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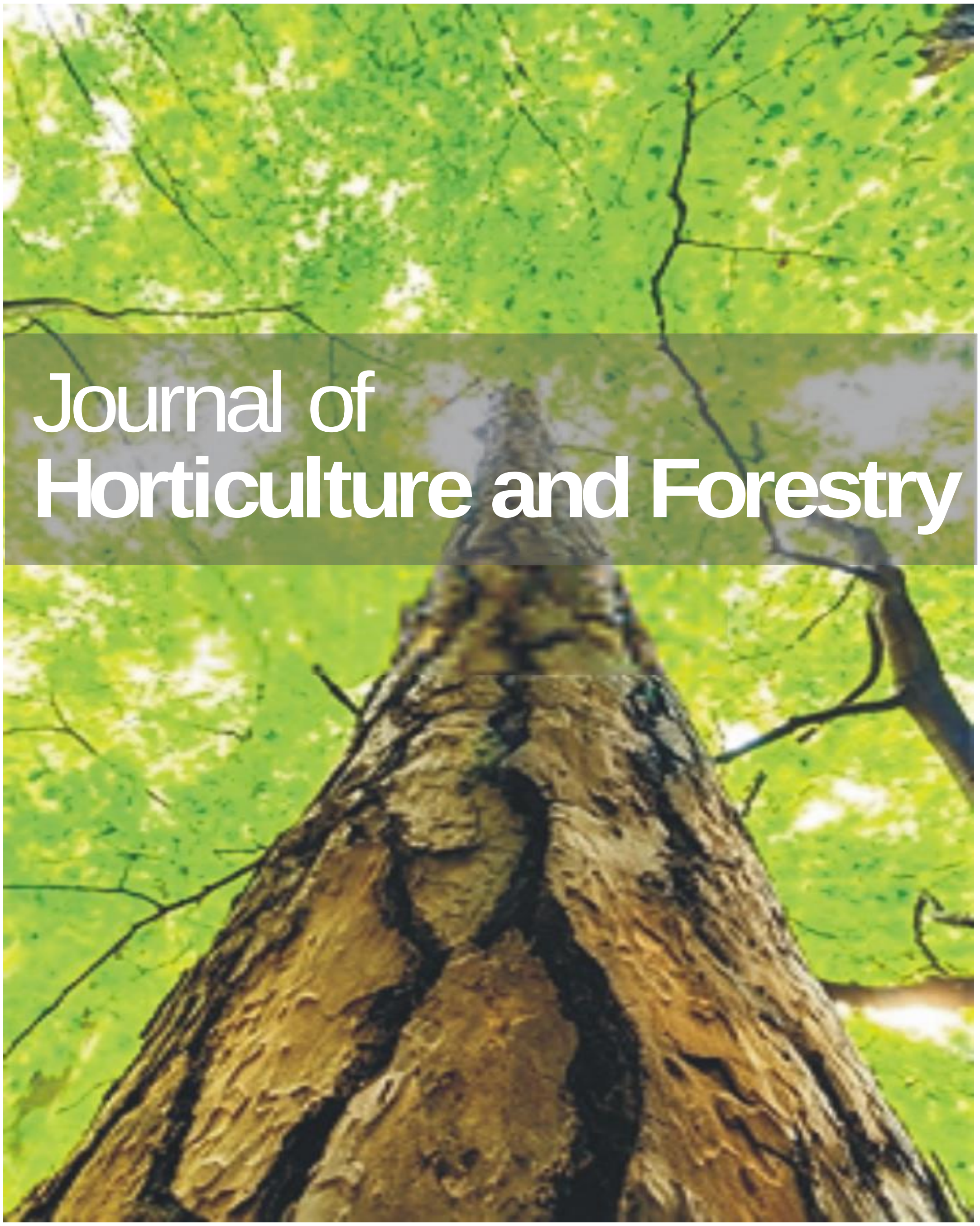

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Full Length Research Paper

Effect of tea processing methods on biochemical composition and sensory quality of black tea (*Camellia sinensis* (L.) O. Kuntze): A review

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Final quality of black tea depends mainly on the chemical composition of the raw tea leaves. Various plucking methods have direct effect both on yield and quality in different cultivated variety and environments. Different literature reports indicated that polyphenols, caffeine, essential oils and amino acids are responsible for aroma and flavor of black tea. The oxidation process begins at rolling step and ends at initial stages of drying process until the heat denature the enzymes, which convert tea polyphenols (catechins) to theaflavins and thearubigins; both are responsible for brightness, color and taste of black tea. TR increased by increasing fermentation period. TF decreased by increasing fermentation period. The essential oils and the amino acids also contribute to characteristic tea taste and aroma. It was found that the essential oils content increased during the withering, rolling and fermentation steps; however this amount decreased during the drying step. But this reduction is compensated by the Millard reaction which is the reaction of amino acids with the sugars during drying, contributing positively to the tea flavor and color. Theaflavin, thearubigins and total color content of black tea stored in accelerated storage condition decreased slightly when compared with tea stored under normal conditions. It is concluded that plucking (interval, season and standard), processing steps and storage system plays major role in maintaining black tea quality.

Key words: Tea processing, black tea, biochemical composition, sensory quality.

INTRODUCTION

Tea (*Camellia sinensis* (L.) O. Kuntze) is an ancient crop that has been cultivated for thousands of years (Jianwei et al., 2016). Tea plant belongs to the *Theaceae* family. It is a woody perennial tree crop and it is diploid crop with a chromosomal number of 30 (2n=30), though some triploid cultivar (*C. sinensis* var. macrophylla and *C. rosaeflora*) have been reported (Devarumath et al., 2002).

Tea plant grows within an air temperature of 18 to 25ºC. Below 13ºC and above 30ºC has been found to reduce shoot growth (Carr, 1972). It is also grown at an altitude of 2200 m.a.s.l. Tea plant requires a minimum rainfall of 1200 mm per annum, but 2500 to 3000 mm per annum is considered as an optimum (Hajiboland, 2017). The soil pH requirement for the growth of tea plant is in

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the range of 4.5 to 5.6. The optimum soil conditions recommended for tea plant growth is a well-drained, deep and well-aerated soil with more than 2% organic matter (de Silva, 2007).

Tea leaves are probably earliest and most consumed herbs. Black tea, processed from the young tender shoot of *Camellia sinensis* (L.) O. Kuntze (Muthumani and Kumar, 2007). Black tea is produced from tea plant after a series of physical and chemical reactions in the various tea processing procedures (Xiaoli et al., 2012). It is the most widely consumed fluids next to water. Approximately worldwide annual production of dry leaves and consumption reaches up to 1.8 million tons and 40 L per year, respectively (Seetohul et al., 2006).

Because of its high content of catechins and tea flavonoids, tea consumption protect against the development of cardiovascular diseases (Hodgson and Croft, 2010). In our world tea consumed as white, green, black, or oolong tea. White and green teas are known as unfermented tea. The polyphenol oxidase enzyme of green tea is inactivated by steaming. Oolong tea is produced by withering and half fermenting the leaves. Thus oolong tea is called “partially fermented tea”. Black tea is known as fermented tea because the leaves are fully fermented, allowing enzymic oxidation of the polyphenols. Different tea processing methods results in variation of chemical component in tea beverages (Hara et al., 1995).

Tea quality mainly depends on the variety of leaf, growing environment, plucking standard, plucking interval and plucking season, manufacturing methods, size of ground tea leaves and infusion preparation. Quality is measured on the basis of liquor brightness, briskness, color, aroma and flavor and leaf appearance (Ramadurai, 2000; Astill et al., 2001).

Studies showed that the main constituents of tea leaves belong to the polyphenol group accounting for 25 to 35% on a dry weight basis also contains various chemical constituents including methylxanthines, amino acids, chlorophyll, carotenoids, lipids, carbohydrates, vitamins, and more than 600 volatile compounds (Chaturvedula and Prakash, 2011). Tea leaf is distinguished by its remarkable content of methylxathines and polyphenol and they are predominantly responsible for those unique properties of tea that account for its popularity as beverage. Taste, flavor, aroma color, brightness and astringency in tea infusions are influenced by polyphenols, caffeine, sugars, organic acids, amino acids and volatile flavor compounds (Obanda et al., 2004).

