IN-SITU MORPHOLOGICAL CHARACTERIZATION AND DIVERSITY ANALYSIS IN TRADITIONAL ARABICA CULTIVARS IN BENGUET

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ABSTRACT

Keywords: *In-situ* Morphological Characterization, Diversity Analysis and Traditional Arabica coffee

The research on Arabica coffee (*Coffeaarabica L.*) was conducted to characterize the collectionalong phenology, relationships, and diversity and determine the nature of association among quantitative characters in Arabica coffee collection.

Collection trips were done in the 13 municipalities of Benguet. During the trips, the Arabica coffee cultivars were characterized in-situ using the coffee descriptor's list (IPGRI, 2006).The general phenological pattern of existing Arabica coffee cultivars in the different study areas was investigated. Estimate of variability for each qualitative character was computed using the standardized Shannon-Weaver Diversity Index. The Ward's method was used for clustering the collections.

A total of 152 Arabica coffee accessions were collected in 13 municipalities of Benguet. Most of the Arabica coffee cultivars were found in the low (1,001 to 1,500 m asl) and mid (1,501-2,000 m asl) mountain zones while a few cultivars were observed in the high hills zone (500-1,000 m asl) such as Itogon, Sablan, Tuba and some parts of Bokod. Typica had the highest number of accessions with 53 followed by San Ramon (35), Granica (30), Bourbon (22), Yellow Caturra (4), Kenya (2), Mondo Nuvo (2), San Ramon Selection (2) and Moka (1).

Granica growing in the high hills zones was the earliest to flower at 33 days from flower bud initiation while San Ramon growing in the mid-mountain zones was the latest to flower. Coffee cultivars in the high hills zone were the earliest to flower compared with those cultivars grown in the low mountain and mid- mountain zones.

The mean diversity index for the quantitative characters of the Arabica coffee accessions was 0.18 which indicates low variation. Six clusters resulted in the 152 Arabica coffee collections. The first cluster consists of 55 accessions belonging to the cultivar Typica mostly from Atok and Kibungan. The second cluster (San Ramon) consists of three sub-clusters.The third cluster constitutes two accessions from Mondo Nuvo cultivars collected from Kibungan and Kabayan. Cluster 4 (Granica) consists of 34 accessions and sub-divided into two sub-clusters. Cluster 5 (Red Bourbon) had 23 accessions. Cluster 6 constitutes a lone accession of Moka collected in Atok.

INTRODUCTION

Coffee is one of the top priority crops in Benguet. Coffee has existed for centuries in the Cordillera Administrative Region (CAR) and has been a part of the culture and lifestyle of the Cordillerans. Among the cultivated species, Arabica is the most popular although other species exists (DA, 2010). Arabica coffee is also regarded as one of the promising industrial crops in the Cordillera highlands. Arabica Typica is the best variety planted in Benguet for the past 100 years (Killip, 2010).

Coffee germplasm was known to be closely associated with C. arabica domestication and has involved conservation in field gene banks because of the non-orthodox nature of coffee seeds. It first began on farms in the center of origin, Ethiopia. Subsequently, worldwide extension of coffee cultivation contributed to the establishment of field gene banks in producer countries (Englemann, 2007).

It is thought that the diversity of coffee species and the genetic diversity within them have been the result of a rapid speciation and adaptive radiation process (Cros 1994; Lashermes et al. 1997). Diversity can be analyzed at the genetic and morphological levels. Only few studies have been undertaken to examine the level of genetic diversity in traditional coffee populations. Filho (2010) found that the genetic make-up of individual cultivars influences all production chains from nurseries to consumers. Cultivar improvement is dependent on genetics, breeding, germplasm conservation and its exploitation. Conservation and exploitation of such broad diversity involves sexual and vegetative reproduction.

Desirable cultivar attributes encompass uniform ripening, short stature, resistance to major pests, consistent quality and unique cup flavors found in primary and secondary gene pools with variably introgressed C. arabica or C. canephora genomes.

Arabica coffee cultivars and strains are known to abound in the province. Through centuries of cultivation, these cultivars may have developed strains through natural selection and mutation. Hue (2005) cited that morphological variability in coffee plantations has large effect on the product quality. A decrease in genetic diversity was reported to have an adverse effect on the ability of populations to cope with environmental changes and thus reducing their chances of long-term persistence (Frankham et al., 2002).

Morphological characterization continues to be the foundation of genetic diversity research at any taxonomic level (Chandran and Pandya 2000). It is still an important tool for the management of crop germplasm collections (Ariyo 1993; Polignano et al. 1993; Annicchiarico and Pecetti 1994), having been used to identify duplicates, to discriminate among material from different geographic areas, to establish core collections, to investigate relationships between landraces and their wild relatives, and to prioritize material for use in breeding programs.

The collection, conservation and characterization of important coffee germplasm are critical in considering the alarming loss of valuable genetic resource. These germplasm are valuable because they represent products of fine-tuned selection over hundreds of years and have evolved dynamically to counter pest, pathogen and environmental pressure.

Germplasm in gene banks must undergo characterization and evaluation. Characterization is done to establish identity of each accession (Bellon, Pham and Jacksonm, 1997). Evaluation is done to enhance the utilization of each accession in future crop improvement (Frankel and Benett, 1980).

Conservation and management of collections requires thorough knowledge of the nature and structure of diversity existing within. Assessment of diversity is significant if the amount of useful genetic variation within a collection is to be maximized (Bretting and Duvick, 1997).

In Brazil, 90% of the cultivars grown are from exploitation of germplasm, hybridization and evaluation in representative growing regions. Since Arabica coffee is self-pollinated, breeding strategies aim to produce homozygous lines developed mainly by pedigree or backcross method (Filho, 2010).

At present, there is scarce information on the existence and diversity of these cultivars and strains in the Philippine highlands. Thus, this study would be helpful in determining the presence or absence of variations within a cultivar and the diversity existing within the population of Arabica coffee in the region. The information generated would be significant in conservation strategies and improvement of Arabica coffee in the region. The in-situ and ex-situ conservation of the Arabica coffee genetic resources are the best approaches to conserve species and ecosystem diversity (Engelmann, 2007).

OBJECTIVES

The research was conducted on Arabica coffee cultivars to:

1. characterize collections as to their phenology, relationships and diversity;
2. determine the nature of association among quantitative characters of cultivars and accessions.

MATERIALS AND METHODS Germplasm collection

Before the scheduled collection trips, verbal and written consent were requested from the mayors and agriculture officers of the different municipalities of Benguet to collect Arabica coffee cultivars in their area of jurisdiction.

Passport data for each accession were gathered. Planting materials were properly collected and labeled. The collected Arabica coffee accessions were brought to Benguet State University (BSU) and are currently being maintained together with other existing strains at BSU-Institute of Highland Farming Systems and Agroforestry (IHFSA) gene bank at Bektey, La Trinidad, Benguet.

