# CHAPTER IV
# RESULTS AND DISCUSSION

## 1. Effects of shading on growth, yield and some quality characters in coffee bean (*Coffea arabica* L. cv. Catimor)

### 1.1 The effects of shading on environment condition

The monthly rainfall and average monthly daytime temperature during growth and development of coffee plants are shown in Figure 6. The rainfall was uni-modal, peaked in June and stopped in October. The temperature was high from March to September and highest in April. In general, rainfall, rain distribution, and temperature greatly affect growth, development and yield of coffee. In this study, mini-sprinkler system was available upon need, and therefore, rainfall and rain distribution could be optimized by irrigation.

The factor limiting growth and yield of coffee would be temperature. When average temperature was considered, the average monthly daytime temperature of 20-25 °C in this study was considered to be optimum for Arabica coffee. However, minimum and maximum temperatures at day and night could also affect growth and yield of coffee. Coffee can expose to high temperature during midday in the tropics if it is grown under full sun. In this case, shading can alleviate this effect and growing Arabica coffee would be productive and profitable. Furthermore, temperature would affect quality of coffee in terms of taste and chemical compositions.

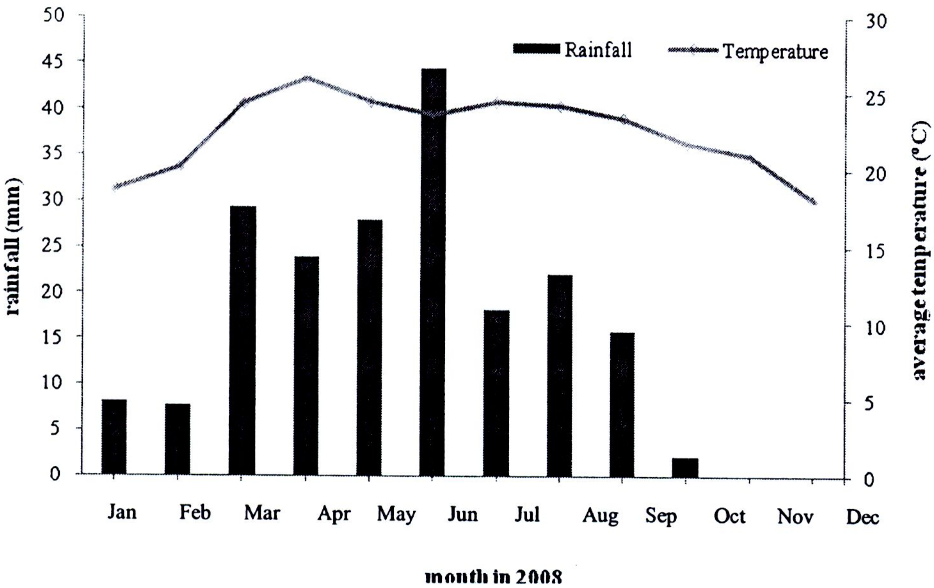



**Figure 6** Monthly rainfall and average temperature under during growth of coffee at Chulabhorn Dam Agricultural Research and Training Station (CRTS), Faculty of Agriculture, Khon Kean University, Chaiyaphum Province, Thailand.

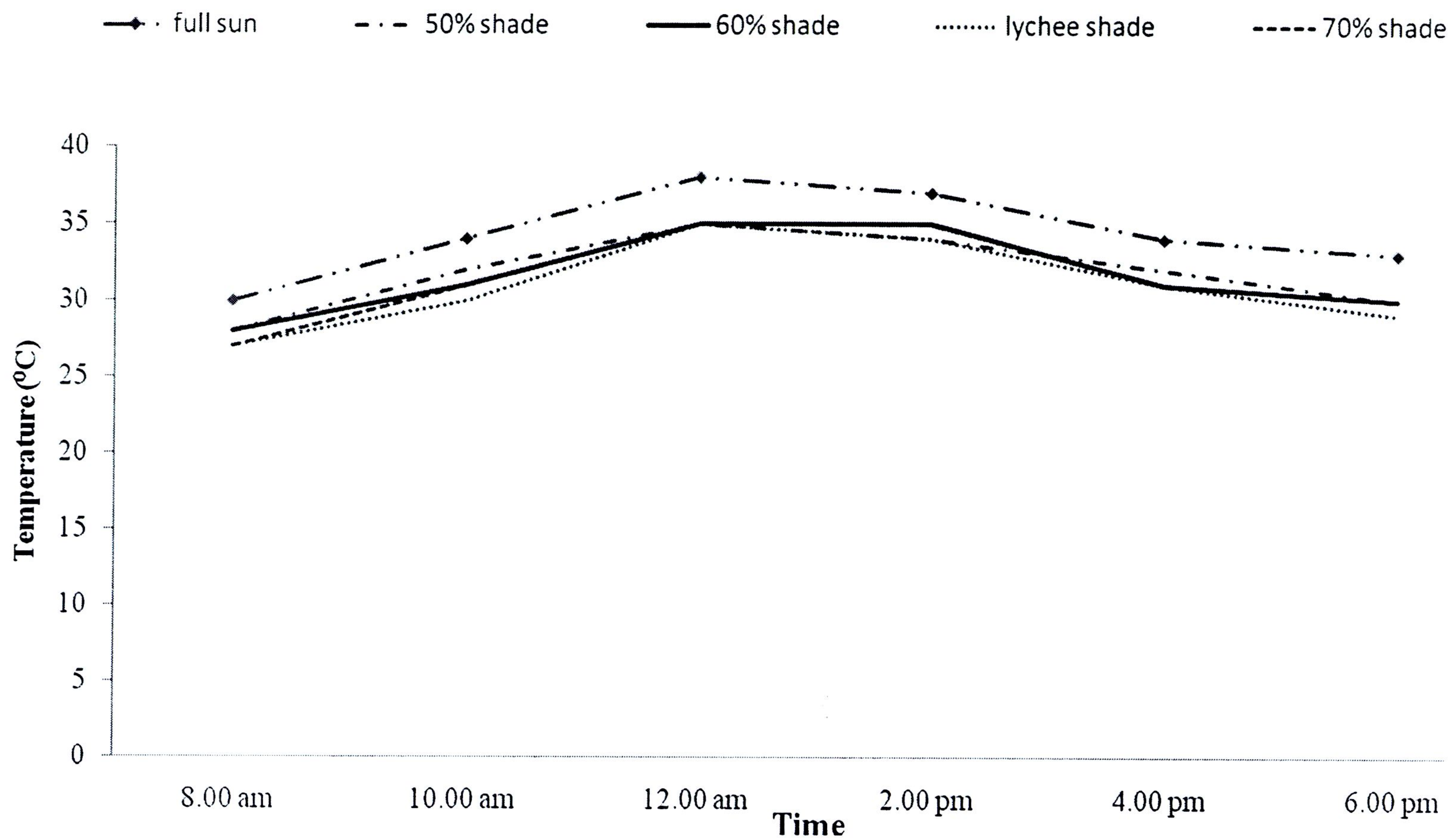



**Figure 7** Temperature during the daytime under different growth conditions of coffee

Figure 7 shows temperatures during daytime of coffee grown under different treatments. Average temperature was measured from the period of sunrise to sunset at six different periods (08.00, 10.00, 12.00, 14.00, 16.00 and 18.00 pm). The highest temperature was observed in the coffee trees grown under full sun, whereas the temperatures under shading conditions were similar for all shading levels and the temperature patterns were consistent throughout the periods of observations. It is clear that the difference in coffee grown under shade and full sun was mainly affected by the difference in daytime temperatures. Therefore, this difference would be expressed in agronomic characters and chemical compositions of coffee beans.

Five growth conditions are described in Table 12. Light intensity for coffee trees grown under full sun was the highest (58,800 Lux) and it was nearly six times greater than 11,050 Lux for 50% shading. The light intensities for the coffee trees grown under shading conditions were rather similar, ranging from 11,050 Lux for 50% shading to 9,080 Lux for 70% shading.

Means and ranges of temperatures were similar to those of light intensities. The highest temperature was found in coffee trees grown under full sun (31 °C), whereas the temperatures in the coffee trees grown under shading conditions were lower, ranging from 30 °C for 50% shading to 27 °C for lychee shade and 70% shading.

Temperature and light intensity thus greatly determined the differences in growth, development and yield of coffee grown under different shading conditions. These parameters also affected on the differences in tastes and chemical properties of coffee beans and similar results were also observed under shade conditions in Brazil (Borkhataria et al., 2006).

**Table 12** Light intensity and canopy temperature of coffee grown under different shading conditions

| **Shading conditions** | **Light intensity (lux)** | **Temperature (°C)** |
|---|---|---|
| full sunlight | 58,800 (45,900-59,800) | 24-34 |
| 50% shade with saran shade cloth | 11,050 (9,900-12,500) | 23-33 |
| 60% shade with saran shade cloth | 10,700 (9,500-11,700) | 20-31 |
| lychee shade | 9,980 (8,200-10,500) | 20-31 |
| 70% shade with saran shade cloth | 9,080 (8,000-10,500) | 20-31 |

Values in parentheses represent the range of light intensity and temperature, respectively

### 1.2 Effects of shading on morphological and physiological characters and yield of coffee

Effects of shading on morphological and physiological characters of coffee beans grown under five shading conditions were investigated. Shading significantly affected morphological and physiological characters of coffee bean, including nutrient concentrations, caffeic acid in leaf, chlorophyll content, plant height, stem size, branch number per plant, nodes per branch, fruits per branch, fresh weight, bean size, 1000-bean weight, and bean yield.

#### 1.2.1 Nutrient, chlorophyll and caffeic acid in leaves

Table 13 shows leaf nutrient concentrations for coffee grown under different shadings. In four of the five samplings, the coffee grown under shade conditions had higher N and K concentrations than did the coffee trees grown under full sun ($p < 0.05$), whereas there was no statistical difference among shading treatments for P.

**Table 13** Leaf nutrient concentrations in coffee grown under different shade conditions

| Light intensity | N (%) | P (%) | K (%) |
|---|---|---|---|
| full sun | $2.59^{b}$ | 0.13 | $1.26^{b}$ |
| 50% shade | $2.71^{ab}$ | 0.13 | $1.39^{a}$ |
| 60% shade | $2.85^{a}$ | 0.14 | $1.42^{a}$ |
| lychee shade | $2.81^{a}$ | 0.13 | $1.45^{a}$ |
| 70% shade | $2.83^{a}$ | 0.12 | $1.43^{a}$ |
| F- test | * | ns | * |
| CV | 2.26 | 4.53 | 2.36 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.05$)

Coffee trees grown under full sun had significantly lower chlorophyll a and chlorophyll b than did the coffee trees grown under shade at all shading levels (Table 13). The differences among the plants grown under different shading treatments were also observed for both chlorophyll a and chlorophyll b, but the differences did not conform to the shading levels.

**Table 14** Chlorophyll a and chlorophyll b in coffee leaf of coffee grown under different shading conditions

| Light intensity | Chlorophyll a (mg/g fresh weight) | Chlorophyll b (mg/g fresh weight) |
|---|---|---|
| full sun | $0.034^{d}$ | $0.013^{d}$ |
| 50% shade | $0.046^{a}$ | $0.017^{ab}$ |
| 60% shade | $0.043^{c}$ | $0.016^{c}$ |
| lychee shade | $0.043^{c}$ | $0.018^{a}$ |
| 70% shade | $0.044^{b}$ | $0.017^{ab}$ |
| F – test | ** | ** |
| CV | 2.43 | 2.77 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$), **, significant at the 0.01 level (two tailed)

Table 15 showed caffeic acid in leaves of coffee trees grown under different shading conditions. High caffeic acid was observed on the third pairs of coffee leaves from the top of the reproductive branches. The lowest caffeic acid was observed on the first pair of leaves from the top and the second and the fourth pairs had intermediate caffeic acid. The patterns of caffeic acid in leaves of coffee trees grown under different shading conditions were rather similar. The leaf pairs near the tops are too young, whereas the third leaf pairs are the most suitable for evaluation of caffeic acid.