TEA MANUFACTURING PROCESS AND ITS EFFECT ON THE QUALITY ATTRIBUTES OF BLACK TEA

Black tea quality is greatly deepened on physical and chemical processes involved in its manufacturing.

Various processes involved in tea manufacturing after picking of leaves are weathering rolling, fermentation, drying, sorting, grading, storage and packaging (Javed, 2015). All the stages are associated with several chemical reactions which determine the quality of end product (Bhuyan et al., 2012)

Harvesting/plucking

Plucking standards

Plucking standards has important aspects to determine black tea quality. The plucking standard has a large effect on yield and quality of the tea. Generally the plucking standard can be explained as fine, medium or coarse. With fine plucking only the first two leaves and the bud are plucked, with coarse plucking standard three or four leaves and the bud are plucked (Wright, 2005). Two leaves and a bud plucking standards are considered the best compromise between yield and quality (Banerjee, 1992). However, some producers use less tender shoots to realize extra biomass production in a plucking round. But coarse plucking standard reduces plucking frequency as longer periods are needed for the development of new shoots to that standard. Over extended period, the advantages in cumulative biomass production may not be significant (Okinda and Bowa, 2012).

Indeed, fine plucking standards of young shoots also improves yields (Waheed, 2002). The black tea caffeine, teaflavins, total ash and total water soluble solids contents declined while thearubigins (Amiri, 2007), crude fiber (Smiechwska et al., 2006) and florid (Lu et al., 2004) increased with course plucking standards.

The quality of black tea declined with coarse plucking standards (Mahanta et al., 1988), in terms of the plain and aroma quality parameters. The observations were attributed to the fact that young tea shoots have high levels of polyphenols (Owuor and Obanda, 1995) making the plain quality parameters of the resultant tea beverages to drop as the leaves become older. Thus the catechins (Flavan-3-ols) responsible for the formation of black tea quality parameters (theaflavins and thearubigins) decreased (Owuor and Obanda, 1995). But chlorophyll whose high level reduces black tea quality increased with maturation of the leaves (Taylor et al., 1992).There is a marked reduction in quality of black tea when the raw material used for processing includes the more mature leaves of the tea shoot. Earlier studies of polyphenolales in Assam tea and in Malawi tea grown at Cambridge, England, had shown that the level of cactine in gallates, galic acid, Theogaline and compound G 36 were maximum in the flush and decreased as the leaf matured. On the other hand, the levels of myricetine glycosides and epigallocatechin were markedly higher in

Table 1. Variation (dry weight basis) of the chemical composition of black tea to plucking standards.

Variable	Plucking standards					
	Bud	1 leaf and bud	2 leaves and bud	3 leaves and bud	4 leaves and bud	5 leaves and bud
Caffeine (%)	3.89	3.42	2.11	1.56	1.29	1.22
Theaflavins (%)	23.21	33.43	34.71	29.99	27.33	22.42
Thearubigens (%)	8.26	12.93	17.81	18.19	18.99	16.68
Total water soluble solids (%)	48.2	50.6	47.9	45.0	41.9	42.6
Ash (%)	7.11	6.78	6.1	6.38	6.37	6.65
Crude fiber (%)	6.76	8.12	10.22	13.68	14.86	16.65
VFC	-	-	-	-	-	-
Sum of Group I	3.61	4.47	4.63	4.86	5.23	5.74
Sum of Group II	8.18	8.30	6.94	5.50	5.06	4.54
F.I. (II/I)	2.26	1.86	1.50	1.13	0.97	0.79

VFC= Volatile flavor compounds, F.I=Flavor index.
Source: Philip et al. (1987).

mature leaves, whilst derivatives of the flavinoles, apigenin and juteolin, were detected in mature leaves only. Again other study of (Obanda et al., 2002) shows that there are differences in yield potential from region to region in different genotypes.

Generally, the variation of plucking standard was shown in the Table 1. According to Philip et al. (1987) investigation fine plucking standard produced high contents of caffeine, TF and total water-soluble solids, whereas the ash content and crude fiber, being lowest. The highest TF content, optimum levels of catechin concentration and polyphenol oxidase activity existed in two leaves and a bud. A coarse plucking standard produced very high TR contents and low TF content due to coarse plucking being attributed because of increased polyphenol oxidase level in mature shoots.

Although the plucking standards of a bud, and one leaf and a bud produced very high-quality teas as indicated by Flavor index, caffeine, TF, total water-soluble solids, crude fiber and Group II Volatile flavor compounds contents, The study suggested that plucking two leaves and a bud, which compromises both the yield and quality should be practiced.

Plucking intervals

The choice of a plucking interval may control the shoot distribution as well as the quality and quantity of crop (Odhiambo, 1988). Frequent interval of plucking result in higher yields as it causes enhanced rates of auxiliary buds development (Grice, 1982). Since apical dominance is more frequently overcome through decapitation of apical shoots (Odhiambo, 1988). Conflicting results have been obtained on the effects of plucking intervals on yields. In Malawi (Mitini, 1989) yield increased with long plucking intervals while in Kenya (Owuor et al., 1997) long plucking intervals decreased yields. When all available leaf was harvested, fine shoots declined and course leaf increased as plucking rounds lengthened. The total theaflavins, caffeine, group 2 VFC and flavor index declined while group 1 VFC and thearubigins increased with longer plucking rounds (Owuor et al., 1997) leading to a decline in quality with long intervals (Asil, 2008 and Okal et al., 2012). The decline was partially attributed to the increase in unsaturated fatty acids (Okal et al., 2012), leading to increase in group 1 VFC in black tea (Owuor et al., 1990). Thus short plucking intervals improves both crop yields and quality.

As a report of Mridul et al. (1985) indicate in Table 2 Organoleptically, teas made from 5-day plucking round are considered to be very good due to the lower content of ash and fiber. On the other hand, black teas made from 7-day plucking round have a balance of VFC, ash, soluble solids and caffeine, and are judged as good tea by tea-tasters. Theaflavine (TF) and thearubigines (TR), which are the most important characteristic compounds in black tea but the amount of such components increased as an interval of plucking extends.

Plucking seasons

The presence of phenolic compounds that are found in young tea shoots are main factors in determining Quality of black tea (Hara et al., 1995). Low total polyphenol content is responsible for low quality black teas (Obanda, 1997). Thus, the total polyphenol levels are important to the quality of black tea, and those levels are affected by their levels occurring in the fresh tea shoots (Harbowy and Balentine, 1997). An early study in central Africa showed that the level of flavanols in the fresh apical

Table 2. Chemical composition of black tea at different plucking round on a dry weight basis with the tasters' evaluation.

Variable	Plucking Interval			
	5 days	7 days	9 days	11days
Ash (%)	5.95	6.15	6.16	6.15
Crude fiber (%)	6.7	7.0	9.4	10.5
Total water soluble solids (%)	44.36	42.47	42.5	41.44
Caffieine (%)	4.4	4.79	4.32	3.81
Theaflavin(TF) (%)	1.12	1.22	1.25	1.4
Thearubigins, (TR) (%)	13.56	13.98	14.19	15.74
TF/TR (%)	0.08	0.09	0.09	0.09
Tasters evaluation	Very good	Good	Good	Fair

Source: Mridul et al. (1985).

shoots was highest during the cold season. As indicated by Lihu et al. (2005) tea shoots plucked during slow growth conditions such as in the winter contained a higher proportion of simple catechins relative to catechin gallates, with epigallocatechin (EGC) being the most significantly affected. In contrast, in the northern hemisphere, total flavanol content is greatest during the height of the growing season (that is, summer) and the least at the end of the season (late autumn). The cool seasons characterized by slow growth usually translate into low production but high quality black teas. Warm wet seasons are characterized by fast growth, high production and low quality black teas (Owuor and Obanda, 2001).

