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Research Article

Effect of altitude and shade on production and physical attributes of Coffee in Gulmi, Syangja and Palpa districts of Nepal

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ABSTRACT

Coffee (*Coffea spps.*) is the second most traded commodity in the world after raw oil. Coffee is grown in mid hills of Nepal from an altitude of 700masl to 1500masl under different shade management practices. Nepalese coffee farmers grow coffee in a traditional way with almost zero application of inorganic fertilizers, pesticides and hence Nepalese coffee is popular as organic coffee or specialty coffee in the world. A study was carried out in three Coffee potent adjoining districts of Nepal: Gulmi, Syangja and Palpa. Ripe coffee cherries were harvested from every 200m altitude from 700masl to 1500masl under shade management and without shade management practices. Different physical attributes such as 1000 cherry weight, wet parchment weight, dry parchment weight, green beans weight, defected beans, and green bean diameter were observed. Production from each altitude level was recorded and highest production (7.04 kg per plant) was obtained from an altitude of 900-1100masl . The highest 1000 cherry weight (1297.17g) and the highest green bean weight (450.33 g) were obtained from 900-1100masl. Under no shade management, number of defected beans were 98 per 1000 beans whereas it was 64 under shade. The interaction of altitude and shade management practice had significant effect upon production ($P=0.035$), 1000 cherry weight ($P<0.001$), dry parchment weight ($P=0.049$) and green bean weight ($P<0.05$). Coffee produced at an altitude of 900-1100masl under shade management practice were found to have higher production and of better quality with fewer defected beans whereas that produced at extreme lower of 700-900masl and extreme higher altitude of 1300-1500masl were found to have lower production and poor quality.

Keywords: Coffee, altitude, shade, interaction, production

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INTRODUCTION

Coffee is a highly cherished international beverage consumed almost every day. It is a high value low volume cash crop. Coffee is grown in more than 70 countries of the world among which Brazil is the highest producer with around 3 million tons production in 2019 (ICO, 2019). Most of the coffee is consumed in USA, Europe and Japan. Two species of coffee are popular *Coffea arabica* (Arabica Coffee) and *Coffea canephora* (Robusta Coffee), the former

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comprising 75% of world trade and the latter 25% (Pinkert, 2004). Among various cash crops, Coffee sector is growing as an emerging agro enterprise with great potential to provide farm employment and income opportunities in the mid hills of Nepal (Kattel, 2017) . Coffee is a promising and potential exportable commodity of Nepal. 513 Mt ton Coffee was grown from 2650 ha of land in the year 2074/75 (MOAD, 2076). Nepal imported Coffee of worth Rs 8,45,39,000 and exported 95 thousand kg worth Rs 5,04,05,000 in the year 2073/074 (NTCB, 2075).

Nepalese coffee farmers grow coffee in a traditional way with almost zero application of inorganic fertilizers, pesticides and hence Nepalese coffee is popular as organic coffee in the world. International markets demand quality coffee. Not only increasing the production and productivity is sufficient but different factors that govern the quality of coffee need to be considered and management practices need to be adopted. Altitude and orchard management practices such as shade management are the major factors that affect coffee production and coffee quality (Worku *et al.*, 2018). Altitude and shade management significantly determine the biochemical and physiological potential for dry matter accumulation which influences the coffee production by altering the coffee maturation time and grain filling duration (Bote & Struik, 2011). Coffee is grown in sloppy areas from an altitude of 700 to 1500 meter above sea level in Nepal (NTCB, 2075). In general, high altitude or shade generally causes a decrease in ambient temperature. This reduces heat-induced stress in plants, increases the leaf to fruit ratio and net photosynthetic rate, and prolongs the berry maturation period (Vaast *et al.*, 2006) . Coffee quality and production also differs under different orchard management practices. Though coffee plantation area is increasing, the productivity is in decreasing trend in recent years in Nepal. Lack of research and development in coffee is the bottleneck to develop the coffee sub sector into viable industry for producers, processors and traders. The research aims to determine the effect of altitude and shade management practices on production, physical attributes and quality of coffee so that they can command good national and international market.

METHODOLOGY

The study was carried out at different commercial coffee farms of three adjoining districts of Nepal Gulmi, Syanga and Palpa which are identified as Coffee potent districts and enlisted in Coffee Superzone under Prime Minister Agriculture Modernization Project (PMAMP). Ripe coffee cherries were harvested from every 200m from 700masl to 1500masl under two different shade management practices: one under shade management and other without shade management replicated three times. Thus in each replication, 8 samples were collected from four levels of altitude 700-900masl, 900-1100masl, 1100-1300masl and 1300-1500masl and 2 levels of shade management practices. Digital altimeter was used for tracking the altitude. Ripe coffee cherries were harvested from 7 to 10 years old coffee plants from the middle of healthy branches from January to April 2020. Selection-10 variety of Coffee Arabica was selected for the study. Two kg sample of ripe coffee cherry was collected from each level of treatment.

