MORPHOLOGICAL VARIATIONS, YIELD PERFORMANCE, AND G X E INTERACTION ANALYSIS IN ARABICA COFFEE CULTIVARS FOR ORGANIC PRODUCTION IN BENGUET

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ABSTRACT

The three-year evaluation of Arabica coffee cultivars for organic production in La Trinidad was concluded through exhaustive gathering of other morphological characters, cupping quality and reaction to pests in order to identify stable cultivars and recommend potential cultivars for organic production. Genotype x environment analysis through the AMMI model was done using the three-year green bean yield of the Arabica coffee cultivars. Correlation analysis was done for both *in-situ* and *ex-situ* morphological characters in Arabica coffee cultivars and accessions. Correlation analysis revealed significant and positive associations of green bean yield with weight of 100 bean seeds, seed length, fruit length and width, leaf width, and number of fascicles per axil, flowers per fascicle, fascicles per node and days from fruit setting to harvesting. Potential Arabica coffee cultivars for recommendation under organic production based on stability of green bean yield, resistance to pests and cupping quality are Granica Broad, Mondo Nuvo, Red Bourbon and MSAC Selection No. 1.

Keywords: Arabica Coffee Cultivars, G X E Interaction Analysis Organic Production

INTRODUCTION

As one of the top priority crops in Benguet, coffee has been a part of the culture and lifestyle of the Cordillera Administrative Region folks. Among the cultivated species, Arabica is the most popular, although other species exist (BPI, 2006). Arabica Typica is the best variety planted in Benguet for the past 100 years (Killip, 2010).

The production system of coffee in Benguet is mostly organic (Tad-awan and Pablo, 2010). Organic coffee production or growing coffee without the use of harmful pesticides or chemicals using processes such as recycling and composting has a natural impact on the environment as it replenishes and maintains soil fertility, and encourages biodiversity. Since coffee is consumed every day, organic production makes a big difference. It is estimated that 11 million hectares of the world's farmland is dedicated to coffee cultivation and the annual consumption of coffee has expanded to 12 billion pounds (Anon., 2001).

The selection of high yielding cultivars that are resistant to biotic and abiotic environmental stresses has become one of the primary objectives in many coffee-producing countries (Bertrand *et al*., 2005).

In Benguet, one of the factors that can contribute to the success of the coffee industry is the availability of cultivars that are adapted under organic production. Arabica coffee cultivars that best respond to organic production are needed at present. The first in the country, this project identified, characterized and recommended cultivars of existing Arabica coffee most appropriate for organic production in La Trinidad basing on morphological variations and yield stability.

The BSU Arabica Coffee Project started evaluating Arabica coffee cultivars for organic production since BSU was certified as an organic Arabica coffee producer and processor in 2007-2008 by the Institute of Market Ecology, an international organic certifying body based at Switzerland.

MATERIALS AND METHODS

The coffee trees were established in 2004. Spacing between trees and rows was 3m x 3m laid-out in randomized complete block design with four replications. All management practices adhered to the standards of organic production (BAFPS, 2003).

Morphological characterization and data gathering

An exhaustive morphological characterization using the descriptors list on coffee (IPGRI, 2006), most data were gathered from August 2011 to May 2012. Yield performance for three years (2009-2011) was analyzed accordingly.

The data gathered were:

1. Leaf characters

a. Leaf length (cm) was measured from the tip to the base of the five sample leaves taken randomly, and

b. Leaf width (cm) was measured from the mid to the end portion of the five samples taken randomly.

2. Flower characters

a. Number of flowers per axil was recorded by counting the flowers per axil. Average of five axils, randomly selected from different nodes from five sample trees,

b. Number of fascicles per node was recorded by counting the number of fascicles per node from five sample trees.Average of five nodes, randomly selected from different branches from five sample trees, and

c. Number of flowers per fascicle was recorded by counting the number of flower per fascicle from five sample trees. Average of five fascicle, randomly selected from different nodes from five sample trees.

3. Fruit characters

a. Fruit length (cm) was measured from the base to the tip of five sample fruits taken randomly, and

b. Fruit width (cm) was measured using a vernier caliper at the widest part of five sample fruits taken randomly.

4. Seed characters (green bean)

a. Seed length (cm) was measured using a vernier caliper from the base to the tip of five sample seeds taken randomly.

b. Seed width (cm), was measured at the widest part of five sample seeds taken randomly.

5. Weight of Fresh berries per tree (kg) was taken by weighing the ripe fresh berries per tree.

6. Weight of marketable seeds per tree (g) was taken by weighing green bean seeds that were free from insect damage and not deformed.

7. Weight of the non-marketable seeds per tree (kg) was taken by weighing green bean seeds that were damaged (cracked), small size and infested with borer.

8. Green bean yield per tree was taken by weighing both marketable and non-marketable green bean seeds.

9. Weight of 100 seeds was obtained by weighing 100 green bean seeds selected at random.

10. Cupping quality. Harvested fresh berries from each sample Arabica coffee cultivars were processed through the wet method. After the green beans were extracted (fresh bean to seed with parchment to green bean) seed with parchment was dried for almost 2 months (parchment will crack). The beans from each cultivar were roasted separately but uniformly for 25 minutes. Eighteen coffee drinkers served as cuppers (Figure 1). Cup quality based on fragrance, aroma, flavor and general acceptability of ground beans were assessed as follows:

a. Fragrance

Scale	Description
0	Weak
1	Slightly strong
2	Strong
3	Potent (fruity)

b. Aroma

Scale	Description
1	Absence of coffee aroma
2	Slightly perceptible coffee aroma
3	Moderately perceptible coffee aroma

Figure 1. Green bean; b. Roasted and ground coffee, and d-i. Cupping evaluation of 10 Arabica coffee cultivars

4	Perceptible coffee aroma
5	Very perceptible coffee aroma

c. Flavor

Scale	Description
1	Absence of coffee flavor
2	Slightly perceptible coffee flavor
3	Moderately perceptible coffee flavor
4	Perceptible coffee flavor
5	Very perceptible coffee flavor

d. General acceptability

Scale	Description
1	Dislike very much
2	Dislike slightly
3	Neither like nor dislike
4	Like slightly
5	Like very much