A direct relationship between the level of EGC in tea shoots and the level of total theaflavins, which are known to be quality indicators, in the resultant black tea, has been found by Sanderson et al. (1972). Thus, the seasonal variations of EGC in green leaves could be a chemical indicator of the seasonal variations in tea quality in central Africa. As a report of Lihu et al. (2005) EGC, epicatechin gallate (ECG), and epigallocatechin gallate (EGCG) were the main flavanols in tea shoots for both *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* grown, with EGCG predominating. EGC showed a higher level in spring than in summer, whereas ECG and EGCG showed higher levels in summer than in spring. Furthermore, it was reported that the levels of ECG and EGCG were higher in young and tender shoots, whereas EGC was higher in the fully developed shoots. This variation of leaf flavanol constituents is thought to be the main factor affecting the quality of the resulting tea (Graham, 1992). Thus, data on EGCG, ECG and EGC levels in the green shoots of fresh tea grown in Australia could be used as an indicator of the seasonal variations in the quality of the resultant black tea. The main black tea polyphenols, theaflavins, impart to black tea the distinct sensory characteristics such as color and taste. The level of total theaflavins of the resultant black tea is highly correlated with the content of EGC in the fresh shoots (Lihu et al., 2005).

As a report of Lihu et al. (2005) indicated in Figure 1 the seasonal variation in the ratio of Cactines Gallates (CGs) to Cactines (Cs) appears to be season dependent, with harvests in the warmer months showing higher ratios and harvests in the cooler months showing lower ratios on the same variety, var. *assamica.*

Withering

The foremost concept of withering of plucked tea shoots was to condition the shoots for subsequent stages of black tea processing (Bhuyan et al., 2012). Following plucking, many biochemical and physiological processes occur. It is a procedure which brings about physical and chemical changes in the fresh shoots to produce quality (Vicky et al., 2012). Withering refers to the changes (physical and chemical) that occur in tea leaf from the time it is detached from the plant to the time of maceration. For practical purpose, withering is often meant for dehydration (through forced or natural air) of fresh tea leaf brought about up to a partial removal of moisture content in the tea manufacturing factory. Excessive manual handling of green tea leaf in normal withering practices invariably causes damage to tea fresh leaves and consequent degradation to made tea quality (Das and Tewari, 2006).

The withering stage has two purposes. Chemical withering begins immediately after the tea leaves are plucked from the tea plant tree. During this process, complex chemical compounds are breaking down into simpler compounds. The other one is physical withering it is the removal of moisture from the tea leaf. During this process, the turgid leaf becomes flaccid. This process also leads to the concentration of sap in the cells of the

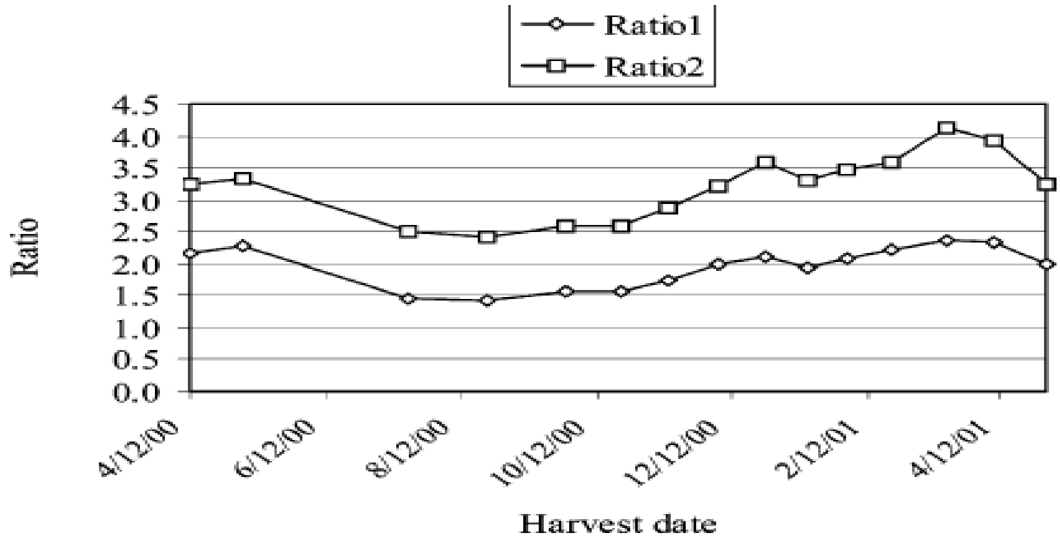

Figure 1. Seasonal variation of the ratios of cactines gallates to cactines in fresh tea shoots (ratio1= (EGCG+ECG)/EGC; Ratio 2=CGs/Cs).Epigallocatechin (EGC), Catechin (C), Epigallocatechin 3-gallate (EGCG) and Epicatechin 3-gallate (ECG), cactines gallates(CGs)
Source: Lihu et al. (2005).

tea leaf. The desired level of moisture can be removed by passing air through the piled leaves (Saptashish and Jolvis, 2016). Studies have shown that during physical withering the moisture content of green leaves is reduced to 60 to 70% (Omiadze et al., 2014; Jabeen et al., 2015). Time, temperature, and relative humidity are the major factors affecting physical withering (Obanda et al., 2004). Tocklai (Tea Research Association, Assam, India) has reported that physical withering requires shorter duration as compared to chemic al withering.

Experimental studies have shown that the withering time beyond 20 h leads to the deterioration of the quality of black tea (Owuor and Orchard, 1989), and hence, withering time should be limited to 18 h (Omiadze et al., 2014). There is no specified withering duration, but 14 to 18 h is generally considered the optimum period Saptashish and Jolvis (2016).

During withering, a certain amount of the solid matter, as well as moisture, is lost from the leaf. This is due to the loss of carbon dioxide by respiration, and can account for 3 to 4% of the dry weight content of the incoming leaf. The relationship between the process of withering and the aroma characteristics of black tea were examined by Mahanta (1988). Many studies have established that the characteristic volatile flavor compounds (VFC) consisting of terpenoids, fresh green (fatty acid derivatives) and aromatic/benzenoids are developed from the nonvolatile aroma precursors with the leaf softening techniques used during withering (Mahanta, 1988; Saikia and Mahanta, 2002). Black tea quality chemical parameters are adversely affected by unsafe practices of withering.

The quality of black tea depends on the commencement of chemical withering or senescence, anaerobic or catabolic phase. Withering involves decrease in protein, increase in amino acids, soluble proteins (Baruah et al., 2012) and cell membrane permeability. Withering is accompanied by reduction of polyphenoloxidase (PPO) activity of tea shoots and affects the oxidative condensation of flavanols (Ullah, 1984). Lipids degradation takes place to an extent of 20% during withering (Hatanaka et al., 1987). Withering temperature is another important factor for quality of tea. Excessive high temperature during withering led to leaf cell matrix destruction which resulted in early uncontrolled fermentation-like reactions.

Shortly withered leaves produce tea with more brightness and briskness due to increase in TF formation. During withering, excessive loss in green leaves moisture content (e.g., long time or high temperature) causes reduction in PPO activity of the leaves (Nihal et al., 2009). Obanda et al. (2004) reported that TF levels decreased with an increase in wither duration and so, the longer the wither duration the less bright liquors became. In addition, Sud and Baru (2000) reported that the lowest values for TF and brightness were observed in rainy season teas, probably due to inconsistent and low degree of withering which decrease the PPO activity. On the other hand, a comparison of the ferment ability of normally withered and freeze withered leaves was carried out by Muthumani and Kumar (2007) and it was reported that TF levels were higher while the liquor was brighter in leaves freeze withered for 4 h.

Table 3. Effect of withering temperature on black tea quality parameters.