**Table 15** Caffeic acid (mg/100 g fresh sample) in different pairs of coffee leaves grown under different shading conditions

| | **Light intensity** | | | | |
|---|---|---|---|---|---|
| **number of leaf pair** | **full sun** | **50% shade** | **60% shade** | **lychee shade** | **70% shade** |
| 1 | $4.08^{d}$ | $4.08^{b}$ | $4.11^{d}$ | $4.12^{b}$ | $4.45^{b}$ |
| 2 | $4.70^{b}$ | $4.91^{a}$ | $4.70^{b}$ | $4.95^{a}$ | $5.03^{a}$ |
| 3 | $4.87^{a}$ | $4.89^{a}$ | $4.97^{a}$ | $5.04^{a}$ | $4.92^{a}$ |
| 4 | $4.26^{c}$ | $4.35^{b}$ | $4.48^{c}$ | $4.51^{b}$ | $4.57^{b}$ |
| F-test | ** | ** | ** | ** | ** |
| CV | 0.76 | 1.19 | 0.44 | 0.98 | 0.85 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$).

**, significant at the 0.01 level (two tailed)

### 1.2.2 Morphological characters, yield and yield components

Coffee beans grown under different shading conditions were significantly different in bean yield, weight of 1000 beans, plant height and branch number per plant (Table 16, 17 and 18).

Coffee yields ranged between 64.6 and 191.5 kg $ha^{-1}$ and 1000-bean weights were in a range from 103.9 to 133.3 g. Coffee grown under lychee trees had the highest yield (191.5 kg $ha^{-1}$) and the largest beans (133.3 g), whereas sun-grown coffee had the lowest yield (64.6 kg $ha^{-1}$) and 1000-bean weight (103.9 g). Coffee yields and 1000- bean weights for coffee grown under 70% shading, 60%

shading, 50% shading were intermediate between lychee shade and full sun, and they were significantly higher than those in full sun. Yield and bean size seemed to be increased towards lower light intensity until they reached optimum and then declined (Table 18).

The results indicated that yield and bean size were consistently increased with lowering light intensity until the optimal light intensity was reached. In this case, lychee tree with average light intensity of 9,980 Lux was the most suitable for higher bean yield and larger bean size. The bean yield and bean size could be lowered if they were over-shaded as indicated by reduced bean yield and bean size in 70% shading.

Plant heights were in a range of 191.20 cm for sun plants and 235.20 cm for lychee shade plant and the number of branches were between 24.43 branches for sun plants and 39.83 branches for lychee shaded plants. The plants grown under shade had taller plants, larger stems and higher number of branches than did the plants grown under sunlight especially those grown under lychee shade.

The most differences for plant height and number of branches were between sun plants and shaded plants, whereas the differences among shaded plants with different light densities were rather low and not in ascending order from lower shade to heavier shade, especially between 60% shading and shading under lychee trees. This could be due to the difference of light intensities between sun plants and shaded plants were quite wide and the differences among shaded plants were rather narrow (58,800 Lux for sun plants and 9,080-11,050 Lux for shaded plants).

Canopy temperatures (20-33 $^{0}$C) of the plants grown under shade were also lower than those grown under full sun (24-34 $^{0}$C) (Table 12). Shade plants could avoid heat stress and high light intensity. Hampson et al. (1996) and Steiman (2008) reported that lower temperature of 3.4 $^{0}$C was observed in coffee trees grown under shade, and the figure was rather close to that observed in this work. These could explain why shade plants grew better and yielded higher than sun plants. It is clear that shaded plants had larger and heavier fruits than did sun plants and they had bigger plants. These effects of shading are beneficial in the view of horticulture. Coffee trees grown under shade generally has lower yield than those grown under full sun but bean size is generally bigger. Light intensity reduces fruit load and, therefore, causes lower yield because of longer internodes, fewer fruiting nodes, lower flower induction and larger bean size. Lower temperature under shade also extends ripening period and the trees take more time for bean filling (Vaast et al., 2006).

Light saturation points of coffee could be as low as 16,200 lux under shade conditions and could be as high as 32,400 lux under full sun (Da Matta, 2004). Light intensity of 58,800 Lux under full sun in this study was much higher than that of 32,400 lux and the sun plants could be severely stressed. In contrast, light intensities between 9,080-11,050 Lux for shaded plants were much closer to 16,200 Lux and would be rather optimum for shade coffee. Therefore, growth and yield of shaded coffee in this study were greater than that of sun coffee.

Muschler (2001) reported in Costa Rica that coffee grown under shade (60% shade) had the highest yield (419 kg $ha^{-1}$), whereas sun-grown coffee had the lowest yield (259 kg $ha^{-1}$). The results in this study were in agreement with the previous report and confirmed the need of shading to lower light intensity and high temperature associated with high light intensity for the optimal growth and yield of coffee.

Table 16 showed the differences among shading conditions for plant height, stem diameter, number of branches per plant, number of nodes per branches, number of fruits per branches and fruit weight. These agronomic parameters were generally highest in coffee trees grown under lychee shade except for number of nodes per branches which was rather confounding. However, all shaded trees gave higher values for number of nodes per branch and other parameters than did the plants fully exposed to the sun. These observations agreed with Da Matta (2004), who reported that, the influence of shaded trees gave higher number of fruits per branches and fruit weight.

**Table 16** Plant height (cm), stem diameter (cm), number of branches, nodes per branch, fruits per branch and fruit weight of coffee beans (g/plants) grown under different shading conditions

| Shade | Height | Stem diameter | Branches number/ plant | Nodes /branch | Fruits / branch | Fruit weight |
|---|---|---|---|---|---|---|
| full sun | 191.20$^{e}$ | 3.10$^{e}$ | 24.43$^{e}$ | 11.33$^{b}$ | 15.66$^{c}$ | 249.00$^{d}$ |
| 50% shade | 223.53$^{c}$ | 3.79$^{c}$ | 32.36$^{d}$ | 12.33$^{ab}$ | 22.66$^{b}$ | 471.33$^{c}$ |
| 60% shade | 227.57$^{b}$ | 3.89$^{b}$ | 36.09$^{b}$ | 13.00$^{a}$ | 24.33$^{ab}$ | 519.33$^{b}$ |
| lychee shade | 235.20$^{a}$ | 3.98$^{a}$ | 39.83$^{a}$ | 12.67$^{ab}$ | 28.00$^{a}$ | 574.67$^{a}$ |
| 70% shade | 220.13$^{d}$ | 3.66$^{d}$ | 35.60$^{c}$ | 13.66$^{a}$ | 24.00$^{b}$ | 506.67$^{b}$ |
| F- test | ** | ** | ** | ** | ** | ** |
| CV | 0.11 | 0.07 | 0.08 | 4.22 | 5.57 | 1.01 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.05$). **, significant at the 0.01 level (two tailed)

It is also clear in Table 17 that coffee trees grown under lychee shade gave the highest values for total ripening fruits per branches, total ripening fruits per plant, total green beans per plant and total coffee beans per plant. The other coffee trees grown under different levels of shading conditions also gave higher values for these characters, compared to the trees grown under full sun. The results emphasized the need of shading to improve yield, agronomic traits and quality of coffee beans in the tropics.

**Table 17** Total ripening fruit/branch, total ripening fruit/plant, total coffee bean/plant (g) and total green bean/plant (g) of coffee beans grown under different shading conditions

| Light intensity | Total ripening fruit/branch | Total ripening fruit/plant | Total green bean/plant(g) | Total coffee bean/plant (g) |
|---|---|---|---|---|
| full sun | 77.59[d] | 249.00[e] | 31.037[d] | 25.86[d] |
| 50% shade | 170.87[d] | 471.33[d] | 68.350[c] | 56.96[c] |
| 60% shade | 192.57[b] | 519.33[b] | 77.027[b] | 64.19[b] |
| lychee shade | 229.81[a] | 574.67[a] | 91.923[a] | 76.60[a] |
| 70% shade | 191.10[c] | 506.67[c] | 76.440[b] | 63.70[b] |
| F- test | ** | ** | ** | ** |
| CV | 1.01 | 1.1 | 1.02 | 1.01 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$) **, significant at the 0.01 level (two tailed)

Coffee trees grown under shading conditions gave larger bean size (bean diameter and bean weight) and bean yield both expressed as bean per plant and bean per hectare (Table 18). The best growing condition was lychee shade showing the highest values for these characters. Growing coffee trees under direct full sun seemed to be severely detrimental to agronomic characters of coffee beans. This could be due to the fact that the plants do not tolerate high light intensity that is associated with high temperature.

These studies have shown an increase in bean size with shade level. Vaast et al. (2006) hypothesized that competition for carbohydrates was the main reason and there was an indirect relationship between yield and bean size linked to that. Under this mechanism, beans of shaded coffee plants are larger because lower yields under shade lead to reduced competition for available photosynthates. This would help explain why the green bean weight and size produced under low and medium shade in this study were larger than the full sun condition.

**Table 18** Bean size, bean weight (g/1000 seed), bean weight per plant, bean yield per plant (g) and bean yield (kg/ha) of coffee beans grown under different shading conditions

| Light intensity | Bean size (mm) | Bean weight (g/1000 seed) | Bean yield per plant (g) | Bean yield (kg/ha) |
|---|---|---|---|---|
| full sun | $4.29^{d}$ | $103.87^{e}$ | $25.86^{d}$ | $64.66^{d}$ |
| 50% shade | $5.75^{c}$ | $120.85^{d}$ | $56.96^{c}$ | $142.40^{c}$ |
| 60% shade | $5.93^{b}$ | $123.60^{c}$ | $64.19^{b}$ | $160.48^{b}$ |
| lychee shade | $6.20^{a}$ | $133.30^{a}$ | $76.60^{a}$ | $191.50^{a}$ |
| 70% shade | $5.80^{c}$ | $125.72^{b}$ | $63.70^{b}$ | $159.25^{b}$ |
| F- test | ** | ** | ** | ** |
| CV | 0.43 | 0.17 | 1.01 | 1.01 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$)

**, significant at the 0.01 level (two tailed)

## 1.3 Effects of shading on color and chemical compounds in coffee bean

### 1.3.1 Color Parameters

Color is a psychological property of food products that affects the enjoyment of eating. Color parameters of coffee bean grown under different shade conditions compared to full sun are shown in Table 19. $L^*$, $a^*$ and $b^*$ indicate whiteness, redness and yellowness, respectively. Difference in colors of coffee beans expressed as $L^*$, $a^*$ and $b^*$ values were not significant ($p < 0.05$) among coffee beans grown under different shade conditions. The values ranged from 67.56 to 68.30, 0.16 to 0.26 and 17.20 to 17.43 for $L^*$, $a^*$ and $b^*$, respectively.

The lack of significant difference among coffee beans grown under different shading conditions indicates that color cannot be used to identify coffee beans grown under different shading conditions, and, therefore, it cannot be used as a criterion for coffee quality. In general, consumers prefer coffee grown under shade than that grown under full sun and shaded coffee gains better price than sun coffee. This could be due to other beneficial qualities of coffee grown under shade such as taste, and chemical properties.

**Table 19** Color values of coffee bean grown under different shade condition

| | Hunter values | | |
|---|---|---|---|
| **Light intensity** | *L** | *a** | *b** |
| full sun | 67.96 | 0.20 | 17.26 |
| 50% shade | 67.70 | 0.26 | 17.20 |
| 60% shade | 66.80 | 0.26 | 17.33 |
| lychee shade | 68.30 | 0.26 | 17.40 |
| 70% shade | 67.56 | 0.16 | 17.43 |
| F-test | ns | ns | ns |
| CV | 0.85 | 19.34 | 0.51 |

Values are expressed in colorimetric units, ns = not significant

1.3.2 Antioxidant Activities

Antioxidant activities of coffee bean extracts were determined by DPPH radical-scavenging activity assay. The assay is a preliminary test to investigate the antioxidant potential of extracts and has been widely used to test the free radical-scavenging ability of various samples (Summa et al., 2006). DPPH, a free radical that absorbs wavelength at 517 nm, was used to study the radical scavenging effects of extracts. The absorption decreases because the antioxidants release protons to this radical. Antioxidants with the interaction with DPPH either transfer an electron or hydrogen atoms to DPPH, thus neutralizing its free radical character. The principle involves in this method is that the antioxidants react with the stable free radicals, i.e., 1,1-diphenyl-2-picrylhydrazyl (deep violet color) and convert them to 1,1-diphenyl-2-picrylhydrazine with discoloration. The degree of discoloration indicates the scavenging potential of the antioxidant sample (Utsunormiya and Higuchi, 1996).