Different physical parameters such as 1000 cherry weight, Cherry diameter, Wet parchment weight, Dry parchment weight, Green Bean weight and Coffee production were measured

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from each level of altitude and shade management practices. Ripe coffee cherries harvested were undergone subsequent processing under wet processing methods to remove the pulp and obtain wet parchment. Moisture level was reduced to 12% by shade drying to obtain dry parchment and green beans. Data was recorded and statistically analyzed using R-Stat. The annual average temperature and rainfall were recorded 20.5°C and 1850 mm respectively. The soil type in the study area was uniform and described as Nitisol, with a pH ranging from 5.5 to 6.5.

Agro meteorological features of study area

Gulmi, Syangja and Palpa receive annual precipitation of 1500-2000 mm, 2000-3000 mm and 1500-2000 mm respectively. Annual maximum temperature ranges from 20-25^0, 25-30^{0}C and 25-30^{0}C in Gulmi, Syangja and Palpa districts respectively whereas annual minimum temperature ranges from 10-15^{0}C in every three districts.
Source: (DOHM, 2017)

RESULTS AND DISCUSSION

Effect of altitude, shade management practice and their interaction on yield

Both altitude and shade management practices were found to have significant effect (P<0.001) upon yield of Coffee. Coffee yield was recorded highest at an altitude of 900-1100masl with production of 7.04 kg from single coffee plant followed by an altitude of 1100-1300masl with production of 6.10kg whereas lowest production was recorded from an altitude of 700-900masl (Table1). Similarly, shade management practice also had significant impact (P<0.001) upon the yield. Coffee under shade management practice had yield of 6.49 kg whereas coffee grown without shade cover had yield of 5.56kg per plant.

Table 1. Effect of different Altitude levels and Shade management practices on production of Coffee, 2020

Treatments	Yield (kg)
Altitude Level	
700-900masl	5.097^c
900-1100masl	7.044^a
1100-1300masl	6.109^b
1300-1500masl	5.858^b
Sem(±)	0.1107
LSD(0.05)	0.475
CV(%)	4.5
Management factor	
With Shade Cover	6.493^a
Without Shade Cover	5.561^b
Sem(±)	0.078
LSD(0.05)	0.237
CV(%)	4.5
Grand Mean	6.027

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

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Significant interaction effect of altitude and shade management practices was observed upon the yield. Highest yield was obtained from 900-1100masl under shade management practice with yield of 7.65kg followed by an altitude of 1100-1300masl under shade with yield of 6.71kg (Fig. 1). The lowest yield per plant was recorded at an altitude of 700-900masl without shade management with yield of 4.59 kg.

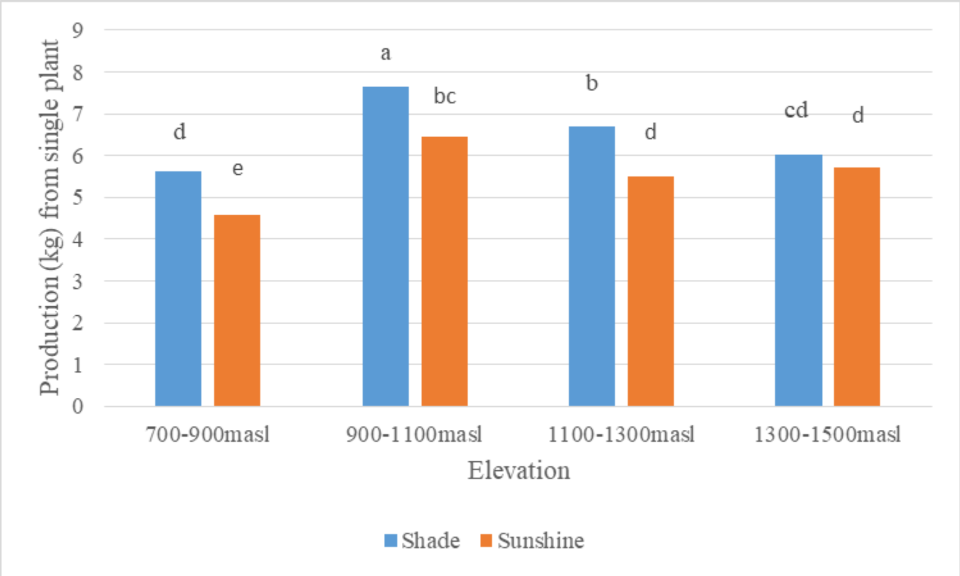

Fig 1. Interaction effect of altitude and shade on coffee production per plant

Vaast *et al.* (2005) also found that high elevations had a positive impact on coffee quality, possibly due to reduced temperatures. As there is less oxygen, coffee plants grown at higher altitudes take longer time to mature than plants grown at lower altitudes (Imru *et al.*, 2015). Comparatively higher altitude favored the production of beans of large size and heavy weight. With warmer climatic conditions at lower altitudes, more rapid maturation of coffee beans occurs, resulting in more immature coffee beans (Worku *et al.*, 2018). In areas where air temperature is relatively cooler, such as at high altitudes, shade levels higher than 40 to 50% are hence not beneficial as growing temperature may decrease below optimum (Tolessa *et al.*, 2017). Promising results under shaded conditions are found because microclimatic factors are greatly influenced by shade trees as shade mitigates extremes in environmental factors that have an influence on soil moisture (Lin, 2007). Plants under shade undertake certain morphological modifications and physiological adaptations and their leaves are capable of absorbing more than 90% of energy contained in wavelengths between 400 and 700nm (Bartlett & Remphrey, 1998).