Temperature (°C)	Treatment	%TF	%TR	%TR (I)	%TR (II)	%TC	%B
22	6 h CPW+ 6 h PW	2.44	19.65	5.17	13.76	6.75	22.13
	12 h PW	1.77	19.46	4.62	14.73	5.62	19.35
30	6 h CPW+ 6 h PW	1.76	20.37	5.60	12.72	6.14	17.62
	12 h PW	1.46	17.88	3.84	14.02	4.73	14.28
35°	6 h CPW+ 6 h PW	1.36	16.20	4.31	0.88	5.10	14.00
	12 h PW	1.18	14.65	3.05	11.60	4.15	12.47

TF= Teaflavine, TR=Thearubigines, TC= Total color, B=Brightness, CPW= Initially kept in 100% humid condition for 6 h was followed by physical withering 6 h. PW= Only physical withering for 12 h.
Source: Baruah et al. (2012).

The extent of withering has been shown to directly affect the levels of volatile compounds, hard withered teas have higher proportion of linalool and its oxides, and the lower levels of hexenal, is the reasons why such teas are more fragrant (Mike, 1998).

In study of Baruah et al., (2012) as shown in Figure 2 storage of shoots before fast physical withering was highly essential for requisite chemical wither to produce quality product. In black tea processing, tea leaves are subjected to different physical stresses which result in the formation of certain reactive oxygen species. By proper regulation of moisture loss in withering, formation of these oxygen species can be controlled and hence oxidative degradation of catechin is minimized. Thus reduction of normal withering time of 12 h from traditional method to 4 h in the modified method gave some favorable biochemical changes for enhancement in brightness and quality of tea. The quality attributes like TF, and brightness increased in this modified method of withering. For a brighter tea infusion, increase of TF is very essential (Wright et al., 2002) and it was achieved here due to restricted oxidative degradation of catechins in W I and W2 where initially shoots were stored at 100% humid condition before fast moisture loss in normal withering

According to (Obanda et al., 1997) at high temperature some unfavorable enzymic reactions occur to produce undesirable amount of TF, TR which are responsible for decreasing or increasing of brightness, flavour index and also sensory parameters of black tea. As a finding of Baruah et al. (2012) shown in Tables 3, TF, TC and brightness was higher at low temperature (22°C).

Another report of Baruah et al. (2012) shows that flavor index is considered as an indicator of quality in tea. Due to optimum quantity in group II and group 1 volatile flavor components (VFC) in W2 flavor index was found to be maximum. Another important observation was made from this experiment was that restriction of moisture loss of tea shoots for a longer period (W) prior to physical wither increased the amount of group II VFC, thus increasing overall quality of the aroma. On the other hand, group 1 volatile components were in the highest quantity when tea shoots were subjected to more stress. The flavor index needs to be optimum to have positive impact on quality.

Cutting and rolling

The primary objective of rolling is size reduction together with a degree of cell damage which permits the exposure of new surfaces to air, in the subsequent fermentation stage. In addition, it presses out the juice and a thin film of juice is coated on the surface of the leaf particle to enhance chemical changes (Javed, 2015). During rolling, cytoplasmic flavonoids are progressively oxidized into quinones as a result of chloroplast polyphenol oxidase and cell wall peroxidase generating yellow to red-brown colors (Harries and Ellis, 1981). The process of rolling releases the enzymes from the leaf as the leaf breaks exposing the juices to natural process of oxidation. The raw materials were rolled in different duration of rolling time. After the completion of rolling operation, the dholes (crush particles) were passed through Rotor vane machine for further crushing. The crushed material received was then passed through C.T.C (Crush, Tear and Curl) machine to make the crushed particles finer. The same materials were passed through a roll breaker to break the twisted balls and slow down the fermentation process. The effect of maceration method on the chemical composition and quality of black tea was examined by Owour et al., (1989). Rolling of tea shoots initiates oxidation of catechins by polyphenol oxidase (PPO), is responsible for the formation of theaflavins (TFs) and thearubigins (TRs). The theaflavins responsible for the formation of Briskness and brightness of the tea

Table 4. Rolling time and its effect on quality of black tea**.**

Color	Taste/flavor	Aroma	Strength	Infusion
Rolling times 20 min				
Light red and dull	Fair	Un-pleasant	Weak	Un-even
Rolling times 25 min				
Bright red	Good	Pleasant	Strong	Mixed
Rolling times 30 min				
Light red and dull	Poor	Un-pleasant	Light	Even

Source: Zobia et al. (2007).

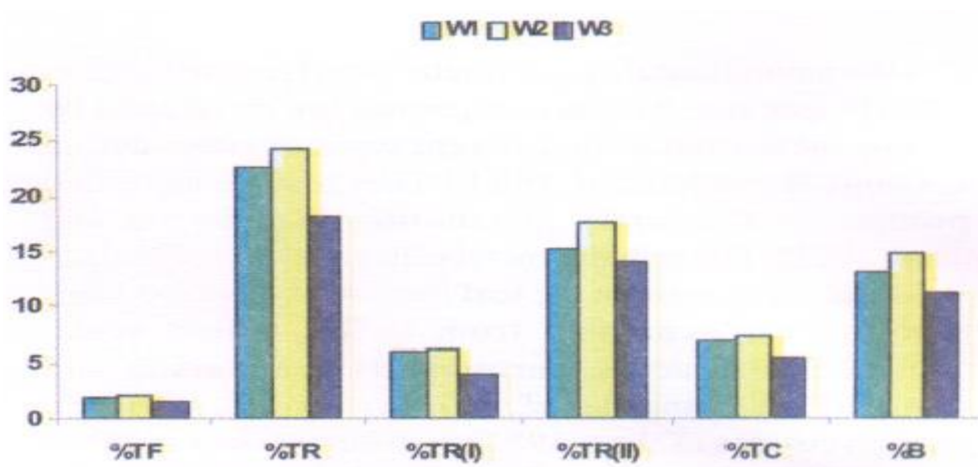

Figure 2. Effect of chemical and physical withering for different times on quality parameters of black tea. WI = Initially kept in 100% humid condition for 4 h was followed by physical withering 8 h. W2= Initially stored for 8 h in 100% humid condition followed by 4 h physical withering.W3= Only physical withering for 12 h.TF= Teaflavine, TR=Thearubigines, TC= Total color, B=Brightness,TR1 and TR2 are fractions of TR.
Source: Baruah et al. (2012).

liquor and Thearubigins, are responsible for the color because of orange brown compounds and taste of tea (Hajiboland, 2017). If the exhaust temperature is less than 49°C, the post fermentation process will continue for a considerable time and will soften the liquor. If the exhaust temperature is greater than 57.2°C the rate of moisture removal is too rapid and results in case hardened tea in which the particles are hard on the outside but incompletely dried within such teas yield harsh liquors and do not keep well (Javed, 2015).

Rolling times have its own impact on general quality of black tea. As the finding of (Zobia et al., 2007) shows that duration of rolling stays for 25 mins gave better results as compared to below and above such minutes time. Table 4 shows rolling durations effect on black tea quality.

Fermentation

Following the leaf disruption stage fermentation is the other critical steps in black tea manufacture because of the significant chemical changes occurring during this phase (Tüfekci et al., 1997). In fermentation stage, an enzymatic oxidation of the polyphenols, especially tea catechins, takes place, leading to the formation of TFs and TRs, they are attributes for the special characteristics of black tea liquors. In black tea production process, about 75% of catechins contained in tea leaves undergo enzymatic transformation consisting in oxidation and partial polymerization (Łuczaj and Skrzydlewska*,* 2005). Enzymes involved in oxidation of catechins are mainly PPO and peroxidase (POD) (Wright et al., 2002).