Differences among shading conditions for antioxidant activity were highly significant (Figure 8). Most shaded plants had higher antioxidant activities than did the plants receiving full sunlight except for 50% shading. Antioxidant activities were the highest (94.1%) in the plants grown under lychee shade and the lowest (89.9%) in the plants grown under full sunlight. The values of antioxidant activities were in the order: lychee shade > 70% shading = 60% shading > 50% shading = full sunlight.

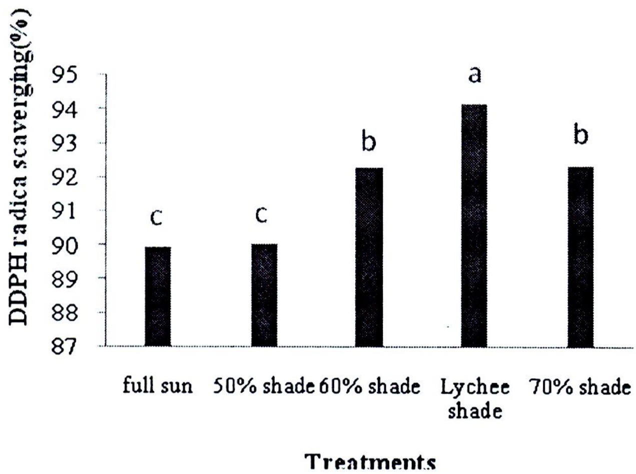



**Figure 8** DPPH radical scavenging activity (%) of coffee beans under five shade conditions. Bars with different letters were significantly different by Bonferroni tests ($p< 0.05$).

1.3.3 Total Phenolic Content

Phenolic compounds contributed directly to antioxidant action. Therefore, it was necessary to investigate total phenolic content expressed as milligrams of gallic acid equivalents (GAE) per gram of coffee beans (Figure 9). Shading conditions were significantly different for total phenolic content. The total phenolic content in the plants grown under lychee trees was the highest (36.6 mg GAE/g), whereas the total phenolic content in the plants grown under 60% shading was the lowest (22.1 mg GAE/g). Most DPPH scavenging activities for the plants grown under shades were significantly higher than that of the plants grown under full sun except for that under 60% shading in which DPPH scavenging under lychee shade was the highest. It is interesting to note here that the plants grown under lychee shade gave the highest total phenolic content and the antioxidant activity was also the highest. This could be due to its phenolic compositions promoting antioxidant activity.

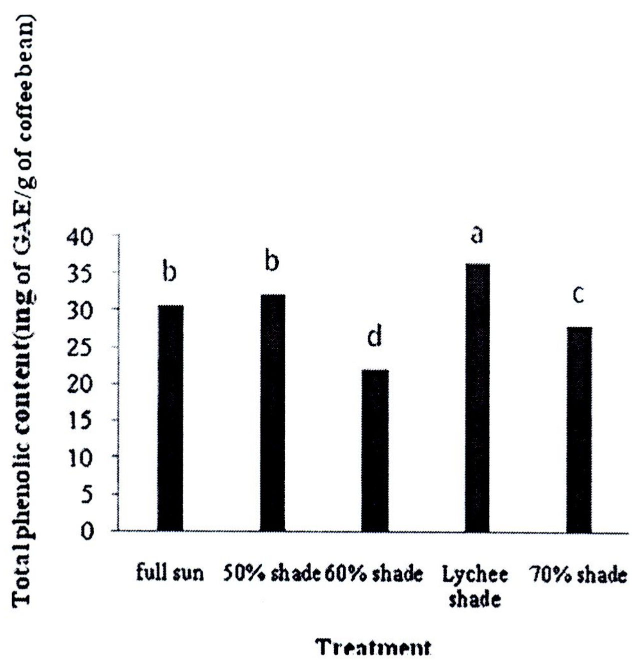



**Figure 9** Total phenolic content of coffee beans under five shading conditions Bars with different letters were significantly different by Bonferroni tests ($p$< 0.05).

1.3.4 Phenolic Acid Compositions

The questions underlying the study are that phenolic acids in coffee beans grown under different shading conditions might be different and which conditions are the most suitable for growing Arabica coffee in the rainfed semi-arid tropics. The study tested five shading conditions varying in light intensities and quantified 10 phenolic acids in order to better understand how shading conditions affect the composition and content of phenolic acids. Phenolic acids varied depending on types and shading conditions.

In general, the phenolic acids that occurred at high values were chlorogenic acid, vanillic acid, caffeic acid, protocatechuic acid and sinapic acid (Table 20), and chlorogenic acid was the highest accounting for 40-77.2 % of total phenolic acids. Chlorogenic acid was the most abundant for all shading conditions. It was increased with lowering light intensity in which the lowest value (62.1 mg/100 g) was under full sun and the highest value (125 mg/100 g) was under lychee trees, whereas protocatechuic acid, vanillic acid and caffeic acid seemed to be reduced with lowering light intensities.

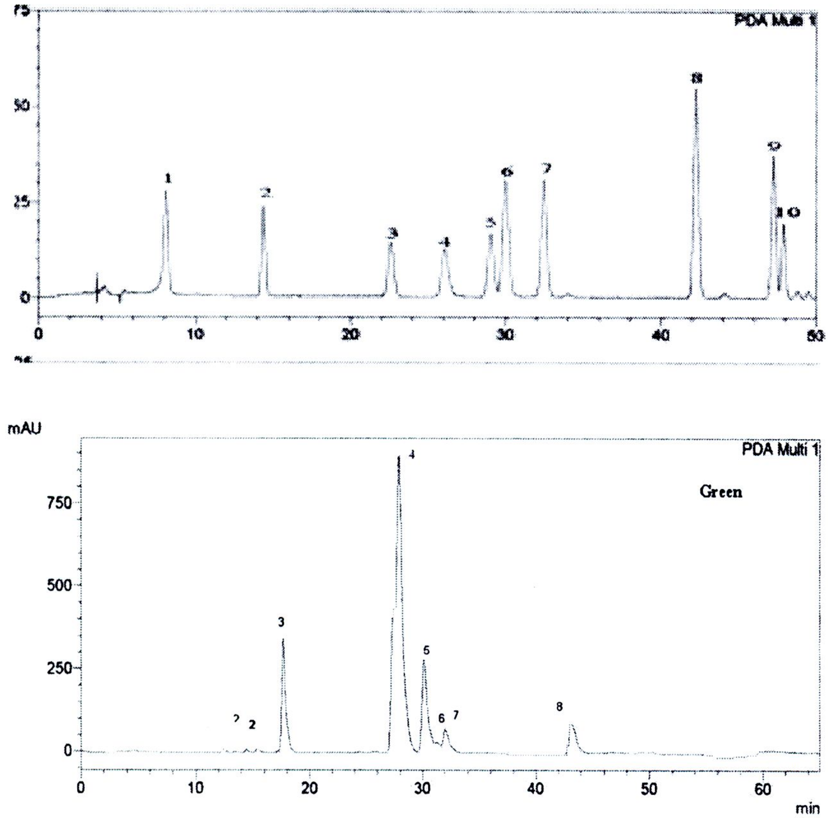
Remarkably, the contents of vanillic acid and caffeic acid were significantly higher in full sun than all shading treatments (Table 20). However, the remaining phenolic acids did not show any consistent pattern and they were present in coffee beans at small amounts. These phenolic acids constituted into total phenolic acid which was in a range of 130.5 mg for 60% shading and 161.9 mg for lychee shade. However, total phenolic acids did not show shading dependency. The contents of total phenolic acids were in order: lychee shade > full sun > 70% shade > 50% shade > 60% shade.

As total phenolic content did not show a consistent pattern among shading conditions, so, it cannot be used as a criterion determining coffee quality. This is possibly due to the fact that total phenolic contents of coffee beans grown under different shading conditions had different phenolic acid compositions. Among phenolic acids in this study, chlorogenic acid was higher under shading conditions than under full sun conditions and, therefore, it can be used as a criterion determining coffee quality. By using this criterion, it is clear that shaded coffee beans are better than coffee beans grown under full sun conditions (Boardman, 1977).

**Table 20** Phenolic-acid contents of coffee beans (mg/100 g fresh sample) grown under different light intensities

| **Phenolic acid** | **Phenolic acid contents** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **full sun** | | **50% shade** | | **60% shade** | | **lychee shade** | | **70% shade** | | | |
| gallic acid | 2.5[c] | (1.6) | nd[d] | (0) | 2.6[b] | (2) | 2.8[a] | (1.7) | 2.6[b] | (1.8) | | |
| protocatechuic acid | 12.1[b] | (7.8) | 21.1[a] | (15.8) | 2.4[e] | (1.8) | 2.5[d] | (1.5) | 2.6[c] | (1.8) | | |
| *p*-hydroxybenzoic acid | 5.2[b] | (3.3) | nd[e] | (0) | 4.3[c] | (3.3) | 5.6[a] | (3.7) | 4.0[d] | (2.7) | | |
| chlorogenic acid | 62.1[e] | (40) | 71.1[d] | (53.4) | 88.6[b] | (67.9) | 125[a] | (77.2) | 73.3[c] | (49.8) | | |
| vanillic acid | 25.1[a] | (16.2) | 6.9[b] | (5.2) | 5.2[d] | (4) | 6.9[b] | (4.3) | 6.3[c] | (4.3) | | |
| caffeic acid | 25.2[a] | (16.2) | 5.2[c] | (3.9) | 4.3[e] | (3.3) | 6.3[b] | (3.9) | 5.1[d] | (3.5) | | |
| syringic acid | 2.8[a] | (1.8) | nd[d] | (0) | 2.5[b] | (1.9) | 2.5[b] | (1.5) | 2.4[c] | (1.6) | | |
| *p*-coumaric acid | 2.3[c] | (1.5) | 14.7[b] | (11.0) | 2.3[c] | (1.8) | nd[d] | (0) | 36.9[a] | (25.1) | | |
| ferulic acid | 6.1[a] | (3.9) | 5.3[b] | (4) | 4.2[d] | (3.2) | nd[e] | (0) | 5.0[c] | (3.4) | | |
| sinapic acid | 11.9[b] | (7.7) | 8.9[e] | (6.7) | 14.1[a] | (10.8) | 10.3[c] | (6.4) | 9.1[d] | (6.2) | | |
| Total phenolic acids | 155.3[b] | (100) | 133.2[d] | (100) | 130.5[e] | (100) | 161.9[a] | (100) | 147.3[c] | (100) | | |

nd=not detected Means followed by the same lower case letter in the same column were not significantly different by Bonferroni tests ($p < 0.05$). Values in parentheses represent the percentage of phenolic acids.




Peaks: (1) gallic acid, (2) protocatechuic acid, (3) *p*-hydroxybenzoic acid, (4) chlorogenic acid, (5) vanillic acid, (6) caffeic acid, (7) syringic acid, (8) *p*-coumaric acid, (9) ferulic acid, and (10) sinapic acid

**Figure 10** Typical chromatograms of standard and green bean phenolic acids of coffee bean

1.3.5 Correlations between antioxidant activity and phenolic compound There was no significant correlation between antioxidant activity determined by DPPH assay and total phenolic content (Table 21). The contents of chlorogenic acid, *p*-hydroxybenzoic acid and gallic acid showed positive correlations with antioxidant activity (r = 0.828; $p \leq 0.01$, r =0.579; $p \leq 0.01$ and r =0.567; $p \leq 0.05$, respectively). On the other hand, antioxidant activity showed negative correlations with vanillic acid (r=-0.533; $p \leq 0.01$), protocatechuic acid (r =-0.786; $p \leq 0.01$) and ferulic acid (r =-0.813; $p \leq 0.01$).

The non significant correlation between total phenolic acid and antioxidant activity was not unexpected because it contained several types of phenolic acids with different compositions and some phenolic acids may not support antioxidant activity or even reduce antioxidant activity. The conclusion was clearly supported by the negative correlations between vanillic acid, protocatechuic acid and ferulic acid with antioxidant activity and the positive correlations between chlorogenic acid, *p*-hydroxybenzoic acid and gallic acid with antioxidant activity. Therefore, individual components of total phenolic acid must be considered when phenolic acids are used as criteria determining coffee quality.

