ARTICLE

Adaptability and stability of organic-grown arabica coffee production using the modified centroid method

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Abstract: *This study aimed to identify promising arabica coffee genotypes for organic systems. The experiments were arranged in a randomized block design, with 30 genotypes and three replications. The adaptability and stability analysis was carried out using the modified centroid method, considering the mean yield of two biennia (2005/2006 and 2006/2007, 2007/2008 and 2008/2009) in three municipalities (Araponga, Espera Feliz, and Tombos), totaling six environments. Significant genotype x environment interaction was observed for yield, and the municipality of Espera Feliz was the only favorable environment. Genotypes were classified into four of the seven groups proposed by the modified centroid method: maximum general adaptability (I), minimum adaptability (IV), mean general adaptability (V), and mean specific adaptability to favorable environments (VI). Cultivars IBC Palma 1, CatucaíAmarelo24/137, Sabiá 708, and H 518 are widely adapted, stable, productive and suitable for organic farming.*

Key words*: Coffea arabica, genotype x environment interaction, principal components, organic agriculture.*

INTRODUCTION

Brazil is the largest coffee producer and exporter in the world, and accounts for about one third of the production and exports worldwide (OECD/FAO 2015). Since its introduction in the country in 1727, coffee has been managed in several ways, always seeking maximum yields, requiring heavy use of chemical inputs, which can negatively impact the environment. This fact, combined with the growing demand by the consumer market, which has increasingly become aware of environmental and social issues involved in the production process, have required the search for more sustainable production systems, such as organic and agroecologically-based ones (Moura et al. 2011).

Organic coffee is the most important category in the segment of certified coffee. Mexico, Honduras, Indonesia, Ethiopia, Colombia and Brazil are the largest organic coffee exporters, accounting for 84% of world trade, and the main destinations are the US, Germany, Belgium, Canada, Sweden and Japan (ICO 2014).

Production and trade of organic coffee have grown worldwide. Coffee export tripled in 2013, when compared with 2005, to approximately one million and two

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hundred bags, while Brazil's share in that period increased from 10,371 to 78,568 bags (ICO 2014). Despite this growth expectation, production in the country is still in its initial stages. This may be associated with unsuitable cultivars, and with the fact that organic farms were established by the conversion of existing conventional farms, keeping the previous cultivars. In fact, crops are formed mostly by the cultivars Catuaí Vermelho, Catuaí Amarelo, and Mundo Novo, which are highly susceptible to rust (*Hemileia vastatrix*), a major coffee disease (Malta et al. 2008). In this context, investments in research are necessary to provide the information for the recommendation of cultivars for organic production. Since coffee is a perennial and biennial crop, research demands long periods of assessments. In addition, coffee producing regions in Brazil have very different characteristics, whichfavor the genotypes x environments interaction. The recommendation of stable cultivars with wide adaptability is an alternative to mitigate this interaction (Cruz et al. 2012). According to Moura et al. (2014), the estimates of adaptability and stability parameters should be analyzed based on biennia yield, aimed at selecting promising cultivars for organic systems.

Stability and adaptability analysis allowed the identification of cultivars with predictable behavior, and which are responsive to environmental variations, in specific or broad conditions (Cruz et al. 2012). Among several methodologies for this purpose, the centroid method (Rocha et al. 2005) has been widely used in several crops, including soybean (Barros et al. 2010, Pelúzio et al. 2010, Barros et al. 2012), tomato (Pereira et al. 2012), sweet potato (Amorin et al. 2011), and coffee (Rocha et al. 2015). The centroid method is based on the principal components methodology, and takes into account the genotype x environment interaction. Its main advantages, when compared with others methods, are the recommendation of genotypes and their classification into four ideotypes of maximum or minimum adaptability in response to the data set, and the use of the estimated probability as a classification criterion, avoiding duplicity of interpretation, and allowing the analysis of a large number of genotypes simultaneously (Rocha et al. 2005). This method has been recently modified by Nascimento et al. (2009), who added three other ideotypes of average performance, providing a greater scope for the genetic characterization and ensuring greater biological sense to the method.