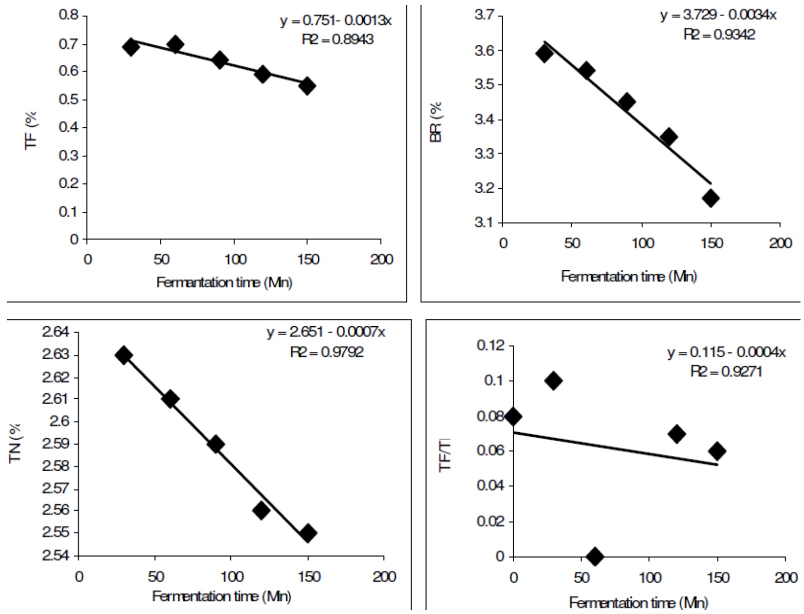

Figure 3. Linear regression between fermentation time as the independent variable (X) and theaflavin (TF), tannin (TN), brightness (BR) and TF/TR ratio as the dependent variables (Y).
Source: Ansari et al. (2011).

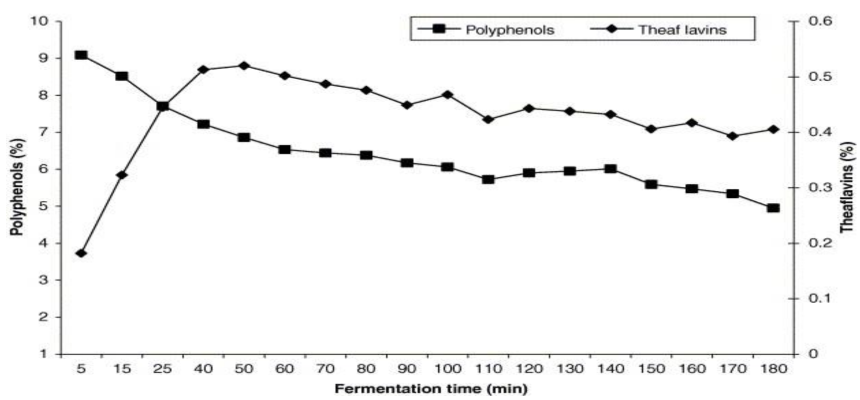

Figure 4. Influence of fermentation durations on the development of black tea quality.
Source: Muthumani and Kumar (2007).

The volatile flavor components are lower in non-fermented tea when compared to fermented tea. Linalool oxides are found in the essential oil extracted from fermented leaves, but not in the homogenates of fresh leaves. Rapid oxidation of polyphenols appears to hamper volatile flavor compound formation in tea leaves (Hazarika et al., 1984). Thus, both duration and temperature of fermentation should be controlled to ensure optimum production of flavor compounds. The enzymic oxidations in fermentation proceed maximally at 28°C, although a temperature range of between 24 and 28°C is thought to be optimal (Mike, 1998).

Ansari et al. (2011) result in Figure 3 that the relation between fermentation time and characteristics related to quality of black tea indicated that fermentation time significantly influences the content and changes of theaflavin (TF), tannin (TN), brightness (BR) and TF/TR characteristics such, characteristics depend on plant genetic potentials.

The study of Muthumani and Kumar (2007) showed in Figure 4 the formation curve of TFs climbed steadily, reaching a maximum at 45 min of fermentation. However, after 110 min shows some fluctuations. This happened because of PPO activity changes.

One study which is done by Moazzam et al. (2012) shows that maintaining medium fermentation temperature (25°C) and short duration (60 min) was ensure greater formation of TFs. The resultant black teas are then brisk, bright, and astringent and probably offer more benefit to human health. A better prediction of liquor brightness and total color of black tea will be achieved with inclusion of TF and TR than could be obtained with TF or TR alone. Briskness and astringency were associated with TF than with TR. Therefore, they were best predicted with TF. Evaluation of brightness by taster was associated to TR, and was best predicted with TR. According to Obanda et al. (2004) the changes in theaflavin and thearubigins during the fermentation period and concluded that increasing the fermentation period decreases theaflavin content and brightness of black tea, whereas thearubigin and total color were increased.

According to Moazzam et al. (2012) variations in fermentation duration were used to achieve maximum levels of different black tea parameters in cultivars. Higher TR content and total color developed on medium fermentation temperature (25°C) with shorter duration of (60 min). Thus medium fermentation temperature and short temperature favors production of thicker and darker colored black tea. Formation of TRs increased with time during the early stages of fermentation. As the fermentation progressed, TRs reached a maximum and then declined slowly (Ping et al., 2018).

Maximum sensory evaluation scores, briskness, brightness and astringent levels at different fermentation temperatures were attained at different fermentation durations. At low fermentation temperature maximum sensory evaluation scores were obtained. Thus production of high quality black teas at lower fermentation temperature requires longer fermentation duration, and maintenance of low fermentation temperature, though requiring longer fermentation duration, ensures that the resultant black teas are of better quality.

Drying

The drying of fermented tea has three major objectives; to terminate the biochemical functions by heat denaturation of the enzyme; to reduce the moisture to increase the shelf stability of black tea and finally, to enhance chemical reactions responsible for black tea character and flavor (Mauskar, 2007).

Especially, the drying procedure dehydrates tea to reduce Moisture content (MC) and to improve tea's smell and taste after thermo-chemical reactions under high temperature. Therefore, the MC of tea not only determines the shelf life of tea, but also affects the physical and chemical reactions in tea processing, so measurement of MC is an important task for producing high-quality of tea (Okamura et al., 2000).

Drying of black tea at 110°C temperature with 1.5 rpm dryer speed produces good quality tea (Table 5). All the lots were dried second time at low temperature (80°C) to remove 95 to 97% moisture, results in good keeping and storage quality. The black tea with high moisture content (more than 6%) loses its quality due to continue fermentation after drying. However Experiment done by Zobia et al. (2007) shows that the processed tea with high moisture contents have short shelf life. Kidist et al. (2013) indicated that as both temperature and duration increased biochemical composition and quality of black tea were decrease.

Storage method and duration

Quality of black tea in its broadest sense is the cumulative effect of all desirable attributes by which it is judged for its market value. Aroma, flavor, briskness, strength and color represent the quality of black tea in general and the concentration of chemical constituents present in a brew affects the quality of tea. Polyphenol (catechin) present in tea gets oxidized to theaflavin and thearubigins during processing of black tea. Caffeine 1, 3, 7-methylxanthine gives a bitter taste to tea. It was found that black tea kept under inappropriate storage conditions for prolonged period lost quality characteristics to a significant level (Cloughley et al., 1981). It was also observed that pigment profile of black tea in Northeast India changed during storage in noticeable level. After one month of manufacture some of the pigments increased and maintained for 8 months or so without much changes (Mahanta, 1988). It was also observed in an experiment at Tocklai that during initial period of storage rapid conversion ofTR-3 took place with corresponding increase of TF. Further change of TR took place with length of storage and TR-3 was converted to TR-l after six months. The study of (Debnath et al., 2012) their experiment shows that (Table 6) theaflavin content of black tea stored in accelerated storage condition decreased slightly and compared with tea stored under normal conditions. It was observed that TR content of tea fluctuated during the period of storage and there was slight increase of TR (13.71%) in the first month when there was slight decrease of TR (11.81%) in the second month in the tea stored under accelerated conditions. There was slight increase of total color (4.73) in the firstmonth and decrease (4.17) in the second month in the accelerated storage samples.

Brightness decreased in tea samples stored under accelerated conditions over control. Caffeine content showed decreasing trend in tea kept under accelerated conditions over normal storage while moisture content of tea increased over control. Microbial population increased

Table 5. Effect of drying temperature on black tea quality.

