REVIEW OF LITERATURE
Chapter - 2

REVIEW OF LITERATURE

A comprehensive review of literature is essential in any research endeavour. The primary purpose of review of literature is to find out the nature and extent of related studies and to ascertain the level of theoretical and empirical works that are being currently done or have already been in the related field. Besides offering insights into current conceptual and methodological issues, the review of literature also throughbare the limitations of research works that have been done in the past and the issues that have yet not been resolved. The review of literature thus helps in setting the future research agenda and prepares the researchers for methodological challenges that he is likely to face. In view of the above, an effort has been made in this chapter, to review the available literature and to document major findings of different studies, research gaps and the recent changes that have taken place both in India and abroad pertaining to this subject. The literature has been reviewed under the following broad heads.

2.1 Soil Physico-chemical properties and plant growth

2.2 Vermiculture and compost

2.3 Quality of Tea Liquor

2.1 Soil Physico-chemical properties and plant growth

It is well documented that to safeguard soil health, a judicious combination of organic and inorganic nitrogen usages is essential. Role of organic manure in maintaining soil health and its influence on the growth and development of crop has been well documented (Sultan, 1995; Rajput and Ram 1997; Singh et al., 1997). Organic manures influence plant growth through its effect on physical, chemical and biological properties of soil besides providing nutrients to plants (Martens et al., 1992; Thampan, 1995). The efficiency of nutrient can also be improved through organic matter addition under integrated nutrient management (Bhatnagar et al., 1992). Incorporation of organic residues showed significantly higher infiltration rate and water holding capacity in field (Mahadkar et al, 1998). In another study conducted by Channabasavanna et al., (2002) showed that incorporation of residues (rice straw, poultry manure, FYM, GLM, GM) reduced bulk density of the soil. Application
of 10 tonnes of vermicompost/ha significantly increased plant height, number of tiller and
dry-matter production of malt barley as compared to control (Roy et al., 2004) and also
showed significant increase in the grain yield. The available NPK status increased to tune of
38.6, 230.5 and 38.6 per cent in the 100 per cent NPK+FYM over absolute control (Mairan et
al., 2005). Tolera et al., (2005) reported increase in Frenchbean and maize yield with
combined use of FYM and inorganic fertilizers over the inorganic fertilizers alone. Raina et
al. (2008) advocated that addition of organic matter with lower C:N ratio (20:1) have
increased the microbial activity, thereby, accelerating rate of mineralization. Raina and
Goswami (1998) have also reported that addition of organic matter accelerates the
decomposition of native soils organic matter, thus leading to higher mineralization and release
of nutrient contents in soil. Application of FYM and vermicompost resulted in a significant
increase in the organic carbon of soil (Maheshrappa et al., 1999). Gunjal et al. (2006)
reported that the yield contributing characters of soybean like number of pods, pod weight,
number of grains/pod, weight of grain/ plant and thousand grain weights are significantly
higher than the control with the conjoint use of organic and inorganic source of nutrients. It is
possible to substitute entire dose of NPK (90, 40, and 40 kg/ha) to scented rice 12 tonnes
sunhemp green leaf manure + 10 tonnes vermicompost/ha or 50 per cent NPK (through
inorganic resources) along with 6 tonnes sunhemp green leaf manure + 5 tonnes
vermicompost/ha without any adverse effect on its grain yield (Mankotia, et al., 2006).
Tomer, et al. (2006) observed that combination of NPK (inorganic) and vermicompost
resulted in a significant increase in tree height, trunk girth, and shoot extension of walnut tree.
The investigation further revealed that combination of inorganic (NPK) and organic
(vermicompost) sources of nutrients improved fruit retention, yield and nut quality in
comparison to inorganic alone. Verma and Bhardwaj (2006) also found that there was
improvement in soil pH, organic carbon and nutrient status by the application of Kohinoor
organic manure and FYM in apple. The investigation further suggested that either application
of FYM 100 kg/tree or Kohinoor organic manure 5-10 kg/tree resulted in significant
improvement in fruit characteristics ( fruit weight, length, breadth and yield) and plant growth
parameters (terminal shoot growth, plant girth, height and spread) over the control. The
growth yield, yield contributing characters and quality of turmeric significantly influenced by
use of organic and inorganic combination over the recommended fertilizer alone (Rao, et al.,
2005). Application of FYM to the soil induced the release of various organic acids during
decomposition which help in greater solubilisation of native and applied nutrients and their
subsequent uptake (Nair and Peter, 1990). Biswas et al. (1971) reported that the application of organic manures improved the soils aggregates resulting in favourable pore geometry, which in turn increased the soil porosity thereby paving the way for good development of rhizomes under the soil. During decomposition of organic matter, non-humic and humic components serve mainly as substrates for soil microbes and contribute to the formation of soil humic components (Dinel et al., 1990). Humic substances are efficient metal complexing agents and suppliers & regulator of plant nutrients. Humic acid enter the plant directly, mediate respiration & act as H⁺ ion acceptor, alter carbohydrate metabolism & promote accumulation of sugars, stimulate peroxidase activity & invertase development, growth of roots & shoots and cell elongation (Vaughan and Linchen, 1976; Schnitzer, 1991).