The recommendation of coffee cultivars for organic systems has presented varieties adapted to different environments, according to the methodology proposed by Eberhart and Russell (Moura et al. 2014). However, this method has some limitations, since they group genotypes in a few classes of adaptability and stability, which requires the use of more modern methods that allow greater flexibility in the classification and selection of genotypes, such as the modified centroid method.

Therefore, the aim of this study was to identify promising coffee genotypes for organic systems, using adaptability and stability analysis with the modified centroid method in different environmental conditions.

MATERIAL AND METHODS

The experiments were arranged in a randomized complete block design, with 30 genotypes (cultivars and lines) and three replications, in the municipalities of Araponga, Espera Feliz and Tombos. The plots consisted of 10 plants, spaced 0.5 m within rows and 4.0 m between rows for short cultivars, and 0.8 m within rows and 4.0 m between rows for tall cultivars. The experimental sites were selected based on the tradition of family farming and organic coffee production, and on different soil and climatic conditions. The municipality of Araponga (lat 20° 40´ S, long 42° 31´ W and alt 1040 m asl), presents mesothermal humid subtropical climate, with minimum and maximum annual average temperature of 14.8 and 26 ºC, respectively; the soils is classified as Oxisol, A moderate, with clayey texture and high potential acidity. Espera Feliz (lat 20° 39´ S, long 41° 54´ W and alt 772 m asl), presents tropical climate and average annual temperatures ranging from 12.8 to 25.3 ºC; the soil is classified as Oxisol, A moderate, with clayey texture. Finally, Tombos (lat 20° 54´ S, long 42° 01´ W and alt 620 m asl), presents warm tropical climate, with seven months of drought, minimum and maximum annual average temperature of 12.6 and 30.8 ºC, respectively; the soil is classified as Paleudult-Yellow soil, A weak, with very clayey texture.

The cultivars and lines used in the study include: short and resistant to rust – 'Paraíso MG H 419-1', 'Obatã IAC 1669-20', 'Tupi IAC 1669-33', 'IAPAR 59', 'Acauã', and the lines H 514 and H 518; short and moderately resistant to rust –'Catucaí Amarelo 24/137', 'Catucaí Vermelho 36/6', 'Catucaí-Açu', 'Catucaí 785/15', 'IBC Palma 1', 'IBC Palma 2','Oeiras MG 685', and 'Sabiá 708'; short, moderately resistant to rust, and resistant to leaf miner – 'Siriema 842'; tall and moderately resistant to rust – 'Canário', 'Icatu Precoce IAC 3282', 'Icatu Vermelho IAC 4045', and 'Icatu Amarelo IAC 2944'; short and susceptible to rust – 'Rubi MG 1192', 'Topázio MG 1190', 'Ouro Verde IAC H 5010-5', 'Catuaí Amarelo IAC 62', 'Catuaí Vermelho IAC 15', 'Caturra Amarelo IAC 476', and 'Caturra Vermelho IAC 477'; tall and susceptible to rust – 'Acaiá Cerrado MG 1474', 'Mundo Novo IAC 379-19', and 'Maragogipe' (Carvalho 2008).

Liming fertilization at planting and top dressing of the experimental areas were based on both soil analysis and on the Lime and Fertilizer Recommendations for coffee crop in Minas Gerais (Ribeiro et al. 1999), using dolomitic limestone, cattle manure, thermophosphate, and double of potassium and magnesium sulfate, which are allowed for organic farming.

Throughout the experiment, soil liming, topdressings, and foliar fertilizations were carried out according to the crop requirement. Nitrogen sources included castor cake, complemented with green manures, such as the legumes *Crotalaria juncea* and *Arachis pintoi,* grown between the coffee rows, and cut at the beginning of flowering. The other nutrients were provided by the same sources used at planting. Foliar fertilization was carried out with the Supermagro biofertilizer. Weeds management included hoeing and regular mowing, and residues were used as mulch.