Effect of altitude, shade management practice and their interaction on 1000 cherry weight

Altitude had significant effect on 1000 cherry weight of coffee ($P<0.001$). 1000 cherry weight was recorded highest at an altitude of 900-1300 masl. 900-1100 masl had 1000 cherry weight of 1297.17gm followed by 1100-1300masl with 1273.83g but were not significantly different (Table 2). However, 1000 cherry weight recorded from an altitude of 700-900masl was lowest and significantly different from that with altitude of 900-1300masl. Coffee from

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high altitude with open or medium shade and early to middle harvest periods gave superior bean quality. Shade management practices also had significant impact upon 1000 cherry weight (P<0.001). Coffee grown under shade had 1258.5g 1000 cherry weight which was significantly different from that grown under direct sunshine with weight 1102.42 g.

Table 2: Effect of different Altitude levels and different Shade management practices on 1000 cherry weight of Coffee, 2020

Treatments	1000 cherry weight (g)
Altitude	
700-900masl	1063.167[b]
900-1100masl	1297.167[a]
1100-1300masl	1273.833[a]
1300-1500masl	1087.667[b]
Sem(±)	10.384
LSD(0.05)	31.497
CV(%)	2.15
Management factor	
Shade	1258.5[a]
Sunshine	1102.417[b]
Sem(±)	7.343
LSD(0.05)	22.27
CV(%)	2.15
Grand Mean	1180.458

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

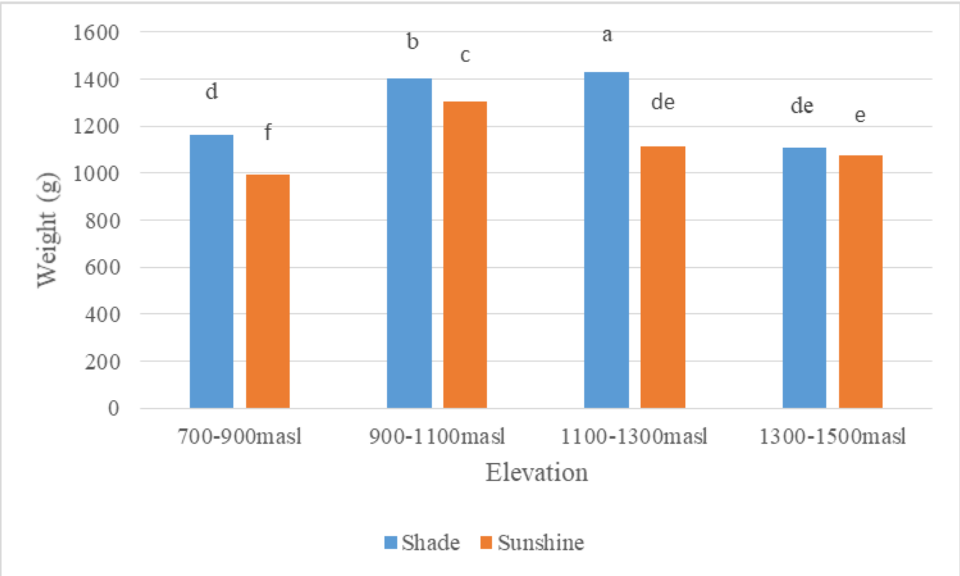

Fig 2. Interaction effect of altitude and shade on 1000 cherry weight

Interaction of altitude and shade also affected the 1000 cherry weight. Highest 1000 cherry weight was recorded at 1100-1300 masl under shade management with 1432g followed by 900-1100masl under shade management with 1369.33 g (Fig. 2). Lowest 1000 cherry weight was recorded at an altitude of 700-900 masl under direct sunshine.

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Shade has been reported to reduce the number of floral initiations per plant and to allow more assimilate partitioning to each developing bean (Imru *et al.*, 2015). *Results showed that solar radiation, temperature, humidity, and soil moisture were correlated with fruit growth, all of which are environmental factors heavily controlled by shade cover* (Lin, 2009). Shaded leaves were darker in leaf color than leaves from plants grown in direct sunlight. Development of dark green leaves shaded condition contribute for higher rate of photosynthesis (Imru *et al.*, 2015). Shade trees like *Grevillea robusta*, *Mimosa scabrella*, *Leucaena leucocephala*, *Hevea brasiliensis* significantly helped to increase production and with compact beans. But at higher altitudes, shade, especially a dense shade, has a negative effect both on acidity and body (Bosselmann *et al.*, 2009) .This indicates that coffee leaves, especially in full sun, did not take full advantage on high solar radiation. Shaded plants undertake certain modifications such as developing thinner and larger leaves with more thylakoids per granum and more grana per chloroplast (Fahl *et al.*, 1994).These modifications allow them to efficiently capture and utilize the available light energy in order to increase their dry matter production.