Color	Taste/flavor	Aroma	Strength	Infusion
Tea drying at 100°C with dryer speed of 1.4 rpm second time dryer temperature 80°C				
Bright red	Good	Fair	Weak	Mixed
Tea drying at 110°C with dryer speed of 1.5 rpm second time dryer temperature 80°C				
Light red	Good	Good	Strong	Mixed
Tea drying at 120°C with dryer speed of 1.6 rpm second time dryer temperature 80°C				
Bright red and light red	Very good	Fair	Weak	Green

Source: Zobia et al. (2007).

Table 6. Showing changes of quality parameters of tea during storage.

Parameter	TF	TR	TC	BR	Caffeine	Moisture (%)	Mold (Cfu/g)%10
Fresh tea	0.99	12.46	3.9	16.51	3.25	3.1	83
1st month normal	0.72	12.41	4.43	13.92	-	10.04	38
Acc. storage	0.71	13.72	4.73	13.25	-	11.13	31
2nd month storage	1.08	12.65	4.65	18.54	2.88	10.97	57
Acc. storage	0.90	11.81	4.17	16.01	2.81	11.29	183
3rd month storage	0.76	19.65	-	-	2.94	9.94	45
Acc. storage	0.84	11.69	-	-	3.28	10.13	40

TF= Teaflavine, TR+Thearubigines, TC= Total color, BR=Brightness.
Source: Debnath et al. (2012).

8 to 9 times in samples stored under accelerated storage over normal storage.

CONCLUSION

Literature reports indicated that quality of black tea is dependent on the chemical composition, in particular, the flavanols of the harvested shoots, and also by the way in which they are handled, processed and stored. Following plucking, many biochemical and physiological processes occur through processing. Among all the processing stages fermentation is the most vital process for determining major quality determining factors for black tea. At a time of drying it is also good to give attention to maintain the moisture content of processed tea otherwise easily deteriorated. Generally at a time of black tea processing it was important to give an attention for each of steps starting from harvesting up to storage systems.
Otherwise it is difficult to fulfill the quality of marketable characteristics for black tea.

CONFLICT OF INTEREST

The author has not declared any conflict of interest.

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Integrated effect of nitrogen and vermicompost levels on yield and yield components of carrot (*Daucus carota* L.) at Woreta, Northwestern Ethiopia

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The N fertilizer or organic resources alone may not provide sufficient amounts or may be unsuitable for improving specific constraints to crop production. In view of this, a field trial was conducted at Woreta ATVET College horticultural farm, Ethiopia to determine integrated effect of nitrogen and vermicompost levels on yield and yield components of carrot, nantes type, during 2017 main rainy season. Nine treatments comprising a factorial combination of three levels of nitrogen (0, 50, and 100 kg N ha^{-1}) and vermicompost (0, 3 and 6 ton vermicompost ha^{-1}) were laid out in a randomized complete block design (RCBD) with three replications. Data were collected on growth factors, root yield and yield components. The results revealed that the main and interaction effects of treatments did not have any significant (P >0.05) effect on plant height and root length. However, main effects of nitrogen affected leaf number and total fresh biomass. Combined application of 50 kg N ha^{-1} and 6 ton vermcompost ha^{-1} significantly (P≤ 0.05) increased total root yield (t/ha), dry root weight (g/plant), harvest index and fresh root weight (g/plant). At this combination, highest total root yield (60 t/ha), harvest index (51%) and fresh root yield (79.8 g/plant) were recorded. It can, thus, be concluded that maximum yield of carrot can be obtained from the combined application of 50 kg N ha^{-1} and 6 t vermicompost ha^{-1}.

Key words: Carrot, nantes, nitrogen, vermicompot, root yield, interaction effect.

INTRODUCTION

Carrot (*Daucus carota* L.) belongs to the family Apiaceae (previously Umbelliferae). Its root is valued as food (salads, soups, steamed or boiled in other vegetable dishes) mainly for its high carotene content. Carrots have gained worldwide acceptance due to their high vitamin A content, acceptable taste, ease of production and relatively long storage life at low temperature (Ali et al., 2006). In Ethiopia, carrots are usually grown on small plots in the backyards of town and peri-urban dwellers mainly for family consumption. According to Ethiopian Central Statistical Agency (2017/18), carrot total production in the country was 17,333.43 tons produced in 4,902.90 ha of land with 3.5 ton/ha productivity despite its suitable agroclimate for carrot production. This productivity is relatively very low compared to world average (21 t/ha) and other carrot producing countries

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Table 1. Treatments' description.

Treatments	Description	Remark
T1	Control	N_0V_0
T2	Zero N + HRV	N_0V_1
T3	Zero N +FRV	N_0V_2
T4	HRN+ Zero vermicompost	N_1V_0
T5	FRN + Zero vermicompost	N_2V_0
T6	HRN+ HRV	N_1V_1
T7	HRN +FRV	N_1V_2
T8	FRN +HRV	N_2V_1
T9	FRN + FRV	N_2V_2

N= nitrogen, V= vermicompost**,** N_0=control, N_1 = 50kg/ha /half recommended nitrogen (HRN), N2 =100kg/ha Full recommended nitrogen (FRN), V_0 = control, V_1=3 ton/ha/half recommended vermocompost (HRV) , V_2 = 6 ton/ha Full recommended vermocompost (FRV).

like Switzerland, Denmark, UK, Sweden, Austria and Israel, where the average per hectare yields are reported to be 40.88, 42.67, 51.88, 54.35, 56.7 and 64.2 tones, respectively (Kahangi, 2004; FAO, 2000). In view of this, a lot of work has to be done in Ethiopia to improve carrot productivity. Integrated nutrient application is useful to fill this gap as imbalanced use of fertilizers leads to loss of soil fertility and adversely impacted agricultural productivity as well as causes soil degradation (Patil et al., 2016; Thiruneelakandan and Subbulakshmi, 2014; Vithwel and Kanaujia, 2013).

Although inorganic fertilization is very important for the healthy plant growth and development, the organic source of nutrients has the advantage of consistent and slow release of nutrients, maintaining ideal carbon:nitrogen (C:N) ratio, improvement in water holding capacity and microbial biomass of soil profile, without any adverse residual effects (Kiros et al., 2018; Yadav et al., 2010). One of the appropriate processes for organic fertilizer production is vermicomposting which converts organic materials (usually wastes) into a humus-like, fine-divided, nutrient rich material known as vermicompost. Vermicomposting technology, using earthworms as versatile natural bioreactors for effective recycling of organic wastes to the soil, is an environmentally acceptable means of converting waste into nutritious composts for crop production. Earthworms make the soil 'soft and porous' by its burrowing actions and excretions containing nutrients with beneficial soil microbes to improve its natural fertility and productivity. In Ethiopia, vermicompost application is getting more emphasis accounted for ease of preparation, input and labor availability, better nutrient composition as well as low cost as compared to inorganic fertilizer (Shanu et al., 2019; Almaz et al., 2017; Girma and Zeleke, 2017; Tesfaye, 2017; Devi et al., 2007). The basic concept pertinent to the principles of integrated nutrient management is the maintenance and possible management of soil fertility for sustaining crop productivity on a long term basis (Hedge and Srinivas, 1989). Therefore, judicious and proper use of organic and inorganic fertilizers is very essential not only for obtaining higher yield and quality but also to maintain soil health and sustainability for longer period. Since integrated nutrient management for the crop is lacking in the study area, this study aimed to evaluate the integrated effect of nitrogen and vermicompost levels on yield and yield components of carrot.

