In India, government and nongovernmental organizations are promoting temporary intercropping of *Jatropha* until the *Jatropha* stands become too dense. It gives the farmers an income during the time that the *Jatropha* is not yet yielding. On the other hand, planting more than one crop in the same field has many advantages. Small farmers used to intercrop, looking for different food plants to spread the risk of a crop failure and anticipating on erratic rainfall. In Africa, for example, the combination of Maize, Beans and Pigeon pea are very common in *Jatropha* intercropping system. If more than one crop is cultivated and harvested with different growing cycles, farmers can use their time more economically. With a better coverage of the area, weeds are suppressed. Pest and disease incidence is lower with intercropping. Crops can benefit from each other.

Plants have been found to produce and store various allelochemicals viz., alkaloids, phenolics and others as preferably defense compounds (Putnam *et al.*, 1989). Although allelochemicals are present in all plant parts, their concentration varies from one part to another (Qasem and Foy, 2001). Allelopathy plays an important role in agro-ecosystems leading to a wide array of interaction and action between crop-crop, crop-weed and tree-crops (Singh *et al.*, 2001).

Some recent studies indicating the phytotoxic/allelopathic effect of aqueous extracts mungbean on soyabean and lettuce (Sukumaran Lertmungkol *et al.*, 2011), two native Iranian wheat varieties on the growth of two corn
varieties (Mehri Saffari and Torabi-Sirchi M.H, 2011), aqueous extracts of
Croton bonplandianum on some crop and weed plants (Swapnal Sisodia and
Badruzzaman Siddiqui M, 2010), Plantago psyllium on germination stages of
four weed (Rahimi et al., 2006), effect of different aqueous extracts of plants
such as Sunflower, Sorghum, Johnson grass, Neem, Eucalyptus and Acacia on
wheat and its weeds (Muhammad Shahid et al., 2006). All these studies indicate
the release of phototoxic chemicals during the preparation of aqueous extracts.

In intercropping, agricultural crops are grown together with agro forestry
plants or other useful crops to gain maximum benefits from both. In this,
allelochemicals that are toxic to crop plants may be released during the
decomposition of litter of these agro forestry plants. In these circumstances, there
is lack of knowledge or information on the allelopathic effect of Jatropha curcas
on the growth and development of the intercropping plants. Several researchers
have reported the release of a variety of secondary metabolites by Jatropha
through leaching, root exudation etc (Nwokocha et al., 2011). These secondary
metabolites may influence the growth and development of the nearby plants by
eliciting stimulatory or inhibitory responses (Waller, 1989).

Therefore, in the present investigation, an attempt has been made to study
the allelopathic effect of Jatropha curcas leaf extract on some selected
intercropping plant species such as Capsicum annum, Phaseolus aureus,
Sesamum indicum and Phaseolus mungo. The experimental results showed that
Jatropha curcas differ in their allelopathic potential on selected intercropping plant species.

5.1. Allelopathic effect of Jatropha curcas leaf aqueous extract on seed germination of selected intercropping plant species (green chilli, green gram, sesame and black gram).

The inhibitory effect of leaf aqueous extract of Jatropha curcas on seed germination of different crop species (green chilli, green gram, sesame and black gram) are shown in Table (1, 3, 5 and 7). The consequence of aqueous leaf extract depends upon the concentration of Jatropha leaf extracts. The inhibition on the seed germination percentage is more at the higher concentration (20% extract concentration equivalent to 0.2% water extractable substances).

Jatropha showed pessimistic effect on seed germination of green chilli, green gram and black gram. The inhibitory effect increased with increase in the concentration of the leaf aqueous extract. Among these intercropping plants, black gram (Phaseolus mungo) was highly sensitive towards Jatropha leaf aqueous extract which showed more than 50% of seeds failing to germinate compared to the control set of seeds. Meantime green chilli (Capsicum annum) revealed 35% of seed failing to germinate at the highest concentration (20%) and green gram (Phaseolus aureus) showed 20% inhibition in the seed germination at the same concentration.
The results of the present study on seed germination show that *Jatropha* leaf aqueous extract has more inhibitory effect to seed germination on the tested intercropping plant species (green chilli, green gram and black gram).

A similar study was made by Abugre, S and Quashie-Sam, S.J. (2010) on the effect of aqueous extracts of *Jatropha curcas* on four traditional crops (*Phaseolus vulgaris, Zea mays, Lycopersicon lycopersicum* & *Hibiscus esculentus*). 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. The study reported that all the crops were affected by different concentrations of aqueous extracts. The most pronounced effect was in the seed germination percentage of all the tested crops.