**Table 21** Correlations (r) between antioxidant activity determined by DPPH assay and total phenolic content, chlorogenic acid, vanillic acid, caffeic acid, protocatechuic acid, sinapic acid, *p*-hydroxybenzoic acid, syringic acid, *p*-coumaric acid, ferulic acid and gallic acid

| **Phenolics** | **Correlation coefficients** |
|---|---|
| Total phenolic content | 0.348 |
| Chlorogenic acid | 0.828** |
| Vanillic acid | -0.533* |
| Caffeic acid | -0.499 |
| Protocatechuic acid | -0.786** |
| Sinapic acid | 0.433 |
| *p*-hydroxybenzoic acid | 0.579** |
| Syringic acid | 0.433 |
| *p*-coumaric | -0.070 |
| Ferulic acid | -0.813** |
| Gallic acid | 0.567* |

*,** significant and highly significant at the 0.05 and 0.01 probability levels, respectively

### 1.3.6 Determination of sugar content in coffee beans

Table 22 showed the contents of sucrose, fructose and glucose from HPLC analysis of coffee bean extracts. Fructose constituted a large portion in all coffee beans grown under different shading conditions, ranging from 0.111 mg/g in coffee beans grown under 60% and 70% shadings to 0.132 mg/g in coffee beans grown under full sun, whereas trace amounts of glucose and sucrose were observed in all coffee beans grown under different shading conditions, ranging from non-detectable amount in coffee beans grown under full sun and 70% shading to 0.051 mg/g for glucose and 0.08 mg/g for sucrose in coffee beans grown under lychee shade and 60% shading, respectively.

The trace amounts of glucose and sucrose, though significantly different, can be ignored. However, the high amounts of 8.12 to 8.46 mg/g were reported previously under full sun and shading conditions (Geromel et al., 2006). The contrasting results should be due to the difference in cultivars used in different studies. The authors also found high amounts of fructose under these growing conditions, ranging from 0.19 to 0.47 mg/g.

The patterns of sugar contents were not consistent across shading conditions. For example, low fructose, sucrose and total sugar were also found in both coffee beans grown under full sun and 70% shading, which were the extreme treatments under investigation. Fructose content of coffee beans grown under full sun (0.132 mg/g) was somewhat higher than those grown under shading conditions (0.111-0.124 mg/g), but the difference was rather small. Therefore, the effect of shading on sugar content of coffee beans is still unresolved and further investigations may be necessary. However, it is possible that the seed sugar was mostly converted into other carbohydrates at harvest, and the sugar content was measured in dry beans.

**Table 22** Sugar compositions in coffee beans grown under different shading conditions

| Shade | Sugar composition (mg/g dw) | | | |
|---|---|---|---|---|
| | Fructose | Glucose | Sucrose | Total |
| full sun | $0.132^{ab}$ | nd | nd | $0.132^{d}$ |
| 50% shade | $0.124^{bc}$ | $0.043^{b}$ | $0.061^{b}$ | $0.228^{b}$ |
| 60% shade | $0.111^{c}$ | $0.044^{b}$ | $0.083^{a}$ | $0.238^{a}$ |
| lychee shade | $0.123^{bc}$ | $0.051^{ab}$ | $0.013^{c}$ | $0.187^{c}$ |
| 70% shade | $0.111^{c}$ | nd | nd | $0.111^{e}$ |
| F- test | ** | ** | ** | ** |
| CV | 3.14 | 6.35 | 8.9 | 2.82 |

Different letters in the column indicate significant differences at $p < 0.01$, nd=not detected

**2. Effects of shading and roasting degree on color, moisture content, percentage losses or gains of antioxidant activity and total phenolic content, some quality characters and cup test in roasted coffee**

Roasting is a preparation process of raw coffee beans for further extraction by heating coffee beans to a certain degree of temperature and time. Physical and chemical changes occur during roasting as affected by temperature and duration. This investigation is that coffee beans grown under different shading conditions might require specific roasting method to obtain the optimal quality which is indicated by color, moisture content, percentage losses or gains of antioxidant activity and total phenolic content, antioxidant activity, sugar and chemical compounds.

**2.1 Color analysis**

Color is one of the most important appearance attributes of food materials, as it influences consumer acceptability (Merken et al., 2001). Besides of consumer acceptability, color is also used in process controlling. Degree of color formation is used for roasting operation control because the brown pigments increase as the browning and caramelization reactions progress (Saklar et al., 2001).

The effects of roasting time on weight loss, moisture and $L^*$, $a^*$, $b^*$ Hunter parameters of ground coffee bean are shown in Figure 11. The parameter $L^*$ showing whiteness of coffee beans decreased progressively with the increased roasting degrees and duration, and the color of the beans turned more brownish. $L^*$ was negatively correlated with the roasting time at a given temperature. The parameter $b^*$ showing the degree of yellowness also decreased but in a smaller extent, whereas the parameter $a^*$ showing redness increased in a similar extent of the parameter $b^*$ but in opposite directions.

Temperature during thermal processing is one of the causes of color degradation in dehydrated products (Lozano and Ibarz, 1997). The color changes in coffee beans may be due to not only the non enzymatic browning reaction, but also to the destructions of pigment present in coffee beans. Degradation of certain bioactive compounds in the coffee bean might be related with the decreasing bioactivity, which was in agreement with the results from Wanyo et al. (2011).

Özdemir and Devres (2000) found in roasted hazelnuts that parameter $b^*$ decreased very similar to that observed in this study. Moss and Otten (1989) reported that the reduction in parameter $b^*$ was slow at initial stages of roasting and sharp reduction occurred at later stages. In general, these findings supported previous reports.

The increase in the parameter $a^*$ was due to the formation of brown pigments through the non enzymatic browning and phospholipids degradation. Increase in parameter $a^*$ during processing was negatively correlated with the decrease in parameter $L^*$. The changes in parameters $b^*$ and $a^*$ observed in this study were similar to those reported previously (Da Porto et al., 1991).

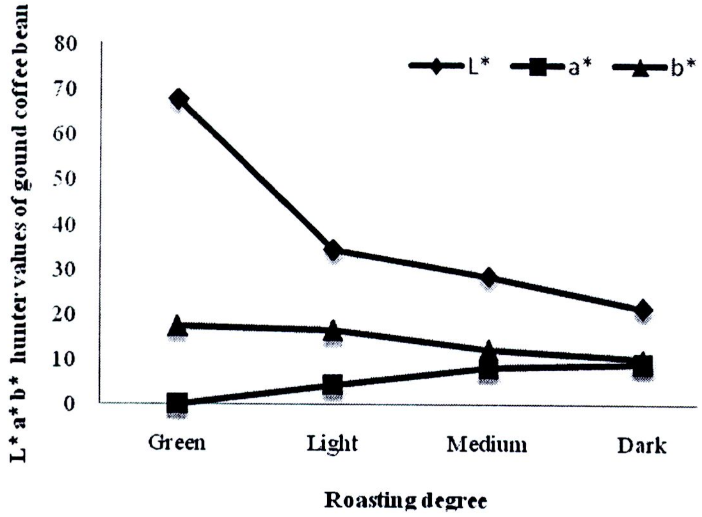



**Figure 11** *L**, *a**, *b** hunter values of ground coffee beans as a function of the roasting degree of coffee beans grown under shading conditions

### 2.2 Moisture content

The changes in moisture content of coffee bean during roasting at 230 °C for 12 min (light), at 240 °C for 14 min (medium), and 250 °C for 17 min (dark) as a function of roasting conditions were presented in Figure 12. Changes in moisture were similar among three roasting temperatures with moistures of 1.74% in light roasted coffee, 1.65% in medium roasted coffee and 1.50% in dark roasted coffee, whereas the original moisture was 10.26% in green coffee. On the other hand, the losses of moistures were calculated as 83.1, 83.9 and 85.4% for light roasted coffee, medium roasted coffee and dark roasted coffee, respectively.

Water loss is a general phenomenon when coffee bean is subjected to roasting. The losses occur in two different phases namely dehydration and pyrolysis. Most water loss occurs during dehydration at the beginning of the roasting processes and very small amount of water is reduced during pyrolysis. In the latter process, water was reduced along with the evolution of $CO_2$ and CO (Casal et al., 2005; Montavon et al., 2003).

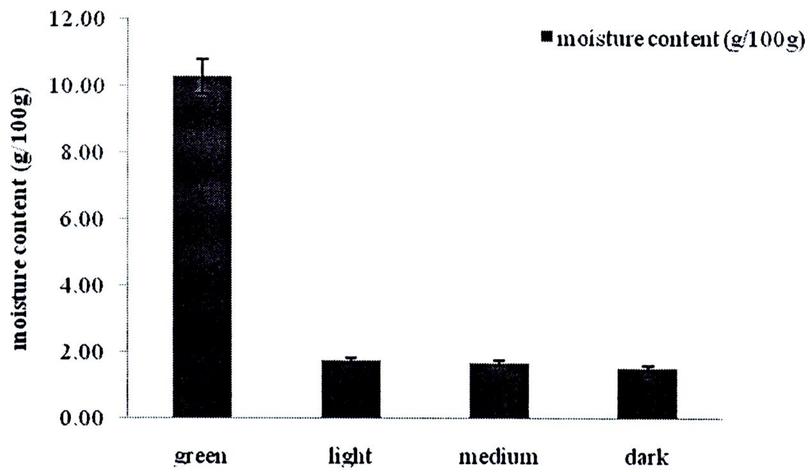



**Figure 12** Levels of moisture in coffee bean to different roasting conditions.

**2.4 Effect of shading and roasting on antioxidant activity and total phenolic content of coffee**

Antioxidant activities of coffee beans grown under different conditions were estimated by DPPH assay and showed in Table 23. Coffee grown under all growing conditions exhibited significantly ($p < 0.05$) active inhibition of the scavenging DPPH radical. Shading conditions were significantly different for antioxidant activities and total phenolic content. The percentage inhibition of coffee beans ranges from 86.77% to 90.54 %. Antioxidant activities of coffee beans harvested from the plants grown under lychee shade were highest (90.54%) and the lowest (86.77%) in coffee bean from the plants grown under full sun ($p < 0.05$). Phenolic compounds contributed directly to antioxidant action and therefore, it was necessary to investigate total phenolic content. These values are expressed as milligrams of gallic acid equivalents (GAE) per gram of coffee bean grown under shaded conditions (Table 23). The total phenolic content of these coffee beans ranged from 23.51 mg GAE/g to 36.26 mg GAE/g (Table 23). The coffee bean grown under lychee shade had the highest total phenolic content (36.26 mg GAE/g) and coffee bean grown under full sun had the lowest total phenolic content (23.51 mg GAE/g) ($p < 0.05$).

**Table 23** Total phenolic content (mg GAE/g) and DPPH radical scavenging activity (%) of coffee beans under five shade conditions

| **Shading conditions** | **Total phenolic content (mg GAE/g)** | **DPPH radical scavenging activity (%)** |
|---|---|---|
| full sun | 23.51$^{e}$ | 86.77$^{d}$ |
| 50% shade | 28.23$^{c}$ | 90.18$^{ab}$ |
| 60% shade | 25.15$^{d}$ | 89.94$^{b}$ |
| lychee shade | 30.31$^{b}$ | 90.54$^{a}$ |
| 70% shade | 36.26$^{a}$ | 88.69$^{bc}$ |
| F- test | ** | ** |
| CV | 2.18 | 0.53 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$) **, significant at the 0.05 level (two tailed)

Roasting conditions were significantly different for antioxidant activities and total phenolic content. The percentage inhibition of coffee beans ranges from 82.46 % to 92.76 %. Antioxidant activities of coffee beans roasted at light levels were highest (92.76 %) and the lowest (82.46 %) in coffee bean roasted at dark levels ($p < 0.05$). Phenolic compounds of coffee bean different roasted conditions (Table 24). The total phenolic content of these coffee beans ranged from 34.79 mg GAE/g to 22.11 mg GAE/g (Table 24). The coffee bean roasted at light levels had the highest total phenolic content (34.79 mg GAE/g) and coffee bean roasted at dark levels had the lowest total phenolic content (22.11 mg GAE/g) ($p < 0.05$).