11. Reaction to Insect Pests

a. Coffee berry borer. Reaction to coffee berry borer was rated as (0) sound (1) slight, (2) moderate, (3) severe

b. Scale/Sucking insects. Reaction to scale/sucking insects was rated as (0) sound (1) slight (2) moderate (3) severe

c. Stem borer. Reaction to stem borer was rated as (0) sound, (1) slight (2) moderate, (3) severe

12. Reaction to coffee diseases

The following scale was used:

Scale	Percentage Infection	Description
1	0%	No disease observed on leaves
2	1-5%	Lesions sparsely distributed on lower leaves
3	6-10%	Many lesions on lower leaves, necrosis evident, very few lesions present on middle leaves
4	11-12%	Numerous lesions present on lower and middle leaves, severe necrosis on lower leaves
5	21-30%	Severe necrosis on lower and middle. Lesions may be present on top leaves but less severe
6	31-40%	Extensive damage to lower leaves, lesions densely present on top leaves
7	41-60%	Severe damage on lower and middle leaves, lesions densely distributed on top of leaves.
8	61-80%	100% damage to lower and middle leaves, present on top leaves with severe necrosis.
9	81-100%	Almost all leaves withering, bare stems present.

Meteorological data

Climatic data were obtained from the PAGASA station based at Benguet State University.

Analysis of data

All quantitative data were subjected to analysis of variance (ANOVA). Significance of difference among treatment means was tested using the Duncan's Multiple Range Test.

Genotype x environment interaction analysis using the AMMI Model

Analyses of green bean yield data from 2009 to 2011 were done using CropStat 7.2.2 version of the International Rice Research Institute (IRRI, 2007).

To determine the G x E interaction of the Arabica coffee cultivars, the Additive Main Effects Multiplicative

Interaction (AMMI) model represented in a formula was used (Gauch, 1992). Results from AMMI provide various summary statistics and graphical displays proven to show trends or clusters in yield patterns and interactions.

RESULTS AND DISCUSSION

Morphological Variations in Arabica Coffee Cultivars

Leaf Characters. The different cultivars significantly differed in their leaf length and width and petiole length (Table 1). Mondo Nuvo significantly recorded the longest and widest leaves and the longest petioles. Moka displayed the shortest and narrowest leaves and shortest leaf petioles. Differences in leaf characters could be attributed to the inherent characteristics of the cultivars (Mishra *et al*. 2010).

Flowering Characters

The different Arabica coffee cultivars significantly differed in the number of flowers per axil, fascicles per node and flowers per fascicle (Table 2). The most number of flowers was produced by Kenya-38 and San Ramon.

Granica Broad and Granica Fine produced the highest number of fascicles per node and number of flowers per fascicle.

Various reports cited that the size and number of Arabica coffee flowers are dependent on the weather.

Table 1. Variations in leaf characters of 10 Arabica coffee cultivars evaluated for organic production in La Trinidad, Benguet

CULTIVAR	LEAF LENGTH (cm)	LEAF WIDTH (cm)	PETIOLE LENGTH (cm)
Granica Broad	16.35^{c}	5.75^{bc}	1.03^{b}
Granica Fine	14.43^{e}	5.78^{bc}	1.05^{b}
Kenya-38	17.70^{ab}	5.95^{bc}	1.10^{b}
Moka	9.48^{g}	2.80^{d}	0.68^{c}
Mondo Nuvo	18.35^{a}	9.03^{a}	1.20^{a}
MSAC Selection No.1	16.03^{c}	6.03^{b}	1.05^{b}
Red Bourbon	16.90^{bc}	6.18^{b}	1.00^{b}
San Ramon	13.08^{f}	6.65^{b}	1.00^{b}
Typica (check)	16.03^{cd}	5.88^{bc}	1.03^{b}
Yellow Caturra	14.90^{de}	5.03^{c}	1.00^{b}
CV (%)	5.66	10.09	6.00

Means with the same letter in a column are not significantly different at 5% level by DMRT.

Table 2. Variations in flower characters of 10 Arabica coffee cultivars evaluated for organic production in La Trinidad, Benguet

CULTIVAR	NUMBER FLOWER PER AXIL	NUMBER FASCICLE PER NODE	NUMBER FLOWER PER FASCICLE
Granica Broad	8^{abc}	6^{a}	6^{a}
Granica Fine	8^{abc}	6^{a}	6^{a}
Kenya-38	9^{a}	5^{ab}	3^{d}
Moka	7^{bc}	4^{b}	4^{c}
Mondo Nuvo	7^{bc}	6^{a}	3^{d}
MSAC Selection No.1	8^{abc}	4^{b}	5^{b}
Red Bourbon	7^{bc}	6^{a}	3^{d}
San Ramon	9^{a}	5^{ab}	4^{c}
Typica (check)	7^{bc}	5^{ab}	3^{d}
Yellow Caturra	8^{abc}	5^{ab}	4^{c}
CV (%)	12.22	13.59	13.59

Means with the same letter in a column are not significantly different at 5% level. by DMRT.

During the dry season, flowers are small, fragrant, and numerous; but during the wet season, the flowers are large, but few. During hot summer months flowers are few in number, small, and imperfectly formed, and do not set fruit (Anon, 2001).

High temperature with a prolonged dry season during blossoming causes abortion of flowers (Camargo, 1985). It should be noted, however, that selected cultivars under intensive management conditions have allowed Arabica coffee plantations to be spread to marginal regions with average temperatures as high as 24-25ºC, with satisfactory yields, as in northeastern Brazil (Da Matta and Ramalho, 2006).

Fruit and Seed Characters

The coffee cultivars significantly varied in their fruit and seed lengths but did not vary on the fruit and seed widths (Table 3). Red Bourbon exhibited the longest fruits while Moka showed the shortest fruits.

