UNIVERSIDAD NACIONAL DE COLOMBIA

Periodicidad: Cuatrimestral
Vol. 70 No. 3 - 2017

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Teléfono: (*4) 430 90 06; Fax: (* 4) 230 04 20
Diagramación: Miryam Ospina Ocampo
Marcación: LandSoft S.A.
Diseño e Impresión: Pato Amarillo Estudio de Diseño
Primera edición: Año 1939
ISSN: 0304-2847
ISSN formato web: 2248-7026
Doi: 10.15446/rfnam

Licencia Ministerio de Gobierno: 275/64

EVALUADORES

El Comité Editorial dentro de sus políticas, envía los artículos a especialistas, con el fin de que sean revisados. Sus observaciones en adición a las que hacen los editores, contribuyen a la obtención de una publicación de reconocida calidad en el ámbito de las Ciencias Agrarias. Sus nombres son mencionados como una expresión de agradecimiento.

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EDITORIAL

Importancia de la apropiación social y el acceso abierto al conocimiento especializado en ciencias agrarias

La Revista Facultad Nacional de Agronomía (RFNA) ha procurado, desde su fundación en 1939, mantener criterios de calidad en el proceso de revisión y publicación, acordes con su política editorial y los estándares nacionales, regionales e internacionales de comunicación científica, sin perder su *ethos* editorial y en particular buscando fortalecer los procesos de investigación, escritura, comunicación y acceso a la ciencia y la tecnología para hacer más productivo el campo a nivel empresarial y de economía campesina.

Próximamente la Revista cumplirá ochenta años de producción editorial; este esfuerzo de la Facultad de Ciencias Agrarias de la sede Medellín, materializa uno de los fines misionales de la Universidad Nacional de Colombia, el cual es "hacer partícipes de los beneficios de su actividad académica y científica a los sectores sociales que conforman la nación colombiana"[1]. Durante estas ocho décadas, la Revista ha publicado 70 volúmenes, 140 números y más de 700 artículos. Al lado de ello, ha fortalecido su proceso de edición, visibilidad e impacto, así lo demuestran los datos: categoría A2 en Publindex (2014), H5 de 8 en Google Scholar (2017)[2], lo que la ubica en el cuartil 1 de su área de conocimiento según Publindex[3], indexación en Scopus (2016) y registro en varios sistemas de información y resumen, como lo son: SciELO Citation Index, SciELO Colombia, Biological Abstracts, CAB Abstracts, Redalyc, Dialnet y Doaj, entre otros.

De esta manera, es posible observar cómo una de las formas de medir la calidad, visibilidad e impacto de una publicación científica es a través de indicadores bibliométricos que buscan clasificar las revistas de investigación en función de su repercusión en la comunidad científica. Dicho proceso requiere que cada revista realice un arduo trabajo de registro en índices bibliográficos de citaciones, bases bibliográficas con comité de selección, catálogos de bibliotecas y redes internacionales de investigación. Sin embargo, se debe mencionar que la relevancia de una publicación científica, medida a través de un indicador cuantitativo como el Factor de impacto, que compara revistas y las categoriza calculando la frecuencia con la cual un artículo promedio de una revista científica es citado en un año o período particular, no permite determinar de forma exacta la calidad de sus artículos, tampoco la integridad académica de los autores y mucho menos la apropiación social del conocimiento.

Hemos visto cómo, las universidades públicas son uno de los lugares en los cuales se genera y socializa la mayor cantidad de conocimiento, por tal razón, la comunicación y acceso son fundamentales para lograr que públicos amplios, más allá de los círculos académicos, se vean beneficiados del conocimiento que la actividad científica y de investigación produce. Cuando la investigación, sobre todo la que es financiada con recursos del Estado, generan bienes públicos o conocimientos que pueden convertirse en bienes públicos, estos últimos deben ser libremente apropiados por aquellos sectores sociales interesados. Es aquí cuando adquiere importancia iniciativas como la *apropiación social del conocimiento*.

La apropiación social del conocimiento se entiende como un proceso que implica, por un lado, la disposición de información científica en un escenario y lenguaje comunes para la sociedad; y por otro, que el ser humano haga suyos tales conocimientos como elementos útiles y necesarios para su beneficio y provecho. La apropiación social del conocimiento, desde lo que el sociólogo Manuel Castells definiría como la *sociedad informacional*, implica, entonces, la democratización del acceso y uso del conocimiento científico, como estrategia para su adecuada transmisión y aprovechamiento entre los distintos actores sociales, que derivará en el mejoramiento de la calidad de vida de las comunidades y sus integrantes.