Morphological characterization of Arabica coffee accessions

During the collection trips, the Arabica coffee cultivars were characterized using the International Plant Genetic Resources Institute (IPGRI, 2006) coffee descriptor's list.

The characters considered were:

- Plant habit. This was described as bush (<5 m - without distinct trunk), shrub or small tree (<5 m - one or more trunks) and tree (>5 m - single trunk)
- Plant height. This was described as very short, short, tall and very tall
- Overall appearance. This was described as elongated conical, pyramidal and bushy.
- Branching habit. This was obtained using the following description:

Scale	Description
1	Very few branches (primary)
2	Many branches (primary) with few secondary branches
3	Many branches (primary) with many secondary branches
4	Many branches (primary) with many secondary and tertiary branches

- Angle of insertion of primary branches. This was described as drooping, horizontal or spreading and semi-erect.
- Stipule shape. This was obtained using the following description:

Scale	Description
1	Round
2	Ovate
3	Triangular
4	Deltate (equilaterally triangular)
5	Trapeziform

• Young leaf color. This was obtained using the following description:

Scale	Description
1	Greenish
2	Green
3	Brownish
4	Reddish brown
5	Bronze

• Leaf shape. This was obtained using the following description:

Scale	Description
1	Obovate
2	Ovate
3	Elliptic
4	Lanceolate

• Leaf shape apex. This was obtained using the following description:

Scale	Description
1	Round
2	Obtuse
3	Acute
4	Acuminate
5	Apiculate
6	Spatulate

• Leaf length (cm). This was taken by measuring five leaf samples taken randomly.

• Leaf width (cm). This was taken by measuring the mid-portion of the five leaf samples taken randomly.

• Leaf petiole length (cm). This was taken by measuring the leaf petiole of five sample leaves.

• Leaf petiole color. This was described as green and dark green.

• Mature leaf color. This was described as green and dark green.

• Number of flowers per axil. This was taken by counting the number of flowers per axil.

• Number of flowers per fascicle. This was taken by counting the number of flowers per fascicle.

• Number of fascicles per node. This was taken by counting the number of fascicles per node

• Fruit color. Color of fruits were described as follows:

Scale	Description
1	Yellow
2	Yellow-orange
3	Orange
4	Orange-red
5	Red
6	Red-purple
7	Purple
8	Purple-violet
9	Violet
10	Black

• Fruit shape. This was described as follows:

Scale	Description
1	Roundish
2	Obovate
3	Ovate
4	Elliptic
5	Oblong

• Fruit length (cm). This was taken by measuring five sample fruits

• Fruit width (cm). This was taken by measuring the mid portion of five sample fruits.

• Fruit thickness. This was taken by measuring the dimension of five sample fruits.

• Pulp thickness. This was described as thin, intermediate and thick.

• Seed length (cm). This was recorded by measuring five sample seeds.

• Seed width(cm). This was taken by measuring five sample seeds.

• Seed thickness. This was recorded by measuring five sample seeds.

• Seed color. This was described as green, yellow and brown purple.

- Seed shape. This was described as follows.

Scale	Description
1	Round
2	Obovate
3	Ovate
4	Elliptic
5	Oblong

Phenology of Arabica Coffee Cultivars

The general phenological pattern of existing Arabica coffee cultivars in the different parts of the study area was investigated. Arabica coffee populations were visited during the different stages such as vegetative, flowering, fruit fill and ripening. During visit, the phenological status of the Arabica coffee cultivars were recorded by counting the number of days from flower buds to inflorescence, fruit setting (pinhead stage), fruit filling, ripening and harvesting.

Diversity Analysis

Estimate of variability for each qualitative character was computed using the standardized Shannon-Weaver Diversity Index, designated as H1 and has the formula:

Where:

$$H1 = -\sum pi \, (\log_2 pi) / \log_2 n$$

pi = frequency of proportion of each descriptor

state n = number of states

The Shannon-Weaver Diversity Index has a value ranging from 0 to 1, where 0 indicates the absence of diversity and 1 indicates maximum diversity. The same formula was applied to the quantitative characters of coffee species and accessions collected in Benguet based on the work of Tadawan and Pablo (2010).

Cluster analysis

The Ward's method was used for clustering the collections. The method easily determines the groupings where each collection belongs so

that collections in the same cluster are more alike than elements in different clusters. Thus, the resulting clusters exhibit high internal homogeneity (within cluster) and high external heterogeneity (between clusters). According to Kaufman and Rousseuw (1990), Ward's method perform well with groups that are multivariate normal and spherical and with equal number of observations.

Since the variables in this study were transformed into a standard normal Z, then the Ward's clustering method is appropriate. The entire procedure may be presented in a dendrogram. A measure of similarity and dissimilarity was computed using the squared Euclidian (Minkowski) distance metric formula.

The same formula was applied on the quantitative characters on coffee species (Tad-awan and Pablo (2010) by construction of frequency classes with the class boundaries equal to some function of mean and standard deviation.

RESULTS AND DISCUSSION

Collection sites

Arabica coffee accessions were collected from the 13 municipalities of Benguet namely Atok, Bakun, Bokod, Buguias, Itogon, Kabayan, Kapangan, Kibungan, La Trinidad, Mankayan, Sablan, Tuba and Tublay classified under the different agro-ecological zones. Most of the Arabica coffee cultivars were found mostly in the low (1,001 to 1,500 m asl) and mid (1,501-2,000 m asl) mountain zones while a few cultivars were observed in the high hills zone (500-1,000 m asl) such as Itogon, Sablan, Tuba and some parts of Bokod (Table 1 and Figure 3).

Germplasm collection

One hundred fifty two (152) Arabica coffee accessions were collected in 13 municipalities of Benguet (Figure 20).

Typica had the highest number of accessions with 53 followed by San Ramon (35), Granica (30), Bourbon (22), Yellow Caturra (4),

Kenya (2), Mondo Nuvo (2), San Ramon Selection (2) and Moka (1). Collected accessions are being maintained at the BSU-Institute of Highland Farming Systems and Agroforestry (IHFSA) gene bank (Fig.3).

Table 1. Arabica coffee cultivars collected in the 13 municipalities of Benguet representing the different agro-ecological zones.