Effect of altitude, shade management practice and their interaction on defected beans

Altitude didn't have significant impact upon number of defected beans. Two groups of defected beans were recorded. The primary defects included full black, fungus attacked and insect damaged beans as well as the presence of foreign matter.

Table 3. Effect of different Altitude levels and Shade management practices on defected beans, 2020

Treatments	Defected Beans (number per 1000 beans)
Altitude Level	
700-900masl	79.5[a]
900-1100masl	85[a]
1100-1300masl	78.83[a]
1300-1500masl	81.5[a]
Sem(±)	2.864
LSD(0.05)	8.68
CV(%)	8.64
Management factor	
With Shade Cover	64.17[b]
Without Shade Cover	98.25[a]
Sem(±)	2.025
LSD(0.05)	6.14
CV(%)	8.64
Grand Mean	81.208

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

The secondary defects included partial black, broken, insect damaged, faded and coated beans. Elephant beans were also observed which were of poor quality and needed to be removed. 78-85 defected beans per 1000 beans were recorded in each altitude range and were not significantly different with varying altitude range (Table 3).However, shade management practices had significant impact upon the number of defected beans (P<0.001). Number of

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defected beans under direct sunshine without shade management was recorded to be 98 whereas it was 64 per 1000 beans for coffee grown under shade management. No significant interaction of altitude and shade level upon defected beans was reported. Shade management was the major factor governing the number of half-filled or incompletely filled beans.Immature coffee beans are found to have significantly influenced the coffee quality. Immature and defected beans decrease the quality and flavor thereby affecting consumer preference. A link between immature coffee beans and higher caffeine and CGA concentrations as well as poor cup quality has been observed earlier (Farah *et al.*, 2006). A link between immature coffee beans and higher caffeine and CGA concentrations as well as poor cup quality has been observed earlier (Joet *et al.*, 2010). As explained by Vaast *et al.* (2006) , this may be due to the fact that coffee trees grown in open sun achieve less complete bean filling attributable to a faster ripening. High temperature according to Farquhar and Sharkey (1982) reduce the electron transport capacity and increase the rates of CO_2 evolution from photorespiration and other sources causing the photosynthetic rate to become lower.

Effect of altitude, shade management practice and their interaction on cherry diameter

Coffee diameter reflects the production and quality. Coffee with large diameter size have comparatively more compact bean filling and contribute for higher weight. Altitude had significant effect upon coffee diameter (P<0.001).

Table 4. Effect of different Altitude levels and Shade management practices on Cherry diameter, 2020

Treatments	Diameter (cm)
Altitude	
700-900masl	1.186[b]
900-1100masl	1.325[a]
1100-1300masl	1.313[a]
1300-1500masl	1.125[c]
Sem(±)	0.014
LSD(0.05)	0.041
CV(%)	2.69
Management factor	
With Shade Cover	1.35[a]
Without Shade Cover	1.12[b]
Sem(±)	0.009
LSD(0.05)	0.029
CV(%)	2.69
Grand Mean	1.237

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

At an altitude of 900-1100masl highest coffee diameter of 1.32cm was recorded followed by an altitude of 1100-1300masl but was not significantly different (Table 4). Lowest coffee diameter with 1.12cm was recorded at an altitude of 1300-1500masl which was significantly different from rest others. Shade had also significant effect upon coffee cherry diameter. Coffee grown under shade had higher diameter of 1.35cm which was significantly different from that grown under direct sunshine with diameter of 1.12 cm.

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Interaction of altitude and shade also had significant effect upon coffee diameter. Highest coffee diameter was recorded at an altitude of 1100-1300masl with diameter of 1.47cm followed by an altitude of 900-1100masl with diameter of 1.45cm (Fig.3). Lowest coffee diameter with 1.03cm was recorded at an altitude of 700-900masl under no shade management practice.