Seed length of the different cultivars was comparable ranging from 9.0 to 11.5 cm with San Ramon recording the longest seeds while Moka displayed the shortest seeds. Seeds were 5.0 to 7.8 mm wide with Granica Broad having the broadest seeds. Dedecca (1957) found that the seed dimensions of *Coffea arabica* were 10 to 18 mm long and 6.5 to 9.5 mm wide.

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Table 3. Variations in fruit and seed characters of 10 Arabica coffee cultivars evaluated for organic production in La Trinidad, Benguet

CULTIVAR	FRUIT LENGTH (cm)	FRUIT WIDTH (cm)	SEED LENGTH (mm)	SEED WIDTH (mm)
Granica Broad	1.68^{b}	1.40	11.0^{ab}	7.8
Granica Fine	1.68^{b}	1.33	10.0^{c}	7.0
Kenya-38	1.70^{b}	1.33	10.8^{abc}	7.3
Moka	1.15^{e}	1.18	9.0^{d}	5.0
Mondo Nuvo	1.70^{b}	1.55	11.0^{ab}	7.3
MSAC Selection No.1	1.68^{b}	1.33	10.3^{bc}	7.3
Red Bourbon	1.85^{a}	1.50	10.0^{c}	7.8
San Ramon	1.50^{cd}	1.33	11.5^{a}	7.5
Typica (check)	1.45^{d}	1.15	10.3^{bc}	7.0
Yellow Caturra	1.60^{bc}	1.35	10.8^{abc}	7.5
CV (%)	4.57	3.97	5.04	7.29

Means with the same letter in a column are not significantly different at 5% level by DMRT.

Yield and yield components

Fresh berries yield per tree. Significant differences on the fresh berries yield per tree among the cultivars were observed (Table 4). Red Bourbon produced the heaviest fresh berries per tree which was comparable with Kenya-38 and Caturra while Moka produced the lowest fresh berries per tree. Red Bourbon, Kenya and Caturra were observed to have large fruits as compared with Moka. This result may show the negative relationships between fruit size and productivity as already documented by earlier studies. Cannell (1985) explained that the reason for the negative impact was the competition for carbohydrates among coffee berries during heavy production cycles.

Weight of 100 green bean seeds (g). Weight of 100 green beans did not vary as cultivars have 20 g or 22 g weight (Table 4). Large seeded cultivars such as Mondo Nuvo, Red Bourbon and San Ramon had 22 g/100 green beans. These cultivars were also observed as high yielding. The rest of the cultivars may be considered as small or medium-seeded as these have an average of 20 g/100 green beans.

Marketable, non-marketable and total green bean yield per tree. Mondo Nuvo significantly produced the highest marketable green bean yield comparable with Red Bourbon (Table 5). Total green bean yield per tree ranged from 100-465 g with Red Bourbon having the highest yield which was comparable with Mondo Nuvo and Yellow Caturra . Except for Moka, all cultivars outyielded the check cultivar Typica.

The yield obtained was very low as compared with yield in other Arabica coffee growing countries. Wild Ethiopian coffee yield was 200-300 kg/ha/year of clean coffee, with 1 MT/ha as maximum. In 1979, the lowest world yield was 120 kg/ha in Sao Tome while the international production was 521 kg/ha, and the highest world yield was 1,736 in Sri Lanka (Duke, 1983).

Due to the low yield of the cultivars under organic production, there is a need to improve management practices such as planting density, appropriate cropping systems, use of biofertilizers and environment-friendly crop protection practices. High yielding local *Coffea arabica* L. cultivars planted under dense system are important strategies to obtain higher coffee productivity. The interaction between coffee plants and the environment is evidenced when selected high yielding cultivars with desirable agronomic characteristics, same age and growing simultaneously in the same field area show different yields (Siqueira *et al*., 1983; Valarini, 2005).

Table 4. Weight of fresh berries and 100 green bean yield per tree of 10 Arabica coffee cultivars for organic production in La Trinidad

CULTIVAR	FRESH BERRIES YIELD PER TREE (kg)	WEIGHT OF 100 BEAN SEEDS (g)
Granica Broad	1.35^{bc}	20^{b}
Granica Fine	1.27^{bcd}	20^{b}
Kenya-38	1.73^{ab}	20^{b}
Moka	0.55^{e}	20^{b}
Mondo Nuvo	1.25^{bcd}	22^{a}
MSAC Selection No.1	1.03^{cde}	20^{b}
Red Bourbon	1.97^{a}	22^{a}
San Ramon	1.02^{cde}	22^{a}
Typica (check)	0.80^{de}	20^{b}
Yellow Caturra	1.60^{ab}	20^{b}
CV (%)	21.77	1.10

Means with the same letter in a column are not significantly different at 5% level by DMRT.

Table 5. Green bean marketable, non-marketable and total yield of 10 Arabica coffee cultivars evaluated for organic production in La Trinidad in 2011

CULTIVAR	GREEN BEAN YIELD (g/tree)		
	MARKETABLE	NON MARKETABLE	TOTAL
Granica Broad	243.6[bc]	80[c]	326282[abc]
Granica Fine	229.2[bc]	70[cd]	299.2[bcd]
Kenya-38	207.2[bc]	60[cde]	267.2[cd]
Moka	99[d]	10[g]	109[e]
Mondo Nuvo	300[a]	40[fg]	340[ab]
MSAC Selection No.1	184.8[cd]	50[def]	234.8[d]
Red Bourbon	335.47[ab]	130[a]	465.47[a]
San Ramon	163.73[cd]	40[fg]	203.73[de]
Typica (check)	95.68[d]	30[ef]	125.68[e]
Yellow Caturra	272[bc]	10[b]	282326.6[bcd] bcd
CV (%)	20.85	24.02	20.32

Means with the same letter in a column are not significantly different at 5% level by DMRT.

Many authors have reported higher coffee yields under dense plant population systems (Camargo *et al*., 2000; Siqueira, 1983). Coffee yield increases are expected as a result of cultivar selection and optimal plant density and management.