En síntesis, la apropiación social del conocimiento le permite a cualquier ciudadano acceder, leer, copiar, usar, modificar, reutilizar y compartir el contenido de las publicaciones científicas sin ningún tipo de barrera legal, económica o tecnológica, haciendo la atribución de autoría. Bajo esta iniciativa, la Revista cuenta con una política de acceso abierto, a través de la cual provee acceso libre e inmediato a su contenido bajo el principio de hacer disponible, sin ningún tipo de barrera, los resultados de investigación al público y apoyar el intercambio de conocimiento de forma global.

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[1] Consejo Superior Universitario. 2005. Acuerdo 011 de 2005: Estatuto general de la Universidad Nacional de Colombia. http:// www.unal.edu.co/contenido/sobre_un/sobreun_naturaleza.htm.

[2] Google citations. 2017. https://goo.gl/zxTM1D.

[3] Resultados preliminares etapa II "Clasificación oficial" Convocatoria No. 768 de 2016 de Colciencias.

Por otra parte, el acceso abierto *open Access* (OA), es una iniciativa mundial que ha adquirido fuerza a medida que ha crecido el número de propuestas e investigaciones ligadas esencialmente a fortalecer el acceso a los resultados de investigación, como respuesta principalmente, al control de los derechos de autor y los altos costos de acceso al conocimiento producido con recursos públicos. Este tipo de iniciativas, que integran mecanismos legales como las licencias *Creative Commons* e infraestructuras tecnológicas basadas en software libre, como el *Open Journal System* (OJS), han permitido que, durante los últimos cinco años, la Revista contribuya en el fortalecimiento de la ingeniería agronómica, ingeniería forestal, ingeniería agrícola y de alimentos, producción animal, biotecnología y estudios transversales, así lo demuestran las siguientes estadísticas:

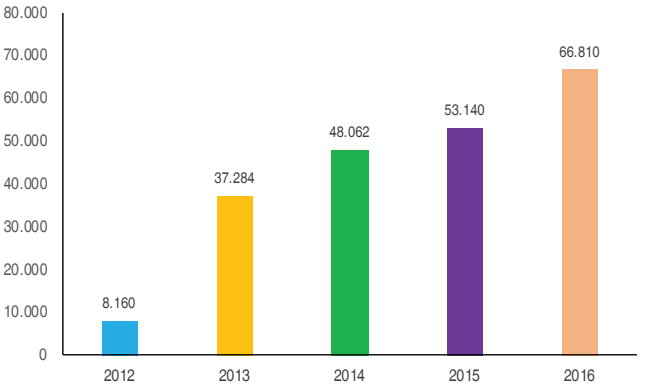

Figura 1. Visitas al sitio web de la Revista Facultad Nacional de Agronomía desde 2012 al 2016. *Adaptado de Google Analytics.*

El incremento exponencial de las visitas realizadas al OJS, sitio web de la Revista, refleja como la apropiación social al conocimiento se puede hacer realidad a través de iniciativas como el acceso abierto, así lo permite ver la Figura 1, en cinco años la visibilidad de la Revista a través de la web ha superado el alcance local, regional e internacional que muy posiblemente no lograría una publicación científica de circulación impresa, con barreras legales, económicas o tecnológicas de acceso.

No.	País	Visitas
1	Colombia	33,387 (49.97%)
2	Mexico	9,681 (14.49%)
3	Peru	4,375 (6.55%)
4	Ecuador	3,489 (5.22%)
5	España	2,317 (3.47%)
6	Argentina	1,712 (2.56%)
7	Venezuela	1,584 (2.37%)
8	Chile	1,466 (2.19%)
9	Brasil	932 (1.40%)
10	Bolivia	900 (1.35%)

No.	País	Visitas
11	Costa Rica	889 (1.33%)
12	Estados Unidos	761 (1.14%)
13	China	654 (0.98%)
14	Guatemala	585 (0.88%)
15	Honduras	346 (0.52%)
16	India	315 (0.47%)
17	Paraguay	310 (0.46%)
18	República Dominicana	256 (0.38%)
19	Nicaragua	247 (0.37%)
20	Panama	205 (0.31%)

