germination and growth of weeds and growing crops of barley (Putnam and De Frank, 1983). Rice (1964)
reported that aqueous extracts of lambsquarter (*Chenopodium album*) and crabgrass (*Digitaria spp.*) inhibited the growth of nitrogen fixing and nitrifying bacteria. The inhibitors present in prostrate knotweed (*Polygonum aviculare*) inhibited the growth of *Rhizobium* and *Azotobacter* (Al-Saadawi and Rice, 1982). Phytotoxins produced during the decomposition of crop residues inhibit the nitrification process in the soil and biological nitrogen fixation in legumes. The maintenance of corn residues on the soil surface increased the concentration of nitrification inhibitors (ferolic and p-coumaric acids) in the soil, which decreased the population of nitrosomonas bacteria and thus increased the concentration of $\text{N}^+$ over $\text{NO}_3^-$ compared with the soil without corn residues (Lodhi, 1981). In south Taiwan, soybean following rice yielded higher when rice residues were burnt than when decomposed in the field, because phenolics produced from decomposing rice residues inhibited the growth of N fixing bacteria (*Rhizobium japonicum*), reduced nodule number and thus decreased biological nitrogen fixation in soybean (Rice, 1971). Similarly, soil incorporation of vines and storage root residues of sweet potato reduced the nodulation and nitrogen fixation in cowpea (Walker and Jellkins, 1986). In an 8-year study at Los Banos, there was found significant decrease in plant stand and yield of succeeding green gram crop (cultivated after green gram) was reported due to allelopathy (Ventura *et al*., 1984). It was caused by the multiplication of harmful soil microbe’s viz., fungi, bacteria, nematodes etc., and accumulation of
their microbial toxins which were phytotoxic to seed germination and seedling growth of green gram.

The phenolic acid has the property of altering mitochondria and chloroplasts membranes, hindering the energy transfer necessary to ion transport, as observed in spinach (Moreland and Novitzky, 1987). Coumarins seem to inhibit mitosis like colchicine, showing antimicrotubule effects. For phenolic acids, polyphenols (but not monophenols) seem to increase IAA-mediated growth by inhibiting IAA oxidative decarboxilation (Tomaszewski and Thimann, 1966). This can be extended for flavonoids. Antifungal flavonoids (pterocarpans) seem to have their activity related to the molecule’s non-planarity and to the presence of small oxygen-containing substituents in specific positions (Perrin and Cruickshank, 1969). Other factors, such as the presence of assymetric carbons and compound solubility as well as other physiochemical properties or the involvement of different receptors must be considered. Phenolic compounds are important in the formation of vegetational patterns and ecological succession processes, showing many applications on forestry and agriculture (Rice, 1987).

While terpenes and nitrogen containing compounds are recognized mostly in anti herbivore interactions, phenolic compounds are also related to defense against pathogens, mechanical support, attraction of pollinators and fruit dispersers, absorption of harmful ultraviolet radiation and in reducing the growth of competing plants (Taiz and Zeiger, 1998). Besides competition for moisture,
light and soil nutrients, plants have developed chemical defense mechanisms (allelopathy), through the use of simple-structured, low molecular weight secondary metabolites, whose effectiveness depend on the speed with which soil microorganisms are able to detoxify and metabolize them (Harborne, 1993). Chemical interactions involving plants and micro-organisms may be compatible or incompatible and begin with elicitor-mediated genetic recognition, which triggers signal amplification and gene activation.

According to Lakshmi Nandakumar and Rangaswamy, N.S. (1985) effects of isovitexin, leucocyanidin, gallic acid, and protocatechuic acid (allelochemicals) on seed germination and subsequent seedling growth of a crucifer *Brassica campestris*, and two legumes, *Lens esculenta* and *R. minima*, as well as effects of isovitexin on rooting of onion bulbs are described. Neither of the flavonoids affected seed germination in any of the three systems studied. However, both the flavonoids promoted seedling growth in *B. campestris* and *L. esculenta*; the promotion of root growth was more marked. At $10^{-5}$ and $10^{-7}$M, isovitexin also promoted rooting of onion bulbs. In the range of $2.27 \times 10^{-4}$M to $3.28 \times 10^{-3}$M, leucocyanidin promoted growth of both root and shoot in L. esculenta, whereas in the range $3.28 \times 10^{-3}$M to $1.64 \times 10^{-3}$M it suppressed seedling growth. In contrast to the flavonoids, the two phenolic acids tested inhibited seed germination at $10^{-3}$M, and at lower concentrations they suppressed seedling growth. The promotive effects of the flavonoids isovitexin and leucocyanidin, especially on root growth, hold promise for the use of such
naturally occurring plant substances in studies on the physiology of plant growth and development.