As a consequence, higher plant demand for soil nutrients, higher nutrient exportation at fruit harvest, and higher amounts of fertilizers are expected. However, Huxley and Cannell (1970) observed that the increase on coffee plantation mineral requirements is not proportional to the increase on plant populations. Hence, they recommended the fertilization in an area basis for dense coffee plantations and not per plant hole as used in the traditional systems (Rea *et al*., 1998).

Cup quality of Arabica coffee cultivars

Cupping is the traditional procedure in the coffee industry to evaluate the quality of green bean coffee. Individual cups of coffee varieties are prepared according to established guidelines (coffeereview.com, 2008).

Fragrance. Fragrance is the smell of the ground coffee before the addition of the water (coffeereview. com, 2008). Two kinds of coffee cultivars based on fragrance were observed. Those cultivars with potent fragrance were Granica Broad, Kenya-38, Moka, Mondo Nuvo and Yellow Caturra (Table 6). The other group composed of Granica Fine, MSAC Selection No. 1, Red Bourbon, San Ramon and Typica had strong fragrance.

Aroma. Aroma is the intensity of the wet ground coffee when the nose first descends over the cup and is enveloped by fragrance (coffeereview.com, 2008). Kenya-38, Moka, Mondo Nuvo, Typica and Yellow Caturra had higher rating or described as having perceptible aroma compared with the other cultivars.

Aroma was known as inherent to the cultivars. Cultivars Kenya, Moka, Mundo Novo, Typica and Yellow Catura were judged to be more aromatic then Granica, Mondo Nuvo, MSAC Selection 1 and Red Bourbon (Table 6). The study of Yigzaw (2005) revealed that coffee quality depends on genetic make-

Table 6. Cupping quality of 10 Arabica coffee cultivars evaluated under organic production in La Trinidad

CULTIVAR	FRAGRANCE (0-3)	AROMA (1-5)	FLAVOR (1-5)	GENERAL ACCEPTABILITY (1-5)
Granica Broad	3 [a]	3 [b]	3	3
Granica Fine	2 [b]	3 [b]	3	3
Kenya-38	3 [a]	4 [a]	3	4
Moka	3 [a]	4 [a]	4	4
Mondo Nuvo	3 [a]	4 [a]	3	4
MSAC Selection No.1	2 [b]	3 [b]	3	3
Red Bourbon	2 [b]	3 [b]	3	4
San Ramon	2 [b]	3 [b]	3	3
Typica (check)	2 [b]	4 [a]	3	4
Yellow Caturra	3 [a]	4 [a]	4	4
CV (%)	0.02	0. 01	0.12	0.16

Means with the same letter in a column are not significantly different at 5% level by DMRT.

Description: Fragrance-0-weak, 1-slightly strong, 2-strong, 3-potent; Aroma-1-absence of coffee aroma, 2-slightly perceptible of coffee aroma, 3-moderately perceptible of coffee aroma, 4-perceptible coffee aroma, 5-very perceptible coffee aroma; Flavor-1-absence of coffee flavor, 2-slightly perceptible of coffee flavor, 3-moderately perceptible of coffee flavor, 4-perceptible coffee flavor, 5-very perceptible coffee flavor; General acceptability-1-dislike very much, 2 -dislike slightly, 3-neither like nor dislike, 4-like slightly, 5-like very much

up and genes control the production of chemical compounds that behave as aroma agents either directly or as aroma precursors expressed during the roasting process.

Flavor. Flavor was described as the distinguishing sensory experience of coffee. It includes both taste and aroma (coffeereview.com, 2008). Only Moka and Yellow Caturra were rated with perceptible coffee flavor while the rest of the cultivars were rated moderately perceptible. Based on the results, among the cup quality characters, only flavor was observed to discriminate the cultivars. This coincides with the conclusion of Agwanda (1999) that flavor rating was the best selection criterion for genetic improvement of cup quality in Arabica coffee. The trait showed high genetic correlation with preference, was easy to determine organoleptically and had relatively high sensitivity in discriminating different coffee genotypes. Hence while selecting a cultivar to be planted; cup quality must be the first priority to be considered.

General acceptability. Acceptability is the overall sensation of drinking a particular coffee which includes fragrance, aroma, and flavor. Kenya-38, Moka, MSAC Selection No.1, Red Bourbon, Typica and Yellow Caturra had the best cupping quality which were liked slightly by the evaluators while Granica Broad, Granica Fine, Mondo Nuvo and San Ramon were neither liked nor disliked (Table 6). Coffee produced from *C. arabica* is known to have a good quality. This characteristic was clearly established for classical varieties like Caturra, Mundo Novo, and other pure lines obtained from pedigree selection.

Yield Performance of Arabica Coffee Cultivars

Based on the 2009 data, Mondo Nuvo significantly produced the highest green bean yield, followed by Red Bourbon and MSAC Selection No.1 (Figure 2). In 2010, there was an increase in yield per tree in all Arabica coffee cultivars. Granica Fine produced the highest yield but did not significantly differ with the yield of MSAC Selection No. 1 and Red Bourbon. Yield of the Arabica coffee cultivars decreased in 2011.

Red Bourbon produced the highest yield while Typica produced the lowest yield. Though a decreasing trend was observed, Granica Fine, Mondo Nuvo and San Ramon were observed to have stable high yields (Figure 2). Consistent low yields were obtained from Moka and Typica during the three consecutive years. Low yield in Moka could be attributed to its inherent small green bean seeds. Typica may be a low yielder cultivar under organic condition. The decreasing trend of green bean yield could be due to various factors. One factor could be the characteristics of the coffee plants under shaded and unshaded condition. Cannell (1976) cited that coffee yields may decrease with increasing shading because coffee tends to flower and produce a good crop each year, whereas under unshaded plantation conditions, the crop have alternate years of heavy flowering and light flowering leading to a biennial production trend. Overbearing exhausts the tree's reserves and limits both the production and retention of leaves, leading to poor crop the next year. This allows an excessive foliage to form which, in turn, permits a profuse flowering and hence a heavy crop. As a consequence, unshaded coffee plantations produce irregularly and, even under good cropping conditions, production is often irregular and follows a biennial pattern.