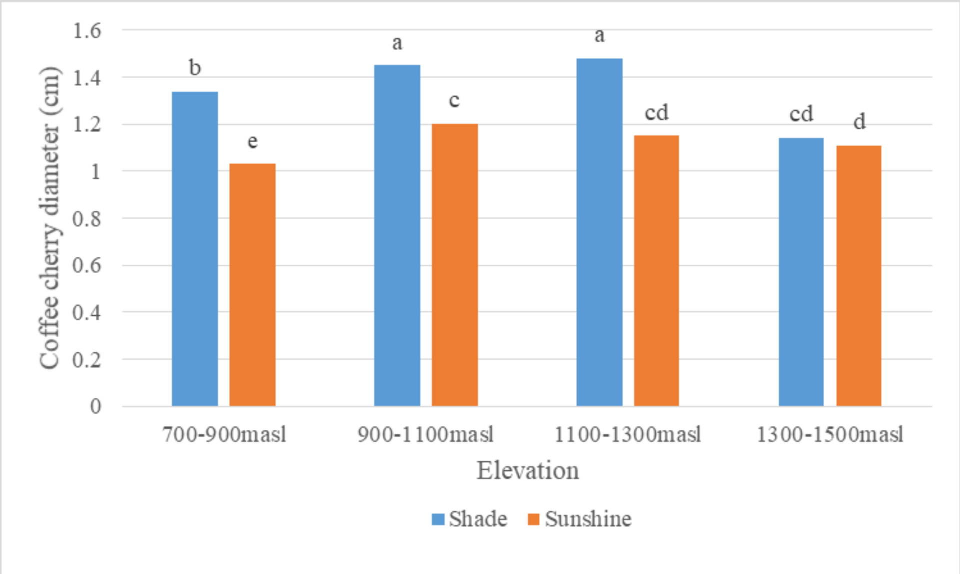

Fig 3. Interaction effect of altitude and shade on coffee cherry diameter

The presence of shade trees resulted in higher individual leaf area and coffee leaf area index and lower leaf fall during the extreme climatic conditions (Skovmand *et al.*, 2009). In addition, shading delays the maturation of coffee berries resulting in better bean filling and larger bean size. Heavier and larger coffee beans was mainly caused by the optimum level of temperature and longer duration of ripening period (Muschler, 2001). Besides, shade trees enhance accumulation of fat matter that increases the intensity of organoleptic characteristics such as aroma, body, acidity, flavor and preference (Lara-Estrada & Vaast, 2007). On the contrary, coffee photosynthesis efficiency is certainly reduced at higher solar radiation due to decrease in stomatal conductance and photo-inhibition (Gutierrez *et al.*, 1994).

Effect of altitude, shade management practice and their interaction on coffee wasted during density sorting

Ripen cherries harvested from the coffee plants were undergone first density sorting. It is the process of separating light weighted, incompletely filled grains from the compacted cherries with the help of water using the principle of floatation. The samples were put in a large drum containing water and the samples were dipped into it. Weight of floating cherries of every sample was recorded.

Altitude had significant effect upon the wastage of coffee cherries during density sorting. Higher wastage was recorded at lower altitude i.e.at 700-900masl where 89.33 g of coffee cherries were floating (Table 5) which were not good enough for further processing and discarded. Lowest wastage was recorded from the altitude range of 900-1100masl which was

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81.33 g. Shade also had significant impact upon cherry wastage during density sorting. Coffee samples collected under no shade management recorded 103.83 g of coffee wastage which was significantly different from that grown under shade management which was 65.67 gram.

Table 5. Effect of different Altitude levels and Shade management practices on Cherry wastage during density sorting, 2020

Treatments	Cherry wastage (g)
Altitude	
700-900masl	89.33[a]
900-1100masl	81.33[b]
1100-1300masl	84.33[b]
1300-1500masl	84[b]
Sem(±)	1.384
LSD(0.05)	4.199
CV(%)	4.001
Shade management factor	
With Shade Cover	65.67[b]
Without Shade Cover	103.83[a]
Sem(±)	0.979
LSD(0.05)	2.969
CV(%)	4.001
Grand Mean	84.75

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

Interaction of altitude and shade also had significant impact (P=0.002) upon the coffee cherry wasted during density sorting. Highest coffee cherry wastage was recorded at 700-900masl under no shade management practices with recording of 113gm and the lowest with value 60.67 was recorded from 900-1100masl under shade management practices (Fig.4).

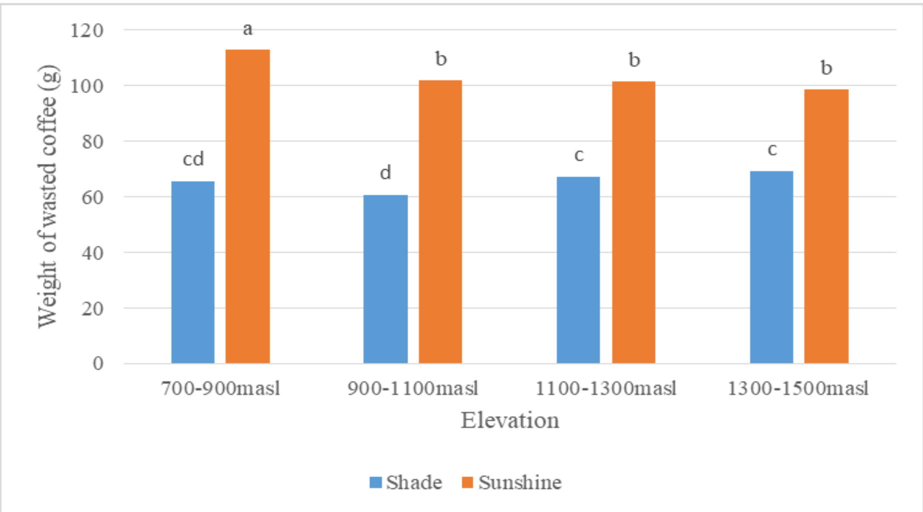

Fig 4. Interaction effect of altitude and shade on coffee wasted during density sorting