Coffee bean yield was assessed, measured in liters, and converted into 60 kg bags ha^{-1} $year^{-1}$, of processed coffee for four years. Analysis was performed using the means of the biennia, in which biennium 1 consisted of the harvests 2005/2006 and 2006/2007, and biennium 2consisted of the harvests 2007/2008 and 2008/2009, in three locations (Araponga, Espera Feliz and Tombos). The combination of each biennium and locations resulted in the formation of six environments: Araponga (2005/2006 and 2006/2007), Espera Feliz (2005/2006 and 2006/2007), Tombos (2005/2006 and 2006/2007), Araponga (2007/2008 and 2008/2009), Espera Feliz (2007/2008 and 2008/2009), and Tombos (2007/2008 and 2008/2009).

Data were examined by the joint analysis of variance, based on the plot means, and the sources of variation were analyzed as block/environments, genotypes, environments and genotype x environment interaction.

Adaptability was analyzed by the centroid method (Rocha et al. 2005), modified by Nascimento et al. (2009). The centroid method compares the Cartesian distances between the genotypes and the seven ideotypes (control genotypes). The control genotypes were established based on the experimental data, in order to represent genotypes of maximum general adaptability (ideotype I), maximum specific adaptability to favorable environments (ideotype II), maximum specific adaptability to unfavorable environments (ideotype III), minimum adaptability (ideotype IV), mean general adaptability (ideotype V), meanspecific adaptability to favorable environment (ideotype VI), and mean specific adaptability to unfavorable environment (ideotype VII). To use this method, the environments were classified into favorable and unfavorable, according to the environmental index proposed by Finlay and Wilkinson (1963):

$$Ij = \frac{1}{g}\sum_i Yij - \frac{1}{ag} Y...,$$

in which Y_{ij} = mean of genotype iin the environment j; Y...= total observations; a = number of environments; and g = number of genotypes. After the formation of the environments and the determination of the reference points (ideotypes), the Cartesian distances between the genotypes and the seven ideotypes were compared.

A measure of spatial probability was calculated using the inverse of the distance between one treatment and the seven ideotypes: $P_{d(i,k)} = \frac{\left(\frac{1}{d_{ik}}\right)}{\sum_i \frac{1}{d_{ik}}}$, in which: $P_{d(i,k)}$ is the probability of having stability similar to the *k*-th centroid, and d_{ik} is the distance of the *i*-th genotype to the *k*-th centroid in the plane formed by the principal component analysis. All statistical analyses were performed using the software Genes (Cruz 2013).

RESULTS AND DISCUSSION

The joint analysis of variance for yield showed significant effects between genotypes, environments, and between the genotype x environment interaction, by the F test at 1% probability (Table 1). The significant genotype x environment interaction shows that yield was influenced by both the genotype and the crop environment, this is a basic premise for adaptability analysis and phenotypic stability of genetic material.

Espera Feliz was the only municipality with favorable environment for yield, represented by the positive index in

Table 1. Summary of the analysis of variance of yield (bags ha^{-1} of processed coffee) of 30 coffee genotypes in six organic farming environments in the Zona da Mata region of Minas Gerais

Sources of variance	df	Mean Squares
Blocks/Environments	12	110.12
Genotypes (G)	29	1141.77**
Environments (E)	5	9511.31**
G x E	145	93.90**
Error	348	52.04
Total	539	
Mean	28.33	
CV (%)	25.47	

** Significant at 1% probability by the F test

Table 2. Estimates of means yield (bags ha^{-1} of processed coffee) of coffee genotypes and environmental index (Ij) for the six organic farming environments in the Zona da Mata region of Minas Gerais, according to the modified centroid method

Environments	Mean	I_j
Araponga (2005/2006 e 2006/2007)	27.09	-1.24
Espera Feliz (2005/2006 e 2006/2007)	29.67	1.34
Tombos (2005/2006 e 2006/2007)	20.96	-7.37
Araponga (2007/2008 e 2008/2009)	24.14	-4.19
Espera Feliz (2007/2008 e 2008/2009)	47.98	19.65
Tombos (2007/2008 e 2008/2009)	20.14	-8.19

Positive I_j = favorable environment
Negative I_j = unfavorable environment

Table 2, with a mean of 38.83 bags ha^{-1} of processed coffee. Possibly, soil and climatic conditions of this municipality were favorable to the growth and development of genotypes in organic farming. On the other hand, the lowest mean yields were recorded in the municipalities of Araponga (25.62 bags ha^{-1} of processed coffee) and Tombos (20.55 bags ha^{-1} of processed coffee), which had negative environmental indices (Table 2) and were classified as unfavorable environments. In Tombos, this mean yield may be due to the high water deficits (116.7mm) in the region (Calderano Filho et al. 2014), higher temperatures and less favorable physical characteristics of the soil; conversely, the municipality of Araponga has low temperatures and high soil potential acidity.