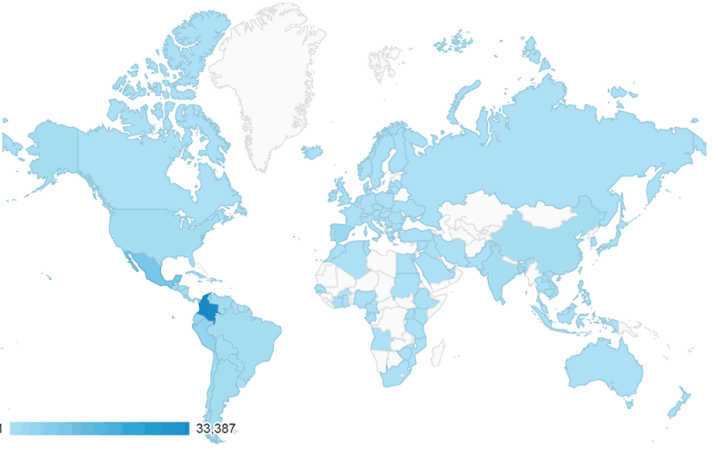

Figura 2. Visitas al sitio web de la Revista Facultad Nacional de Agronomía por país durante el 2016. *Adaptado de Google Analytics.*

Además de los primeros 20 países de la Figura 2, la Revista ha tenido visitas de otros 95 países, al lado de ello, es importante destacar que la Revista es leída por países de los cinco continentes del mundo. La participación más representativa de lectores la tiene los países de América Latina, no obstante, es significativa la participación de lectores de países asiáticos como China e India.

Los anteriores resultados permiten pensar que la apropiación social y acceso abierto al conocimiento son un componente estructural y vital para el desarrollo de cualquier país, este tipo de iniciativas aportan a equilibrar la balanza de la concentración del poder a través del conocimiento, además, abren la puerta a una pluralidad de puntos de vista, de paradigmas científicos y formas de edición.

Para finalizar, es posible decir que la apropiación social y el acceso abierto al conocimiento desde la web están en el corazón de las personas que trabajan en la construcción de un mundo más justo, libre y sensato.

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Research article

http://www.revistas.unal.edu.co/index.php/refame

Revista Facultad Nacional de Agronomía

Genetic analysis of morpho-physiological traits and yield components in F_2 partial diallel crosses of bread wheat (*Triticum aestivum* L.)

UNIVERSIDAD NACIONAL DE COLOMBIA

Análisis genético de caracteres morfo-fisiológicos y componentes de rendimiento en cruzamientos dialélicos parciales en F_2 de trigo pan (*Triticum aestivum* L.)

doi: 10.15446/rfna.v70n3.61927

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ABSTRACT

Wheat breeding in the semi-arid region of Algeria aims to develop new cultivars combining high productivity and good abiotic stress tolerance. Therefore, it is essential to understand the genetic control of these characteristics. Nine parents of bread wheat and 20 derived F_2 hybrid populations developed in a partial diallel scheme (group 1 composed 5 parents and group 2 contained 4 parents) were evaluated with three replications at the Experimental Station of the National Agronomic Research Institute of Algeria (INRAA), Setif Unit, during the 2012-2013 crop season. Results of the diallel analysis, indicated that the components associated with additive effects were more relevant than those associated with the dominance effects for most of the studied traits. Based on the proportion between dominant and recessive genes in all parents, the dominant alleles were present in greater frequency in group 1. Values of the gene proportion with positive and negative effects in the parents revealed an unequal distribution of dominant genes in the parents for almost all the traits except for chlorophyll content and grain number per spike which showed a symmetric distribution. The average degree of dominance indicated over-dominance for most of traits, suggesting that selection for these traits, in early generations, will be less efficient.

Keywords:
Breeding
Genetic parameters
Inheritance
Selection
Semi-arid

RESUMEN

El mejoramiento genético del trigo en la región semiárida de Argelia tiene como objetivo desarrollar nuevos cultivares que combinen alta productividad y buena tolerancia al estrés abiótico. Por lo tanto, es esencial la comprensión del control genético de estos caracteres. Nueve padres de trigo panadero y 20 poblaciones híbridas F_2 derivadas, desarrolladas en un esquema de dialelo parcial (grupos 1 y 2 compuestos por 5 y 4 padres, respectivamente), se evaluaron usando tres repeticiones en la Estación Experimental del Instituto Nacional de Investigaciones Agronómicas de Argelia (INRAA), Unidad Sétif, durante la temporada de cultivo 2012-2013. Los resultados del análisis dialélico indicaron que los componentes asociados a los efectos aditivos fueron más relevantes que aquellos asociados con los efectos de dominancia para la mayoría de las características estudiadas. Basados en la proporción entre genes dominantes y recesivos de todos los padres, los alelos dominantes estuvieron presentes con mayor frecuencia en el grupo 1. Los valores de la proporción de genes con efectos positivos y negativos en los padres revelaron una distribución desigual de genes dominantes para casi todas las características, excepto el contenido de clorofila y el número de granos por espiga, que mostraron una distribución simétrica. El grado promedio de dominancia indicó sobredominancia para la mayoría de los caracteres estudiados, lo que sugeriría una menor eficiencia de selección en las primeras generaciones.