AGRO-ECOLOGICAL ZONE	MUNICIPALITY	TYPICA	SAN RAMON	RED BOURBON	YELLOW CATURRA	GRANICA	KENYA	MONDO NUVO	MOKA	SAN RAMON SELECTION	TOTAL
Mid-mountain zone (1,501-2,000 masl)	Atok (Caliking Sayet,Topdac, Abiang)	6	4	3	-	3	-	-	-	-	16
	Bakun (Amposungan, Poblacion)	2	3	-	-	-	-	-	-	-	4
	Buguias (Amlimay)	3	1	1	-	1	-	1	-	-	8
	Itogon (Ampocao)	1	-	1	-	1	-	-	-	-	3
	Kabayan (Tawangan)	2	2	1	-	2	-	-	-	1	8
	Mankayan (Guinawang, Tabio)	4	3	-	-	-	-	-	-	-	7
	Tublay Ambassador)	4	3	2	-	2	-	-	-	-	11
Low mountain zone (1,001-1,500 masl)	Atok (Caliking proper)	1	1	1	-	1	-	-	1	-	5
	Buguias (Poblacion)	1	1	-	-	2	-	-	-	-	4
	Bokod (Daclan, Karao, Bobocbisal)	2	1	1	-	2	-	-	-	-	6
	Itogon (Loacak, Tuding, Ampocao)	2	1	-	-	2	-	-	-	-	5
	Kabayan (Batan,Gusaran, Pacso,Adaoay, Bashoy)	1	1	1	-	1	1	-	-	-	5
	Kapangan (Labueg, Sagubo)	2	1	1	-	-	-	-	-	-	4
	Kibungan (Poblacion,Sagpat)	7	3	4	3	3	1	1	-	-	22
	La Trinidad (Puguis, Wangal, Beckel)	5	2	2	1	2	-	-	-	1	13
	Tublay (Baayan)	5	4	4	-	3	-	-	-	-	16
High hills mountain zone (500-1,000 masl)	Tuba (Taloy Norte Belis and Daclan)	2	1	-	-	2	-	-	-	-	5
	Itogon (Tinongdan)	1	1	-	-	-	-	-	-	-	2
	Sablan (Kamog, Banangan)	1	1	-	-	2	-	-	-	-	4
	Bokod (KaraoBagongpurok)	1	1	1	-	1	-	-	-	-	4
	TOTAL	**53**	**35**	**24**	**4**	**30**	**2**	**2**	**1**	**2**	153

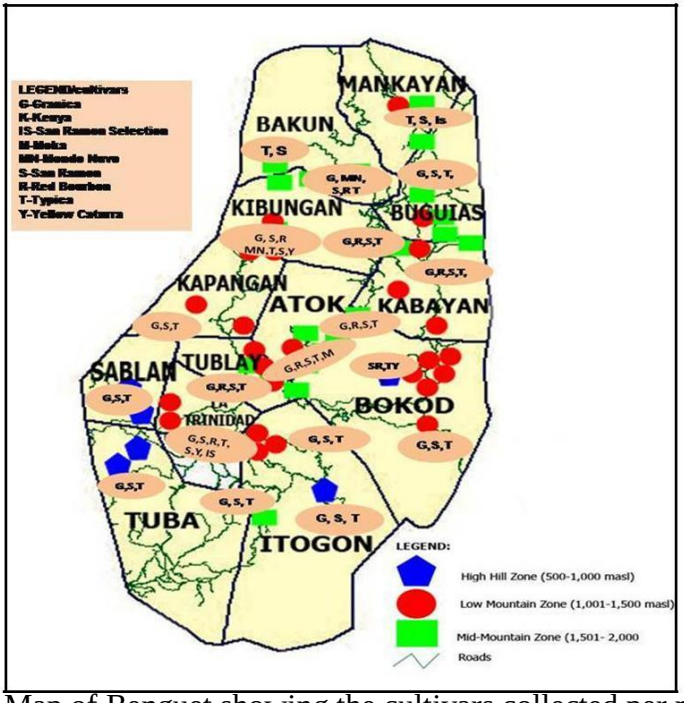

Figure 2. Map of Benguet showing the cultivars collected per municipality in different agro-ecological zones

Figure 3. Over view of the Arabica coffee gene bank at BSU-IHFSA

Phenology of Existing Arabica Coffee Cultivars in Benguet

Phenology is the study of the timing of recurring biological events in the animal and plant world, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species (Lieth, 1974). In plants, these events include leaf unfolding, flowering, fruit ripening, color changing and leaf fall.

Plant phenology is done to observe and record the periodically recurring growth stages. In agriculture, phenological data is important as input for crop models, and for the timing of management activities (Koch, 2011).

Camargo (2001) proposed six different phenological phases, taking a total of two years of Coffea arabica L. in Brazil, starting in September of each year. The phases are: 1st phase: vegetative, with seven months, September to March, with long days; 2nd phase: also vegetative, April to August, with short days. At the end of this phase, July and August, the plants enter in relative dormancy with formation of one or two small pair of leaves that usually do not flourish. The maturation of the reproductive buds comes starting by the beginning of April; 3rd phase: flowering and grain expansion, September to December. The 4th phase: grain formation, January to March; 5th phase: grain maturation, main flowering; 6th phase: senescence and death of the non-primary productive branches, in July and August.

Granica growing in the high hills zones was the earliest to flower at 33 days from flower bud initiation while San Ramon growing in the mid-mountain zones was the latest to flower (40 days). Granica, Red Bourbon, San Ramon and Typica flowering occurs in the month of April until the 1st week of May.

It was observed that in the high hills zone, the coffee plants were the earliest to flower compared with those cultivars in the low mountain and mid- mountain zones. After blossoming pin-head, (small, green fruits) or fruit setting stage takes place from the 2nd week of May to June. Granica growing in the high hills zones was the earliest to set fruit at 35 days after flowering followed by Red Bourbon and Typica. San Ramon growing at mid-mountain zones was the latest to set fruits at 44 days (Table 2).

Granica and Red Bourbon growing in the high hill zones were the earliest to fill fruit at 105 days after fruit setting while San Ramon growing at mid-mountain zone was the latest to fill fruit at 115 days after fruit setting.

Ripening of Arabica coffee in Benguet varies among the agro-ecological zones. Granica, Red Bourbon and Typica were the earliest to be harvested at 60 days while San Ramon growing at the mid-mountain zone

was the latest to be harvested at 72 days after fruit setting. Generally, the coffee berry ripening begins during the months of October and November. Harvesting is done until February and March. Ripening stage for Arabica coffee berries in the high hills zone starts from October and harvesting lasts up to February. Arabica coffee in the low and mid-mountain zone starts to

PHENO-LOGICAL EVENT		GRANICA			RED BOURBON			SAN RAMON			TYPICA		
	MONTH	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
Flower buds to inflorescence	April to May(1st week)	33	36	36	34	37	39	34	38	40	34	36	37
Pinhead stage (size is around 2-4mm)	May (2nd-3rd week) to June	35	40	42	37	40	42	37	42	44	37	40	40
Filling stage	June (last week) to Sept.	105	109	112	105	111	112	107	113	115	108	112	112
Ripening to harvesting	Oct. and Nov. until Feb.to March	60	64	66	60	64	66	62	70	72	60	62	64

Z1– High hill zone (500-1000 masl)), Z2 - Low mountain zone (1001-1500 masl) and Z3 - Mid-mountain zone (1501-2000 masl)

Qualitative Characters

Growth and branching habit. All Arabica coffee accessions are characterized as shrub or small tree with sympodial growth development and numerous primary and secondary branches (Table 3). Plant height ranged from very short to tall. As to overall appearance and angle of insertion of primary branches, most of the cultivars had bushy and horizontal or spreading branches except for San Ramon Selection and San Ramon with elongated conical and semi-erect (compact) branches.