The use of shelter trees reduce overbearing and buffer biennial fluctuations of crop yields. This should reduce exhaustion of the coffee tree, and allow it to satisfactorily produce for a longer period. On economic grounds, higher yields per harvest in unshaded plantations might be compensated for, within given limits, by the larger number of more regular crop harvests in shaded plantations. Beaumont and Fukunaga (1958) likewise cited that alternate bearing or the habit of the coffee tree to produce a heavy crop in one year and to produce a light crop in the second year is the major characteristic of the tree. Heavy fruit production in one year is accompanied by severe defoliation, small berries, and even dying back of the vertical branches. The same observation was reported by Wamatu *et al*. (2003) that coffee yield fluctuates from year to year in Kenya.

Reaction to Diseases

Coffee blight (*Colletotrichum sp*. Noack), brown eye spot (*Cercospora coffeicola* Berk. Curtis), sooty mold (*Capnodium sp.*), die back (*Colletotrichum sp*. Noack) and coffee berry disease (*Colletotrichum sp*. Noack) were observed in all the Arabica coffee cultivars. However, disease infection during the rating period was minimal.

Reaction to insect infestation

Three of the economically important insect pests of Arabica coffee namely; thrips (*Ceratothripoides sp.*); green scale insect (*Coccus viridis* green), and coffee berry borer (*Hypothenemus hampei* ferrari) were assessed (Table 7). Granica Fine, MSAC Selection and Typica had slight infestation with coffee berry borer infestation. Minimal infestation of green scale insect and thrips were observed among the cultivars.

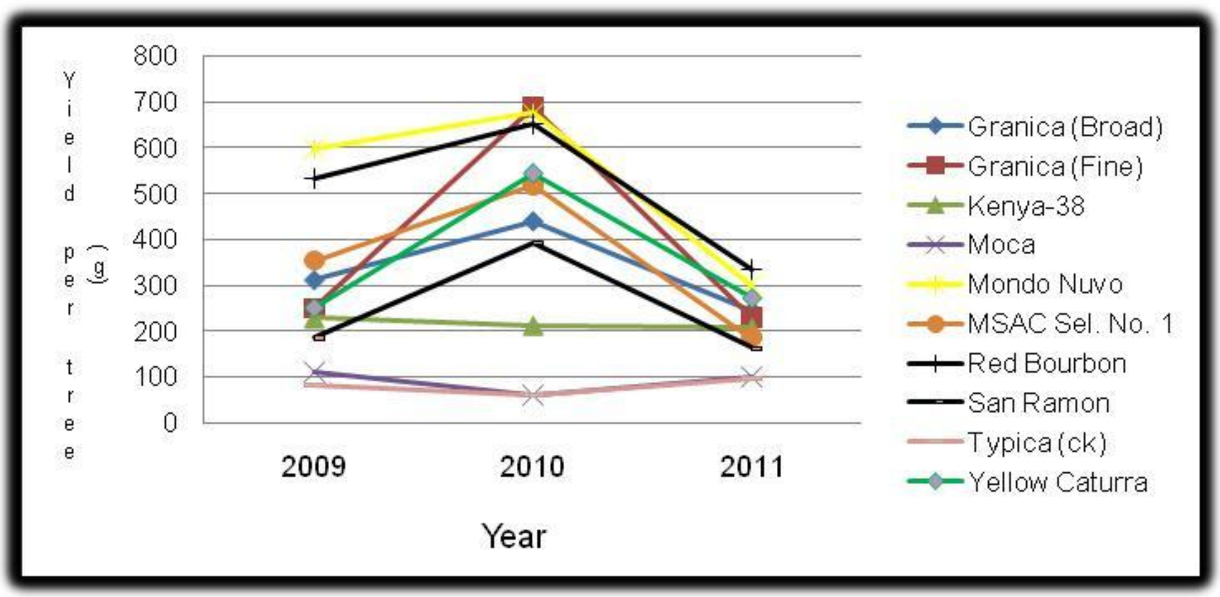


Figure 2. Green bean yield of Arabica coffee cultivars for three consecutive years

Table 7. Reaction of Arabica coffee cultivars to insect pests infestation under organic production in La Trinidad

CULTIVAR	RATING		
	Coffee berry borer	Green scale insect	Thrips
Granica Fine Leaf	0.7	1.3	0.8
Granica Broad Leaf	1.3	1.3	1.0
Moka	1.0	1.5	0.7
MSAC Selection	0.7	1.3	1.0
Typica(check)	0.7	1.4	1.0
San Ramon	1.1	1.6	0.7
Red Bourbon	1.0	1.0	0.8
Yellow Caturra	1.1	1.0	0.8
Mundo Novo	1.4	1.4	1.2
Kenya	1.3	1.2	1.2

Description:
- *Coffee berry borer. (0) sound (1) slight, (2) moderate, (3) severe*
- *Scale/Sucking insects. (0) sound (1) slight (2) moderate (3) severe*

Correlation analysis among characters of Arabica coffee cultivars

Among the characters, weight of 100 bean seed per tree, fruit berries per tree, seed length, fruit length and width, number of fascicle per axil, number of flower per fascicle, number of fascicle per node, leaf width and leaf petiole length had positive significant correlations with green bean yield per tree (Table 8). This indicates that as yield increases per tree, the mentioned parameters also increase.

The significant associations of fruit and flower characteristics were established by Anim-Kwapong (2010). Genetic associations further studied in production seasons established that fruit-set was in fact the most important reproductive trait that determined coffee yields at both the early and late reproductive stages of the coffee plant. On the other hand, Walyaro and Van der Vossen (1979) working on Arabica coffee observed negative genetic association of number of flowers per node with fruitset and yields. Gichimu and Omondi (2010) found highly significant correlation between the total number of berries and the main growth and yield characters and correlation between the total number of berries and the bearing primaries was slightly higher than that between the total number of berries and percent bearing primaries.

Vegetative characters such as leaf width and leaf petiole length having positive and significant correlation with Arabica coffee yield were explained by earlier studies. It is likely that the positive effects of good vegetative growth to yields are due to the availability of reserves which provide yield enhancing assimilates (Walyaro and Van der Vossen, 1979; Walyaro, 1983; Cilas *et al*., 1998).