2.2 Vermiculture and compost

Earth worm play a vital role in soil biology as versatile bioreactor. They can consume all kind of organic matter; eat as much as their own body weight per day and extract granular structure stable casting (Vermicasting) with enhanced internal porosity. Tapiador (1981) study further advocated that 1000 tonnes of moist organic matter can be converted by earthworm into 300 tonnes of compost. The role of vermicompost or vermicast as a super manure or bio-fertilizer in the crop production and maintenance of soil health has already been reported (Edward and Lafty, 1977; Lee, 1985). Besides influencing physico-chemical properties of soils, vermicompost is also known to contain growth promoting substance, enhancing microbial activity and prevent nitrogen loss by leaching (Shinde et al., 1992; Sultan, 1995). When compared with the availability of nutrients from most of the bulky organic manures, the release of nutrients from the added vermicompost is more rapid leading to early and better plant growth (Saikia et al., 2008). Concept of vermi-stabilization (utilizing earthworm as biological agent for stabilization of organic wastes) represent a technology, that is, according to Loehar et al. (1988), environmentally sound, need not be energy, capital or equipment intensive and does not require extensive management. The average nutrient content of vermicompost is N-1.60 per cent, P₂O₅- 2.20 per cent, K₂O-0.67 per cent, Ca-0.99 per cent and Mg-0.15 per cent (Ghosh, 1994). Tea pruning contain considerable amount of nutrients, which could be returned to field by decomposing it. Retaining of pruning litter (twigs) in the mature tea plantation, returns 82 kg N/ha, 17.5 kg P₂O₅/ha and 68.4 kg K₂O/ha to the soil.
Biradar et al. (2000) advocated that rainy season is more congenial for earthworm multiplication and vermicompost production than either winter or summer seasons; this was due to the availability of higher level of moisture in rainy season. Vermicompost improve quality of plants along with physical and biological properties of soil (Singh et al., 2003). Aqueous extract of vermicompost (AVC) inhibit the spore germination of several fungi at low concentration (0.1-0.5%). Application of vermicompost resulted in significantly influenced growth characters and yield attributing characteristics of rainfed sorghum. However, all the growth parameters and yield attributing characters recorded were maximum with 3.0 ton vermicompost/ha (Bhalerao et al., 2001).

Poduval et al. (2002) reported that bio-fertilizer \textit{(Azospirillum and Azotobacter)} not only increased plant growth (shoot length, number of leaves, leaf area etc.) and nutrient status of cashewnut but also reduced the chemical fertilizer use. Sadanand and Hamza (1998) showed that application of organic cakes increased nutrient availability as well as improved physical condition of the soil, which led to increased yield and curcumin content of turmeric.

Deka et al. (2004) studied the effect of different mulch material on the growth of rubber seedling and found significant differences for plant height between mulched and un-mulched plots. Mulching with plant material helped in maintaining the soil temperature and soil moisture at an optimum level, which favoured plant growth. Organically produced cashewnut fetched 30 per cent increased price when exported. Yadukumar and Nandan (2005), further advocated that composting of recyclable biomass by adding 20 per cent cow dung slurry, rock phosphate and phosphate solubilising microorganism (PSM) is the best for achieving C/N ratio (10:08), nutrient and beneficial microorganisms within six months after imposing treatment. Application of FYM to the soil induced the release of various organic acids during decomposition which helped in greater solubilisation of native & applied nutrients and their subsequent uptake (Nair and Peter, 1990).

Earthworms can play a variety of important roles in agro-ecosystems. Their feeding and burrowing activities incorporate organic residues and amendments into the soil, such as, enhancing decomposition, humus formation, nutrient cycling and soil structural development (Mackay and Kladivko, 1985; Kladivko et al., 1986). Earthworm burrows persist as macropores which provide low resistance channels for root growth, water infiltration and gas exchange (Kladivko and Timmenga, 1990; Zachmann and Linden, 1989). Quality, quantity and placement of organic matter is a main determinant of earthworm abundance and activity.
in agricultural soils (Edward, 1983; Lofs, 1983), as are disturbances of the soil by tillage, cultivation and the use of pesticides (Doran and Werner, 1990).

2.2.1 Earthworm Ecology

Earthworm species can be classed in one of three morpho-ecological groupings (Bouche, 1977) viz; epigeic species, endogeic species and species which build permanent, vertical burrows that penetrate the soil deeply were termed anecics by Bouche. s. Anecics have profound effects on organic matter decomposition, nutrient cycling and soil formation. The most common examples are the night crawlers sold by fish-bait dealers consisting of *Lumbricus terrestris* and *Aporrectodea longa*.

Palatability of different types of litter to earthworms may depend on nitrogen and carbohydrate content and the presence of polyphenolics such as tannins (Satchell, 1967). Earthworms prefer materials with a low C/N ratio, such as clovers, to grasses which have a higher C/N ratio (Ruz et al., 1988). Colonization of litter residues by microorganisms also increases palatability (Cortez et al., 1989), as does leaching of feeding inhibitors.

2.2.2 Benefits of Earthworms

Deep burrowing species such as *L. terrestris* can burrow through compacted soil and penetrate plough pans, creating channels for drainage, aeration and root growth (Joschko et al., 1989). The work by Shipitalo and Protz (1989) elucidated some of the mechanisms by which earthworms enhance soil aggregation. Ingested aggregates are broken up in liquid slurry that mixes soil with organic material and binding agents. The defecated casts become stable after drying. Stewart et al. (1988) also presented evidence that earthworms initiate the formation of stable soil aggregates in land degraded by mining.

In forest ecosystems earthworms, especially litter feeders such as *L. terrestris*, can consume all the litter deposited on the soil surface within a period of several weeks (Knollenberg et al., 1985) or months (Satchell, 1967). Incorporation of litter by earthworms in apple orchards can be an important mechanism for preventing outbreaks of scab fungus, spores of which are transmitted from litter to new foliage by spring rains. Raw (1962) found a high correlation between *L. terrestris* biomass and apple leaf litter incorporation, with over 90 per cent of litter incorporated during the winter when this species was abundant. Incorporation of surface litter may be an important function of earthworms in no-tillage agro-ecosystems.
Introduction of earthworms to areas not previously populated has led to improvement of soil quality and productivity in New Zealand grassland (Martin, 1977), on drained Dutch polders in heathland in Ireland (Van, 1977; Curry and Bolger, 1984) and in mining spoils in the U.S. (Vimmerstedt and Finney, 1973).