Palabras clave:
Mejoramiento
Parámetros genéticos
Herencia
Selección
Semiárido

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Received: January 13, 2017; Accepted: April 17, 2017

Rev.Fac.Nac.Agron. 70(3): 8237-8250. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

Bread wheat (*Triticum aestivum* L.) is one of the major food grain crops in the world, as it provides 20% of the total energy and protein in the human diet (FAO, 2016). It occupies an important position among the field crops cultivated in Algeria. Genetic improvement of wheat yield is the most targeted trait by breeders to enhance wheat production and meet the demand of a continuous population growth. This goal can be achieved either directly by selecting for high yield or indirectly by improving yield components and morphological traits, such as plant height, thousand-kernel weight, number of spikes and number of grains per spike (Hannachi *et al.*, 2013). In this context, knowledge of the genetic control of these traits related to wheat grain yield is essential in a breeding program to draw a selection strategy and manage the offspring. Several authors have tried to assess the genetic basis of traits involved in yield determination. The results are often inconsistent and scarce; however, a predominance of additive gene action has been observed with dominance effects for most traits studied (Saad *et al.*, 2010; Rashid *et al.*, 2012; Zare-kohan and Heidari, 2012; Nazir *et al.*, 2014). Several breeding strategies have been proposed and could be planned towards the genetic understanding of important traits of the concerned population (Mumtaz *et al.*, 2015). The best known are the Griffing (1956), Gardner and Eberhart (1966) and Hayman (1954) diallel approaches. These models are the most common designs used in wheat breeding programs, however, the use of diallel crosses is often limited due to the large number of crosses required to evaluate a certain group of parents. Also, there is not always interest to evaluate all possible combinations through a full diallel, mainly due to the difficulty of obtaining sufficient number of hybrid seeds and interest in combining the desirable traits to generate superior inbred lines. The partial diallel approach developed by Hayman (1954) and modified by Viana *et al.* (1999) is a promising alternative to study the gene effects and inheritance of plant architecture using F_1 and/or F_2 generations obtained from crosses involving homozygous parents (Cruz *et al.*, 2004). This information helps breeders to define the appropriate breeding strategy and (to) choose the most suitable parents to optimize the selection gain (Falconer and MacKay, 1996). In this method, the genetic analysis allows inferences about the basic mechanism of traits inheritance and assesses the potential of parents used to obtain promising segregating populations. The objective of this study was to estimate the genetic effects involved in the control of chlorophyll content, heading time, plant height and yield related traits in F_2 populations of bread wheat (*Triticum aestivum* L.) by mean of partial diallel scheme outlined by Viana *et al.* (1999, 2000, 2001).

MATERIALS AND METHODS

Plant Material

The experiment was conducted at the Algerian National Institute of Agronomic Research (INRAA), Setif Unit, Algeria (36°12'N, 05°24'E, 981 m asl). The climate is of a semi-arid type, with a total rainfall from September to June of 427.4 mm for the 2012-2013 cropping season. The soil is a calcisol of fine-grained texture (38.4% clay, 42.7% silt, 18.7% sand) and carbonate bearing (26.6% $CaCO_3$), with a pH of 8.2 and 1.35% organic matter (Kribaa *et al.*, 2001). Plant material utilized was generated from crosses among nine bread wheat varieties (Table 1), chosen on the basis of differences in adaptation and morpho-physiological characteristics (Fellahi *et al.*, 2013). These varieties were divided into two contrasting groups and crossed in 2011 in a partial diallel scheme. Group 1 was composed of five lines: $Acsad_{901}$, $Acsad_{899}$, $Acsad_{1135}$, $Acsad_{1069}$ and Ain Abid, and group 2 consisted of four lines, Mahon-Demias, Rmada, Hidhab and El-Wifak. The F_0 resulting seeds were grown in 2011-2012 crop season to develop the F_1 generation. The 20 F_2 hybrids, were planted along with their parents in 2012-2013 season in a randomized complete block design with three replications. The plots consisted of two rows of 10 meters with a spacing of 0.2 m between rows and 0.2 m between plants in the row. Thirty competitive plants were tagged before heading and data were recorded in each plant. The following traits were evaluated: number of calendar days from emergence to 50% heading (DHE, days); flag leaf chlorophyll content (Chl, CCI), estimated with a CCM-200 chlorophyll meter (Opti-Sciences, Tyngsboro, MA, USA); plant height (PHT, cm), measured from the ground level to the tip of spike excluding awns; number of spikes per plant (SN, No.), counted at physiological maturity; spike weight (SW, g), obtained by weighting each individual selected plant; number of grains per spike (GN) present in the plant; thousand-kernel weight (TKW, g), recorded by counting four 250 grain subsamples from each plant; above-ground biomass (BIO, g) and grain yield (GY, g), by individually threshing of each plant.