Leaf Characters

Young and mature leaf color. The young leaf color of different Arabica coffee cultivars ranged from a rating of 1-greenish to 5-bronze and mature leaf color ranged from green to dark green (Figure 3).

Leaf shape and leaf shape apex. Most accessions displayed elliptic leaf shape. Only Moka was observed to have a unique lanceolate leaf shape. On the other hand, most of the accessions had acuminate leaf apex shape while San Ramon Selection, San Ramon and Mondo Nuvo hadapiculate leaf apex shape (Figure 3).

Leaf petiole color and young shoot color. Young petiole color ranged from green to dark-green. Most of the accessions displayed bronze shoot color except for Granica and Yellow Caturra exhibiting a greenish leaf shoot color.

Flower characters. All Arabica coffee accessions had small, white, and very fragrant flower. Flower bud occurs before blossoming (Figure 4a) and is borne in the axils of the leaves in clusters (Figure 4b). The flowers are also tubular and the five anthers of the stamens protrude from the top of the corolla tube, together with the top of the two-cleft pistil.

a.

b.

Fruit Characters. Fruit color and shape.Unripe fruits were green in all cultivars but variations were observed at ripening. Orange berry was observed in Granica (Figure 6), yellow in Yellow Caturra, dark-purple in Red Bourbon, Kenya and Mondo Nuvo. San Ramon, San Ramon Selection, Typica and Moka have red fruit. Most of the cultivars displayed ellip-tic fruit except for Moka and Mondo Nuvo which displayed roundish fruit. Typica displayed oblong fruit shape.

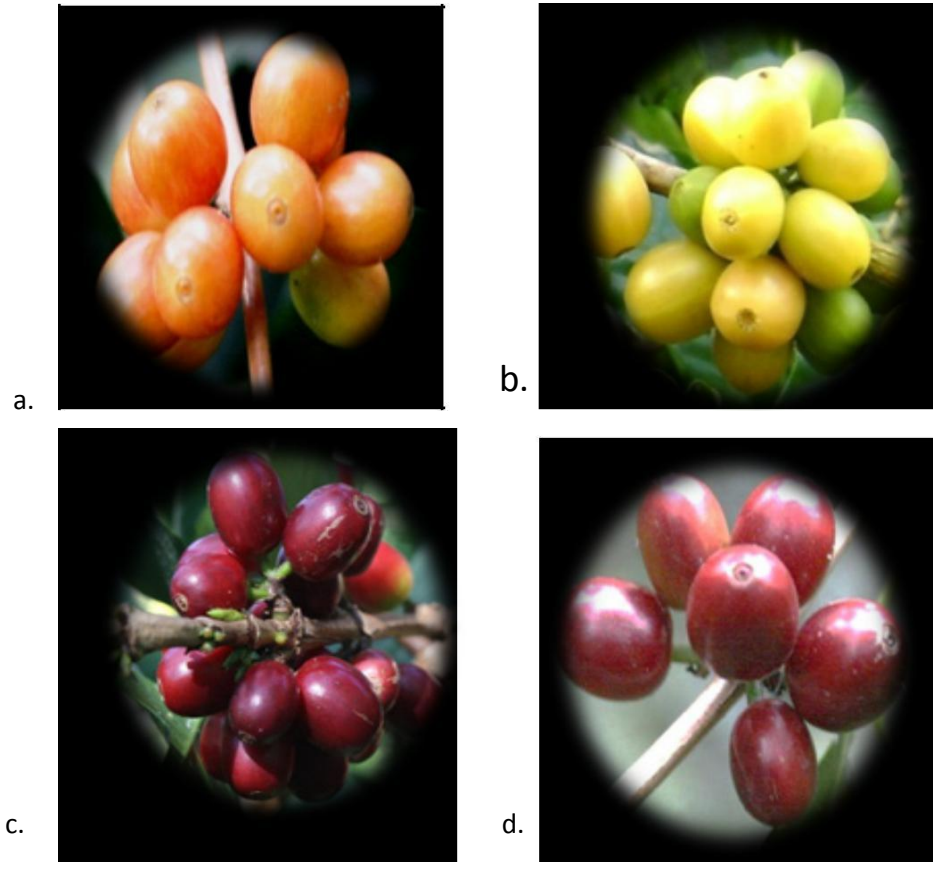

Fig.5. Berries of Arabica coffee cultivars:
a. Granica
b. Yellow Caturra
c. Red Bourbon, Kenya and Mondo Nuvo;
d. San Ramon, Typica and Moka

Seed Characters

Seed shape and color. Most of the green beans of the cultivars were oblong except for Moka, which displayed roundish seeds covered with a thin membrane (silver skin) called parchment. All accessions had yellow seeds when not hulled (with parchment) but green when hulled (Figure 6).

Fig.6 **a**. Un-hulled seed (with parchment) **b.** de-hulled seed (green bean)

Pulp thickness. Most of the Arabica coffee cultivars had thin pulps except for Kenya and Mondo Nuvo with intermediate and thick pulp, re-spectively (Table 3).

Table 3.Qualitative characteristics of Arabica coffee cultivars in Benguet

CULTIVAR	PLANT HABIT	PULP THICKNESS	FRUIT COLOR
Granica	Short	Thin	Orange
Kenya-38	Tall	Intermediate	Red-Purple
San Ramon Selection	Very short	Thin	Red
Moka	Tall	Thin	Red
MundoNuvo	Short	Thick	Red-Purple
Red Bourbon	Tall	Thin	Red
San Ramon	Very short	Thin	Red
Typica	Tall	Thin	Red
Yellow Caturra	Short	Thin	Yellow

Quantitative Characters

Leaf length, width, and petiole length. Among the cultivars, Mondo Nuvo growing at low and mid-mountain zones recorded the longest and widest leaves and petioles, which ranged from 0.7cm to1.20 cm. The results substantiate the report of Coste (1992) that leaf length and width of Arabica varieties ranged between 10-15 cm and 4-6 cm, respectively (Table 4).

Flowers per axil, fascicles per node, and flowers per fascicle (#). Granica growing in low and mid-mountain zones registered the highest number of flowers per axil (9) likewise with Kenya growing in low mountain zones while Moka (5) had the lowest number of flowers per axil. Number of fascicles per node ranged from 5 to 6. It was observed that all of the cultivars had three to four flowers per fascicle.