Earthworm casts are sources of nutrients for plants. Lumbricids in a pasture soil produced casts that contained 73 per cent of the nitrogen found in the ingested litter, indicating both the importance of earthworms in incorporating litter nitrogen into the soil and the inefficiency of nitrogen digestion by earthworms (Syers et al., 1979). Earthworms increase the amount of nitrogen mineralized from organic matter in soil. Because nitrification is enhanced in earthworm casts, that is, the ratio of nitrate-N to ammonium-N tends to increase when earthworms are present (Ruz et al., 1988). Nitrogen-fixing bacteria are found in the gut of earthworms and in earthworm casts, and higher nitrogenase activity, meaning greater rates of N-fixation, are found in casts when compared with soil (Simek and Pizl, 1989).

Earthworms may increase levels of metabolic activity in soils, as measured by the amount of CO$_2$ evolved, yet nematode abundance and microbial biomass may decrease (Yeates, 1981; Ruz et al., 1988). This occurs because earthworms reduce the amount of substrate available to other decomposers and ingest other decomposer organisms as they feed. This process would tend to accelerate nutrient cycling rates.

2.2.3 Management Effects on Earthworms

Earthworms are not favored by tillage, and in general, greater the intensity and frequency of disturbance, lower will be the population density or biomass of earthworms (Haukka, 1988; Mackay and Kladivko 1985; Gerard and Hay, 1979; Barnes and Ellis, 1979). Agricultural soils are generally dominated by species adapted to disturbance, low organic matter content, and a lack of surface litter. Earthworms are dependent on moderate soil moisture content, and cultivation tends to have a negative effect on earthworms by decreasing soil moisture. Earthworm populations are usually significantly depressed in cropped fields relative to pasture or undisturbed lands. Lumbricids in a South African soil were decreased by cultivation to about one-third of original levels. Some common agricultural lumbricids are *Allolobophora chlorotica*, the *Aporrectodea caliginosa* species complex (*A. trapezoides*, *A. turgida*, and *A. tuberculata*), and *L. terrestris*. Species common to organic rich habitats, such as *E. foetida* are rarely found (Lee, 1985). *Aporrectodea trapezoides* was less affected than
Eisenia rosea, possibly because it is able to burrow more deeply in the soil and escape the zone of disturbance (Reinecke and Visser; 1980). Gerard and Hay (1979) reported 93 earthworms per square meter in normally plowed plots, including *A. caliginosa*, *A. chlorotica*, *A. longa*, and *L. terrestris*. Earthworm abundance increased in plots that received disk cultivation, or no-tillage treatment. Earthworm abundance doubled in no-tillage soybeans as compared with ploughing (Mackay and Kladivko, 1985).

A major function of tillage is to decrease bulk density of soil and increase porosity but it only increases microporosity. Macropores, which may be of physical or biological origin and which can play an important role in conducting water rapidly into the soil, are destroyed by tillage. For instance, a 67 per cent decrease in the rate of infiltration after ploughing a tropical forest soil was attributed to the destruction of earthworm burrows. Infiltration in an adjacent arable soil, which was initially much lower than in the forest soil, increased by 23 per cent after plowing because the surface crust was broken (Aina, 1984). Infiltration increases in cropped soils when organic mulch is added due to the increased activities of earthworms in these soils and the production of macropores (Slater and Hopp, 1947). Soil compaction caused by agricultural traffic can also decrease earthworm populations (Bostrom, 1986).

A study in Denmark found that 200 ton/ha of manure was optimal for increased earthworm abundance and biomass (Andersen, 1980). *L. terrestris*, *A. longa*, and *A. caliginosa* were increased by manure, while *A. rosea* and *A. chlorotica* were not influenced. Organic mulches enhance earthworm habitat by moderating microclimate and supplying a food source. In corn plots in Pennsylvania, earthworms were most abundant in treatments that were not ploughed before winter and where corn residues had been chopped and left as a mulch, regardless of whether the plots were organically or conventionally managed (Werner and Dindal, 1990).

Effects of agricultural pesticides on earthworms depend on the chemical used. Herbicides tend to have low toxicity for earthworms, but can cause population reductions by decreasing organic matter input and cover from weed plants. Fungicides and fumigants tend to be very toxic to earthworms. Application methods may have unique effects on ecological groups of soil animals. For instance, the fungicide benomyl caused reductions of field populations of earthworms. Anecics such as *L. terrestris* were most susceptible to surface applications, and were less affected by incorporation of the pesticide into the soil. Because *L. terrestris* forms permanent burrows, it does not come into contact with subsurface soil beyond
its burrow. However; endogeic species such as *A. caliginosa*, which continuously extend their burrows as they feed in the subsurface soil, were most susceptible when benomyl was incorporated (Edward and Brown, 1982).

### 2.2.4 Organic Matter and Nitrogen Cycling

Kretzschmar and Ladd (1993) conducted a laboratory study of the decomposition of subterranean clover (*Trifolium subterraneum*) foliage incubated in columns of loamy sand. Clover foliage was incorporated at varying depths and soil was compacted at varying pressures. The earthworm *Aporrectodea trapezoides* was then added to some columns, but not to others. Results suggested that if herbage was deeply incorporated or the soil highly compacted, the earthworm alleviated the problems of decreased oxidation rates, and thereby promoted decomposition of the residues.