**Table 24** Total phenolic content (mg GAE/g) and DPPH radical scavenging activity (%) of coffee beans in different roasting levels

| Roast level | Total phenolic content (mg GAE/g) | DPPH radical scavenging activity (%) |
|---|---|---|
| Green | 29.96[b] | 91.72[b] |
| Light | 34.79[a] | 92.76[a] |
| Medium | 28.81[c] | 89.94[c] |
| Dark | 21.11[d] | 82.46[d] |
| F- test | ** | ** |
| CV | 2.18 | 0.53 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$) **, significant at the 0.05 level (two tailed)

Combined effect of shading conditions and roasting levels on antioxidant activity was observed (Table 25). The percentage inhibition of coffee beans ranges from 72.70% to 94.38 %. Antioxidant activities of coffee beans harvested from the plants grown under 70% shade and roasted at light levels were the highest (94.38%) and the lowest (72.70%) in coffee bean from the plants grown under 50% shade and dark roasted ($p < 0.05$).

Phenolic compounds contributed directly to antioxidant action and therefore, it was necessary to investigate total phenolic content. These values are expressed as milligrams of gallic acid equivalents (GAE) per gram of coffee bean grown under shaded conditions (Table 25). Combined effects of shading conditions and roasting levels on total phenolic content were observed. The total phenolic content of these coffee beans ranged from 14.10 mg GAE/g to 45.50 mg GAE/g (Table 25). The coffee bean grown under lychee shade and light roasted had the highest total phenolic content (45.50 mg GAE/g) and coffee bean grown under 50% shade and dark roasted had the lowest total phenolic content (14.10 mg GAE/g) ($p < 0.05$). Similar observations were reported by Baggenstoss et al., (2008) and Karakaya and Tas (2001) that light roasted coffee beans had the highest total phenolic content.

Thermal processing has been reported to have both adverse and favorable effect on total phenolic acid. Roy et al., (2007) and Chan et al., (2009) found in vegetable that phenolic content was reduced by thermal processing. Thermal processing may release more bound phenolic acids from the breakdown of cellular constituents. Although disruption of cell walls releases the oxidative and hydrolytic enzymes, the enzymes can destroy the antioxidants in fruits and vegetables (Chism and Haard, 1996). Therefore, degradation of polyphenol compounds by thermal process may result in the releasing of antioxidant compounds which have different chemical and biological properties (Tsai et al., 2002). However, there were increases in total phenolic content following combined far-infrared radiation-hot air treatment of mulberry leaves (Wanyo et al., 2011).

**Table 25** Total phenolic content (mg GAE/g) and DPPH radical scavenging activity (%) of coffee beans under five shade conditions and different roasting levels

| Shade | Roasted | Total phenolic content (mg GAE/g) | DPPH radical scavenging activity (%) |
|---|---|---|---|
| full sun | Green | $30.72^{e}$ | $90.01^{fg}$ |
| | Light | $36.57^{b}$ | $91.42^{def}$ |
| | Medium | $31.24^{e}$ | $88.81^{gh}$ |
| | Dark | $22.72^{ij}$ | $87.81^{hi}$ |
| 50% shade | Green | $32.26^{de}$ | $89.91^{fg}$ |
| | Light | $26.92^{fg}$ | $93.25^{abc}$ |
| | Medium | $20.77^{j}$ | $91.04^{ef}$ |
| | Dark | $14.11^{l}$ | $72.70^{kl}$ |
| 60% shade | Green | $22.11^{j}$ | $92.25^{cde}$ |
| | Light | $34.31^{cd}$ | $92.63^{bcd}$ |
| | Medium | $31.54^{e}$ | $88.87^{gh}$ |
| | Dark | $24.97^{gh}$ | $86.98^{i}$ |
| lychee shade | Green | $36.57^{b}$ | $94.14^{ab}$ |
| | Light | $45.51^{a}$ | $92.15^{cde}$ |
| | Medium | $35.96^{bc}$ | $93.01^{abc}$ |
| | Dark | $27.03^{fg}$ | $79.71^{k}$ |
| 70% shade | Green | $28.16^{f}$ | $92.31^{cde}$ |
| | Light | $30.62^{e}$ | $94.38^{a}$ |
| | Medium | $24.56^{i}$ | $87.97^{hi}$ |
| | Dark | $17.28^{k}$ | $85.08^{j}$ |
| F- test | | ** | ** |
| CV | | 2.18 | 0.53 |

Different letters in the same column indicate significant differences between different conditions ($p < 0.01$) **, significant at the 0.05 level (two tailed)

**2.3 Percentage losses or gains of antioxidant activity and total phenolic content**

Total phenolic acid and DPPH radical scavenging activity of roasted coffee beans were compared with that of green coffee beans and presented in Figure 13. The increases in phenolic contents of 51.08% and 27.77% were observed in light roasted coffee beans and medium roasted coffee beans, respectively, whereas the decrease of 1.55% was observed in dark roasted coffee beans. In addition, the decreases in DPPH radical scavenging activity were observed in all coffee beans with values of 0.52%, 2.07% and 10.26% for light roasted coffee beans, medium roasted coffee beans and dark roasted coffee beans, respectively.

The increases in total phenolic acid in light roasted coffee beans and medium-roasted coffee beans should be due mainly to water loss. However, the decrease in total phenolic acid in dark roasted coffee beans should be mainly due to thermal cracking of total phenolic acid resulted from high heat. High temperature during dark roasting also destroys sensory characteristics and radical scavenging activity of coffee beans.

Thermal processing can improve the properties of naturally occurring antioxidants or induce the formation of new compounds with antioxidant properties, so that the overall antioxidant activity increases or remains unchanged (Tomaino et al., 2005). Therefore, degradation of polyphenol compounds by thermal process may result in the releasing of antioxidant compounds which have different chemical and biological properties (Tsai et al., 2002; Williams et al., 1995).

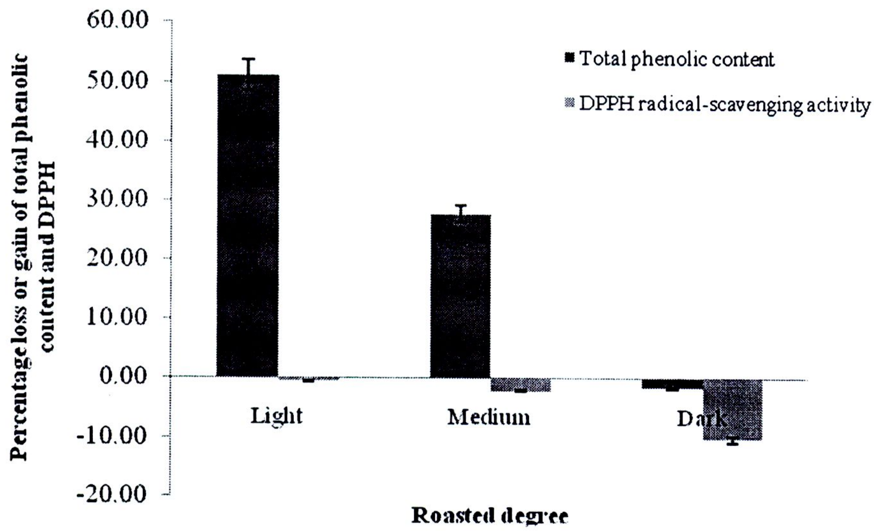



**Figure 13** Percentage loss or gain of total phenolic content and DPPH radical-scavenging activity for coffee bean samples after roasted compared to green bean

### 2.5 Effect of shading and roasting degree on phenolic acid compositions

Phenolic acid compositions contributed directly to antioxidant action. A possible explanation is that the phenolic compounds of district reactivity are affected differently by shading and roasting degree. The contents of individual phenolic acids in coffee bean extracts are summarized in Table 26-28, and typical chromatograms of phenolic acid compounds from green beans, light-, medium-, and dark-roasted coffee beans are shown in Figure 14.

Shading conditions result in significantly different amount of phenolic acids of coffee bean. Coffee grown at all growing conditions exhibited significantly different levels of phenolic acids ($p < 0.05$). Among the five shading conditions studied coffee beans harvested from the plants grown under full sun gave the highest protocatechuic acid, vanillic acid, caffeic acid, syrigic acid and ferulic acid (12.24 mg/100 g fresh sample, 12.12 mg/100 g fresh sample, 10.81 mg/100 g fresh sample, 4.91 mg/100 g fresh sample, 9.55 mg/100 g fresh sample, respectively). Coffee beans harvested from under 60% shade gave the highest *p*-hydroxybenzoic (21.32 mg/100 g fresh sample) and chlorogenic acid (54.07 mg/100 g fresh sample) (Table 26).

Roasting conditions were significantly different for phenolic acids of coffee bean (Table 27). The phenolic acid of green bean had the highest chlorogenic acid, caffeic acid and sinapic acid (84.10 mg/100 g fresh sample, 9.24 mg/100 g fresh sample and 10.89 mg/100 g fresh sample, respectively). The coffee bean roasted at medium roasted had the highest protocatechuic acid, *p*-hydroxybenzoic and vanillic acid (14.60 mg/100 g fresh sample, 27.27 mg/100 g fresh sample and 13.68 mg/100 g fresh sample, respectively)

Combined effect of shading and roasting degree on phenolic acids was shown in Table 28. Total phenolic acid compound was the highest (145 mg/100 g fresh sample) for green beans and then it was reduced with higher heat until it reached 108 mg/100 g fresh sample at dark roasting level. The results indicated that heat destroyed phenolic acids during the course of roasting.

Changes in individual phenolic acids were also different at different steps of heat treatments. Significant reductions in protocatechuic acid, chlorogenic acid, vanillic acid, caffeic acid, ferulic acid and sinapic acids were observed from un-roasted to light roasted level, whereas gallic acid, *p*-hydroxybenzoic acid and *p*-coumaric acids seemed to be increased.

Gallic acid, chlorogenic acid and sinapic acid were reduced from light roasted level to medium roasted level. However, there were the increments in protocatechuic acid, *p*-hydroxybenzoic, vanillic, caffeic, syringic and ferulic acids as affected by higher heat. Most phenolic acids were reduced from medium roasted level to dark roasted level except for chlorogenic acid, syringic acid, ferulic acid and sinapic acid which were significantly increased.

Chlorogenic acid presented at high concentrations in all coffee beans grown under different shading conditions (Table 28). Chlorogenic acid seemed to be higher under medium shading conditions (50 and 60% shadings). Vanillic acid and caffeic acid were also found at high concentrations but much lower than chlorogenic acid. Differences in the amounts of vanillic acid and caffeic acid were high under different growing conditions. In general, high vanillic acid and caffeic acid were found under lower shading conditions especially under full sun. Other phenolic acids were found in smaller amounts and the patterns of the presence under different shading conditions were not clear.

When coffee beans were subjected to low heat (light roasted level), differences in individual phenolic acids were observed compared to those in green beans (Table 28). Chlorogenic acids and caffeic acids expressed consistent reductions across shading levels, and gallic acid, *p*-hydroxybenzoic acid and syringic acid showed consistently increases, whereas the remaining phenolic acids did not showed consistent patterns.

Chlorogenic acid was generally increased from medium roasted level to dark roasted level except for coffee bean grown under 50% shading. In contrast to chlorogenic acid, vanillic acid seemed to be reduced in most cases except for coffee bean grown under full sun. Similar to vanillic acid, protocatechuic acid showed reduction in most cases except for coffee bean grown under 60% shading. The other phenolic acids showed rather inconsistent patterns which were both reduction and increase under different shading conditions.