Fruit length and width (cm). Among the cultivars, Mondo Nuvo and Kenya growing at low and mid-mountain zones recorded the longest fruits while Red Bourbon recorded the widest fruits. Fruit thickness ranged from 0.5 to1.3 cm. MundoNuvo and Red Bourbon had the thickest fruits (Table 4).

Seed length and width. Kenya-38 and Red Bourbon growing in mid-mountain zones had the longest seed (1.2cm) while Moka registered the shortest seeds (1.8cm). Seed width of the different cultivars ranged from 0.4to 0.7 cm (Table 4).

Weight of 100bean seeds (green bean). Red Bourbon, San Ramon, San Ramon Selection, and Mondo Nuvo produced the heaviest weight of 100 seeds (22g) while Moka had the lightest weight of 18g per 100green bean seeds (Table 4).

Fresh berries yield per tree (kg). Mondo Nuvo produced the highest yield of fresh berries per tree with 3.2kg growing both in low and mid-mountain zones followed by Yellow Caturra (2.4kg) while Typica and Granica growing in low mountain zones had the lowest yield at 1.33kg per tree (Table 4).

Total seed yield per tree (green bean). Mondo Nuvo growing in the low and mid-mountain zones produced the highest yield with 0.80 and

0.77 kg/tree, respectively while Typica had the lowest yield at 0.10kg/tree (Table 4).

Table 4. Quantitative characters of Arabica coffee cultivars growing across zones in Benguet

CULTIVAR CHARACTER	GRANICA			RED BOURON			SAN RAMON			TYPICA			SAN RAMON SELECTION		MONDO NUVO		KEN-YA	MOKA	YELLOW CATURRA
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_2	Z_3	Z_2	Z_3	Z_2	Z_2	Z_2
Leaf length (cm)	16.6	16.6	16.6	16.9	17	17	13	13	14	17	16.7	16.7	14.8	15	19	18.5	17.3	9.6	17.7
Leaf width(cm)	6	6	6	6.2	6.1	6.1	6.8	6.8	6.7	5.9	5.9	5.9	5.2	7.5	9.1	9.1	5.8	2.8	5.8
Leaf Petiole length (cm)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.2	1.2	1.1	0.7	1
Flowers/axil (#)	8	9	9	7	7	7	7	7	7	7	7	8	7	9	7	7	9	5	8
Flowers/fascicle (#)	3	3	4	4	3	3	3	4	4	3	4	4	3	4	4	4	3	3	4
Fascicles/node (#)	4	5	4	4	6	6	5	5	5	4	4	4	5	4	5	5	5	4	5
Fruit length (cm)	1.6	1.6	1.6	1.8	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.7	1.7	1.7	1.1	1.6
Fruit width (cm)	1.4	1.5	1.5	1.6	1.4	1.6	1.4	1.4	1.4	1.5	1.6	1.4	1.4	1.3	1.5	1.5	1.5	1.2	1.4
Fruit thickness (cm)	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.1	1.3	1.1	1.5	1.1	1	0.5	1.3	1.3	1.2	1.2	1.2
Seed length (cm)	1.1	1.1	1.1	1.1	1.1	1.2	1	1.1	1.1	1.1	1.1	1.1	1.1	1	1.1	1.1	1.2	0.8	1.1
Seed width (cm)	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.8	0.8	0.4	0.7	0.7	0.7	0.7	0.7
100-green bean weight(g)	20	20	20	22	22	22	22	22	22	20	20	20	20	22	22	22	20	18	21
Fruit yield/tree (kg)	1.4	1.1	2	1.3	1.8	2.1	2.1	1.7	2	1.1	1.3	1.3	1.5	1.6	3.2	3.2	1.5	2	2.4
Total green bean yield/tree (kg)	0.25	0.37	0.37	0.22	0.3	0.7	0.33	0.3	0.3	0.1	0.16	0.16	0.29	0.3	0.8	0.77	0.18	0.36	0.41

Z_1– High-hill zone (500-1000 masl)), Z_2 - Low mountain zone (1001-1500 masl) and Z_3 - Mid-mountain zone (1501-2000 masl)

Diversity Analysis of Arabica Coffee Accessions Collections Based On Qualitative and Quantitative Characters

Qualitative Characters

The computed diversity indices of the qualitative characters ranged from 0.00 to 0.20 with a mean diversity value of 0.03. Low variation was observed for the plant height, overall appearance, and angle of insertion of primary branches. Other qualitative characters had no variation (Table 5).

QUALITATIVE CHARACTERS	DIVERSITY INDEX
Plant height	0.20
Overall appearance	0.11
Angle of insertion of primary branches	0.20
Mean Diversity Index	0.03

Quantitative Characters

Diversity values ranged from 0.04 to 0.28. Number of days from fruit setting to harvest exhibited the highest diversity index (0.28). Most of the accessions had similar if not the same fruit thickness and number of flower per axil (0.24), leaf length and number of days from emergence to flowering (0.22), total seed yield per tree, fruit width and number of days from flowering to fruit setting (0.20), and weight of 100- bean seed, seed width, number of flower per fascicle, and number of fascicles per node (Table 6).

The mean diversity index for the quantitative characters of the Arabica coffee accessions was 0.18 indicating low variation. The result corroborates with the findings of Tad-awanet al. (2010) that low variation existed among coffee species and accessions in Benguet. The low variation indicates narrow genetic base of the Arabica coffee germplasm in Benguet. This is understood since Arabica coffee is an introduced crop in the Philippines.

In Ethopia, which was believed to be the origin of Arabica coffee, considerable phenotypic diversity was observed in cultivated and traditionally recognized landraces of Arabica coffee (Teketay, 1999; Dessalegn, 2002). Montagnon and Bouharmont (1996) classified wild and cultivated coffee accessions from Ethiopia according to their geographic origin using 18 agro-morphological characters. Silvarollaet al. (2004) identified three naturally decaffeinated Arabica coffee trees out of 300 accessions collected from Ethiopia. Similarly, a number of investigators reported the presence of cup quality variation among different Arabica coffee genotypes (Walyaro, 1983; Selvakumar and Sreenivasan, 1989; Roche, 1995).

Coffee arabica is the most important species for good quality coffee. Whereas many varieties and mutants of C. arabica are present in several Coffeagermplasm **C**ollections in many countries throughout the world, it has been reported that the genetic base of the cultivated varieties is rather narrow (Berthaud and Charrier, 1988). Under this circumstance, there is a reduced variability even at DNA level.