Ruz *et al.* (1988) studied organic matter breakdown and nitrification as influenced by the earthworms *Lumbricus rubellus* or *Eisenia fetida*. The study was conducted in 2-liter laboratory glass incubation chambers containing soil (fine sandy loam) and earthworms (10 per chamber). The researchers observed an approximately 50 per cent increase in mineral nitrogen after 11 weeks' incubation with earthworms as compared to control. Test plants (ryegrass, *Lolium* sp.) grown in the various treatments following incubation observed a 25 per cent increase in nitrogen uptake.

### 2.2.5 Soil Structural Changes

Lee and Foster (1991) composed a review article suggesting that earthworm burrows are important for water infiltration only when irrigation or rainfall exceeds the soil capacity for capillary uptake. Moreover, anecic earthworms (those that make deep, permanent, vertical tunnels) may block burrow entrances with soil or plant material, or position their bodies to obstruct flow down the burrows. Any of these phenomena make earthworm burrows less effective in promoting water infiltration.

Zhang and Schrader (1993) conducted laboratory studies on the aggregate stability of "natural," worm-induced, and pressure-induced aggregates. Worm-induced aggregates from castings and burrow linings were less stable than 'natural' aggregates, but more so than those formed by human agency through mere compression. The authors considered it unlikely that earthworms rupture mineral particles by compression, but did suggest that the chemical bonds of natural aggregates may be ruptured during ingestion by earthworms. The tensile
strength (resistance to crushing) of aggregates formed by the three species of earthworms assessed was as follows: *Lumbricus terrestris*, *Aporrectodea longa* and *Aporrectodea caliginosa*. Tensile strength was positively correlated with organic matter content in the worm-formed aggregates.

Lee and Smettem (1995) recommend the establishment on farmlands of deep-burrowing anecic earthworm species, to enhance water infiltration. Such species, including *L. terrestris*, are typically scarce in California orchards and vineyards, yet have been successfully established in apple orchards. Once established, *L. terrestris* substantially enhances the disappearance of leaf litter (Werner, 1996). The species is also believed important in increasing decomposition of cover-crop residues left on the surface, and the liberation of soil nitrogen (Binet and Trehen, 1992).

### 2.3 Quality of Tea Liquor

Literature regarding the quality parameters of made tea has been reviewed in this chapter under the following headings:

#### 2.3.1 Caffeine

Bhatia (1961) reported that the bud contains the highest amount of caffeine which generally goes on declining in lower leaves; while stem of shoot contains the lowest. Millin *et al.* (1969) stated that the interaction products of caffeine with TFs and TRs contribute to briskness as well as thickness of tea brew. Caffeine contributes bitterness to the tea brew by making complex with phenols (Nakagawa and Ishima, 1971 and Nakagawa, 1975). Wickremasinghe and Perera (1973) analysed the stem, apical bud and first, second, third & fifth leaves of tea shoots and showed that caffeine and polyphenol oxidase activity were higher in younger than in mature leaves. The tender stem contained relatively low levels of polyphenols, caffeine and polyphenol oxidase activity. Pure caffeine is bitter, and the detection threshold is around 3ppm in water. However, in the tea brew, caffeine forms a complex with the TFs and TRs as a result, the bitterness of caffeine as well as TFs and TRs are lost. Caffeine plays an important role in taste and briskness of tea beverage.

High level of caffeine enhances the creaming property of black tea (Dev Choudhury *et al.*, 1980). Cloughley (1982) reported that caffeine content of made tea is affected by seasonal, genetic, agronomic and cultural factors. In the tea beverage, caffeine concentration ranges from 2 to 4 per cent (Blouch and Tarka, 1983). Tsushida and Takeo (1984) found that
caffeine content of freshly plucked tea shoots increased from 20 per cent to 50 per cent after 48 hours at 25°C. The tender younger shoot which is the consequence of shorter plucking intervals, was found to contain higher caffeine content (Owuor and Chavanji, 1986). Sud and Badyal (1989) reported that the highest average content of caffeine occurred in March/April (Spring).