These results are corroborated with the findings of Yuan Ma *et al.*, (2011). Aqueous extracts of *Jatropha curcas* leaves and roots inhibited the growth of corn (*Zea mays*) and tobacco (*Nicotiana tabacum*) and increased the inhibition when the concentration of extracts was increased. It suggests that the extracts may have inhibitory substance which possesses allelopathic potential. Caamal-Maldonado *et al.*, (2001) reported that the tomato seed germination was inhibited by aqueous velvet bean leachate.

The results of another research conducted by Heisey (1990) corroborate with the results of the present study. Heisey observed that the leaflets among various plant parts of *Alianthus altimissia* showed the highest inhibitory effect on
seed germination of several crop and weed species viz, *Pisum sativum* and *Zea mays*. Leaf extracts of several trees like *Grewia oppositiflora*, *Ficus roxburghii* and *Bauhinia variegata* tested by Kaletha *et al.*, (1996) showed a higher rate of inhibition on the germination of maize, cowpea, finger millet and soybean.

In the present study, it is also observed that *Jatropha curcas* leaf aqueous extract shows stimulatory effect on seed germination, especially in sesame. It showed nearly 5% stimulatory effects as compared with the control plants.

The stimulatory effect on seed germination results showed the close conformity with the results suggested by Dhole, J.A. *et al.*, (2011). It indicates that, the effect of aqueous crude extracts of *Amaranthus tricolor*, *Euphorbia heterophylla*, *Physalis angulata*, *Alternanthera sessilis* and *Portulaca oleracea* on *Sorghum vulgare*. Among these extract only *Portulaca oleracea* showed stimulatory effect on seed germination of *Sorghum vulgare*.

Since the quantities of allelochemicals vary among different plant tissues (Nwokocha *et al.*, 2011, Putnam and Duke, 1978 and Rice, 1984) the higher rate of inhibition by leaf extracts may be caused by the presence of higher amount of allelochemicals in the leaf. In fact, the content of allelochemicals was higher in the leaf extracts than the stem, root and seed extracts as is evident from the quantification studies (Table 26 and 27).
5.2. Allelopathic effect of *Jatropha curcas* leaf aqueous extract on seedling growth (plumule and radicle) of selected intercropping plant species (green chilli, green gram, sesame and black gram).

Allelopathic effect of *Jatropha curcas* leaf aqueous extract on *green chilli, green gram, sesame and black gram* was assessed against the growth of plumule and radicle length based on bioassay studies (Table 1, 3, 5, 7).

Inhibition of seedling growth by the extracts of many plants has been reported in a few crop and weed species: *Acacia nilotica* in Sorghum, egg plants and green chillies (Bhumibhamon et al., 1980), by *Acacia tortilis* in pearl millet, cluster bean and sesame (Sundramoorthy and Kalra, 1991) by *Ruta graveolens* in *Portulaca oleracea* weed (Aliotta, G. and Cafiero, G., 1999) and by *Capsicum annum* in *Chenopodium album*, *Amaranthus retroflexus*, *Plantago lanceolata*, *Rumes crispus*, *Solanum nigrum* and *Crisium* sp. (Gonzalez et al., 1997).

**Allelopathic effect on radicle growth**

The extract of *Jatropha* leaf showed the inhibitory effect on radicle growth of green chilli and sesame in all treatment as compared with the control plants. In both the crop plants, the drastic reduction in the radicle growth was observed at the highest concentration. Meanwhile, stimulatory effect was observed in radicle growth on green gram and black gram. The rate of inhibition showed more than 50% in green chilli and sesame (Table 1, 3, 5, and 7).
The inhibition to radicle length may be due to the size of the seeds. As sensitivity of plants to allelochemicals is related to seed size (Heisey, 1990), the larger seed size of the crop plants was less affected than smaller seed size. Meantime, radicle elongation of wheat was found by An et al., (1996) to be more sensitive to the aqueous extracts of silver grass than coleoptiles and germination percentage.

Allelochemical activity of plants is measured by the sensitivity of radicle in the bioassay (Heisey, 1990). Hence Jatropha curcas, showed high allelopathic negative impact on sesame, green chilli and black gram, especially on radicle growth.

**Allelopathic effect on plumule growth**

Several researchers have reported the allelopathic effect of many plant extracts on the growth of plumule length: by Asphodelus tenuifolius and Fumaria indica in growth of maize (Nasira Jabeen and Moinuddin Ahmed, 2009), by Leucaena leucocephala on mungbean and soybean (Shapla, et al., 2011), by Prosopis juliflora on wheat (Sazada Siddiqui et al., 2009).