Table 6. Computed diversity indices of quantitative characters of Arabica coffee collections

QUANTITATIVECHARACTER	DIVERSITY INDEX
Total seed yield per tree	0.20
Weight of 100-bean seed	0.14
Fresh berries yield per tree	0.15
Seed length	0.11
Seed width	0.14
Fruit length	0.21
Fruit width	0.20
Fruit thickness	0.24
Flowers/axil (#)	0.24
Flowers/fascicle (#)	0.14
Fascicles/node (#)	0.14
Leaf length	0.22
Leaf width	0.17
Leaf petiole length	0.04
Days from emergence to flowering (#)	0.22
Days from flowering to fruit setting (#)	0.20
Days from fruit setting to harvest (#)	0.28
Mean Diversity Index	**0.18**

Cluster Analysis

Cluster membership. The application of Ward's method of classifying the 152 Arabica coffee accessions bared six clusters (Table 7 and Figure7). The first main cluster consisted of 55 accessions belonging to the cultivar Typica mostly from Atok and Kibungan and further subdivided into two sub-clusters. The second main cluster (San Ramon) consisted of three sub-clusters composed of 23, 7, and 3 accessions, respectively.

The third cluster constituted two accessions from Mondo Nuvo cultivars (MN001 and MN002) collected from Kibungan and Kabayan. Cluster 4 (Granica) had 34 accessions sub-divided further into two sub-clusters with 4 and 30 accessions, respectively (Figure7). Cluster 5 (Red Bourbon) had 23 accessions consisting of 2 sub-clusters with 7 and 16 accessions, respectively. Cluster 6 had a lone accession of Moka collected in Atok (Figure 7).

Cluster Characteristics

Cluster 1 (Typica) had a characteristic of wide seeds, long fruits, many flowers and early fruit setting. Cluster 2 (San Ramon) with sub-cluster 1 was composed of accessions with long and wide fruits and seeds.

Sub-cluster 2 was composed of accessions with high green bean yield per tree while accessions in the sub-cluster 3 were characterized with wide leaves and many flowers per axil. Cluster 3 (Mondo Nuvo) accessions were characterized by long and wide fruits, long leaves and petioles; and high green bean yield (Table 8).

Cluster 4 (Granica) accessions were characterized with many flowers per axil. Sub-cluster 1 was composed of accessions with thick fruits, long seeds, and heavy 100green bean weight. Sub-cluster 2 accessions had long leaves and petioles; broad leaves, wide fruits and seeds; and longer days from flowering to fruit setting (Table 8).

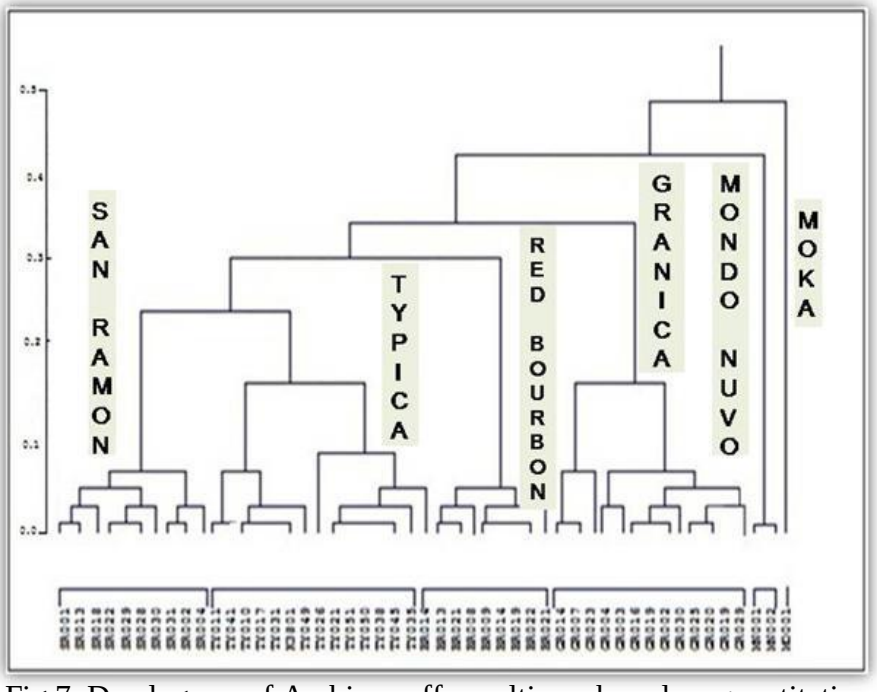

Fig.7. Dendogram of Arabica coffee cultivars based on quantitative characters

Clusters 5 (Red Bourbon) with sub-cluster 1 accessions were characterized by long seeds and longer time to bear flowers; many flowers per axil, flowers per fascicle; and shorter days from fruit setting to harvesting. Its sub-cluster 2 accessions were characterized by long leaves, thick and wide fruits, and numerous fascicles per node. Cluster 6 (Moka) wass composed of one accession with unique characters such as narrow

fruits and leaves; small seeds, fruits, leaves, and petioles; numerous flowers per axil; low yield; and shorter days from emergence to flowering (Table 8).

The morphological diversity among the Arabica cultivars was low. Nevertheless, six main clusters were formed representing Typica, San Ramon, Mondo Nuvo, Granica, Red Bourbon, and Moka.

These C. arabica cultivars are characterized as self-compatible tetraploid species with low genetic diversity which has been attributed to its allotetraploid origin, reproductive biology and evolution process (Lashermeset al., 1996). Although low variability was observed, the sub-clustering may also mean variability among accessions within a cultivar. Variability may be caused by mutation within the cultivars.

It can be noted that the coffee trees were cultivated for centuries in Benguet; thus the possibility of mutation. Mutation had a big role in the development of the varieties such as "Caturra" from a Bourbon plantation in Brazil, "Pacas" variety in Santa Ana in 1949, and "Villa Sarchi" variety in Costa Rica in the 50's and 60's (SCC, 2012).

The Salvadoran Coffee Council (2012) describes the origin and characteristics of similar Arabica coffee cultivars. "Typica" from Yemen were the oldest coffee varieties with genetic base for the first coffee plantations grown in America and Asia.

It is known for its resistance and high yield. "Bourbon", propagated from the Bourbon Island was possibly a natural mutation derived from a number of Arabica types from Yemen and Ethiopia later brought to Reunion Island (formerly known as Bourbon Island). It was then introduced in East Africa, Brazil, and other Latin American countries (SCC, 2012).

All the varieties found in Latin America grown through the mid-20th century shared the same genetic base of the first "Typica" coffee grown successfully in the Amsterdam Nursery. Between 1860 and 1870 Bourbon coffees were introduced into Brazil and Central America. The selection program in 1930's in Brazil using Bourbon plantations resulted in best lines more productive than Typica such as Bourbon Amarello or Yellow Bourbon and the Bourbon Vermelho (Red Bourbon). In Guatemala, successive selections produced a variety "Bourbon Chocolá" (SCC, 2012).