During manufacturing process of black tea, the caffeine content increased partly due to release of complex molecules which contain caffeine molecule as a part of its make up (Yamanishi, 1990). In 4 months old tea seedlings, greater than 99 per cent of the total caffeine was in the leaves and caffeine content was higher in old leaves. The caffeine content of black tea was affected by the shooting period and the time within the shooting period. It was determined that the processing methods did not have a significant effect on the caffeine content. Caffeine content in tea shoots decline from about 4.7 per cent in the bud to about 2.9 per cent in the third leaf. Fine plucking therefore, produces higher amounts of caffeine (Fujimori et al., 1991; Baumann et al., 1996). Caffeine content increased to a maximum of 34.5 ml/g in July and then decreased. Caffeine concentrations ranged from 22.1 ml/g of fresh weight in February to 52.9 ml/g in May (Suzuki et al., 1991). In summer, caffeine content of the leaves in the sheltered tea gardens increased by 4.31 to 14.41 per cent, resulting in a positive effect on green tea quality (Yao and Chen, 1992). The caffeine concentration ranges from 2.5 to 5.5 per cent (dry weight basis) in fresh tea leaves, and from 2 to 4 per cent in brews. The tea shoots from the Assamica are richer in caffeine than those from the sinensis variety (Ikeda et al., 1993). The amount of caffeine decreased from the first shooting period to the third, and also from the beginning of each shooting period to the end (Gokalp and Nas, 1993). Among the constituents of tea, caffeine and polyphenol are the most significant, which make the best beverage. Tea contains 1 to 5 per cent of caffeine and 15.0 per cent of soluble polyphenols. The range of caffeine content in Bangladesh tea is 3.3 to 4.75 per cent and that of polyphenol is 22.0 to 31.0 per cent. The caffeine composition of Bangladesh tea is above average but the polyphenol content is much higher than that of the other countries (Choudhury, 1993). Principal component analysis showed that there were positive correlations of caffeine with (-) EGC, and of (-) EGC with (+) EC and (+) catechin in fresh green leaves. Contents of caffeine, (-) EGC and (-) EGCG in fresh green leaves constituted the first, second and third principal components, respectively, and it is proposed that integration of these components reflects the potential theaflavin synthesis and black tea quality of tea clones (Liang et al., 2003). Ohta et al. (1995) showed that caffeine was
concentrated in the leaves and not detectable in the roots. Bae et al. (1996) showed that cultural methods had little effect on caffeine content of leaves. The caffeine content of leaves tended to decrease with later harvesting dates (Gulati and Ravindranath, 1996). Ashu et al. (1996) reported that caffeine content of tea is highest during early flush (April-June) then decreases during rainy flush (July- August) and slightly increases during backend flush (September-October). Yeh, et al. (1998) analysed several commercial tea drinks for their catechin and caffeine contents and it was found that caffeine content (60-300 ppm) was always higher than the concentration of total catechins (19-146 ppm). The catechin contents in the samples decreased after prolonged storage.

Tea quality decreased from the bud downwards. Caffeine and polyphenols which are important in the quality of the tea liquor, are less in the third leaf as compared to the second leaf and the bud. Teas made from two leaves and a bud illustrated the necessity for a good standard of picking (Ahmed and Muraleedharan, 1998).

Tea shoots comprising mainly two leaves and the apical bud were harvested from different types of tea plants and it was found that caffeine content in infusions were relatively high in cambodiensis and assamica types (Ashu et al., 1999). Khorijan had highest total nitrogen and caffeine contents. Caffeine content in light germinated seedlings was significantly higher than in dark germinated seedlings (Lu et al, 1999).

Singh (2002) observed that caffeine content in tea shoots reduces as the shoots get older. Caffeine content is maximum in bud, followed by 1st leaf, 2nd leaf and 3rd leaf in the order. Caffeine determines the creaming behaviour of tea. Caffeine is an important constituent of the infused brew responsible for briskness of the liquor due to its association with TF and TR. Ramamoorthy (2003) reported that caffeine content increased with extent period of withering.

2.3.2 Polyphenols

The relation between colour and strength of tea liquor in terms of chemical compounds was studied by Roberts (1958), who concluded that primarily the colour is due to polyphenolic content and polyphenol oxidase activity in green tea leaf. The percentage of polyphenols in tea shoots varied with agro-climatic conditions, cultural practices and seasons of its harvest. Polyphenols are highest during early flush which decline during rainy flush and slightly increase in backend flush (Sanderson and Kanapatchipillai, 1964; Wickremasinghe et al., 1966). Polyphenols are the major compounds of tea shoots. The presence of high
quantities of polyphenols (17-30 %) makes tea bush different from other plant species (Millin and Rustidge, 1967). Bhatia and Ullah (1968) showed a progressive decline of phenolic content of tender part to older parts of shoot system therefore, fine plucking produced good quality tea. Sakamoto (1970) observed that the desired greenish yellow colour of the liquor is believed to be dependent on the composition and the level of polyphenolics. Astringency of tea brew is as a result of polyphenols in tea (Nakagawa, 1975; Nakagawa and Ishima, 1971). Neither the amounts of individual polyphenols or polyphenol oxidase activity nor the total flavonol content were correlated with the quality ranking of the polyphenols (Roberts and Fernando, 1981). Sud and Badyal (1989) reported that highest average content of polyphenols occurred in September/October.

In summer, the polyphenol content of the tea leaves in sheltered tea gardens decreased by 3.2 to 10.4 per cent (Yao and Chen, 1992). Total polyphenol content and polyphenol oxidase activity varied between cultivars. Total polyphenol content was correlated with quality parameters (brightness, TR and TF). Polyphenol oxidase activity showed large variations with growing period and little correlation with quality parameters except thearubigins and total polyphenol content (Obanda et al., 1992).

Dhoedham had high leaves of nitrogenous constituents and polyphenols. There were not highly significant seasonal changes in polyphenols and catechin contents (Wang et al., 1992). Polyphenoloxidase (Catechol oxidase) activity and polyphenol metabolism decreased significantly with S application resulting in a reduced polyphenol content which was good for the quality of green tea (Ye et al., 1994). Hara et al. (1995) showed that the polyphenols in green tea are hardly oxidised, but they are non-enzymatically oxidised in yellow and dark teas. White, oolong and black teas are fermented; white having the least and black having the most fermentation. Lin et al. (1996) reported that the young leaves (apical bud and two leaves) were richer (2.7 folds) in polyphenols than old leaves (from the tenth to the fifteenth leaves). Also, the tea polyphenols were higher in summer than in spring. Longjing tea (unfermented green tea) contained the highest concentration of EGCG and polyphenols, whereas, Assam black tea (most fermented) contained the least.