In Jatropha curcas, the bioassay result revealed that the inhibitory effect on plumule growth was observed in green chilli and black gram. The effect was highly significant in green chilli, and black gram, which showed about 75% inhibitory effect at the highest concentration (Table 1, 3, 5, 7).
Abugre, S and Quashie-Sam, S.J (2010) reported earlier about the allelopathic effect of *Jatropha curcas* on *Phaseolus vulgaris*, *Zea mays*, *Lycopersicon lycopersicum* & *Hibiscus esculentus*. 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*, *L. lycopersicum*, *P. vulgaris* and *H. esculentus*, respectively.

The present findings are in close agreement with those of Jadhar and Gayanar (Jadhar, B.B. and D.G. Gayanar, 1992) which revealed that the percentage of germination, plumule and radicle length of rice and cowpea, were decreased with increasing concentration of *Acacia auriculiformis* leaf leachates.

Interestingly, the plumule growth was stimulated by *Jatropha curcas* leaf aqueous extract on sesame and green gram. The stimulatory effect was concentration dependent and also the effect was highly significant.

These agree with the general information; it is known that plant extracts have an inhibitory effect on the plant growth belonging to various genuses. Likewise, there are numerous reports on the inhibitory effect of plant extracts on plumule growth (Kocacalışkan and Terzi, 2001; Ercisli et.al., 2005; Jefferson and Pennacchio, 2003; Rietwelt, 1983). However, the extracts obtained from some plants have the stimulatory effect, depending on the kind of extract and treatment doses on the plant growth (Coder Kim D, 1999). Similar results are found in the present bioassay study results on plumule growth.
5.3. Allelopathic effect of *Jatropha curcas* leaf aqueous extract on plant growth (root length, shoot length, yield, root nodules and biomass weight) of selected intercropping plant species (green chilli, green gram, sesame and black gram).

**Allelopathic effect on root growth**

In pot culture studies, the aqueous leaf extracts of *Jatropha curcas* decreased or inhibit the root growth on green gram. The inhibitory effect was increased with increase in the concentration of extract. A maximum of 20% reduction was observed in root growth at the highest concentration as compared with control root growth (Table 2, 4, 6, 8). Similar result was reported by (Sisodia and Siddiqui, 2008, 2009). The inhibition effect was found to increase with increasing concentrations of different aqueous extracts.

These results are in agreement with those of Shapla *et al.*, (2011) the effect of *Melia azadirachta* growth parameters of mungbean and soybean. The effect on root growth was highly inhibited. The inhibitory effect may be due to the roots of plant expose to allelochemicals, which showed the brownish, stunted and void of root hairs. This might be due to rapid inhibiting effect on respiration of root tips, which ultimately reduced elongation. The identical results were reported by Qasem and Foy (2001)

Remarkably stimulatory effect was observed in *Jatropha curcas* leaf aqueous extract on root growth in green chilli, sesame and black gram. In green gram, root growth increased when the concentration of leaf aqueous extracts was
increased. But the maximum stimulatory effect was observed at 5 and 10% concentrations, when compared with control and rest of the concentrations. The similar pattern was followed in sesame also. Meantime, black gram root growth was stimulated only at 10% concentration as compared with control plants. At the highest concentration, root growth was inhibited (Table 2, 4, 6, 8). Therefore, the optimistic effects on the root growth depend upon the concentrations of *Jatropha curcas* leaf aqueous extract.

Muhammad Shahid *et al.*, (2006) reported on the, allelopathic effect of Eucalyptus on root growth. Accordingly, the results revealed that Eucalyptus extract stimulate the root growth on wheat as compared with control plants.

Therefore, the stimulatory effect may be due to concentration of *Jatropha curcas* leaf extract. In green chilli, sesame and black gram to exhibit a stimulated response in lower concentration. Identical results were reported by Anjum and Bajaw (2005) and Nasim *et al.*, (2005). The studies of Khan *et al.*, (2005) also revealed differential response of wheat and its weeds to different tree extracts.

**Allelopathic effect on shoot growth**

The aqueous extract from *Jatropha curcas* inhibited the shoot growth in green chilli and black gram only at the highest concentration. In the lower concentrations, the shoot was stimulated (10%) as compared with control plants and the effect was also highly significant. In the case of green gram and sesame, the shoot growth was increased by increasing the concentration of leaf aqueous extracts. In addition to this, biomass weight also showed similar pattern of
inhibition and stimulatory effect on the tested intercropping plants (Table 2, 4, 6, 8).

The present results in shoot growth have showed close agreement with some earlier research reports such as soybean and lettuce (Sukumarn Lertmengkol et al., 2011), in Sorghum and ground nut by *Ficus bengalensis* (Manikandan, 2000), in ground nut by bamboo (Eyini et al., 1989), in ground nut and corn by Eucalyptus (Jayakumar et al., 1990).