**Table 26** Phenolic acids in coffee beans grown under different shading conditions

| Shade | Gallic acid | Protocatechuic acid | *p*-hydroxybenzoic acid | Chlorogenic acid | Vanillic acid | Caffeic acid | Syringic acid | *p*-coumaric acid | Ferulic acid | Sinapic acid | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| full sun | $6.81^{b}$ | $12.24^{a}$ | $16.22^{b}$ | $48.43^{c}$ | $12.12^{a}$ | $10.81^{a}$ | $4.91^{a}$ | $12.25^{b}$ | $9.55^{a}$ | $8.24^{c}$ | $141.59^{a}$ |
| 50% shade | $6.85^{a}$ | $11.23^{b}$ | $12.56^{d}$ | $43.99^{e}$ | $9.79^{b}$ | $5.15^{c}$ | $1.47^{e}$ | $7.33^{c}$ | $4.87^{e}$ | $7.92^{d}$ | $111.19^{d}$ |
| 60% shade | $5.28^{c}$ | $8.15^{d}$ | $21.32^{a}$ | $54.07^{a}$ | $9.36^{c}$ | $5.96^{b}$ | $2.58^{d}$ | $7.41^{c}$ | $5.75^{c}$ | $8.27^{b}$ | $128.16^{b}$ |
| lychee shade | $3.14^{e}$ | $9.22^{c}$ | $7.77^{e}$ | $49.34^{b}$ | $7.98^{d}$ | $4.26^{d}$ | $3.69^{b}$ | $2.62^{d}$ | $5.40^{d}$ | $9.23^{a}$ | $102.39^{e}$ |
| 70% shade | $5.07^{d}$ | $7.41^{e}$ | $15.82^{c}$ | $47.03^{d}$ | $7.72^{e}$ | $5.23^{b}$ | $3.41^{c}$ | $15.79^{a}$ | $7.33^{b}$ | $7.60^{e}$ | $122.68^{c}$ |
| F- test | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| CV | 0.11 | 0.1 | 0.11 | 0.09 | 0.09 | 0.09 | 0.11 | 2.85 | 0.1 | 0.08 | 0.22 |

Means followed by the same lower case letter in the same column were not significantly different by Bonferroni tests ($p < 0.05$).

**, significant at 0.01 probability level

**Table 27** Phenolic acids in coffee beans in different roasting levels

| Roast level | Gallic acid | Protocatechuic acid | *p*-hydroxybenzoic acid | Chlorogenic acid | Vanillic acid | Caffeic acid | Syringic acid | *p*-coumaric acid | Ferulic acid | Sinapic acid | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| green | $2.09^{d}$ | $8.15^{c}$ | $3.85^{d}$ | $84.108^{a}$ | $10.07^{b}$ | $9.24^{a}$ | $2.03^{d}$ | $11.30^{b}$ | $4.13^{c}$ | $10.89^{a}$ | $145.87^{a}$ |
| light | $11.56^{a}$ | $6.38^{d}$ | $7.73^{c}$ | $55.855^{b}$ | $6.32^{d}$ | $2.56^{d}$ | $2.95^{c}$ | $13.34^{a}$ | $3.44^{d}$ | $9.74^{b}$ | $119.89^{b}$ |
| medium | $4.17^{b}$ | $14.60^{a}$ | $27.27^{a}$ | $20.754^{d}$ | $13.68^{a}$ | $8.69^{b}$ | $3.47^{b}$ | 7.42c | $5.04^{b}$ | $5.64^{d}$ | $110.72^{c}$ |
| dark | $3.89^{c}$ | $9.46^{b}$ | $20.10^{b}$ | $33.595^{c}$ | $7.51^{c}$ | $4.63^{c}$ | $4.39^{a}$ | $4.26^{d}$ | $13.71^{a}$ | $6.76^{c}$ | $108.33^{d}$ |
| F- test | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| CV | 0.11 | 0.1 | 0.11 | 0.09 | 0.09 | 0.09 | 0.11 | 2.85 | 0.1 | 0.08 | 0.22 |

Means followed by the same lower case letter in the same column were not significantly different by Bonferroni tests ($p < 0.05$).

**, significant at 0.01 probability level

**Table 28** Phenolic acid contents (mg/100 g fresh sample) of coffee beans grown under different shade conditions and roasted different levels

| shade | roasted | chlorogenic acid | vanillic acid | caffeic acid | gallic acid | protocatechuic acid | *p*-hydroxybenzoic acid | syringic acid | *p*-coumaric acid | ferulic acid | sinapic acid | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | 62.13$^{h}$ | 25.07$^{a}$ | 25.23$^{a}$ | 2.53$^{q}$ | 12.05$^{h}$ | 5.17$^{p}$ | 2.83$^{g}$ | 2.26$^{k}$ | 6.11$^{h}$ | 11.94$^{c}$ | 155.32$^{b}$ |
| | L | 63.02$^{g}$ | 6.87$^{i}$ | 3.03$^{s}$ | 15.97$^{b}$ | 8.62$^{k}$ | 6.05$^{n}$ | 2.75$^{h}$ | 32.23$^{b}$ | 5.46$^{i}$ | 2.81$^{l}$ | 146.83$^{c}$ |
| | M | 24.03$^{p}$ | 4.07$^{q}$ | 8.32$^{e}$ | 4.61$^{g}$ | 15.29$^{d}$ | 28.49$^{e}$ | 6.07$^{c}$ | 8.52$^{d}$ | 6.80$^{g}$ | 11.19$^{d}$ | 117.39$^{j}$ |
| full sun | D | 44.58$^{j}$ | 12.48$^{f}$ | 6.66$^{h}$ | 4.10$^{i}$ | 12.99$^{f}$ | 25.17$^{f}$ | 7.99$^{a}$ | 5.99$^{f}$ | 19.84$^{a}$ | 7.04$^{m}$ | 146.83$^{c}$ |
| **mean** | | **48.43** | **12.12** | **10.81** | **6.81** | **12.24** | **16.22** | **4.91** | **12.25** | **9.55** | **8.24** | **141.59** |
| | G | 71.09$^{d}$ | 6.89$^{i}$ | 5.20$^{j}$ | nd | 21.10$^{a}$ | nd | nd | 15.06$^{c}$ | 5.32$^{j}$ | 8.98$^{j}$ | 133.65$^{e}$ |
| | L | 53.61$^{i}$ | 7.05$^{h}$ | 3.34$^{m}$ | 16.19$^{a}$ | 4.46$^{n}$ | 9.19$^{i}$ | nd | 3.85$^{ij}$ | nd | 8.51$^{k}$ | 106.20$^{l}$ |
| | M | 31.32$^{m}$ | 22.45$^{b}$ | 8.95$^{d}$ | 5.46$^{f}$ | 15.97$^{c}$ | 33.59$^{b}$ | 2.95$^{e}$ | 8.051$^{de}$ | 3.36$^{q}$ | 5.21$^{p}$ | 137.31$^{d}$ |
| 50% shade | D | 19.96$^{r}$ | 2.79$^{r}$ | 3.13$^{r}$ | 5.74$^{e}$ | 3.397p | 7.47$^{l}$ | 2.94$^{e}$ | 2.36$^{k}$ | 10.80$^{e}$ | 9.01$^{i}$ | 67.60$^{p}$ |
| **mean** | | **43.99** | **9.79** | **5.15** | **6.85** | **11.23** | **12.56** | **1.47** | **7.33** | **4.87** | **7.92** | **111.19** |
| | G | 88.63$^{b}$ | 5.24$^{n}$ | 4.31$^{l}$ | 2.60$^{o}$ | 2.434$^{s}$ | 4.29$^{q}$ | 2.45$^{m}$ | 2.29$^{k}$ | 4.19$^{l}$ | 14.07$^{b}$ | 130.52$^{g}$ |
| | L | 67.44$^{e}$ | 6.39$^{k}$ | 3.19$^{q}$ | 10.89$^{d}$ | 3.86$^{o}$ | 8.58$^{j}$ | 2.64$^{i}$ | 15.46$^{c}$ | 3.63$^{p}$ | 10.89$^{e}$ | 132.98$^{e}$ |
| | M | 22.29$^{q}$ | 14.42$^{c}$ | 9.50$^{b}$ | 3.58$^{k}$ | 13.00$^{f}$ | 42.23$^{a}$ | 2.61$^{k}$ | 7.36$^{e}$ | 4.10$^{n}$ | 2.88$^{s}$ | 121.97$^{i}$ |
| 60% shade | D | 37.94$^{k}$ | 11.38$^{g}$ | 6.84$^{g}$ | 4.04$^{j}$ | 13.28e | 30.18$^{d}$ | 2.62$^{j}$ | 4.53$^{hi}$ | 11.08$^{c}$ | 5.26$^{o}$ | 127.17$^{h}$ |
| **mean** | | **54.07** | **9.36** | **5.96** | **5.28** | **8.15** | **21.32** | **2.58** | **7.41** | **5.75** | **8.27** | **128.16** |
| | G | 125.39$^{a}$ | 6.90$^{i}$ | 6.34$^{i}$ | 2.75$^{m}$ | 2.55$^{r}$ | 5.76$^{o}$ | 2.46$^{l}$ | nd | nd | 10.34$^{g}$ | 162.51$^{a}$ |
| | L | 29.84$^{n}$ | 4.55$^{p}$ | nd | 2.76$^{m}$ | 10.42$^{i}$ | 7.66$^{k}$ | 6.75$^{b}$ | nd | 4.16$^{m}$ | 15.69$^{a}$ | 81.84$^{o}$ |
| | M | 12.65$^{t}$ | 14.34$^{d}$ | 7.44$^{f}$ | 4.46$^{h}$ | 16.03$^{b}$ | nd | 2.89$^{f}$ | 5.52$^{fg}$ | nd | 3.30$^{r}$ | 66.64$^{q}$ |
| lychee shade | D | 29.49$^{o}$ | 5.07$^{o}$ | 3.23$^{p}$ | 2.59$^{o}$ | 7.89$^{l}$ | 17.64$^{h}$ | 2.65$^{i}$ | 4.98$^{gh}$ | 17.45$^{b}$ | 7.57$^{l}$ | 98.57$^{n}$ |
| **mean** | | **49.34** | **7.98** | **4.26** | **3.14** | **9.22** | **7.77** | **3.69** | **2.62** | **5.40** | **9.23** | **102.39** |

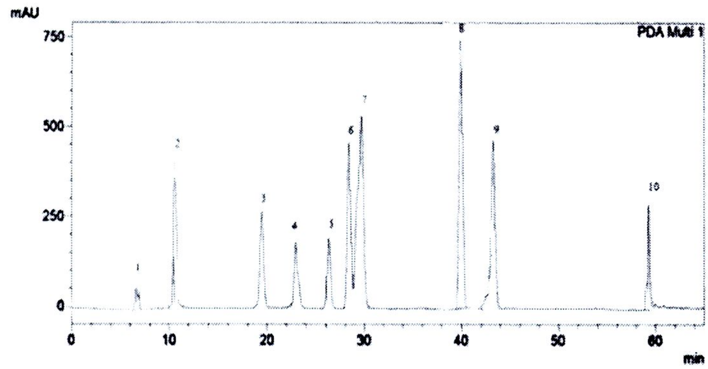
**Table 28** (continued) Phenolic acid contents (mg/100 g fresh sample) of coffee beans grown under different shade conditions and roasted different levels. (cont.)