A negative significant correlation exists between seed width and number of days from fruit setting to harvesting. This may imply that increase in seed width and longer days from fruit setting to harvesting may cause decrease in green bean yield. The inverse association between days from fruit setting to harvesting with yield implies that longer days for fruit setting results in low yield of cultivars. The negative association of seed width with yield may mean cultivars with wide seeds have low yield.

Sera (1987), using multiple regression, concluded that significant selection indices such as production of fruits, height, canopy diameter can be used in the first two years of production. The results showed the effectiveness of pre-selection for yield in coffee can be achieved using indices during initial stages of production and certain growth characters that are highly associated with yield.

Table 8. Correlation coefficient among 17 quantitative morphological characters of Arabica coffee under La Trinidad, Benguet condition

Parameters	Tsy/t	W100sb	Fby/t	Sl	Sw	Fl	Fw	Ft	Nfpa	Nfpf	Nfpn	Ll	Lw	Lpl	NdE-F	NdF-Fs	NdFs-H
Tsy/t	1																
W100sb	0.444*	1															
Fby/t	0.839**	0.235ns	1														
Sdl	0.262ns	0.387ns	0.281**	1													
Sdw	-0.635**	0.355ns	0.694**	0.755**	1												
Ftl	0.824**	0.306ns	0.837**	0.415*	0.848**	1											
Ftw	0.928**	0.634**	0.677**	0.382ns	0.606**	0.774**	1										
Ftth	0.335ns	0.061ns	0.484**	0.230ns	0.485*	0.514**	0.300ns	1									
Nfpa	0.107ns	-0.185ns	0.337ns	0.593**	0.426*	0.304ns	0.111ns	0.412*	1								
Nfpf	0.104ns	-0.409*	-0.041ns	0.055**	0.202ns	0.177ns	0.049ns	0.007**	0.340ns	1							
Nfpn	0.693**	0.573**	0.462*	0.279*	0.432*	0.552**	0.724**	-0.348ns	-0.150ns	-0.005ns	1						
Ll	0.761**	0.230ns	0.628**	0.520**	0.753**	0.841**	0.618**	0.313ns	0.197ns	0.061ns	0.528**	1					
Lw	0.516**	0.641**	0.318ns	0.644*	0.701**	0.149ns	0.684**	0.649**	0.148ns	0.118ns	0.646**	0.278ns	1				
Lpl	0.534**	0.294ns	0.493*	0.787**	0.649**	0.282ns	0.701**	0.778**	0.374*ns	0.051ns	0.532**	0.899ns	0.893**	1			
NdE-F	0.312ns	0.340ns	0.588**	0.211ns	0.493*	0.506**	0.253ns	0.254ns	-0.132ns	-0.581**	0.292ns	0.641**	0.330ns	0.388ns	1		
NdF-Fs	0.005ns	0.650**	-0.083ns	0.455*	0.265ns	0.089**	0.194ns	0.342ns	0.224ns	-0.158ns	-0.012ns	0.075ns	0.452*	0.226ns	-0.063**	1	
NdFs-H	-0.457*	0.185ns	-0.537**	0.303ns	-0.287ns	-0.567**	-0.219ns	-0.292ns	0.292ns	0.034ns	-0.206ns	0.508ns	0.070ns	0.300ns	-0.504**	0.402*	1

* and ** indicate significant correlations at 0.05 and 0.01, respectively.

Total seed yield per tree (Tsy/t)
Weight of 100 seed bean (W100sb)
Fruit/berry per tree (Fby/t)
Seed length (Sdl)
Seed width (Sdw)
Fruit length (Ftl)
Fruit width (Ftw)
Fruit thickness (Ftt)
Number of flower per axil (Nfpa)
Number of flower per fascicle (Nfpf)
Number of fascicle per node (Nfpn)
Leaf length (Ll)
Leaf width(Lw)
Leaf petiole length (Lpl)
Number of days from emergence to flowering (NdE-F)
Number of days from flowering to fruit setting (NdF-Fs)
Number of fruit setting to harvesting (NdFs-H)

Genotype x environment interaction using AMMI model in green bean yield of Arabica coffee cultivars for three years

Environments. An Arabica coffee cultivar showing high positive interaction in an environment has the ability to exploit the agro-ecological conditions and is therefore best suited to that environment. AMMI analysis permits estimation of interaction effect of a genotype in each environment and it helps to identify genotypes best suited for specific environmental conditions. In this particular study, the three environments are the years 2009, 2010 and 2011 (Table 9). Average temperature ranged from 20.77-21.07oC. Relative humidity was highest in 2011 (87.28%) and lowest in 2010 (85%). Amount of rainfall was highest in 2012 (12.22 mm/hr). According to various authors, Arabica coffee generally performs well in cool climate.

The optimum temperature range is 15 to 30°C. For successful Arabica production, an average annual rainfall of 1,600 to 2,500 mm well distributed over 8 to 9 months is desirable. A well-defined dry period of 3 to 4 months between December to March is necessary for flower bud differentiation and uniform blossom in Arabica coffee (Clifford and Wilson, 1985; Clarke and Macrae, 1985).

AMMI 1 biplot for green bean yield in Arabica coffee cultivars. Genotypes (Arabica cultivars) with yields higher than the grand mean (330 g) were Granica Broad, Granica Fine, Red Bourbon, MSAC Selection 1 and San Ramon. Genotypes San Ramon, Red Bourbon and MSAC Selection 1 had similar main effects which means that, these have almost similar yields across environments. The environment (year) giving the highest green bean yield was 2010 (Figure 3).