Allelochemicals may inhibit plant growth by affecting the cell division, elongation and ultra-structure of cells or by altering the normal physiological processes such as photosynthesis, respiration, mineral uptake and enzyme activity (Tseng et al., 2003).

Thapar and Singh (2003) reported the depletion of chlorophyll and protein content in *Parthenium* due to allelochemicals derived from *Amaranthus viridis*. Polyphenolic compounds and other allelochemical compounds are known to change the permeability of plasma membrane. Rapid loss of integrity of the plasma membrane under the influence of allelochemicals cause the cellular leakage (Abbas et al., 1992). Allelochemicals may be inhibiting the photosynthetic process resulting into depletion of food reserve, i.e. carbohydrate and protein. As a result, net assimilation is reduced causing reduction in shoot and root growth.
The stimulatory effects in shoot growth have been reported only in a few crop species, such as Sorghum and groundnut by *Ficus bengalensis* (Manikandan, 2000), by *Cassia angustifolia, Sphaeranthus indicus* and *Azadirachta indica* in wheat (Alam, 1990).

**Allelopathic effect on yield**

*Jatropha curcas* leaf aqueous extract showed the stimulatory effect on yield in green chilli and green gram. The stimulatory effect was concentration dependent. In the case of green gram the yield increased by increasing the concentration of the extract. At the highest concentration, it showed more than 50% yield as compared with control plant. But in green chilli, the maximum growth was achieved at 5% concentration as compared with control plant. In the highest concentration, the yield was decreased as compared with treatments, even though it was higher than control plants (Table 2, 4, 6, 8).

These findings are in agreement with the findings of Muhammed Naseem *et al.*, (2009) which provided allelopathic effect of sunflower water extract on weed control and wheat productivity. They found out the significant stimulatory effect on increasing the yield of wheat when it was treated with aqueous extracts of sunflower as compared with control productivity.

Meantime *Jatropha* showed inhibitory effect on yield in sesame and black gram at the highest concentration as compared with control and other treatments. But in the lower concentration (10%) both the crop plant yields increased to a
considerable amount as compared with control plant yield. These results are corroborated with the findings of Ebrahim Gholamipour Alamdari and Deokule (2009) which noted allelopathic effect of some weeds on paddy rice yield. The yield was significantly affected by the weeds extracts.

These effects were probably due to the variation in the concentration of allelochemicals released from *Jatropha* leaf water extract. These findings are in line with the work of Cheema (1988), Kimber (1973) and Purvis et al., (1985), who reported the differential allelopathic effects. Allelopathic effect on plant growth depends on concentration of compounds (Einhelling *et al.*, 1985; Rice, 1984; Wilson and Rice, 1968).

**Allelopathic effect on root nodules**

In pot culture studies, *Jatropha curcas* leaf aqueous extracts showed the stimulatory effect on root nodules number in green gram and black gram as compared with control plants. Both the leguminous plants showed more than 50% increase of root nodules number increased over the control plants.

The stimulatory effect on root nodules number may be due to the presence of more flavonoids in root. Meanwhile, the quantification of allelochemicals result also showed the presence of more flavonoids in root next to tannin. The flavonoids are released from root to soil through leaching process. In addition to their role as chemo attractants for rhizobia in the pre-infection stage, flavonoids
produced by the host plant have long been suspected to play a direct role in nodule formation (Hirsch, 1992).

At the highest concentration (20%), in green gram and black gram showed the reduction in root nodules number when it was compared with 10% treatment of *Jatropha curcas* leaf aqueous extract. This may be due to the higher concentration of tannin in *Jatropha curcas* root. This agrees with the general information about the tannins that are known to inhibit nodulation in beans and other legumes when applied to the soil (Blum and Rice, 1969; Muthukumar et al., 1985). According to Wolff et al., (1993) tannins can affect number of nodule during early stages of plant development in *Phaseolus vulgaris*.

5.4. Allelopathic effect on *Jatropha* intercropping field experiment

**Allelopathic effect of green chilli intercropping with *Jatropha***

Green chilli (*Capsicum annum*) was intercropped with *Jatropha curcas* in the field experiment. It showed stimulatory effect on shoot growth, number of fruit per plant, fruit weight and biomass weight over the control plant. Meantime, root growth was inhibited as compared with control plant (Table 9).

**Allelopathic effect of green gram intercropping with *Jatropha***

Allelopathic effect on intercropping field experiment result revealed that
the green gram growth was stimulated over the control plants. The stimulatory effect was highly significant as compared with control plants. In addition to this, number of pod per plant, grains weight, biomass weight and number of root nodules also increased over the control plants (Table 10).

**Allelopathic effect of sesame intercropping with *Jatropha***

In intercropping field, sesame showed inhibitory effect on root growth, number of capsule per plant and grains weight as compared with control plants. Surprisingly, the shoot growth was stimulated and it was significant over the control plants (Table 11).