Vinson and Dabbagh (1998) found that black and green teas were not significantly different in their phenol content and antioxidant strength. Prior et al. (1999) reported that total phenolics ranged from 32 to 147 mg/g in different commercial tea samples. Liebert et al. (1999) brewed green and black tea from 0.5 minutes upto 10 minutes under different brewing conditions and found that the phenolic content increased with the brewing time. The total
phenolics increased from 33.8 mg/100 ml after 0.5 minutes up to 68.4 mg/100 ml after 10 minutes brewing time. Stirring during brewing led to higher phenolic yields in the extract. Thus, phenolics in stirred black tea ranged from 44.5 mg/100 ml (0.5 minutes) to 96.7 mg/100 ml (10 minutes). Chopping the tea leaves resulted in the highest content of phenolics. Ramaswamy (1999) analyzed that indigenous China jat (Camellia sinensis var. Sinensis) in which the flush is small in size and dark green in colour, contains 10 to 17 per cent polyphenols as compared to the flush of hard leaved Assam variety which contains 25 to 55 per cent polyphenol on dry weight basis.

Lakenbrink et al. (2000) stated that the flavonoids comprised the major proportion (93 to 94 %) of the total phenolics. At brew time up to two minutes, the composition of the brew solids with flavonoids again comprising the major proportion (86 to 88 %) of the total phenolics. The efficiency of extraction in brewing (2 minutes) of total phenolics, total flavonoids, catechins and TFs was up to 33 to 55 per cent of the total available in the leaf. Yuan et al. (2000) stated that teas with high ratio of phenol to free amino acids were usually good in taste and appearance. Mao et al. (2000) observed that the extraction of tea polyphenol from Phyllostachys Pubescens under different conditions showed its maximum content in leaves and branches that is 72.22 to 75.33 per cent, respectively, when measured by spectrophotometric methods. Kumar et al. (2001) analysed that in the black tea samples which were prepared from the tipped material using standard procedure, the level of total polyphenols was lower in the fresh shoots of first tipped in material as against the normal shoots. Gong et al. (2002) reported that the contents of tea polyphenols decreased with increased storage time and temperature. Chemical wither resulted in increase in caffeine, polyphenol oxidase and organic acids which may affect the black tea polyphenol composition and hence the colour and mouth feel of the liquor (Sharma and Sharma, 2003).

2.3.3 Liquor characteristics of made tea

Roberts (1958) reported that high values of tea could be correlated with high levels of theaflavins and adequate levels of thearubigins. By and large, theaflavins are considered to be an important parameter for determining the quality of made tea (Roberts and Smith, 1961; Nakagawa, 1970; Wickremasinghe and Perera, 1973). Roberts and Smith (1961) who gave the terms 'TF' and 'TR', stated that TRs are as important to the flavour and quality of black tea as the TFs. TFs impart the mouth sensations of 'briskness', 'freshness', and 'aliveness' while TRs are responsible for 'body' and 'richness' of tea brew. Roberts (1962) defined thearubigins
as acidic, brown, phenolic pigments. TFs, TRs and high polymerised substances formed during black tea processing are known to influence the colour of black tea due to their high concentration (Roberts, 1962; Ramaswamy and Lakshminarayanan, 1978; Ramaswamy and Thanaraj, 1981). Thearubigins which comprised of about 0 to 19 per cent of black tea was held responsible for colour, strength and mouthfeel of tea liquor (Roberts and Smith, 1963; Thanaraj and Ramaswamy, 1981). TFs which were reported to comprise 0.20 to 0.30 per cent of dry weight of black tea, contributed to astringency, briskness, brightness and colour of tea liquor (Roberts and Smith, 1963). Deb and Ullah (1968) and Biswas et al. (1971) have demonstrated good correlation between prices and TF as well as TFs + TRs. Later, evidence from chemical degradations led to the conclusion that TRs are polymeric proanthocyanidins (Brown et al., 1969).

Experiments in Malawi (Hilton and Ellis, 1972) have shown very good correlation between TFs content of plain teas with prices and/or tasters' evaluations; in North-East India. Determination of theaflavins and thearubigins give a precise measurement of colour and brightness of tea liquors and the valuation of made tea (Hilton and Ellis, 1972; Hilton and Palmer Jones, 1973; McDowell et al., 1990; Taylor et al.; 1992). Wickremasinghe and Perera (1973) observed that black teas made from leaves of differing maturity and from tender stems showed marked differences in organoleptic properties in TF and TR contents. The reasons for the differences in the quality, strength and colour are ascribed to the proportions of the different polyphenols, polyphenol oxidase activity, caffeine, theanine, theagallin and an undifferentiated compound content of the raw material from which the black tea was processed.

Studies carried out by Upasi-TRI (Thanaraj and Ramaswamy, 1980) have shown their testers' evaluation on overall cup characters in terms of nominal valuation are in good agreement with total liquor colour of black teas. Roberts and Fernando (1981) found that there exist some correlation between polyphenol content and quality which can be used as criterion for colonel selection. Further, TF content showed some correlation but that was not quantitatively related to the polyphenol content or polyphenol oxidase activity. Thus, the correlations were not clear enough to be used as an absolute measure of quality. The biochemical and physiological role of chlorophylls, carotenoids and phenolics in relation to quality has been explored (Mahanta and Hazarika, 1984). Quality of tea was reported to be dependent upon plant genetics, chemical and biochemical compositional changes in green tea shoots during different flushes (Hazarika and Mahanta, 1984; Ranganathan and Natesan,
1987). Optimum fermentation has been assessed by chemical analysis of tea leaves during the process of tea manufacture for theaflavins profile to achieve proper balance between theaflavins content which is essential for good cup of tea (Owuor and Reeves, 1986). High chlorophyll content in made black tea was found to affect adversely the quality of tea by rendering grassy taste to the tea liquor (Lelyveld and Smith, 1989; Lelyveld et al., 1990). Owuor (1991) found that with the time changes in TFs, TRs and caffeine (plain tea quality parameters) were smaller than changes in the aroma. Saba et al. (1991) reported that thearubigins and theaflavins constituents present in black tea have been used to assess the quality of tea even for trade (McDowell et al., 1995).