| shade | roasted | chlorogenic acid | vanillic acid | caffeic acid | gallic acid | protocatechuic acid | *p*-hydroxybenzoic acid | syringic acid | *p*-coumaric acid | ferulic acid | sinapic acid | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | $73.29^{c}$ | $6.25^{l}$ | $5.14^{k}$ | $2.57^{p}$ | $2.61^{q}$ | $4.03^{r}$ | $2.41^{n}$ | $36.90^{a}$ | $5.04^{k}$ | $9.09^{h}$ | $147.34^{c}$ |
| | L | $65.37^{f}$ | $6.73^{j}$ | $3.25^{o}$ | $11.97^{c}$ | $4.57^{m}$ | $7.16^{m}$ | $2.61^{k}$ | $15.18^{c}$ | $3.94^{o}$ | $10.82^{f}$ | $131.62^{f}$ |
| | M | $13.47^{s}$ | $13.10^{e}$ | $9.23^{c}$ | $2.71^{n}$ | $12.73^{g}$ | $32.03^{c}$ | $2.84^{g}$ | $7.63^{e}$ | $10.95^{d}$ | $5.61^{n}$ | $110.31^{k}$ |
| 70% shade | D | $36.01^{l}$ | $5.85^{m}$ | $3.29^{n}$ | $3.00^{l}$ | $9.73^{j}$ | $20.07^{g}$ | $5.79^{d}$ | $3.44^{j}$ | $9.38^{f}$ | $4.88^{q}$ | $101.46^{m}$ |
| **mean** | | **47.03** | **7.72** | **5.23** | **5.07** | **7.41** | **15.82** | **3.41** | **15.79** | **7.33** | **7.60** | **122.68** |
| F- test | | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| CV | | 0.11 | 0.1 | 0.11 | 0.09 | 0.09 | 0.09 | 0.11 | 2.85 | 0.1 | 0.08 | 0.22 |

nd =not detected

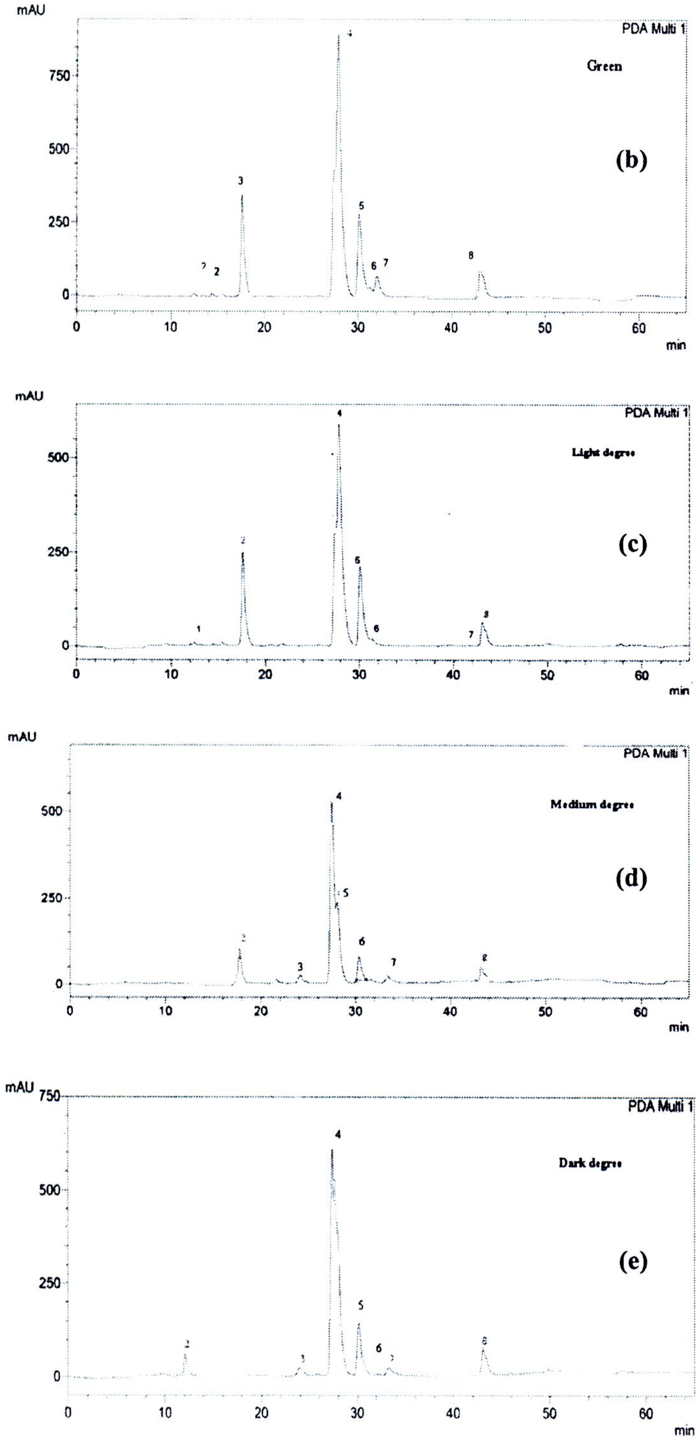
Means followed by the same lower case letter in the same column were not significantly different by Bonferroni tests ($p< 0.05$).

G= green bean, L=light roasting, M=medium roasting and D=dark roasting, **, significant at 0.01 probability level




Peaks: (1) gallic acid, (2) protocatechuic acid, (3) *p*-hydroxybenzoic acid, (4) chlorogenic acid, (5) vanillic acid, (6) caffeic acid, (7) syringic acid, (8) *p*-coumaric acid, (9) ferulic acid, and (10) sinapic acid

**Figure 14** Typical chromatograms of standard phenolic compounds (a).




Peaks: (1) gallic acid, (2) protocatechuic acid, (3) *p*-hydroxybenzoic acid, (4) chlorogenic acid, (5) vanillic acid, (6) caffeic acid, (7) syringic acid, (8) *p*-coumaric acid, (9) ferulic acid, and (10) sinapic acid.

**Figure 14** Typical chromatograms of green bean (b), light (c), medium (d) and dark (e) (cont.)

The correlation coefficients were calculated from all shading conditions and, therefore, they represented overall relationships among character under study. Different phenolic acids showed both positive and negative correlations with antioxidant activity. Positive and significant correlation coefficients were observed between antioxidant activity with ferulic acid (r = 0.96; $p \leq 0.01$) and negative and significant correlation coefficients were found between antioxidant activity with chlorogenic acid (r = -0.93; $p \leq 0.01$) (Table 29).

The phenolic acids having negative and significant correlations with antioxidant generally had negative correlation coefficients with chlorogenic acids as indicated by significant correlation coefficients between chlorogenic acid with ferulic acid (r =-0.99; $p \leq 0.05$). In contrast, the phenolic acids having positive correlation coefficients with antioxidant activity were also positively significant correlated with ferulic acid.

Vanillic acid and caffeic acid were significantly and positively associated (r = 0.99; $p \leq 0.01$) and both of them had negative correlation coefficients with antioxidant activity and chlorogenic acid. In addition to negative relationship with antioxidant activity and chlorogenic acid, protocatechuic acid also had negative correlations with *p*-hydroxybenzoic acid, syringic acid and gallic acid and these phenolic acids had positive correlations with antioxidant activity and chlorogenic acid although some correlation coefficients were not significant.

**Table 29** Correlations among phenolic acids and total phenolic contents

| | TPC | DPPH | GA | PCCA | ChA | VA | CFA | *p*-OH | SyA | *p*-CA | FA | SNA | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DPPH** | 0.35 | 1.00 | | | | | | | | | | | |
| **GA** | -0.03 | -0.18 | 1.00 | | | | | | | | | | |
| **PCCA** | 0.27 | 0.34 | 0.35 | 1.00 | | | | | | | | | |
| **ChA** | -0.93** | -0.93** | -0.53 | 0.44 | 1.00 | | | | | | | | |
| **VA** | 0.57 | 0.40 | 0.30 | 0.30 | -0.47 | 1.00 | | | | | | | |
| **CFA** | 0.55 | 0.38 | 0.25 | 0.34 | -0.44 | 0.99** | 1.00 | | | | | | |
| ***p*-OH** | -0.14 | -0.31 | -0.78** | 0.28 | 0.29 | 0.12 | 0.31 | 1.00 | | | | | |
| **SyA** | 0.11 | -0.05 | -0.78** | 0.95** | 0.21 | 0.35 | 0.39 | 0.26 | 1.00 | | | | |
| ***p*-CA** | 0.26 | 0.26 | -0.03 | -0.32 | -0.40 | -0.31 | -0.33 | -0.31 | -0.21 | 1.00 | | | |
| **FA** | 0.94** | 0.96** | 0.50 | -0.44 | -0.99** | 0.43 | 0.40 | 0.32 | 0.19 | 0.25 | 1.00 | | |
| **SNA** | 0.23 | 0.26 | -0.36 | 0.45 | 0.061 | 0.20 | 0.23 | 0.17 | 0.35 | 0.24 | 0.36 | 1.00 | |
| **Total** | -0.33 | -0.54 | -0.30 | 0.68* | 0.40 | 0.42 | 0.45 | 0.52 | 0.61 | 0.41 | 0.42 | 0.53 | 1.00 |

*, significant at the 0.05 level (two tailed); **, significant at the 0.01 level (two tailed)

GA, gallic acid; PCCA, protocatechuic acid; *p*-HO, *p*-hydroxy benzoic acid; ChA, chorogenic acid; VA, vanillic acid; CFA, caffeic acid; SyA, syringic acid; *p*-CA, *p*-coumaric acid; FA, ferulic acid; SNA, sinapic acid

## 2.6 Effect of shading and roasting on sugar content in coffee bean

The HPLC analysis of extracts of coffee bean revealed the contents of several types of sugars, namely, sucrose, fructose and glucose (Table 30-31). Fructose was the only sugars detected in all samples, whereas sucrose was not detected in medium and dark roasted. Fructose was the most predominant sugar in all coffee beans, (0.116 mg/g to 0.123 mg/g) followed by glucose and sucrose, which range from 0.016 mg/g to 0.071 mg/g and 0.031 mg/g to 0.047 mg/g, respectively. The result showed general trend when coffee bean grown under different growing condition was roasted at different levels. Total sugar value was the highest (0.241 mg/ g) for light roasted and then it was reduced with higher heat until it reached 0.130 mg/g at dark roasting level.

Changes in individual sugar were also different at different steps of heat treatments. Significant increment in fructose, glucose and sucrose were observed from un-roasted to light roasted level, whereas coffee bean sugars from light roasted level to medium roasted level were significantly reduced. Especially, sucrose was not detected in medium and dark roasted. Light roasted level presented the highest concentrations of fructose, glucose and sucrose (0.213 mg/g, 0.071 mg/g and 0.047 mg/g, respectively).

**Table 30** Sugar composition in coffee bean grown under five growing conditions and roasted at three roasting levels

| Roasted | Sugar composition (mg/g dw) | | | |
|---|---|---|---|---|
| | **Fructose** | **Glucose** | **Sucrose** | **Total** |
| Green | $0.116^{b}$ | $0.031^{b}$ | $0.031^{b}$ | $0.178^{b}$ |
| Light | $0.213^{a}$ | $0.071^{a}$ | $0.047^{a}$ | $0.331^{a}$ |
| Medium | $0.116^{b}$ | $0.022^{c}$ | nd | $0.138^{c}$ |
| Dark | $0.109^{b}$ | $0.031^{b}$ | nd | $0.130^{d}$ |
| F- test | ** | ** | ** | ** |
| CV | 8.9 | 6.35 | 3.14 | 2.82 |

Different letters in the column indicate significant differences at $p < 0.01$. Significant at the 0.01 level (two tailed) nd=not detected

**Table 31** Sugar composition in coffee bean grown under different shading conditions and roasted at different conditions

| **Shade** | **Roasted** | **Sugar composition (mg/g dw)** | | | |
|---|---|---|---|---|---|
| | | **Fructose** | **Glucose** | **Sucrose** | **Total** |
| full sun | Green | 0.136[ab] | nd | nd | 0.136[g] |
| | Light | 0.121[bc] | nd | nd | 0.121[g] |
| | Medium | 0.111[c] | 0.051[cd] | nd | 0.162[f] |
| | Dark | 0.121[bc] | 0.041[cde] | nd | 0.162[f] |
| 50% shade | Green | 0.121[bc] | 0.041[cde] | 0.061[d] | 0.223[d] |
| | Light | 0.141[a] | 0.071[b] | 0.041[e] | 0.253[c] |
| | Medium | 0.111[c] | nd | nd | 0.111[g] |
| | Dark | 0.111[c] | nd | nd | 0.111[g] |
| 60% shade | Green | 0.111[c] | 0.041[cde] | 0.082[b] | 0.234[d] |
| | Light | 0.111[c] | 0.041[cde] | 0.079[c] | 0.231[d] |
| | Medium | 0.121[bc] | nd | nd | 0.121[g] |
| | Dark | 0.111[c] | nd | nd | 0.111[g] |
| lychee shade | Green | 0.121[bc] | 0.051[cd] | 0.011[f] | 0.183[e] |
| | Light | 0.121[bc] | 0.041[cde] | 0.121[a] | 0.283[b] |
| | Medium | 0.111[c] | nd | nd | 0.111[g] |
| | Dark | 0.121[bc] | 0.041[cde] | nd | 0.162[f] |
| 70% shade | Green | 0.111[c] | nd | nd | 0.111[g] |
| | Light | 0.121[bc] | 0.201[a] | nd | 0.322[a] |
| | Medium | 0.121[bc] | 0.041[cde] | nd | 0.162[f] |
| | Dark | 0.121[bc] | 0.041[cde] | nd | 0.161[f] |
| F- test | | ** | ** | ** | ** |
| CV | | 3.14 | 6.35 | 8.9 | 2.82 |

Different letters in the column indicate significant differences at $p < 0.01$. Significant at the 0.01 level (two tailed) nd=not detected

### 2.7 Relationships among shading levels, roasting degree and sugar compositions

The relationships among fructose, glucose, sucrose, total sugar compositions were studied at five shading levels and three roasting conditions. Glucose was significantly and positively correlated with shading level (r = 0.30, $p \leq 0.05$), fructose (r = 0.31, $p \leq 0.05$) and total sugar contents (r = 0.82, $p \leq 0.01$). Total sugar contents were significantly and positively correlated with fructose (r = 0.37, $p \leq 0.01$), glucose (r = 0.82, $p \leq 0.01$) and sucrose (r = 0.67, $p \leq 0.01$) whereas had significant and negative correlation with roasting level (r = -0.39, $p \leq 0.01$) (Table 32).