**Allelopathic effect of black gram intercropping with *Jatropha***

The intercropping field experiment showed positive effect on black gram intercropped with *Jatropha curcas*. The shoot, root number, pod per plant, grains weight, biomass weight and root nodules were increased over the control plants (Table 12).

The present results in intercropping showed close agreement with some earlier research report such as tomato intercropped with *Tagetes erecta* and *Amaranthus hypochondriacus* (Olga Gomez-Rodriguez *et al.*, 2007), in tomato intercropped with chinese chive (Jing Quan Yu., 1999), in intercropping between corn and peanut (Zakiya Ahmed Hassan *et al.*, 2008), in carrot and root parsley
intercropping with onion (Marzena Blazewicz-Wozniak and Dariusz Wach 2011).

Increased shoot growth and yield in the intercropping system may be due to the soil borne pathogens which were controlled by allelochemicals released by *Jatropha curcas* in the field (Jing Quan Yu, 1999). Although intercropping is not compatible with modern monoculture agriculture, it is well suited to many farmers who have small land areas because it may render higher yields and yield stability (Altieri, 1999; Gliessman, 2002). It is also reported that during the intercropping system, plant may release allelochemicals or secondary metabolites in the soil; this may reduce the populations of plant-parasitic nematodes and other disease causing organisms, such as fungi, bacteria, insects, and some viruses (Hethelyi *et al*., 1986). Therefore, crop plants can be grown free from soil borne pathogenic diseases in the intercropping field. This might be one of the reasons for stimulation of the plant height or growth during the intercropping system.

**5.5. Jatropha curcas yield (seed) in intercropping field experiment.**

The field experiment result revealed that *Jatropha curcas* had showed stimulatory effect on yield, especially in *Jatropha curcas* intercropped with green gram and black gram. The highest increase in seed yield was observed in *Jatropha* intercropped with green gram. The stimulatory effect was significant as compared with control field. Meanwhile, inhibitory effect on the yield was
observed, when *Jatropha* was intercropped with sesame and green chilli. But more inhibitory effect was observed in sesame and the effect was highly significant while compared with control. In the case of green chilli, the effect on *Jatropha* seed yield was not significant as compared with control (Table 13).

Ghanbari and lee (2003) and Forozmand *et al.*, (2005) have reported earlier that a relatively higher forage yield with later compared to earlier harvest time has been reported by several workers who have been working with wheat. The mean dry matter yield averaged over harvest times by different maize - cowpea intercrops was significantly greater than comparable sole crops (Dahmardeh *et al.*, 2010). Therefore, inclusion of green gram and black gram in sole or intercrop systems might make extra soil nitrogen available to *Jatropha curcas* during intercropping system. This may leads to increase the seed yield of *Jatropha curcas* during the intercropping field, especially with leguminous plants.

5.5. Bioassay studies of selected phenolic acid (coumarin, catechin and kaempferol) on seed germination and seedling growth in selected intercropping plant species (green chilli, green gram, sesame and black gram).

Effect of coumarin on seed germination of green chilli, green gram, sesame and black gram.

The bioassay studies of phenolic acid coumarin showed inhibitory effect on seed
germination in all the tested crop species such as green chilli, green gram, sesame and black gram. The inhibitory effect was concentration dependent. In green chilli, at the highest concentration (5.0mM), it showed that nearly 29% of the seeds are failed to germinate than the control plants. At the same concentration, green gram showed 20% inhibition on the seed germination as compared with control plants. Meanwhile, sesame showed 25% of inhibition in 5.0mM concentration over the control seed germination percentage. Finally, black gram showed 23% inhibition on seed germination at the highest concentration of phenolic acid coumarin. Therefore, coumarin showed more inhibitory effect on seed germination in green chilli (29%), and followed by sesame (25%), black gram (23%) and green gram (20%) (Table 14 to 25).

These findings are in agreement with that of Seyed Mehdi Razavi et al., (2010). The effect of coumarin on seed germination and seedling growth in lettuce (Shekoofeh Enteshari and Farzaneh Ahrabi., 2012) in canola seed germination and seedling growth (Flávia Tavares Colpas et al., 2003) in soybean seed germination and seed borne fungi.

Effect of coumarine on root growth of green chilli, green gram, sesame and black gram

The allelopathic effect of coumarin showed significant inhibitory effect on root growth in all tested crop plants except in the green chilli at 5.0mM concentration. In this concentration it showed stimulation, but when compared
with control plant the effect was not significant. The phenolic acid coumarin showed more inhibitory effect on sesame root growth at highest concentration (5.0mM) as compared with other crop plants such as green chilli, green gram and black gram. It showed nearly 50% inhibitions in root growth. The least inhibitory effect was observed in green gram at the highest concentration nearly 12 % over the control root growth (Table 14 to 25).