Owuor and Obanda (1995) reported that astringency of tea liquors varied with the TF content which also affected the sensory evaluation of black tea. Wilkie and Burton (1995) concluded that leaves should never be compressed at any stage during handling and should never be allowed to heat up to 40°C. Acceptable tea quality should result if leaves reach to the factory within five hours of plucking and their temperature remain below 35°C during the entire period. Owuor and Obanda (1995) determined that the extent of TFDG (Theaflavin-3, 3'-digallate) determines the quality and not the total amount of Theaflavins present. Both temperature and humidity affected tea quality, but fine manipulation was the most important factor (Guo et al., 1996).

The overall quality of tea was greater with raised shears in tea clones TV-7 and TV-9 but liquor strength was greater with flat shears. The type of shears used had little effect on the quality of tea clone TSS-450. Hand plucking produced the best quality tea in all the three tea types. Temperature about 30°C during withering process of black tea manufacture was reported to decrease the TFs, brightness, flavour index and sensory evaluation score of black tea (Owuor and Obanda, 1996).

Gulati and Ravindranath (1996) recorded maximum TFs, TRs and caffeine content in the infusions of the early flush of orthodox Kangra tea, quality degradation during main flush and a slight improvement of quality towards the winter flush. Mashingaidze and Tomlins (1997, Part-II) studied the effects of tea leaf density in different kinds of sacks on the quality of made tea and found that in the leaf held for more than 3 hours; leaf temperature, broker's valuations and total TF content of the made tea were little affected by leaf density. With leaf held for 3 to 6 hours, the optimum leaf density was found to be 150 kg/m³, corresponding to 6 kg/m³ in an industrial sack, 7 kg/m³ in a fertilizer sack and 14 kg/m³ in a net sack. With leaf held for 9 hours, loss in quality with increasing leaf density was rapid. It
was concluded that leaf temperature is not always a reliable indicator of loss of made tea quality.

Mashingaidze and Tomlins (1997, Part-IV) found that with severely damaged leaf in sacks, repeatedly dropped from head height onto a concrete floor, the loss in valuation for clones SFS 150 was 5 per cent and for SFS 204 was 8 per cent, and the decline in TF contents were 10 per cent and 17 per cent, respectively. Dropping sacks of leaf 8 times resulted in 30 per cent leaf damage, but there was no significant decline in valuation; TF content declined significantly only with SFS 150. Damaged leaf turned red more rapidly than undamaged leaf. Mashingaidze and Tomlins (1997, Part-VI) observed that total TF content of all teas declined gradually with increasing red leaf incidence.

A commercially available plant efficiency analyser, which measure chlorophyll fluorescence could detect signs of leaf deterioration before any visible changes. Brokers' valuations and total TF content declined markedly when the chlorophyll fluorescence of the third leaf declines corresponding to holding a sack for 9 hours, where leaf temperature reaches 46°C resulted in 60 per cent red leaf incidence. Obanda et al. (1997) reported that the formation of TFs and the TRs fractions TRS I and TRS II in black tea were affected by withering temperature and leaf moisture status. Humid conditions were more favourable for TF formation than dry withering conditions, TRS I and TRS II formation were more favoured by cold dry withering or warm humid withering conditions than by cold humid or warm dry conditions.

Owuor and Obanda (1997) proposed that increase in temperature at post-plucking and prior to maceration of leaves reduces plain black tea quality with respect to TF and TR content, brightness and colour. Tea leaves that became red on withering produced black tea with low TF content and brightness, but with high TR content and colour. Sensory evaluation of such tea was low, and tasters described it as thick and muddy. Mixing this bad leaf with good leaf resulted in tea of intermediate quality. The addition of upto 10 per cent of bad leaf to good leaf tea resulted in an insignificant quality reduction.

Deka and Bhattacharyya (1997) observed that the optimum fermentation time during different flushing seasons is dependent on TF content which in turn determine the organoleptic characters and thereby the cash value of teas. Formation of TRs and total soluble sugar content of teas influence the quality of made teas. Under-fermentation produces less TF and TR which in turn results in less brightness and thin liquor. Proper fermentation produces balanced liquor with brightness, briskness and strength. Over-fermentation produces dull, flat
and heavy liquor due to less TF and more TR. TF formation is favoured at low temperature and peaks at about 28°C to 30°C. Therefore low temperature leads to brisk tea because of more TF.

Nakano (1998) reported that the middle height skiffing position which range between 40 to 60 mm above the plucking surface of the second crop, showed the enhancement of tea quality. However, the higher skiffing position, especially over 70 mm above the plucking surface of the second crop, appeared to decline the shape or colour of made tea, aroma, colour of liquor and taste. Obanda et al. (1998) reported that the time lapse between plucking and processing has significant influence on the formation of chemical quality parameters of black tea in a commercial factory. For leaf reaching the factory on the same day of plucking (day 1 leaf), total TFs and individual TF of leaves both changed due to fermentation time and wither duration, but total thearubigins and colour levels varied more due to fermentation duration than wither duration. For leaf that reached the factory on the second day after plucking (day 2 leaf), there was diminished response in the formation of the black tea chemical quality parameters due to fermentation and withering durations. The results suggested that in the commercial manufacture of day 2 leaf no significant quality losses are likely to be incurred by processing it immediately after arrival to the factory.