Table 8. Main cluster and sub-cluster characteristics of Arabica coffee

Cultivars and Accessions in Benguet CLUSTER NUMBER	SUB-CLUSTER	NUMBER	CULTIVAR	CHARACTERISTIC
1	1.1	29	Typica	Wide seeds; long fruits; many flowers; early fruit setting
	1.2	26		
Sub-total		55		
2	2.1	23	San Ramon	Many flowers; wide leaves
	2.2	7		
	2.3	3		
Sub-total		37		
3		4	Mondo Nuvo	High yield; wide seeds; many flowers; long and wide fruits; long and wide leaves
4	4.1	4	Granica	High yield; many flowers; early flowering
	4.2	30		
Sub-total		34		
5	5.1	7	Red Bourbon	High yield; long seeds; wide leaves; early fruit setting
	5.2	16		Long leaves; thick and wide fruits;numerous fascicles per node.
Sub-total		23		
6		1	Moka	Early fruit setting; low yield

Bi-plot Analysis

Figure 8 shows the bi-plot characteristics of all the Arabica coffee accessions. The graph shows the association between plant characteristics and the different accessions.

Cluster 1 was highly associated with fruit berries per tree and fruit thickness and early harvesting; hence, characterized as early maturing. Cluster 2 was highly associated with long days from flowering to fruit setting and to harvesting; thus, classified as late maturing.

Cluster 3 was superior in seed yield and fruit berries per tree and characterized with long and wide fruits; thus, can be considered as high yielding. Cluster 4 was highly associated with number of flowers per axil; thus, most productive in terms of flower produced. Cluster 5 was highly associated to longer days to flowering; hence, late bloomer.

Cluster 6 had low association with yield and yield components such as weight of 100 green beans, seed length, fruit length, and width; thus, a low yielder.

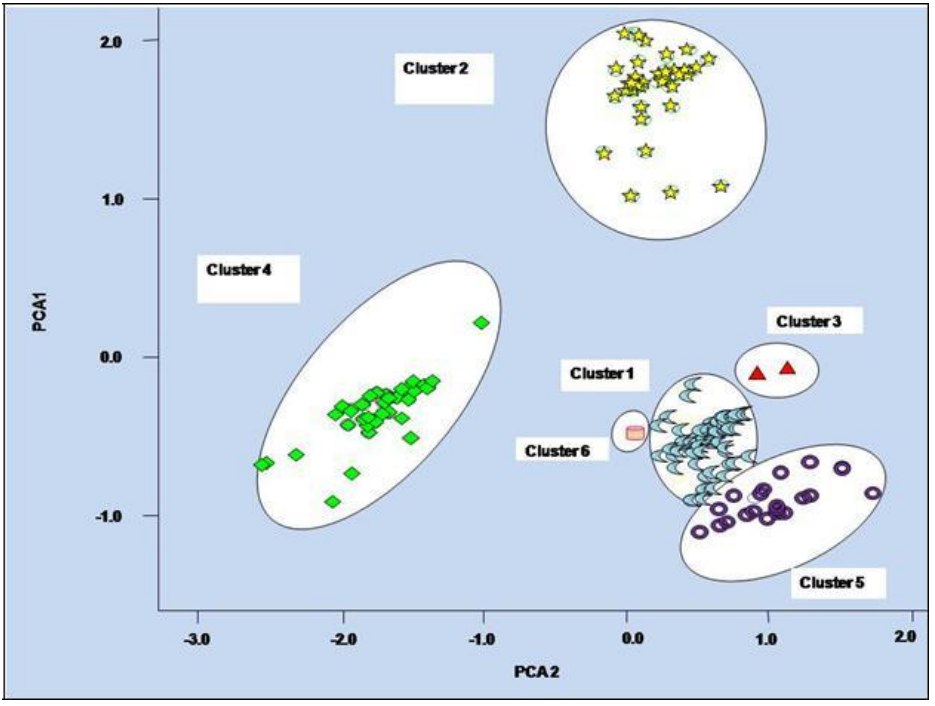

Fig.8. Bi-plot of characters of Arabica Coffee cultivars within a cluster

Principal Component Analysis of Quantitative Characters

The results of the principal component analysis for all the Arabica accessions are presented in Table 9. Principal component analysis shows that 83.96% of the variation was contributed by the six principal components. Number of days from flowering to fruit setting was the major contributor of the variation in the first principal component in which 30.96% of the variation was noted. A 46.3% of the total variability among the evaluated accessions accounted for the second principal component which originated from the number of days from flowering to fruit setting as well as from fruit setting to harvesting.

The third principal component, which explained 12.30% of the most variation among accessions was due to the variation in total seed yield and fruit berries per tree, fruit length, fruit width, leaf length, leaf width, and leaf petiole length. The fourth principal component which explained 11.44% of the total variation was associated with variation due to number of flower per axil.

The fifth principal component, which explained 7.52% of the total variation among accessions, was due to seed length and number of days from emergence to flowering.

And the sixth and last principal component explained the 6.43% of the total variation among accessions along weight of 100 seeds, seed length, fruit length, fruit width, number of flowers per axil, leaf length, leaf width, leaf petiole length, and number of days from emergence to flowering.

Phenotypic Correlations between Green Bean Yield andAgronomic Traits in Arabica Coffee

Table 10 summarizes the correlation coefficient among the 17 quantitative characters of Arabica coffee accessions. Green bean yield per tree had significant positive correlations with weight of 100 bean seeds per tree, seed length, fruit length, width and thickness, leaf width, leaf petiole length, and number of fascicles per axil, flowers per fascicle, fascicles per node, and days from fruit setting to harvesting.

This indicates that for every increase in characters, there is a corresponding increase in seed yield per tree. On the other hand, green bean yield had negative correlations with seed width, leaf length, number of days from emergence to flowering, and number of days from flowering to fruit setting.

Table 10. First six principal components for 17 quantitative characters of 152 Arabica coffee accessions

CHARACTER	PRINCIPAL COMPONENT					
	PC1	PC2	PC3	PC4	PC5	PC6
Total green bean yield per tree (g)	0.275	-0.733	0.228	-0.411	-0.012	-0.095
Wight of 100 bean seeds (g)	0.681	0.02	0.517	-0.22	-0.166	0.063
Fresh berries yield per tree (kg)	0.261	-0.593	0.143	-0.44	-0.064	-0.137
Seed length (mm)	0.069	0.024	0.514	-0.335	-0.396	-0.24
Seed width (mm)	-0.447	0.053	-0.137	0.45	0.32	0.164
Fruit length (mm)	-0.445	-0.375	0.602	0.034	-0.034	0.085
Fruit width (mm)	-0.151	-0.362	0.418	-0.01	-0.091	0.427
Fruit thickness (mm)	0.511	-0.336	0.257	-0.387	-0.206	0.213
Flowersaxil (#)	-0.301	-0.429	-0.129	0.493	-0.106	0.415
Flowers/fascicle (#)	-0.523	-0.168	-0.33	0.486	0.021	0.152
Fascicles/node (#)	-0.546	-0.341	0.236	-0.211	-0.276	0.462
Leaf width (cm)	0.624	-0.188	0.571	0.217	0.264	0.046
Leaf petiole length (cm)	-0.001	-0.248	0.777	0.34	0.411	-0.024
Days from emergence to flowering (#)	-0.447	0.584	0.49	-0.174	-0.033	-0.058
Days from flowering to fruit setting (#)	0.858	0.293	0.119	0.105	-0.072	0.036
Days from fruit setting to harvest (#)	0.723	-0.279	-0.291	0.227	-0.013	0.125
Eigen value	9.29	4.59	3.69	3.43	2.25	1.9
%variation explained	30.96	15.31	12.30	11.44	7.52	6.43
Cumulative % variation explained	30.96	46.27	58.57	70.01	77.53	83.96