In the adaptability and stability analysis, the first two principal components accounted for over 86% of the total variation (Table 3), which was above the values for alfalfa by the methods of modified centroid (Nascimento et al. 2009) and multiple centroid (Nascimento et al. 2015), generating a two-dimensional plot of genotype dispersion (Figure 1). Heterogeneous distribution of genotypes was observed for yield; however, some points (genotypes) were very close to four of the seven proposed centroids, allowing the classification of genotypes as maximum general adaptability (ideotype I), minimum adaptability (ideotype IV), mean general adaptability (ideotype V), and mean specific adaptability to favorable environments (ideotype VI). These results allow the breeder to recommend genotypes that are widely adapted to a number of environments or to a specific environment. Nevertheless, a large number of points (genotypes) dispersed in the central region of the graphic was noticed, which makes genotypes grouping difficult (Figure 1). A similar trend has been observed by several authors (Rocha et al. 2005, Barros et al. 2010, Pelúzio et al. 2010, Amorin et al. 2011, Barros et al. 2012, Pereira et al. 2012). Thus, the estimate of the probability associated

Table 3. Estimates of the eigenvalues and cumulative percentage of variance explained by the principal components

Root	Root (%)	% Accumulated
3.9686466	66.14	66.14
1.2337021	20.56	86.71
0.3214533	5.36	92.06
0.2719255	4.53	96.60
0.1329512	2.22	98.81
0.0713213	1.19	100.00

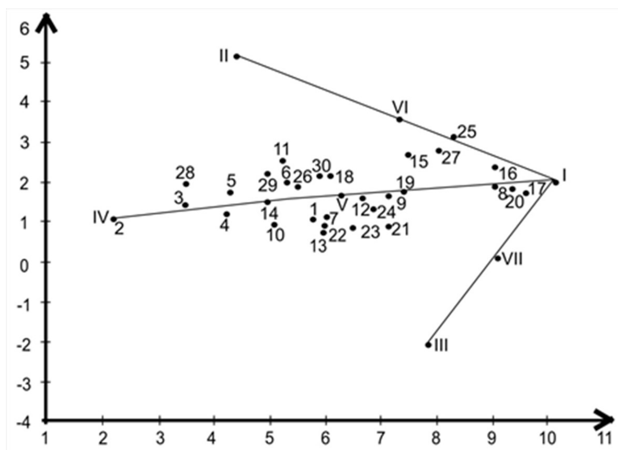

Figure 1. Scores scatter plot of the first two principal components of the yield analysis (bags ha^{-1} of processed coffee) of 30 genotypes in six organic farming environments in the Zona da Mata region of Minas Gerais. The seven points numbered with Roman numerals represent the ideotypes: I - maximum general adaptability; II - maximum specific adaptability to favorable environment; III - maximum specific adaptability to unfavorable environments; IV - Minimum adaptability; V - mean general adaptability; VI - mean specific adaptability to favorable environment, and VII - mean specific adaptability to unfavorable environments. PC1, principal component 1; PC2, principle component 2.

with genotype classification provides amore reliable recommendation, according to the degree of adaptability to the different environments studied (Rocha et al. 2005), as shown in Table 4.

Most genotypes presented mean general adaptability (ideotype V) with mean yield of 26.84 bags ha^{-1} of processed coffee; however, Obatã IAC 1669-20, Rubi MG 1192, and Catucaí 785/15 presented the highest probabilities (above 40%) of belonging to this group (Table 4). Moura et al. (2013) reported variability among genotypes belonging to this group for rust resistance in organic farming, which should be considered when recommending these genotypes, since the use of agrochemicals to control diseases is not allowed in organic agriculture. Among the genotypes that make up this group, Obatã IAC 1669-20, Tupi, and IAPAR 59 stood out for presenting higher yields in the conventional systems; the first (Obatã IAC 1669-20) was classified as tolerant genotype (Mendonça et al. 2016), and the last two (Tupi and IAPAR 59) were classified as coffee with resistance to rust (Shigueoka et al. 2014).