The year 2010 had an average temperature of 21oC. Mean relative humidity and rainfall were 85% and 8.34 mm/hr, respectively (Table 9). The high yield could be attributed to the optimum conditions for production. The optimal temperature for Arabica coffee growth is between 15°C and 24°C (Wilson,1985; Gay *et al*., 2006), although several sources give more specific ranges, Alègre (1959) concludes that favorable mean temperatures for coffee plant growth lie between 16°C and 23°C, with the optimum from 18°C to 21°C (Barros *et al*, 1997; Da Matta, 2004; Lin, 2007). Descroix and Snoeck (2004) stated that the optimum mean night time temperature is 18°C, and the optimum daytime temperature is 22°C. Optimal annual rainfall for arabica coffee lies within the range of 1,200-1,800 mm (Alegre, 1959, cited from Da Matta, 2004; Descroix and Snoeck, 2004).

Table 9. Mean annual temperature, relative humidity and rainfall during the years 2009, 2010 and 2011 in La Trinidad

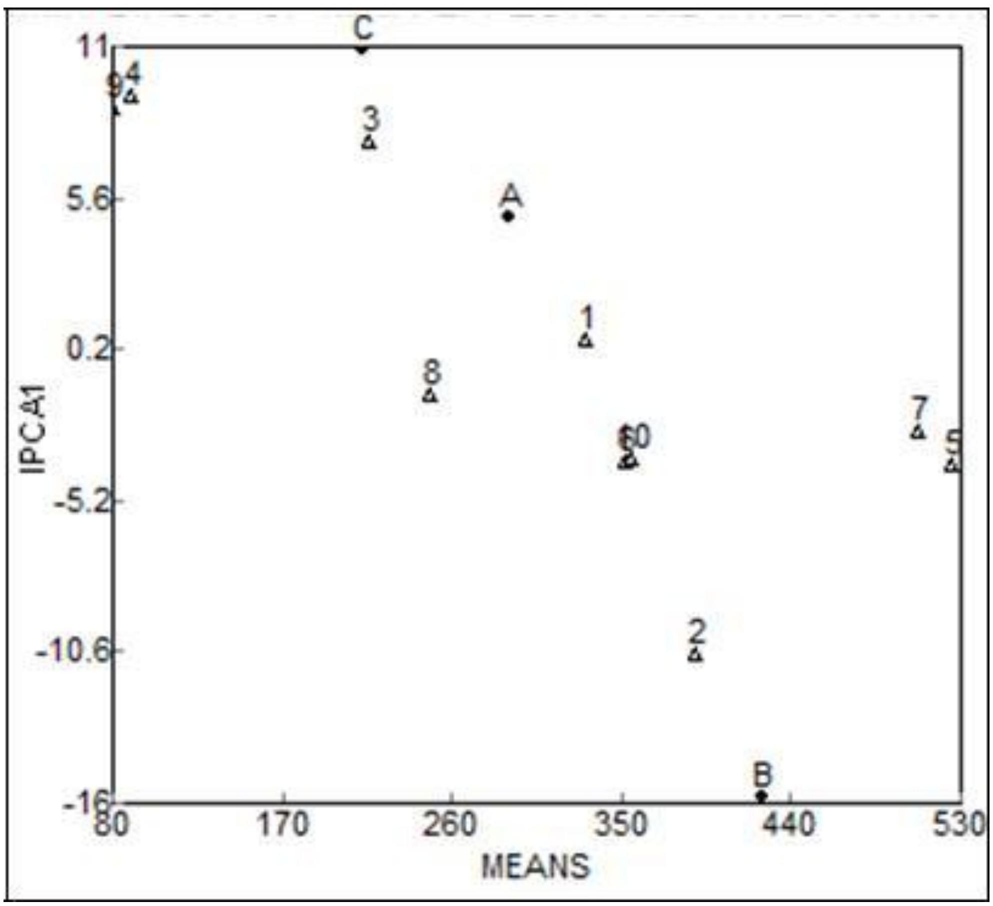
	AVERAGE TEMPERATURE (^{0}C)			RELATIVE HUMIDITY (%)			RAINFALL (mm/hr)		
MONTH/YEAR	2009	2010	2011	2009	2010	2011	2009	2010	2011
January	19.98	20.43	21.90	85.00	86.50	80.00	0.03	T	1.40
February	20.35	20.15	14.33	83.50	84.00	86.00	1.75	T	T
March	21.58	20.90	20.18	85.00	78.00	82.00	0.90	0.02	1.90
April	21.60	22.00	24.00	86.50	84.50	83.00	7.50	3.00	1.30
May	21.53	22.55	21.50	88.50	86.00	89.70	9.00	7.02	13.70
June	21.60	22.28	22.20	88.00	87.50	88.00	16.20	13.60	13.70
July	20.93	21.90	20.90	86.00	86.50	90.50	12.44	14.00	14.50
August	20.90	21.93	20.23	88.50	89.00	92.20	22.40	9.60	43.10
September	21.58	20.90	20.73	90.39	89.00	89.50	10.65	8.20	29.90
October	20.28	20.25	22.15	90.00	89.50	92.00	42.85	20.10	12.10
November	20.43	20.55	20.74	84.00	84.00	88.00	T	6.04	2.20
December	18.93	18.98	20.33	80.50	81.00	86.50	0.50	1.80	0.60
Mean	20.81	21.07	20.77	86.32	85.46	87.28	11.29	8.34	12.22

Mean with the same letter in a column are not significantly different at 5% level. DMRT

The different environments or the years differ in main effects, meaning, yields obtained were different in each year. The genotypes with PC1 scores close to zero (Figure 3) expressed favorable conditions for yield performance whereas the larger scores depicted specific adaptation to a certain year with PC1 scores of the same sign (Ebdon and Gauch, 2002). Genotypes Red Bourbon, San Ramon and Typica, therefore, had stable yields for the three years while genotypes Moka, Mondo Nuvo and Yellow Caturra yielded best in 2011. Genotypes Granica Fine and MSAC Selection yielded best in 2010 while Granica broad yielded best in 2009.