MATERIALS AND METHODS

The field experiment was conducted at Woreta Agricultural Technical Vocational Education and Training College, northwest, Ethiopia during June to September 2017 rainy season. The study area is characterized by uni-modal rainfall pattern with annual average rainfall of 1259 mm. The mean maximum, mean minimum and annual average temperatures are 28.2, 11.5 and 19.9°C. The field soil and vermicompost samples of the experiment were analyzed and documented (Table 2). Two different factors were considered in the study. They were three nitrogen (0, 50,100, kg ha^{-1}) and vermicompost levels (0, 3 and 6 ton ha^{-1}) arranged in factorial RCBD design with three replications. Vermicompost inputs were using green leaf, cow dung and soil with 5:1:0.2 proportions respectively. There were 9 treatments for these factor combinations (Table 1). A carrot type known as "Nantes" was used for the experiment. The size of each plot was 1 m × 1 m = 1 m^2 with a net plot area of 0.64 m^2. The seeds were drilled and covered lightly with soil (Jeptoo et al., 2013). A distance of 1 m was maintained between plots and blocks. There were 5 rows per plot having 20 plants per row with the spacing of 20 × 5 cm. Thinning was done 30 and 40 days after emergence of the plants to maintain the recommended spacing of 5 cm between plants (Vithwel and Kanaujia, 2013; Mehedi et al., 2012). Before planting, beds were prepared to fine tilt by ploughing and disking using tractor. Since nitrogen is a mobile element, urea was applied in split; 50% during planting and the other 50% thirty five days after emergence. Vermicompost was incorporated into the experimental plots one week before sowing. It was applied in trenches of about 5-15 cm depth and thoroughly mixed with the soil and buried. Other cultural practices were done as required.

In the study, growth parameters such as average leaf number per plant, plant height (cm)**,** root length (cm), root girth (cm), yield of fresh biomass yield (g/plant), fresh root weight (g/plant), dry root weight (g/plant), total root yield (t/ha), harvest index (hi%) and total yield of dry biomass (g/plant) were collected and analysed. Data were subjected to analysis of variance using SAS software (2003).

RESULTS AND DISCUSSION

Growth parameters

Leaf number

Statistically, there was significant difference in main effects of nitrogen for this parameter (P<0.05) while vermicompost and interaction effects did not show statistical significant difference. As far as nitrogen is concerned, the highest leaf number (10.3) was recorded at 50kg N/ha which was in par with nitrogen at 100 kg N/ha (Table 3). Whereas, the lowest leaf number (8.6)

Table 2. Laboratory results for analyzed field soil and vermicompost samples.

Parameter	Soil and vermicompost sample	
	Field soil	Vermicompost
pH	6.28	7.22
EC	67.8 mS/cm	3.07 mS/cm
Soil texture	Clay loam	Sandy loam
% Organic matter	4.1	27
% Organic carbon	2.4	16
Total N (%)	2.05	135
Ava. P (Olsen)	24	597
Exchangeable potassium (K, cmol/kg))	1.0	7.9
Exchangeable sodium (Na, cmol/kg))	0.2	1.7

EC= electrical conductivity; N=nitrogen; Ava.P= available phosphorus, Exc K =exchangeable potassium; Exc.Na= exchangeable sodium.

Table 3. Plant height of carrot as influenced by the main effects of nitrogen**.**

Nitrogen levels (kg/ha)	Leaf number
0	8.6^{b}
50	10.3^{a}
100	9.7^{ab}
LSD	0.98
CV	10.10

Means with the same letter(s) in the table were not significantly different at 5% probability level according to least significant difference. LSD (5%) = least significant difference at P = 0.05, CV (%) = Coefficient of variation in percent.

was recoded at the control. Application of urea might have provided adequate N which is associated with high photosynthetic activity and vigorous vegetative growth.

Plant height (cm)

Data regarding plant height depicted non- significant differences for main and interaction effects. Numerically, the tallest plant height (56.2 cm) was recorded on plots that receive 50 kg N /ha and 3ton vermicompost/ha followed by (54.6 cm) on plots where 100 kgN/ha and zero vermicompost was applied (Table 4).

Root length (cm) and root girth (cm)

Applications of urea and vermiccompost levels neither alone nor in combination had a significant ($P<0.05$) for root length. Despite this fact, the tallest root length (16.6 cm) followed by (13.0 cm) was obtained on plots which received 50 kgN/ha and 6 ton vermicompost/ha and the control (Table 4). In contrast, there was significant difference in interaction effects for root girth ($P <0.01$). The highest root girth (11.6cm) was recorded at combination of 50kg N/ha with 6ton vermicompost/ha while the lowest root girth (7.5 cm) was recorded at the control. The results are in agreement with Mehedi et al. (2012) who reported that the application of organic matter with NPK increased the diameter of carrot root.

Yield parameters

Total fresh biomass (g/plant) and fresh root weight (g/plant)

Statistically, there was no significant difference for main and interaction effects of treatments for this parameter. Despite this fact, the highest total fresh biomass (237.5 g/plant) was recorded at combination of 50 kg N/ha with 6 ton vermicompost /ha while the lowest (114.7 g/plant)

Table 4. Effect of nitrogen and vermicompost levels on carrot growth parameters.

Ts	Treatment combination	Growth parameter		
		Plant height (cm)	Root length (cm)	Root girth (cm)
T_1	Control	48.2	13.0	7.5[b]
T_2	Zero N + HRV	50.50	15.9	8.3[b]
T_3	Zero N +FRV	54.4	13.4	8.3[b]
T_4	HRN+ Zero vermicompost	51.7	13.5	8.4[b]
T_5	FRN + Zerovermicompost	54.6	15.1	8.5[b]
T_6	HRN+ HRV	56.2	13.9	9.1[b]
T_7	HRN +FRV	54.1	16.6	11.6[a]
T_8	FRN +HRV	52.8	15.3	8.5[b]
T_9	FRN + FRV	48.9	16.1	8.2[b]
CV ()		6.41	12.38	9.42
Sig.		ns	ns	**

* and ** indicates significant difference at probability level of 5% and 1% respectively. Ns = non-significant, CV= coefficient of variation.

Table 5. Effect of nitrogen and vermicompost levels on carrot yield parameters.

Treatments	Yield parameter					
	Total fresh biomass (g/plant)	Fresh root weight (g/plant)	Total dry biomass (g/plant)	Dry root weight (g/plant)	Harvest index	Total root yield (t/ha)
T1	114.7	49.5[d]	61.7	6.0[c]	34.5[c]	22.6f
T2	154.8	51.5[abc]	92.7	7.2[bc]	37.2[bc]	29.9e
T3	152.1	71.9[abc]	90.8	7.7[bc]	38.4[bc]	34.6[d]e
T4	164.4	73.5[abc]	74.9	8.1[bc]	40.5[bc]	41.3[bcd]
T5	169.4	55.2[bcd]	76.2	8.7[b]	40.9[bc]	43.4[bc]
T6	221.9	77.3[ab]	82.3	8.6[b]	43.2[b]	48.1[b]
T7	237.5	79.8[a]	99.6	11.2[a]	51.3[a]	60.8[a]
T8	168.2	64.2[abcd]	87.9	7.8[bc]	39.2[bc]	36.7[cd]e
T9	153.7	74.5[ab]	92.3	8.4[b]	40.0[bc]	37.3[cd]
CV	9.12	12.56		10.38	5.90	5.19
Sig.	ns	*	ns	*	**	***

Means with the same letter(s) in the table were not significantly different. *, ** and *** indicates significant difference at probability level of 5, 1 and 0.1%, respectively. Ns = non-significant.

was recorded at the control (Table 5).

The interaction effect of nitrogen fertilizer and vermicompost (P<0.05) had also pronounced on

Table 6. Total dry biomass weight of carrot as influenced by the main effects of nitrogen.

Vermicompost (t/ha)	Total dry biomass weight (g/plant)
0	70.9^{b}
3	87.6^{ab}
6	94.2a
LSD	0.98
CV	12.55

Means with the same letter(s) in the table were not significantly different at 5% probability level according to least significant difference. LSD (5%) = least significant difference at P = 0.05, CV (%) = Coefficient of variation in percent.

effect on fresh root weight. The highest fresh root weight (79.8 g/plant) when 50 kg N/ha was combined with 6 ton vermicompost per ha followed by T6 which was in par with T9, T4, T3, and T8 (Table 5). While the lowest (49.5 g) fresh root weight was recorded at the control (Table 4). Chatterjee et al. (2014) on their study on evaluation of vegetable wastes recycled for vermicomposting and its response on yield and quality of carrot reported that vermicompost from wastes from non-legume and legume family at 2:1 ratio resulted in high root weight.