Table 1. Name, pedigree and source of the parental wheat genotypes used in the partial diallel crosses.

Genotypes	Pedigree	Source of material
	Group 1	
Acsad$_{901}$	Acsad529/4/C182.24/C168.3/3/Cno*2/7C//CC/Tob-0s	ACSAD (Syria)
Acsad$_{899}$	Acsad529/4/C182.24/C168.3/3/Cno*2/7C//CC/Tob-1s	ACSAD (Syria)
Acsad$_{1135}$	Prl/Vee6//Myna/Vul/3/Prew	ACSAD (Syria)
Acsad$_{1069}$	Zahrai I-14//HD21699/Bow's'	ACSAD (Syria)
Ain Abid	AS8189 'A'	Spain
	Group 2	
Mahon-Demias	Landrace	Balearic Islands (Spain)
Rmada	Vee's/Bow's//Alondra's/Pavon's	ACSAD (Syria)
Hidhab	HD1220/3*Kal/Nac CM40454	CIMMYT (Mexico)
El-Wifak	K134/4/Tob//Bman/Bb/3/Cal/5/Bucc	CIMMYT (Mexico)

ACSAD: Arab Center for the Studies of Arid zones and Dry lands, CIMMYT: International Maize and Wheat Improvement Center.

Statistical Analyses

The data collected for each trait were tested for the normal distribution of frequency using Kolmogorov-Smirnov test. The statistical procedures adopted for the analysis of variance involved the partitioning of the genotype source of variation into the parents, crosses and the contrast parents vs. crosses according to Viana *et al.* (2000). The means were grouped by the Scott and Knott (1974) test at a 5% probability level. The traits showing significant differences were further subjected to diallel cross analysis. Analysis of the partial diallel was performed according to the model proposed by Viana *et al.* (1999, 2000, 2001), adapted from the method of Hayman (1954) using parents and the F_2 generation. The following non-genetic and genetic parameters were estimated and their statistical significance was tested via *t* test.

D_1 = Genetic variation due to additive genetic effects of group 1
D_2 = Genetic variation due to additive genetic effects of group 2
D_3 = Genetic variation due to additive genetic effects in both groups of parents
H_1 = Genetic variation due to dominant genetic effects of group 1
H_2 = Genetic variation due to dominant genetic effects of group 2
h^2 = Dominance effects over all loci
F = Mean of covariance between additive and dominant genetic effects
E = Expected environmental component of variation

From the genetic components estimates, the following genetic parameters were determined, and their interpretations are related exclusively to the parental genotypes used in this study.

$(H_1/D)^{1/2}$ = Average degree of dominance over all loci
$H_2/4H_1$ = Proportion of positive and negative alleles
K_D/K_R = Proportion between dominant and recessive genes in all parents
$(K^+ - K^-)^2/K$ = Direction of dominance
h^2/H_2 = Number of effective factors
h^2_{ns} = Narrow sense heritability

The additive-dominant model validity was performed based on testing the values of the coefficient of regression of

offspring parent covariance (*Wr*) on parental array variance (*Vr*), against zero and against one for each trait. All statistical analyses were performed using the program Genes, version 2014.6.1 (Cruz, 2013).

RESULTS AND DISCUSSION

Analysis of Variance and Mean Performance

The results of the analysis of variance indicated significant differences between genotypes for nearly all traits, except for GY, which was not significant (Table 2). Partitioning the genotype effect indicated significant differences between all parents, between genotypes within each group of parents, and among groups of genotypes (Table 2). The contrast Parents vs. F_2, was highly significant for HD, PHT and SN, while the F_2 populations exhibited significant differences for almost all evaluated traits, except for SW, BIO and GY, which were not significant at the 5% probability level.

Table 2. Mean squares of plant traits studied in the partial diallel mating system.