**Table 32** Correlation coefficients (r) among shading levels, roasting degree and sugar compositions

| | Shading | Fructose | Glucose | Roasting level | Sucrose |
|---|---|---|---|---|---|
| Fructose | -0.19 | | | | |
| Glucose | 0.30* | 0.31* | | | |
| Roasting level | 0.00 | -0.23 | -0.15 | | |
| Sucrose | 0.03 | 0.07 | 0.13 | -0.45** | |
| Total | 0.21 | 0.37** | 0.82** | -0.39** | 0.67** |

*, significant at the 0.05 level (two tailed); **, significant at the 0.01 level (two tailed)

## 3. Sensory evaluations of roasted coffee

The panelists were asked to assess the effects of roasting level on the aroma, acidity, body, preference and bitterness of roasted coffee beans from plants grown under five shading conditions (Table 33-37).

For full sun coffee, light roasting gave the highest values of aroma, acidity, body, preference and bitterness followed by medium roasting and dark roasting, respectively (Table 33). Coffee extracts are considered high value products for beverage and alcoholic beverage, bakery, and even instant coffee industries. The quality of coffee extracts obtained using different extraction methods were recently compared by Sarrazin et al. (2002), who studied which method provided an extract with sensory characteristics as close as possible to that of coffee. Ramos et al.

(1998) and Oliveira et al. (2001), also trying to obtain roasted coffee aromatic oil with an aroma as similar as possible to that of the original brewed coffee, optimised the operational variables of the supercritical $CO_2$ extraction based on the sensory analysis of the aromatic extract.

**Table 33** Sensory evaluation of coffee beans grown under full sun condition and subjected to different roasting degrees for aroma, acidity, body, preference and bitterness

| Roasting | Aroma | Acidity | Body | Preference | Bitterness |
|---|---|---|---|---|---|
| L | 3.2$^{a}$ | 2.9$^{a}$ | 3.3$^{a}$ | 2.9$^{a}$ | 3.0$^{a}$ |
| M | 2.7$^{b}$ | 2.0$^{b}$ | 2.7$^{b}$ | 2.7$^{a}$ | 2.8$^{b}$ |
| D | 1.4$^{c}$ | 1.5$^{c}$ | 1.1$^{c}$ | 1.2$^{b}$ | 1.3$^{b}$ |
| F-test | ** | ** | ** | ** | ** |
| CV | 0.41 | 0.41 | 0.42 | 0.37 | 0.36 |

L=light, M=medium and D=dark **, significant at 0.01 probability level

Similar patterns of sensory profiles were observed for coffee grown under 50% shading condition (Table 34). The highest values of aroma, acidity, body, preference and bitterness were observed in coffee roasted at light heat, followed by medium heat and high heat, respectively. By using this criterion, it is clear that light roasted are higher quality than all conditions (Montavon et al., 2003).

**Table 34** Sensory evaluation of coffee beans grown under 50% shading condition and subjected to different roasting degrees for aroma, acidity, body, preference and bitterness

| Roasting | Aroma | Acidity | Body | Preference | Bitterness |
|---|---|---|---|---|---|
| L | $3.3^a$ | $2.5^a$ | $3.3^a$ | $3.5^a$ | $3.2^a$ |
| M | $2.7^b$ | $1.7^b$ | $2.6^b$ | $3.0^b$ | $3.0^a$ |
| D | $1.2^c$ | $1.3^c$ | $1.8^c$ | $1.5^c$ | $1.4^b$ |
| F-test | ** | ** | ** | ** | ** |
| CV | 0.57 | 0.51 | 0.41 | 0.46 | 0.44 |

L=light, M=medium and D=dark

**, significant at 0.01 probability level

Again, the patterns of sensory profiles were still similar for coffee grown under 60% shading and subjected to different levels of roasting (Table 35). Light roasting gave the highest values for aroma, acidity, body, preference and bitterness, followed by medium roasting and dark roasting, respectively.

**Table 35** Sensory evaluation of coffee beans grown under 60% shading condition and subjected to different roasting degrees for aroma, acidity, body, preference and bitterness

| Roasting | Aroma | Acidity | Body | Preference | Bitterness |
|---|---|---|---|---|---|
| L | $3.2^a$ | $3.1^a$ | $3.0^a$ | $3.5^a$ | $3.3^a$ |
| M | $2.6^b$ | $1.7^b$ | $2.9^a$ | $2.5^b$ | $2.5^b$ |
| D | $1.2^c$ | $1.4^b$ | $1.4^b$ | $1.2^c$ | $1.4^c$ |
| F -test | ** | ** | ** | ** | ** |
| CV | 0.46 | 0.49 | 0.36 | 0.41 | 0.55 |

L=light, M=medium and D=dark

**, significant at 0.01 probability level

For coffee beans grown under lychee shade, the coffee beans subjected to different roasting condition were statistically different for body, aroma, acidity, preference and bitterness (Table 36). The quality parameters conformed with the other shading conditions in which light roasting gave the highest values for body, aroma, acidity, preference and bitterness followed by medium roasting and dark roasting, respectively (Moreira et al., 2005).

**Table 36** Sensory evaluation of coffee beans grown under lychee shading condition and subjected to different roasting degrees for aroma, acidity, body, preference and bitterness

| Roasting | Aroma | Acidity | Body | Preference | Bitterness |
|---|---|---|---|---|---|
| L | $3.1^{a}$ | $3.3^{a}$ | $2.6^{a}$ | $2.9^{a}$ | $3.5^{a}$ |
| M | $2.2^{b}$ | $2.3^{b}$ | $2.7^{a}$ | $2.4^{a}$ | $2.9^{b}$ |
| D | $1.3^{c}$ | $1.7^{b}$ | $1.9^{b}$ | $1.5^{b}$ | $1.3^{c}$ |
| F-test | ** | ** | ** | ** | ** |
| CV | 0.47 | 0.71 | 0.55 | 0.70 | 0.55 |

L=light, M=medium and D=dark

**, significant at 0.01 probability level

For aroma, acidity, body, preference and bitterness, coffee beans grown under 70% shading and subjected to three levels of roasting were significantly different (Table 37). Coffee beans roasted at light heat were the highest for these characters and higher than those roasted at the highest heat. However, coffee beans roasted at medium heat were intermediate between those roasted at low heat and high heat.

**Table 37** Sensory evaluation of coffee beans grown under 70% shading condition and subjected to different roasting degrees for aroma, acidity, body, preference and bitterness

| **Roasting** | **Aroma** | **Acidity** | **Body** | **Preference** | **Bitterness** |
|---|---|---|---|---|---|
| L | $3.3^{a}$ | $2.8^{a}$ | $2.7^{a}$ | $3.4^{a}$ | $3.0^{a}$ |
| M | $2.4^{b}$ | $2.6^{a}$ | $2.9^{a}$ | $2.9^{b}$ | $2.6^{a}$ |
| D | $1.8^{c}$ | $1.8^{b}$ | $1.3^{b}$ | $1.4^{c}$ | $1.6^{b}$ |
| F-test | ** | * | ** | ** | ** |
| CV | 0.68 | 0.64 | 0.61 | 0.46 | 0.50 |

L=light, M=medium and D=dark

*, significant at the 0.05 level, **, significant at 0.01 level (two tailed)

**3.1 Relationships between roasting levels and sensory characteristics of coffee bean grown under different shading conditions**

In general, there were positive and significant inter-relationships among aroma, acidity, bitterness, body and preference (Table 38, 39, 40 and 41). The relationships were rather consistent across shading conditions. However, positive but non-significant correlations were found between body with acidity (r=0.28) and body with bitterness (r=0.37) under lychee shade (Table 41) and between bitterness and acidity (r=0.34) under 70% shading (Table 42).

Negative and significant correlations were observed between all quality characters (aroma, acidity, bitterness, body and preference) with roasting. The results showed that these characters were reduced with degrees of roasting and the evaluation panel preferred light roasting to high roasting.

**Table 38** Correlation coefficients (r) among acidity, aroma, bitterness, body, preference and roasting level in full sun

| | Acidity | Aroma | Bitterness | Body | Preference |
|---|---|---|---|---|---|
| Aroma | 0.70** | | | | |
| Bitterness | 0.56* | 0.74** | | | |
| Body | 0.66** | 0.71** | 0.79** | | |
| Preference | 0.59** | 0.78** | 0.81** | 0.77** | |
| Roasting level | -0.80** | -0.83** | -0.79** | -0.88** | -0.81** |

*, significant at the 0.05 level (two tailed); **, significant at the 0.01 level

**Table 39** Correlation coefficients (r) among acidity, aroma, bitterness, body, preference and roasting level in 50% shade

| | Acidity | Aroma | Bitterness | Body | Preference |
|---|---|---|---|---|---|
| Aroma | 0.67** | | | | |
| Bitterness | 0.46* | 0.62** | | | |
| Body | 0.50* | 0.70** | 0.66** | | |
| Preference | 0.51** | 0.70** | 0.75** | 0.75** | |
| Roasting level | -0.71** | -0.84** | -0.80** | -0.81** | -0.80** |

*, significant at the 0.05 level (two tailed); **, significant at the 0.01 level

**Table 40** Correlation coefficients (r) among acidity, aroma, bitterness, body, preference and roasting level in 60% shade

| | **Acidity** | **Aroma** | **Bitterness** | **Body** | **Preference** |
|---|---|---|---|---|---|
| Aroma | 0.55* | | | | |
| Bitterness | 0.59** | 0.81** | | | |
| Body | 0.53* | 0.63** | 0.69** | | |
| Preference | 0.72** | 0.84** | 0.84** | 0.64** | |
| Roasting level | -0.75** | -0.87** | -0.85** | -0.74** | -0.90** |

*, significant at the 0.05 level (two tailed); **, significant at 0.01 level

**Table 41** Correlation coefficients (r) among acidity, aroma, bitterness, body, preference and roasting level in lychee shade

| | **Acidity** | **Aroma** | **Bitterness** | **Body** | **Preference** |
|---|---|---|---|---|---|
| Aroma | 0.63** | | | | |
| Bitterness | 0.54* | 0.59** | | | |
| Body | 0.28 | 0.43* | 0.34 | | |
| Preference | 0.50* | 0.81** | 0.60** | 0.53* | |
| Roasting level | -0.71** | -0.88** | -0.74** | -0.47* | -0.81** |

*, significant at the 0.05 level (two tailed); **, significant at 0.01 level

**Table 42** Correlation coefficients (r) among acidity, aroma, bitterness, body, preference and roasting level in 70% shade

| | Acidity | Aroma | Bitterness | Body | Preference |
|---|---|---|---|---|---|
| Aroma | 0.37* | | | | |
| Bitterness | 0.34 | 0.52* | | | |
| Body | 0.39* | 0.55** | 0.46* | | |
| Preference | 0.53** | 0.74** | 0.71** | 0.73** | |
| Roasting level | -0.51** | -0.81** | -0.75** | -0.63** | -0.85** |

*, significant at the 0.05 level (two tailed); **, significant at 0.01 level