The genotypes IBC Palma 1, Catucaí Amarelo 24/137, Sabiá 708, and H 518had maximum general adaptability, and stood out from the others (ideotype I). These genetic materials were highly productive (up to 40 bags ha^{-1} of processed coffee), regardless of the assessed environment, and presented high potential for organic farming. All genotypes belonging to this group are genetically resistant to rust and are also promising when evaluated by Moura et al. (2014), using the method of Eberhart and Russel, which can be attributed to the association between this method and the method used in this study, as reported by Nascimento et al. (2013).

Table 4. Estimates of means yield (bags ha^{-1} of processed coffee), classification of coffee genotypes into one of the seven groups proposed by the modified centroid method, and the probability associated with the classification of each genotype

Genotypes	Classification	Probabilityy	Yield
IBC Palma 1	I: Maximum general adaptability	0.3194	40.75
Catucaí Amarelo 24/137		0.2748	40.89
Sabiá 708		0.3923	42.64
H 518		0.3629	41.79
Maragogipe	IV: Little adaptability	0.8735	10.79
Acaiá Cerrado MG 1474		0.3193	16.66
Mundo Novo IAC 379-19		0.2341	19.40
Caturra Vermelho IAC 477		0.2829	16.80
Icatu Amarelo IAC 2944	V: Mean general adaptability	0.2896	26.13
Icatu Vermelho IAC 4045		0.2529	20.13
Icatu Precoce IAC 3282		0.2769	25.07
Catucaí 785/15		0.4064	27.09
H 514		0.3141	32.39
Acauã		0.2644	22.86
Topázio MG 1190		0.2811	24.85
Ouro Verde IAC H 5010 - 5		0.3867	29.86
Catuaí Amarelo IAC 62		0.2913	26.04
IAPAR 59		0.3124	22.93
Obatã IAC 1669-20		0.4583	27.91
Oeiras MG 6851		0.3023	33.32
Siriema 842		0.2952	31.35
Canário		0.2821	26.19
Tupi IAC 1669-33		0.3031	28.71
IBC Palma 2		0.309	30.25
Catucaí Açu		0.2923	24.89
Caturra Amarelo IAC 476		0.2782	22.96
Rubi MG 1192		0.4168	27.04
Catuaí Vermelho IAC 15	VI: Mean specific adaptability to favorable environment	0.2964	34.41
Catucaí Vermelho 36/6		0.3307	38.47
Paraíso MG H 419-1		0.2703	37.34

The cultivars Catuaí Vermelho IAC 15, Catucaí Vermelho 36/6, and Paraíso MG H 419-1 had mean specific adaptability to favorable environments (ideotype VI), being responsive to environmental improvement and indicated only for high-tech crops and favorable soil and climate conditions. These cultivars should be used with caution, since according to Borém et al. (2017) these genotypes are suited for environmental conditions that can be controlled for high performance. In this group, only the genotype Catuaí is highly susceptible to leaf rust, which is coffee's main disease, as evidenced by Shigueoka et al. (2014). Nevertheless, this cultivar has high yield in organic system (Table 5), reinforcing the need for suitable fertilizer, especially when it comes to the use of susceptible genotypes.

Only 13.32% of the genotypes were classified as of little adaptability (ideotype IV); all of them were genetically susceptible to rust and presented low yield, which is undesirable for the selection process due to their unpredictable behavior. Furthermore, this group contains cultivars Caturra Vermelho and Maragogipe, which are old and little genetically improved.

The findings of this study confirm that the evaluation of adaptability and genotypic stability by the modified centroid method is effective in the identification of productive cultivars adapted to organic farming system under different environmental conditions. Cultivars IBC Palma 1, Catucaí Amarelo 24/137, Sabiá 708 and H 518 are widely adapted, stable, productive and suitable for organic farming.

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