Source of variation	df	Chl	HD	PHT	SN	TKW	SW	GN	BIO	GY
Block	2	169.34	16.38	210.41	9.59	3.06	91.31	62.47	111.58	37.83
Genotype	28	39.07**	23.96**	316.53**	5.02**	19.09**	23.84*	157.85**	70.29*	9.79^{ns}
Parents (P)	8	50.25**	36.24**	537.88**	4.62*	30.26**	26.94^{ns}	194.88**	117.75**	12.04^{ns}
Group 1 (G_1)	4	55.56**	12.34**	132.64**	2.06^{ns}	22.75**	42.62*	160.02*	60.53^{ns}	20.67*
Group 2 (G_2)	3	59.87**	79.44**	1143.78**	6.14*	50.25**	15.01^{ns}	207.99**	206.53**	4.44^{ns}
G_1 vs. G_2	1	0.11^{ns}	2.26 ^{ns}	341.10**	10.28*	0.29^{ns}	0.00^{ns}	295.04*	80.27^{ns}	0.33^{ns}
F_2	19	36.40**	17.82**	227.82**	4.96**	15.04**	21.48^{ns}	150.47**	49.96^{ns}	7.70^{ns}
P vs. F_2	1	0.22^{ns}	42.48**	231.23**	9.21*	6.78^{ns}	44.01^{ns}	1.78^{ns}	76.64^{ns}	31.42^{ns}
Error	56	12.34	3.10	12.60	1.68	5.19	13.46	49.37	34.07	8.03

df: degrees of freedom, Chl: Chlorophyll content, HD: Heading date, PHT: Plant height, SN: Number of spikes, TKW: Thousand-kernel weight, SW: Spikes weight, GN: Number of grains per spike, BIO: Biomass, GY: Grain yield. ns, *, **: non-significant and significant at 5% and 1% of probability, respectively.

The Scott-Knott means grouping test revealed significant differences between and within the two parental groups (Table 3). Within group 1, $Acsad_{899}$ had the highest average for Chl (40.38 unit) and for TKW (39.47 g), while $Acsad_{1135}$ was the tallest parent (73.10 cm) with 6.93 spikes per plant. The parent Ain Abid showed the highest means for HD, PHT, SW, GN, BIO and GY, with mean values of 138.67 days, 76.60 cm, 22.79 g, 63.57 g, 30.79 g and 15.09 g, respectively (Table 3). In group 2, Mahon-Demias had the longest vegetative cycle (142.00 days) and was the tallest (104.81 cm) parent, expressing higher tillering ability (9.23 spikes), heavier grain weight (40.78 g). This parental line also showed the highest SW (19.48 g), BIO (38.93 g) and GY (12.46 g). Hidhab had the highest mean for Chl (38.98 unit) with more grains (52.22 grains) (Table 3). In general, group 2 parents were taller with higher SN and TKW, fewer GN and more BIO. The two groups of parents were similar in Chl, HD, SW and GY. Compared to their parents means, the F_2 hybrids varied depending on the cross and the trait; being shorter, late, expressing lower tillering capacity and more grains.

Adequacy of Additive-Dominance Model

The data collected on the traits were subjected to two adequacy tests to check the validity of the additive-dominance model. The first test was carried out by joint regression analysis of *Vr* and *Wr*. According to Mather and Jinks (2013), the data will be only valid for genetic interpretation if the value of regression coefficient *b* must deviate from zero but not from unity. The second test was the t^2 test which is an *F* after rotation by 45°. The results of two scaling tests indicated that the hypotheses of the genetic analysis were partially satisfied for all traits under study considering both parental groups (Table 4). ANOVA of grain yield did not show significant difference among genotypes (Table 2), this result does not justify the further genetic analysis of the considered trait. Partial failure of the assumptions described by Hayman (1954) indicates a more complex

Table 3. Summary of the Scott-Knott cluster analysis of the partial diallel cross parents at 5% probability.