Rani and Mallareddy (2006) in their study on effect of different organic manures and inorganic fertilizers on growth, yield and quality of carrot documented that maximum fresh carrot weight (55.23 g) was significantly higher with integration of neem cake /4t ha^{-1}/ and half the recommended dose of NPK treatments. Zakir et al. (2012) on their study about influence of commercially available organic vs inorganic fertilizers on growth yield and quality of carrot reported that recommended dose of inorganic fertilizers (RDIF) (197.6, 148.2, 148.2 and 98.8 kg ha^{-1} urea, triple super phosphate (TSP), muriate of potash (MOP) and gypsum, respectively and recommended dose of Biomeal (RDB) (6 t ha^{-1}) gave maximum fresh root weight (66.89 g/plant). Vithwel and Kanaujia (2013) studying integrated nutrient management on productivity of carrot and fertility of soil reported that application of 50% NPK (40:20:20 kg ha^{-1}) + 50 % farm yard manure (FYM,10 t/ha) + biofertilizers/Azospirillum and Phosphotika/ recorded maximum values of all yield attributing characters such as root length (18.88 cm), root diameter (4.14 cm), root weight (90.37 g). Similarly Mehedi et al. (2012) reported that combined application of 150 kg N ha^{-1} and 15 t cow dung ha^{-1} gave highest fresh root weight. The study is also in line with works of different researchers (Rahman et al., 2018; Yourtchi et al., 2013).

Dry root weight (g/plant)

For dry root weight, both main and interaction effects of treatments resulted in statistically significant difference (P<0.05). The highest dry root weight (11.2 g) was obtained from combination of 50 kgN/ha with 6ton/ha vermicompost followed by T5 which was in par with T6, T9, and T4 treatments. While the lowest (6.0 g) dry root weight obtained was from control (Table 5).

This result is consistent with the findings of different researchers. Rani and Mallareddy (2006) in their study on effect of different organic manures and inorganic fertilizers on growth, yield and quality of carrot stated that dry root weight of carrot reported that maximum dry root weight (6.8 g) was observed with castor cake (4 t/ha) in combination with half the recommended dose of NPK(50: 30:40). Zakir et al. (2012) on their study about influence of commercially available organic vs inorganic fertilizers on growth yield and quality of carrot reported that recommended dose of inorganic fertilizers (RDIF) (198 148, 148 and 99 kg ha^{-1} urea, TSP, MOP and gypsum, respectively and recommended dose of Biomeal (RDB) (6 t ha^{-1}) resulted in the highest dry root weight (9.97 g).

Total dry biomass (g/plant)

The effect of vermicompost was statistically significant (P ≤ 0.05) on total dry biomass (Table 6). The highest and lowest amounts of this trait were recorded at 6 t ha^{-1} and 0 t ha^{-1}, with 94.2 and 70.9 g, respectively. The results showed that vermicompost had the best response on this parameter. The results are in conformity with the findings of many works on carrot (Tomar et al., 1998) and potato (Alam et al., 2007).

Total root yield (t/ha)

Significant variation was found in respect of gross yield of root due to main and interaction effects (P<0.01). The highest root yield (60 t/ha) was recorded at treatment combinations of half recommended nitrogen (50 kg N per ha) and full recommended vermicompost (6 ton/ha) followed by T6 which was in par with T5 and T4. The lowest total root yield (22.6 t/ha) was recorded at the control (T1). This yield increment could be attributed to increased growth parameters at this treatments combination (Table 5). The better efficiency of vermicompost in combination with inorganic fertilizers might be also due to the fact that vermicompost would have provided the micronutrients in an optimum range to the plant. It would have enhanced the metabolic activity through the supply of such important micronutrients in the early growth phase which in turn must have encouraged the overall growth and due to the cumulative effect of all yield components *viz*., root length, root diameter, fresh and dry weight of root. The slow release of nutrients from vermicompost and their better utilization by carrot throughout the growing period might have also resulted in higher root yields of carrot. Several other works have also reported the highest plant growth due to the combined application of organic manures and chemical fertilizers in tomato (Kiros et al., 2018; Mebrahtu and Solomun, 2018; Kumar and Venkatasubbaiah, 2017; Patil et al., 2016; Tripathi et al., 2015; Prativa and Bhattarai, 2011; Alam, 2006).

Other studies also reported positive influence of integrated nutrient management on carrot. Rani and Mallareddy (2006) in their study on effect of different organic manures and inorganic fertilizers on growth, yield and quality of carrot stated that root yield of carrot was significantly affected with integrated nutrient management practices. According to these authors, maximum root yield was observed with castor cake (4t/ha) in combination with half the recommended dose of NPK (50:30:40).

Sylvestre et al*.* (2015) on their study on effect of poultry manure and NPK (17-17-17) on growth and yield of carrot stated that maximum carrot yield was found by integrating 5tha^{-1} poultry manure with 150 kgha^{-1}NPK which was in par with sole application of 10 tha^{-1} poultry manure. Mehedi et al. (2012) on their part found that combination of 150 kg N ha^{-1} and 15 t cow dung ha^{-1} resulted in the best performance in gross yields of carrot (51.22 t ha^{-1}). The highest gross carrot yield (67.47t ha^{-1}) was obtained from the treatment of inorganic fertilizers (290 kg Urea, 225 kg TSP and 250 kg MP) plus 5t mustard oil cake ha^{-1} (Alom, 2004). Vithwel and Kanaujia (2013) reported that integrated application of chemical fertilizers, organic manures and biofertilizers alone or in combination significantly increased the yield and yield attributing characters of carrot compared to control (50 % NPK + 50% FYM + biofertilizers). In agreement with this study, Subenthung et al. (2012) also reported that combined application of 50% pig manure + 50% NPK recorded maximum plant height (50.16 cm), number of leaves (14.43), leaf area (185.86 cm^2) and root yield (522.51 t ha^{-1}).

In general, fertilizer integration positive effect on yield could be attributed to the positive effect of all the yield components viz., root girth, fresh weight and dry weight of root. Furthermore, this increased yield may be due to better availability and uptake of nitrogen and other nutrients in combination of vermicompost which might have led to the balanced C/N ratio and increased activity of plant metabolism. Combined usage of organic fertilizers with inorganic fertilizers not only helps to improve the yield and quality of carrot but also help in conserving the soil health.

Harvest index (HI)

For this parameter, there was statistically significant difference for nitrogen and vermicompost main effects as well as their integration (P<0.01). The highest harvest index (51.3) was recorded at treatment combinations of half recommended nitrogen (50 kg N per ha) and full recommended vermicompost (6 ton/ha). The next rank was occupied by T6, T5, T4, and T9 treatments having similar statistical implication. The lowest (34.5) harvest index was recorded at T1 (control) treatment. Sylvestre et al*.* (2015) in their study on effect of poultry manure and NPK (17-17-17) on growth and yield of carrot stated that maximum carrot harvest index was found by integrating 5 tha^{-1} poultry manure with 150 kg ha^{-1}NPK which was similar with sole application of 10t ha^{-1} poultry manure. The current study is also in line with the work of Yagoub et al. (2012).

Conclusion

The results of this experiment indicated that combination of nitrogen and vermicompost nutrition played an important role on growth, yield and yield contributing characters of carrot. It was found that most of the characters that govern the production of carrot were influenced and increased the yield. From production, sustainability and environmental points of view, a combination of 50 kg N ha^{-1} with 6 ton vermicompost ha^{-1} may be suggested for maximizing carrot production under Woreta Agricultural College farm condition. Since the present study was conducted in only one agro ecological zone and season, further investigations need to be carried out in other agro- ecological zones of Ethiopia.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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