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Bosselmann *et al.* (2009) also reported that at extreme high altitudes with lower temperatures due to excess shade trees resulted in reduced coffee bean quality. Altitude favored the production of beans of large size and heavy weight. These increments in bean size and weight were accompanied by a high accumulation of fat matter (Lin, 2009). The ideal growing temperature of Arabica coffee ranges between 18 and 21°C and values above or below this optimum level predisposes coffee beans to incomplete maturation and poor quality (Morais, Caramori *et al.*, 2006).

Effect of altitude, shade management practice and their interaction on wet parchment weight

Ripe coffee cherries harvested after density sorting were undergone wet method of processing. Generally, wet-processed coffee beans have a better aroma (Selmar *et al.*, 2006) and a higher consumer acceptance than dry-processed ones. Initially, ripe cherries were pulped using pulping machine. After removing the pulp, the parchment needs to be fermented for 24-48 hrs so that the mucilage can be removed from the parchment. After fermenting, the parchment was washed with water and dried in shade. After washing, wet weight of the parchment was taken with the help of precision weighing balance. Altitude had significant effect upon wet weight of the parchment. Highest parchment weight was recorded at an elevation of 900-1100masl with 1283.67 g followed by 1100-1300masl with 1143.67 g (Table 6). Lowest parchment weight was recorded at an altitude of 700-900masl with 954.17g.

Shade also had significant impact upon the parchment weight (P<0.001). Coffee grown under shade had higher parchment weight of 1198 g which was significantly different from that grown under direct sunshine.

Table 1: Effect of different Altitude levels and Shade management practices on wet parchment weight, 2020

Treatments	Wet Parchment weight (g)
Altitude	
700-900masl	954.17[c]
900-1100masl	1283.67[a]
1100-1300masl	1143.67[b]
1300-1500masl	1096.67[b]
Sem(±)	20.781
LSD(0.05)	63.03
CV(%)	4.54
Shade Management factor	
With Shade Cover	1198.00[a]
Without Shade Cover	1041.08[b]
Sem(±)	14.69
LSD(0.05)	44.56
CV(%)	4.54
Grand Mean	1119.54

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

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Interaction of altitude and shade management also had effect upon the parchment weight (P=0.04). Highest parchment weight was recorded from 900-1100masl under shade management practices followed by 1100-1300masl under shade management practices. Very high altitude, very low altitude and direct sunshine showed negative effect upon parchment weight. Lowest parchment weight was recorded from 700-900masl under no shade management practice with value of 858.67 g (Fig.5).

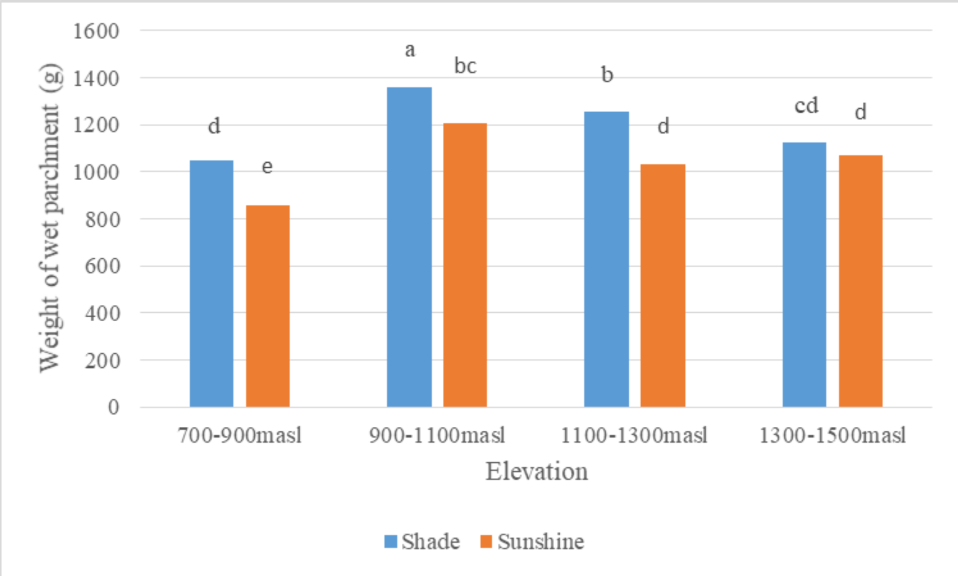

Fig 5. Interaction effect of altitude and shade on wet parchment weight

In general, high altitude or shade generally causes a decrease in ambient temperature. This reduces heat-induced stress in plants, increases the leaf to fruit ratio and net photosynthetic rate, and prolongs the berry maturation period (Ramalho *et al.*, 2000). Under this situation, there is more carbohydrate supply to developing beans and time for bean filling. In this regard, an increase in sucrose content of coffee beans with altitude and shade was observed (Subedi, 2005).