Ramaswamy et al. (1998) conducted a study to compare hand plucking and shear plucking of shoots. The chemical quality parameters and sensory evaluation of black teas changed with plucking method. Hand plucked teas were very rich in their green leaf biochemical precursors and had higher contents of made tea quality constituents than shear plucking. However, tea obtained by shear plucking from a field continuously sheared over a prolonged period (5 years), was found to be superior to that obtained by shear plucking from a field previously under hand-plucking. Owuor and Obanda (1998) analysed that catechin levels in green leaf, total TFs, brightness, TRs, colour, flavour index and sensory evaluation decreased with coarseness of the plucking standard. The decrease in total TFs level was due to a decrease in all the individual TFs. All the individual TF levels decreased with coarse plucking standards and the decrease was greatly in galloylated TFs, especially in TF digallate, compared with simple TF. Short fermentation times produced black teas with higher brightness and flavour index, but lower TFs, TRs and colour. Irrespective of plucking standards; TF-3-gallate, theaflavin-3 and 3’-digallate levels increased, resulting in the increase in TF digallate equivalents. Brightness and flavour index decreased while TRs, colour and Groups I & II volatile flavour compound levels increased with long fermentation. The results
support the factory practice of not changing the fermentation times with changes in plucking standard.

TFs, TRs and high polymerised substances as well as total liquor colour, brightness and briskness exhibited a marked progressive decline in tea made from shoots with increasing blister blight severity (Ashu et al., 1999). Ashu et al. (1999) reported that TFs, TRs and caffeine content in infusions were relatively higher in Cambodiensis and Assamica types. Yamanishi (1999) stated that the concentrations of TFs and TRs in black tea vary considerably with the conditions of manufacturing process. Dudeja (1999) reported that the quality of black tea is determined by the amount of TF and TR and by the TF:TR ratio. The brightness, briskness and strength are determined by TF content whereas whilst body and colour are associated with TR content. Infact, there is a positive correlation between the TF content and the market value of the black tea. Viewing this, the highest possible level of TF content in the manufactured black tea is desired.

A degree of withering of 600-650 mg/g during the first, second and fourth seasons was best for the development of significantly higher brightness and total colour characteristics (Sud et al., 2000). Jose (2001) reported that the proportion of TF1 decreased from August to February, that of TF4 increased over the same period and the proportions of TF2 and TF3 remained fairly constant during the period. TF1 increased from 2 leaves and a bud stage to 4 leaves and a bud, while that of TF4 decreased during this period. Those of TF2 and TF3 remained constant during this period. The amount of total TF decreased from September to February. Tea made from finer plucked shoots (2 leaves and a bud) had higher TF than that from coarse plucked shoots (4 leaves and a bud).

Wright et al. (2002) analysed that the sum of the TFs of the black tea correlated well with the value of the tea. Of the individual TFs determined in the black tea, the highest correlation was obtained with TF-3-monogallate and free TF-B followed by TF-A showed the steepest slopes against value, making them good indicators for value. The TF-digallate content didn't show significant correlation with value. The individual TF content thus can be used for optimising the black tea manufacturing process.

Singh (2002) found that under-fermentation has less TF and TR which results in less brightness and thin liquor. Proper fermentation produces balanced liquor with brightness, briskness and strength. Over-fermentation produces dull, flat and heavy liquor due to less TF and more TR.
Liang et al. (2003) analysed chemical composition, colour differences of black tea infusions and their relationships with sensory quality assessed by tea tasters. There were significant correlations between the individual quality attributes. The parameters correlating significantly with the total quality score were classified into four groups namely nitrogen compounds, phenol compounds, tea pigments and infusion colour indicators. The regression of the total quality score upon the principal components gives a highly significant relationship.

Ramamoorthy and Venkateswaran (2003) showed that the catechins that take part in enzymic oxidation during fermentation in the presence of polyphenol oxidase results in the formation of black tea pigments viz., TF, TR etc. TF is responsible for briskness and brightness while TR is responsible for colour and strength of the liquor. The enzyme polyphenol oxidase is actively involved in biochemical changes when the leaf temperature is maintained below $35^\circ$C. After the fermentation, to have maximum TF in made tea, the enzyme should be deactivated during initial stages of drying. The TF level dropped to 0.73 per cent in BOP grade and 0.91 per cent in the PD grade when the fresh leaf was subjected to high temperature as compared to the TF level of 1.19 per cent and 1.40 per cent in tea made from good leaf. Proper handling of green leaf is therefore necessary to exploit the quality of tea. During drum fermentation stage most of the catechins are converted into TF and TR. For this conversion the enzyme polyphenol oxidase plays a vital role. Maintaining optimum level of temperature at every stage of CTC tea manufacture is essential to exploit the quality from the raw material and to achieve higher level of TF content and thereby better price realization.

The most important quality attribute viz., theaflavin, responsible for brightness and briskness of the liquor progressively increased with withering time. The theaflavin level was higher by 28 per cent in leaf grade in the treatment without withering. A similar trend was noticed in the thearubiggin content also (Ramamoorthy, 2003).

TF is higher in drum cum floor fermentation. Similarly, total liquor colour is also higher in drum cum floor fermenting method. Thus, there is a significant improvement in the drum cum floor fermentation in all the quality parameters. The improvement in the quality parameters in the drum cum floor fermentation may be due to build up of favourable temperature inside the drum and better contact between air and dhool in the initial stage of fermentation (Ramamoorthy, 2003). Total liquor colour and water extract increased from 2.29 per cent to 3.46 per cent in the leaf grade and from 3.83 to 4.42 per cent in the dust grade (Ramamoorthy, 2003).