These results are corroborated with the findings of Xiang Li et al., (2011). Exogenous application of 4-MU (Coumarin derivatives) to Arabidopsis thaliana seeds affected germination and led to reduced primary root growth, formation of bulbous root hairs, and irregular detached root caps accompanied by reorganization of the actin cytoskeleton in root tips before seedling establishment. According to Vaughan, D. and Ord, B (2006) at relatively high concentrations (1 mM), ferulic, vanillic, p-coumaric, p-hydroxybenzoic, syringic and caffeic acids inhibited root growth in Pisum sativum.

These phenolic acids (ferulic, vanillic, p-coumaric, p-hydroxybenzoic, syringic and caffeic acids) also profoundly affected the root morphology in terms of extension of growth of the main root and the number and size of the lateral roots. The precise growth effects depended on phenolic acid. At the highest concentrations it inhibited the length of main root. The phenolic acids also inhibited the cell division. To produce the maximum growth effect, phenolic acids must be present continuously. Lower concentrations (1 µM) of the phenolic acids also affected root growth and morphology.
Effect of coumarin on shoot growth of green chilli, green gram, sesame and black gram

The efficacy of phenolic acid coumarin showed stimulatory effect on shoot growth in green chilli and green gram in its lower concentration. But the effect was highly significant only in green gram at 1.0mM concentration as compared with control and rest of the crop plants shoot growth. The inhibitory effect was observed in sesame and black gram, but the effect was increased with increasing concentration of coumarin. The pehnolic acid coumarin showed more inhibitory effect on shoot growth in black gram as compared with rest of the crop plants. It showed nearly 40% reductions in shoot growth (Table 14 to 25).

These results are corroborated with the findings of Razavi et al., (2010) i.e simple coumarin, 7- prenyloxy coumarin and auraptene entirely inhibit shoot growth of lettuce at concentration higher than 100µgml. The mechanism of phytototoxicity of coumarin was also pointed out. Phytotoxic coumarins inhibit photosynthetic phosphorylation in a dose-dependent manner (Anya et al., 2005).

Effect of catechin on seed germination of green chilli, green gram, sesame and black gram.

The bioassay studies of phenolic acid catechin showed inhibitory effect on seed germination percentage as compared with control seed germination. The highest inhibitory effect was observed in black gram. It showed that nearly 35%
of seeds failed to germinate as compared with control seed germination. The inhibitory effect also increased with increasing concentration of catechin (Table 14 to 25).

George Buta and William R. Lurby (1985) demonstrated the effect of allelopathic compounds of phenolic acid such as catechin and epicatechin on seed germination and seedling growth. These phenolic acid effects on germination and early seedling growth of *Lepedeza* seeds were inversely related to the quantities of these phenolic acids.

**Effect of catechin on root growth of green chilli, green gram, sesame and black gram.**

The efficacy of phenolic acid catechin showed stimulatory effect on root growth in green chilli and sesame only in its lower concentration, but the effect was significant only in sesame over the control root growth. Meanwhile, inhibitory effect was observed in green gram and black gram. The highest inhibitory effect was observed in green chilli as compared with other crop plants. It showed nearly 24% inhibitions in root growth as compared with control root growth (Table 14 to 25).

**Effect of catechin on shoot growth of green chilli, green gram, sesame and black gram.**

The allelopathic effect of catechin on shoot growth was observed in all the selected crop plants. Interestingly, the shoot growth was stimulated in green
gram and sesam. The stimulatory effect was increased with increase in the concentration of catechin. In green gram, it showed nearly 45% stimulations in shoot growth over the control plants. In case of sesame, it showed nearly 20% stimulatory effects in shoot growth. Meanwhile, inhibitory effect was observed in green chilli and black gram. In green chilli showed the highest inhibitory effect on shoot growth among the tested crop plants, that nearly 50% inhibition in shoot growth over the control plants (Table 14 to 25).

These findings are in agreement with those of Bais et al., (2002) who reported that (−)-catechin was phytotoxic to a number of plant species at 50 μg ml⁻¹ concentration. Physiological symptoms such as necrosis of the leaves and discoloration of the roots were seen at the 600 μg ml⁻¹ concentration; however, plants were still viable after 7 days.

Demuner et al., (1996) discovered that two diterpenes isolated from seed oils of P. polygalaeiflorus stimulated radicular growth in C. sativus at 100 ppm, but had a significant inhibitory effect at 1000 ppm. Root secreted catechin has a similar effect on some of the tested plants, showed increased growth of shoots at lower concentrations of catechin. In addition, root callus formation visible when G. aristata seeds were germinated on media treated with 10–50μgml⁻¹ of catechin indicated that this phytochemical could act as a plant growth regulator. The results of the present study indicate that the presence of catechin in Jatropha curcas leaf may also play a role in modulating the growth of tested crop plants.
Effect of kaempferol on seed germination of green chilli, green gram, sesame and black gram.