Effect of altitude, shade management practice and their interaction on dry parchment weight

Wet parchment are dried in the shade for about 7-8 days. Coffee parchment are considered to be dried if the moisture level of parchment drops to 11-12%. Moisture of the parchment can be measured with the help of Moisture-meter. Special care should be taken while drying the parchment. It should not be dried directly above the soil as the ground smell affects the coffee quality. Hence, they are dried in the shaded nets 1-2 meters above the ground.

Altitude had significant effect on dry parchment weight (P<0.001). Highest dry parchment was recorded at an altitude of 900-1100masl with 558.67 g followed by an altitude of 1100-1300masl with 489 g and was significantly different (Table 7). Lowest dry parchment was recorded at an altitude of 700-900masl.

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Shade had also significant effect upon the dry parchment weight. Coffee grown in shade were found to have higher dry parchment weight in comparison to those grown under direct sunshine. Coffee grown under shade management practices had 517.17 gram of weight which was significantly different from that grown without shade management with weight of 445.17 gram.

Table 7. Effect of different Altitude levels and Shade management practices on dry parchment weight, 2020

Treatments	Dry Parchment Weight (g)
Altitude	
700-900masl	408[c]
900-1100masl	558.67[a]
1100-1300masl	489[b]
1300-1500masl	469[b]
Sem(±)	8.852
LSD(0.05)	26.85
CV(%)	4.51
Shade Management factor	
With Shade Cover	517.17[a]
Without Shade Cover	445.17[b]
Sem(±)	6.259
LSD(0.05)	18.98
CV(%)	4.51
Grand Mean	481.17

Interaction of altitude and shade also played a significant role in determining the dry parchment weight of coffee (P=0.049). Highest dry parchment weight was recorded at an altitude of 900-1100masl under shade management practice with value of 601.67 g followed by an altitude of 1100-1300masl with shade management practice with value 537 g and was significantly different (Fig. 6). Lowest dry parchment weight was recorded at an altitude of 700-900masl without shade management practices.

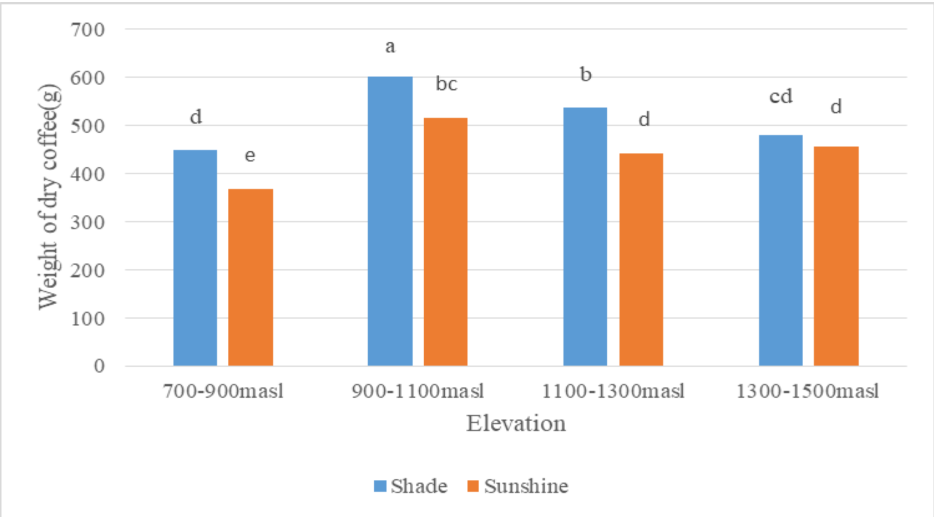

Fig 6. Interaction effect of altitude and shade on dry parchment weight

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The shaded coffee plants produced larger cherries due to slower maturation, resulting in larger bean size (Morais *et al.*, 2006). Coffee berries ripened faster in full sun than in shade due to exposition to higher temperatures (Imru *et al.*, 2015) . Harvest peak was delayed by about six weeks under the shade of timber trees. This longer period of maturation under shade resulted in a longer and hence better bean filling. High temperature accelerates bean ripening and automatically results a shorter time intervals between the different harvest periods (Morais *et al.*, 2006). Moreover shaded plants had greater biochemical and physiological potential for high dry matter accumulation (Lin, 2009).

Effect of altitude, shade management practice and their interaction on green bean weight

Dry parchment after having moisture level reduced to 11-12% are gathered from the shaded area and are undergone further processing steps. They are processed under huller machines to separate the husks from the dried parchment to yield green coffee beans. Such green coffee beans are further roasted at different temperatures as per the requirement of the consumers and roasted beans are grinded to yield final coffee as a product.