Genotypes	Chl	HD	PHT	SN	TKW	SW	GN	BIO	GY
$Acsad_{901}$	32.01^{c}	136.33^{b}	59.58^{f}	5.07^{b}	33.52^{b}	12.42^{b}	48.72^{a}	19.69^{b}	8.14^{a}
$Acsad_{899}$	40.38^{a}	138.00^{a}	65.28^{d}	5.87^{b}	39.47^{a}	16.44^{a}	48.82^{a}	24.00^{b}	11.36^{a}
$Acsad_{1135}$	34.93^{b}	134.67^{b}	73.10^{c}	6.93^{b}	38.39^{a}	17.76^{a}	44.27^{b}	21.23^{b}	11.83^{a}
$Acsad_{1069}$	39.52^{a}	134.00^{b}	68.10^{d}	5.50^{b}	34.59^{b}	15.80^{b}	50.65^{a}	20.69^{b}	9.58^{a}
Ain Abid	30.84^{c}	138.67^{a}	76.60^{b}	6.87^{b}	33.89^{b}	22.79^{a}	63.57^{a}	30.79^{a}	15.09^{a}
Mahon-Demias	29.42^{c}	142.00^{a}	104.81^{a}	9.23^{a}	40.78^{a}	19.48^{a}	32.96^{b}	38.93^{a}	12.46^{a}
Rmada	35.45^{b}	133.00^{b}	68.30^{d}	7.40^{b}	34.69^{b}	18.35^{a}	48.40^{a}	24.17^{b}	12.40^{a}
Hidhab	38.98^{a}	140.67^{a}	63.41^{e}	6.63^{b}	31.30^{b}	15.19^{b}	52.22^{a}	23.60^{b}	10.85^{a}
El-Wifak	38.81^{a}	132.00^{b}	66.20^{d}	5.90^{b}	37.93^{a}	15.06^{b}	44.65^{b}	20.30^{b}	9.98^{a}
Group 1 mean	35.54	136.33	68.53	6.05	35.97	17.04	51.21	23.28	11.20
Group 2 mean	35.67	136.50	75.68	7.29	36.18	17.02	44.56	26.75	11.42
Parents mean	35.71	135.08	75.24	7.30	36.67	18.57	47.94	26.85	12.60
F_2 mean	35.54	136.33	68.53	6.05	35.97	17.04	51.21	23.28	11.20

Chl: Chlorophyll content, HD: Heading date, PHT: Plant height, SN: Number of spikes, TKW: Thousand-kernel weight, SW: Spikes weight, GN: Number of grains per spike, BIO: Biomass, GY: Grain yield. Means followed by the same letter are not significantly different at 5% probability level by the Scott-Knott test.

genetic system implicated in the inheritance of the said traits. However, it is possible to make estimates of the population parameters and genetic components of these traits, even though such estimates will be less reliable than they would have been if all the assumptions were satisfied. Results of genetic analysis studies showing partially adequate model were reported in wheat (Farooq *et al.*, 2011), rice (Mahmood *et al.*, 2004), sorghum (Wilson *et al.*, 1978), cotton (Ali and Awan, 2009) and Soybean (Fronza *et al.*, 2004).

Table 4. Scaling test for adequacy of additive-dominance model based on regression analysis for the different plant traits studied in the partial diallel mating system.

Source of variation	df	Chl	HD	PHT	SN	TKW	SW	GN	BIO
		Group 1							
Regression	1	76.86	152.74	7478.58	1.11	11.24	38.59	210.08	540.43
Deviation	3	5.51	3.88	28.34	0.01	3.48	0.34	19.62	36.62
$b \pm SE_b$		0.83±0.22	0.95±0.12	0.94±0.35	1.08±0.06	0.78±0.09	0.90±050	0.86±0.08	0.31±0.09
t (H_0: $b=1$)		-0.726^{ns}	-0.306^{ns}	1.315^{ns}	-2.393^{ns}	-0.193^{ns}	-1.691^{ns}	-7.100*	2.129^{ns}
F (= t^2) (H_0: $b=0$)		0.331^{ns}	0.071^{ns}	-1.474^{ns}	1.999^{ns}	-0.568^{ns}	1.453^{ns}	4.525*	-4.330*
		Group 2							
Regression	1	15.07	0.38	491.83	0.03	0.37	10.06	61.80	103.78
Deviation	2	17.31	1.82	63.38	0.01	2.97	5.84	202.63	38.81
$b \pm SE_b$		0.38±0.41	0.04±0.28	0.71±0.32	1.70±0.61	0.15±0.08	0.19±0.55	0.52±040	-0.13±0.24
t (H_0: $b=1$)		-1.500^{ns}	-3.366*	1.151^{ns}	-9.849*	-1.463^{ns}	-1.166^{ns}	-4.568*	0.710^{ns}
F (= t^2) (H_0: $b=0$)		0.629^{ns}	1.467^{ns}	-2.169^{ns}	5.613*	0.322^{ns}	0.488^{ns}	1.720^{ns}	-2.066^{ns}

Chl: Chlorophyll content, HD: Heading date, PHT: Plant height, SN: Number of spikes, TKW: Thousand-kernel weight, SW: Spikes weight, GN: Number of grains per spike, BIO: Biomass. ns and *: non-significant and significant at 5% of probability.