The phenolic acid Kaempferol showed inhibitory effect on seed germination in all the tested crop plants (green chilli, green gram, sesame and black gram). The inhibitory effect was increased with increase in the concentration of kaempferol. The highest inhibitory effect was observed in black gram, which showed that 40% of seeds were failed to germinate as compared with control.

Effect of kaempferol on root growth of green chilli, green gram, sesame and black gram.

The allelopathic effect of kaempferol was assessed in terms of root growth. The stimulatory effect was observed only in green gram and black gram, but stimulatory effect on root growth was showed only in lower concentration of both the crop plants. In the highest concentration 5.0mM, root growth was inhibited. There was no stimulatory effect observed in sesame. The kaempferol showed maximum inhibitory effect on root growth in green chilli as compared with other crop plants.

Effect of kaempferol on shoot growth of green chilli, green gram, sesame and black gram.

The efficacy of phenolic acid kaempferol showed stimulatory effect on shoot growth in green gram and sesame only in lower concentration. At the highest
concentration, the shoot growth was inhibited than the control shoot growth. Green chilli and black gram showed inhibitory effect on shoot with increase in the concentration of Kaempferol. Kaempferol showed maximum inhibitory effect on shoot growth in black gram that showed nearly 70% reductions in shoot growth as compared with control plants.

The results of the present study of phenolic acid on seed germination and seedling growth of selected crop plants are in line with some of the researcher (Hegaz and Fadl-Allah., 1995; El-Khatib and Hegazy 1999). They have reported that, in the seedling stage the susceptibility of allelochemicals like phenolic acid increased or decreased some morphological abnormalities in treated plants. They suggested that seedling growth is more affected by the allelopathic interaction than in seed germination.

In addition to this, phenolic acid controls the growth hormones during the seedling growth. Tmaszewski and Thimann (1966) reported that monophenols had stimulated the decarboxylation of indole-3-acetic acid (IAA), while polyphenols had synergized IAA-induced growth by counteracting IAA. Accordingly, this may be one of the reasons in the present results on bioassay of phenolic acid that brought about stimulatory or inhibitory effect on shoot and root growth of the tested crop plants during the bioassay studies.
5.5. Quantification of Allelochemicals in *Jatropha curcas*

**Quantification of phenols in *Jatropha curcas***

The quantification of phenolic acid in *Jatropha curcas* was analyzed. The total phenolic acid was quantified which revealed 1.30% in the whole plant. The distribution of phenolic acid in different plant sources was analyzed. Accordingly, more concentration of phenolic acid was quantified in leaf (0.55%) followed by stem (0.35%) and least in root (0.20%) followed by seed (0.30%) (Table 26, 27). The individual Phenolic acids were identified in *Jatropha curcas* leaf by HPTLC methods. The HPTLC profile of phenoilc acid revealed the presence of coumarin, catechin and kaempferol (Figure 17-28 and Table 28).

The determination of allelopathic effect of *Jatropha curcas* leaf aqueous extracts on green chilli, green gram, sesame and black gram was based on bioassay, pot and field experiments. These experimental results revealed more inhibitory effect of *Jatropha* leaf extract on shoot growth at the highest (20%) concentration in green chilli, root growth in green gram and black gram (20% concentration), the seed germination percentage was affected in all tested crop plants such as green chilli, green gram, sesame and black gram. This inhibitory effect may be due the presence of allelochemicals like phenolic acids. Similar results were reported by Abugre and Quashie (2010) in *Jatropha curcas*.

This phenomenon is a result of phyto-chemical presence in *Jatropha curcas*. These chemicals are largely classified as secondary metabolites (such as
alkaloids, isoprenoids, phenolics, flavonoids, terpenoids and gluconolates etc) (Nazir et al., 2007). Swaminathan et al. (1989) reported that the potential compounds, which are able to induce inhibitory effect on germination, are identified as phenolic acids. The release of phenolic compounds, adversely affect the germination and growth of plants through their interference in energy metabolism, cell division, mineral uptake and biosynthetic processes (Rice, 1984).

**Quantification of Flavonoids in *Jatropha curcas***

*Jatropha curcas* showed the presence of flavonoids higher than the phenolic acids. The total flavonoids content was quantified which revealed 8.60% in the whole plant. The distribution of flavonoids in different plant source was analyzed. Accordingly, the more concentration flavonoids was quantified in leaf (2.50%) followed by seeds (2.37 %) and least in stem (1.41%) followed by seeds (2.32) (Table 26, 27). The individual flavonoids were identified in *Jatropha curcas* leaf by HPTLC methods (Figure 39-44 and Table 30). The HPTLC profile of flavonoids revealed the presence of seven different types of flavonoids.