Altitude had significant effect upon the green beans ($P<0.001$). Highest green bean weight was recorded at an altitude of 900-1100masl with weight of 450.33 gram (Table 8) followed by an altitude of 1100-1300masl with weight of 394.17 g and was significantly different. Lowest green bean was obtained from altitude of 700-900masl and was recorded to be 328.83 g. Shade also had significant effect on green bean. Coffee grown under shade management practice has green bean yield of 417.08 g which was significantly different from that grown under direct sunshine with weight of 358.67 g and was significantly different.

Table 8. Effect of different Altitude levels and Shade management practices on green bean weight, 2020

Treatments	Green Bean Weight (g)
Altitude	
700-900masl	328.83[c]
900-1100masl	450.33[a]
1100-1300masl	394.17[b]
1300-1500masl	378.17[b]
Sem(±)	7.168
LSD(0.05)	21.74
CV(%)	4.52
Shade Management factor	
With Shade Cover	417.08[a]
Without Shade Cover	358.67[b]
Sem(±)	5.069
LSD(0.05)	15.37
CV(%)	4.52
Grand Mean	387.88

Note: SEm= Standard Error of mean, LSD= Least Significant Difference, CV=Coefficient of Variation, S=Significant, Values with same letters on column are not significantly different at 5% DMRT (Duncan Multiple Range Test)

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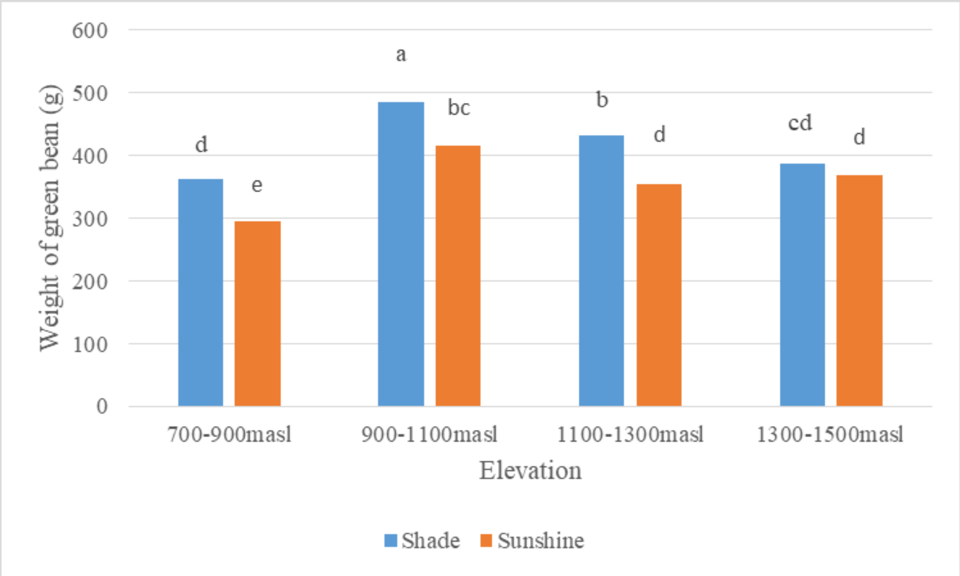

Fig 7. Interaction effect of altitude and shade on green bean weight

Altitude and shade interaction also significantly affected the green bean yield. Highest green bean yield was obtained from an altitude of 900-1100masl under shade which was recorded as 485.33 g followed by an altitude of 1100-1300masl under shade with value 433 g and was significantly different (Fig. 7). Lowest green bean yield was obtained from an altitude of 700-900masl under no shade management practice which yielded 295.67 g of green bean.

Higher altitude with shade cover enhance the coffee plants for better bean filling, larger bean size, improved biochemical composition and higher cup quality (Vaast *et al.*, 2005) . The slower maturation favors the production of fruits of higher quality, since there is an increase on the accumulation of sugar and soluble solids (Morais *et al.*, 2006). Coffee bean weight increased with increasing altitude. Shade delays maturation period resulting in better bean filling and larger bean size resulting in better quality of coffee (Bote & Struik, 2011).

CONCLUSION

There is a greater scope for mid hill farmers, which occupy most of the area, to produce more quality beans with higher production. Growing the coffee plants in medium shaded conditions and selectively harvesting the beans at middle harvesting periods could potentially increase the percentage of good quality beans. From analysis of several physical attributes of coffee under different altitudes and different level of shade management we can conclude that highest production and better quality of coffee are produced from an altitude of 900-1100masl. Shade has positive significant effect upon several physical attributes of coffee such as yield, 1000 cherry weight, coffee diameter and green bean weight and hence recommended to grow coffee under shade management practices. Similarly, interaction effect of altitude and shade was also observed positive for several parameter like yield, 1000 cherry weight, coffee cherry diameter, dry parchment weight and green bean weight and the values were promising for an altitude of 900-1100masl under shade management practice.

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Authors' contributions

M. Paudel carried out the research, analyzed and prepared the final manuscript. K. Parajuli, S. Regmi and S. Budhathoki helped in data recording, edit and revision.

Conflict of Interest

The authors declare that there are no conflicts of interest in this paper.

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