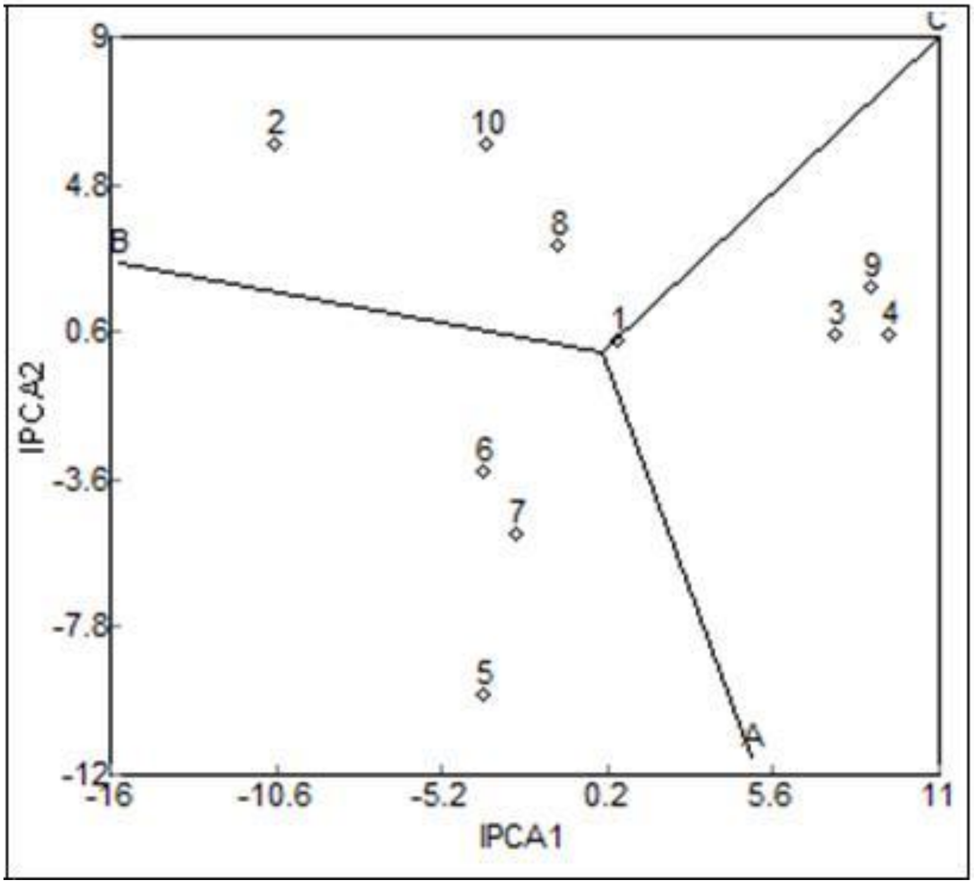
AMMI 2 bi-plot for green bean yield in Arabica coffee cultivars. For the AMMI 2 model, IPCA 2 scores were considered in interpreting GEI that accounts for 18% of the interaction sum of squares as suggested by Gauch and Zobel (1997).

A bi-plot is generated using genotypic and environmental scores of the two AMMI components (Vargas and Crossa, 2000). When IPCA 1 was plotted against IPCA 2, the closer the genotypes score to the center (Figure 4), indicating the more stable they are (Purchase, 1997). The AMMI 2 bi-plot (Figure 4) shows that the stable genotypes were Granica Broad, Red Bourbon and San Ramon being nearest to the center. Granica Fine, Moka, Mondo Nuvo, Yellow Caturra and MSAC Selection which were located far from the center may be considered unstable. Another interpretation of the AMMI 2 bi-plot is to visualize the IPCA scores (Yan and Kang, 2003). According to the analysis, ideal genotypes are those that should have large IPCA 1 scores (high mean yield) and small (absolute) IPCA2 scores (high stability). Based on this interpretation, the ideal Arabica coffee genotypes were Granica Broad, Red Bourbon Typical and San Ramon (Figure 4).



1. GRANICA (BROAD)
2. GRANICA (FINE)
3. MOKA
4. MONDO NUVO
5. MSAC SELECTION
6. RED BOURBON
7. SAN RAMON
8. TYPICA
9. YELLOW CATURRA

Figure 3. AMMI 1 bi-plot of nine Arabica coffee varieties for green bean yield for three years in La Trinidad



1. GRANICA (BROAD)
2. GRANICA (FINE)
3. MOKA
4. MONDO NUVO
5. MSAC SELECTION
6. RED BOURBON
7. SAN RAMON
8. TYPICA
9. YELLOW CATURRA

Figure 4. AMMI 2 bi-plot of nine Arabica coffee varieties for green bean yield for three years in La Trinidad

RECOMMENDATIONS

Based on the evaluation done under organic production and G x E analysis, Granica Broad, Red Bourbon. MSAC Selection No.1 and San Ramon are confirmed potential cultivars, thus, recommended for organic production in La Trinidad or locations with similar conditions.

Arabica coffee is an important crop for the region's or country's sustainable socio-economic status since it provides livelihood to people solely dependent on coffee cultivation. Similar to other crops, there is a continuous need for improved coffee germplasm to meet the ever-changing demands of environment and markets, but it is also a difficult crop using conventional improvement efforts.

The information generated in this study can be disseminated to various stakeholders especially the policy makers to help sustain the Arabica coffee industry in Benguet. Similar studies can be done in other coffee producing areas in the CAR region.

Molecular techniques can be employed to determine variability among the coffee accessions collected and more accurate estimation of genetic diversity. These modern techniques will likewise help in conservation and maintaining purity of selected cultivars for organic production.

This research may be a start of collaborative and synergistic studies on Arabica coffee improvement in the region and country as a whole. These collaborative efforts are expected to get impetus that will result in the development of new coffee varieties and production and postproduction technologies, which may improve and sustain the Arabica coffee industry.

ACKNOWLEDGMENT

The researchers gratefully acknowledge the following who in one way or another made this research endeavor possible:

• Philippine Council for Agriculture, Aquatic and

Natural Resources Research and Development (PCAARRD) funded the research;

• Benguet State University for the counterpart fund ;

• Highland Agriculture Research and Resources and Development Consortium (HARRDEC) for the support in the implementation;

• Local government units of the 13 municipalities of Benguet permitted and helped the researchers in their area of jurisdiction;

• Dr. Salvacion Z. Beligan for the statistical analysis.

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