Some of the plant phenolics as allelochemicals take part in allelopathy and affect seed germination and seed growth, thereby reducing plant productivity. On the other hand, these allelochemicals may be used to control pests, plant pathogens and in the eradication of weeds. The effects of different concentrations of coumarin (0, 0.05, 0.5, 5 and 10 Mm) on seed germination, seedling growth, and pigments content, activity of catalase and guaiacol peroxidase were investigated. Pigments content was measured spectrophotometrically, catalase and guaiacol peroxidase activities were determined at 240 and 436 nm. Coumarin reduced seed germination and seedling growth of canola Hyola 401 cultivar. Chlorophyll content was also decreased in the presence of this phenolic compound. Low molecular weight antioxidants, such as carotenoids and anthocyanins, were increased by coumarin. At higher concentrations of coumarin, catalase activity was not decreased significantly. Guaiacol peroxidase, an antioxidant enzyme showed a significant increase in activity in the presence of this phenolic compound. Hence, it was concluded that this allelochemicals investigation could result in the development of herbicides with less adverse effect on environment and ecosystem. The presence of some phenolic compounds can reduce canola yield, therefore, elimination of weeds, containing these compounds is very important, from allelopathic point of view, to enhance canola production. (Shekoofeh Enteshari and Farzaneh Ahrabi., 2012)
2.12.16. Crop residues

In monocropping, the crop and weed residues do not pose any management problems. Because residues are incorporated into the soil sufficiently ahead of planting time, to allow their complete decomposition and thus toxins released during the decay become harmless to the succeeding crop. However, since 1960’s multiple cropping systems have been introduced (owing to availability of short duration and high yielding varieties of crops) in areas where climate and irrigation facilities are favourable for crop production throughout the year. The adoption of multiple cropping systems in subtropical and tropical countries under irrigated conditions have firstly, led to a greater production of crop residues over monocropping. Secondly, where more than two crops are raised per calendar year, there is little time gap (fallow period) between the harvest of previous crop and sowing of next crop and for the decomposition of crop residues. Thereby, the succeeding crops are sown in the crop residues of previous crops. In these systems, the crop residues are incorporated into the soil, to facilitate the sowing of subsequent crops.

The crop residues add a variety of organic and inorganic compounds to the soil system. These compounds may be liberated during the decomposition of stubble residues or synthesised by microbes using the residues as a nutrient source, besides in stubble mulch agriculture, these may be also leached directly from stubble residues (Oleszek and Jurzysta, 1987; Hicks et al., 1988).
2.13. Green Gram

In India, pulse crops are grown on about 24 million ha area with a total annual production of about 15 million tones. *Phaseolus aureus* L Wilczek, commonly known as greengram or mungbean is the most widely distributed of the six cultivated Asiatic *Vigna* species and is of immense importance because of its adaptation to short growing seasons, low water supply, soil fertility conditions, and particular crop rotation and crop mixtures (Baldev, 1988; Sadaphal, 1988). Greengram is widely cultivated in the southern half of Asia. In recent years greengram has been introduced into east and central parts of Africa, the USA and parts of Australia. Due to increasing popularity of the crop in non-traditional regions, seasons and crop combinations, the acreage in India has increased considerably in recent years. Early studies on taxonomy and classification of greengram were compiled by Bose (1932). According to Vavilov (1926) and Zukovskij (1962) green gram originated in the Indian sub-continent. The diversity of mungbean and other related species is well dispersed in the Himalayas, the distribution extending to the northeastern region and to down south into peninsular India. A secondary centre of diversity exists in the Indo-Gangetic plains.

2.14. Black Gram

Black gram is considered to have been domesticated in India from its wild ancestral form (*V.mungo var.silvestris* Lukoki, Marechal & Otoul). Center of genetic diversity is found in India (Zeven and De Wet. 1982). Natural
distribution of \textit{V.mungo var.silvestris} ranges from India to Myanmar (Tateishi. 1996). Black gram (\textit{Phaseolus mungo}) is an important pulse crop of our country. It belongs to the family leguminosae and subfamily papilionaceae. The chromosome number of this crop is 2n = 2x = 22 (Bhatnagar \textit{et al.}, 1974). Black gram is a grain legume widely cultivated as intercrop in India and other Asian countries. It is part of the diet for millions of people in these countries and a cheap source of protein with 17 - 34% of protein in seeds (Gour, 1993). An important feature of the mashbean plant is its ability to establish a symbiotic partnership with specific bacteria, setting up the biological N2-fixation process in root nodules by rhizobia that may supply the plant's needs for N (Mahmood and Athar, 2008; Mandal \textit{et al.}, 2009).

2.15. Green Chilli

Chilli (\textit{Capsicum annum}) is one of the most important spice- cum-vegetable crop grown in India with great export potential. Chilli is a native of new world sub tropics. Gradually chilli is grown over 1.4 million hectare, producing about 18.8 mt of fresh and dry fruits in India. The crop occupies an area of 0.9m.ha with annual production of 0.9 mt dry chilli in India.

2.16. Sesame

Sesame (\textit{Sesamum indicum}) is one of the oldest cultivated plants in the world. It was a highly prized oil crop of Babylon and Assyria at least 4,000 years ago. Today, India and China are the world's largest producers of sesame,
followed by Burma, Sudan, Mexico, Nigeria, Venezuela, Turkey, Uganda and Ethiopia. World production in 1985 was 2.53 million tons on 16.3 million acres.

Sesame was introduced to the United States in the 1930s. Domestic production has been limited because of the lack of cultivars that can be harvested mechanically. In 1987, the sesame acreage in this country was less than 2,500 acres, about half of which were in Texas. The U.S. imports about 40,000 tons of seed and 2,200 tons of sesame oil annually, primarily from South America.

Sesame (*Sesamum indicum*), is an oilseed cultivated worldwide for its seeds which contain approximately 50% oil of very high quality (47% oleic acid and 39% linoleic acid) and 25% protein especially rich in methionine and tryptophan (Ashri, 1989). Biswas *et al.*, (2001) reported a value of 47% oil for the seeds. The seeds have been valued throughout history for their contributions to diet (in snacks and as soup ingredient), medicine, industry and household uses (Morris, 2002).