The allelopathic effect of *Jatropha curcas* was assessed on the basis of bioassay studies, pot experiment and field experiments. Based on these studies, the results showed the stimulatory and inhibitory effect on shoot and root growth which depended on the concentrations, for example in the case of green gram.
and sesame the shoot and root growth was stimulated by increasing the concentration of *Jatropha* leaf aqueous extract, especially in 5 and 10% treatments. This promotive effect may be due to the presence of more quantity of flavonoids in *Jatropha curcas* leaf extracts. The results of the present study are in line with Lakshmi Nandakumar and Rangaswamy (1985). 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 the studies on the physiology of plant growth and development.

In addition to this the present study revealed that the number of root nodules increased in green gram and black gram. This may be due to the presence of flavonoids. Flavonoids play a major role in root nodule formation and also stimulates the nodule gene during the root nodulation process (Hirsch, 1992).

**Quantification of alkaloids in *Jatropha curcas***

The quantification of alkaloids in *Jatropha curcas* revealed the presence of 10.99% of total alkaloids. The total alkaloids were distributed in different plant sources such as leaf (4.50%), seed (2.82%), stem (1.92%) and root (1.75%) (Table 26, 27). The individual alkaloids were identified in *Jatropha curcas* leaf by HPTLC methods. The HPTLC profile of alkaloids revealed the presence of seven different types of alkaloids such as colchicine, emetine and scopolamine (Figure 29-38 and Table 29)
The results of the bioassay experiment of the present study revealed that the seed germination percentage of green chilli, green gram, sesame and black gram was affected by *Jatropha curcas* leaf aqueous extracts. This inhibitory effect may be due to the presence of more alkaloid content in *Jatropha* leaf extracts. Many studies reported about the germination and growth inhibition of alfalfa, and Italian ryegrass by alkaloidal compounds or alkaloidal extracts from other plants (Petroski *et al*., 1990; Staden *et al*., 1995; Bagchi *et al*., 1997).

In addition to this, *in vitro* experiments, with more than 70 alkaloids, indicate that most alkaloids are toxic or inhibitory to more than one group of organisms including plant seedlings, bacteria, insects and mammals (Wink *et al*., 1998).

**Quantification of tannin in *Jatropha curcas***

The quantification of tannin in *Jatropha curcas* was analyzed (Table 26, 27). The total tannin was quantified which revealed that 15.84 % in the whole plant. The distribution of tannin in different plant sources was analyzed. Accordingly, the more concentration tannin was quantified in leaf (7.42%) followed by seed (4.0 %) and least in stem (1.74%) followed by root (2.68 %).

Among these allelochemicals (phenols, flavonoids, tannins and alkaloids), tannin showed the presence of the highest quantity (15.84%) followed by alkaloids (10.99%), the least quantity is phenols (1.30%) followed by flavonoids (8.60%) in *Jatropha curcas*. 
Since J. curcas stem, leaf, root and seed extracts have showed the presence of phytochemicals like saponins, tannins, glycosides, alkaloids, flavonoids and phenols (Akinpelu et al., 2009; Igbinosa et al., 2009) it shows that these allelochemicals play a major role in allelopathic effect of Jatropha curcas.

Finally, the results of allelopathic effect of Jatropha curcas leaf aqueous extracts showed stimulatory as well as inhibitory effect on the tested crop plants. The stimulatory effect was observed mostly in the lower concentrations (5 and 10% concentration). Meanwhile, the inhibitory effect was noticed mostly at the higher concentrations (15 and 20%). This agrees with the general information that the response to allelochemicals may be due to the concentration dependence (Ashrafi et al., 2007). Allelochemicals that inhibit the growth of some species at certain concentrations might stimulate the growth of the same or different species at different concentrations (Narwal, 1994).

Based on the data and results, it is concluded that the allelopathic effect of Jatropha curcas was concentration dependent. Jatropha curcas leaf aqueous extract showed the positive effect on all the variables in green gram and sesame in all the treatments. But in the higher concentration Jatropha showed negative impact on green chilli and black gram. In addition to this, the field experiment result on Jatropha intercropped with green gram and black gram showed positive effect on the Jatropha seed yield. Therefore, green gram is highly suitable and black gram is suitable for Jatropha intercropping system. During the
intercropping system both plants are benefited. In addition to this, based on the yield of green chilli and sesame in the intercropping system, it showed positive effect towards *Jatropha* intercropping system.