PC = principal component

Association of fruit length with fruit width, number of flowers per axil, leaf length, leaf petiole length, and number of days from emergence to flowering was found significant and positive while the association with number of days from flowering to fruit setting to harvesting was found significant but negative. Correlations of number of flowers per axil with number of flowers per fascicle and number of fascicles per node were found significant and positively correlated. The number of days from emergence to flowering had significant negative correlation with green bean yield per tree, which implies that earliness in flowering may be achieved at the expense of green bean yield per tree. Similar results found by some researchers on the same subject show positive andsignificant association of characters with green bean yield. Walyaro and Vossen (1979) claim that girth at base of stem and percentage bearing primaries of Arabica coffee were significantly associated with yield; thus, efficient selection indices. Similarly, Bouharmont (1998) found that morphological traits, stem diameter, plant height, and number of primaries were genetically correlated to the yield in Arabica coffee. Indirect prediction of yield using morphological traits gave the same value for expected genetic gain as the prediction based on cumulated yield over four years.

Table 11. Correlation coefficient among 17 quantitative morphological characters of Arabica coffee

	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	0.369*	1															
Fby/t	0.947**	0.290*	1														
Sdl	0.242*	0.389*	0.221*	1													
Sdw	-0.282*	-0.534**	-0.267*	-0.324*	1												
Ftl	0.220*	-0.017	0.121	0.166*	0.081	1											
Ftw	0.208*	0.061	0.134	0.102	0.007	0.552**	1										
Ftth	0.498**	0.577**	0.439**	0.270*	-0.507**	0.064	0.067	1									
Nfpa	0.018	-0.334*	-0.013	-0.200*	0.325*	0.238*	0.159	-0.162*	1								
Nfpf	0.276*	-0.558**	-0.274*	-0.309*	0.421*	0.007	-0.034	-0.439**	0.662**	1							
Nfpn	0.225*	-0.111	0.142	0.173*	0.112	0.458	0.335*	0.067	0.400**	0.245*	1						
Ll	-0.129	-0.405**	-0.183*	0.081	0.374*	0.612**	0.250*	0.377*	0.222*	0.343*	0.605**	1					
Lw	0.365*	0.665**	0.222*	0.186*	-0.159	0.078	0.138	0.301*	-0.087	-0.318*	-0.170*	-0.278*	1				
Lpl	0.197*	0.219*	0.065	0.143	0.127	0.520**	0.325*	0.102	0.127	-0.054	0.093	0.364*	0.655**	1			
NdE-F	-0.314*	0.051	-0.254*	0.294*	0.072	0.225*	0.039	-0.285*	-0.218*	-0.045	0.171*	0.529**	-0.113	0.117	1		
NdF-Fs	-0.003	0.657**	0.037	0.110	-0.369*	-0.412**	-0.201*	0.380*	-0.312*	-0.469**	-0.516**	-0.721**	0.524**	0.040	-0.23*	1	
NdFs-H	0.248*	0.314*	0.204*	-0.255*	-0.203*	-0.349*	-0.141	0.291*	0.057	-0.165*	-0.337*	-0.663**	0.388**	-0.060	-0.75**	0.588**	1

Total seed yield per tree (Tsy/t)
Weight of 100 seed bean (W100sb)
Fruit/berryberry per tree (Fby/t)
Seed length (Sdl)
Seed width (Sdw)
Fruit length (Ftl)
Fruit width (Ftw)
Fruit thickness (Ftt)
Number of flowers per axil (Nfpa)
Number of flowers per fascicle (Nfpf)
Number of fascicles 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 fruits from setting to harvesting (NdFs-H)

* and ** indicates significant correlations at $p \leq 0.05$ and 0.01, respectively

found that morphological traits, stem diameter, plant height, and number of primaries were genetically correlated to the yield in Arabica coffee. Indirect prediction of yield using morphological traits gave the same value for expected genetic gain as the prediction based on cumulated yield over four years.

SUMMARY AND CONCLUSION

Germplasm Collection Sites and Cultivars/Accessions Collected

One hundred fifty-two/three(152/3?) Arabica coffee accessions were collected from the 13 municipalities of Benguet classified under the different agro-ecological zones. Most of the Arabica coffee cultivars were found mostly in the low and mid-mountain zones while few cultivars were observed in the high hill zone. Typica had the highest number of accessions with 53 followed by San Ramon (35), Granica (30), Bourbon (24), Yellow Caturra (4), Kenya (2), Mondo Nuvo (2), San Ramon Selection (2) and Moka (1). Currently, collected accessions are being maintained at the BSU-Institute of Highland Farming Systems and Agroforestry (IHFSA) gene bank.

Phenology of Arabica Coffee Cultivars

Granica and Red Bourbon growing in the high hill zones were the earliest to fill fruit at 105 days after fruit setting while San Ramon growing at mid-mountain zone was the latest to fill fruit at 115 days after fruit setting. Ripening of Arabica coffee in Benguet varies across agro-ecological zones. Granica, Red Bourbon, and Typica were the earliest to be harvested at 60 days while San Ramon growing at the mid-mountain zone was the latest to be harvested at 72 days after fruit setting. Arabica coffee in the low and mid-mountain zones starts turning ripe from November and harvesting lasts until March.

RECOMMENDATIONS

Collected accessions being maintained at the BSU- IHFSA gene bank can be further evaluated for selection of potential coffee accessions. Arabica coffee researchers can also work on the cultural management practices aspect. The variation detected among accessions and cultivars is an indication of not pure cultivars; thus, further characterization using molecular markers can be done. This is significant in selection or future improvement of the crop and more importantly determining the purity of the best performing cultivar for seed production.

The presence of sub-cluster within a cluster may indicate new variants; thus showing a promise of selection for potential accessions for the improvement of Arabica coffee in Benguet.

Among the characters, weight of 100 bean seeds per tree, fruit berries per tree, seed length, fruit length and width, number of fascicles per axil, number of flowers per fascicle, number of fascicles per node, leaf width, and leaf petiole length can be used as selection indices for high yield in Arabica coffee under organic production.

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