Genetic Parameters Estimation

The estimates of the genetic and non-genetic parameters for the traits under study are shown in Tables 5 and 6. Chl genetic components of variation (D_1, D_2 and D_3) showed positive and significant values at 5% probability, indicating the presence of additive effects in the inheritance of this trait (Table 5). The estimate (D_1 - D_2) was less than zero (-1.4), suggesting greater variability in group 2. Genetic components due to the dominance effects (H_1 and H_2) were positives but only H_1 parameter was significant, suggesting the presence of dominance effect in the group 1. These results were confirmed by the significance of *F* estimates for the parents $Acsad_{901}$ and $Acsad_{1135}$ (Table 5). However, the positive and significant estimate of *F* value in group 2 for Mahon-Demias suggested the predominance of dominant alleles for this parent. The

Table 5. Estimates of the component of genetic and environmental variation, their standard deviations for the different plant traits studied in the partial diallel mating system.

Parameter	Chl	HD	PHT	SN	TKW	SW	GN	BIO
D_1	18.2±3.6*	3.8±2.2	43.9±7.0*	0.4±0.4	7.3±1.8*	13.9±1.8*	53.0±28.5*	19.8±7.3*
D_2	19.6±3.6*	26.1±2.2*	380.9±7.7*	1.7±0.4*	16.4±1.8*	4.7±1.8*	69.0±28.5*	68.5±7.3*
D_3	14.0±6.1*	11.0±3.8*	182.6±11.8*	1.5±0.6*	8.6±3.0*	7.0±3.0*	70.1±47.9	39.0±12.3*
F 1	47.7±21.6*	72.0±13.5*	-157.4±41.6*	-2.8±2.2*	22.7±10.7*	1.7±10.4	-222.6±169.0	73.6±43.3
F 2	-33.7±21.6	-47.0±13.5*	-279.9±41.6*	-3.6±2.2	39.5±10.7*	26.3±10.4*	-1.3±169.0	92.1±43.3*
F 3	62.8±21.6*	34.4±13.5*	278.5±41.6*	-11±2.2*	42.1±10.7*	-36±10.4*	82.7±169.0	6.5±43.3
F 4	-1.3±21.6	49.9±13.5*	23.1±41.6*	0.3±2.2	4.1±10.7	-11.2±10.4	-8.4±169.0	41.6±43.3
F 5	1.2±21.6	81.7±13.5*	542.0±41.6*	1.1±2.2	20.1±10.7	28.2±10.4*	65.8±169.0	193.1±43.3*
F' 1	51.9±21.9*	12.7±13.6	175.9±42.1*	-3.9±2.2	33.6±10.8*	37.1±10.5*	103.7±170.9	84.2±43.8
F' 2	0.7±21.9	-16.4±13.6	-18.4±42.1	-4.7±2.2*	15.8±10.8	-17.4±10.5	-118.8±170.9	43.0±43.8
F' 3	-23.2±21.9	-1.6±13.6	15.8±42.1	1.7±2.2	26.6±10.8*	4.6±10.5	144.2±170.9	6.5±43.8
F' 4	41.6±21.9	-7.6±13.6	78.4±42.1	-1±2.2	39.8±10.8*	1.8±10.5	-40.7±170.9	-10.7±43.8
$H_1(1)$	133.2±60.2*	39.2±37.5	107±115.8	8.2±6.2	88.2±29.8*	56.7±29.0*	487.3±469.9	146.8±120.4
$H_1(2)$	54.4±58.7	48.7±36.6	92.4±113.0	1.3±6.0	27.0±29.1	60.7±28.3*	243.6±458.7	132.4±117.5
H_2 *1*	52.4±57.5	18.4±35.8	87.9±110.6	0.8±5.9	16.1±28.5	32.1±27.7	350.9±448.9	70.0±115.1
H_2*2*	46.0±57.5	51.0±35.8	105.7±110.6	1.7±5.9	6.0±28.5	53.1±27.7	192.8±448.9	100.6±115.1
H_2 *3*	45.9±57.5	23.8±35.8	66.1±110.6	2.6±5.9	4.7±28.5	60.6±27.7*	202.7±448.9	119.6±115.1
H_2 *4*	45.7±57.5	27.7±35.8	75.7±110.6	4.2±5.9	11.6±28.5	32.2±27.7	242.4±448.9	92.0±115.1
H_2 *5*	34.7±57.5	19.6±35.8	107±110.6	2.3±5.9	10.2±28.5	38.0±27.7	221.6±448.9	61.1±115.1
H_2*' 1*	32.6±57.0	27.2±35.5	79.6±109.6	1.0±5.9	5.7±28.2	31.2±27.5	217.1±445.0	56.9±114.0
H_2*' 2*	30.5±57.0	17.6±35.5	94.1±109.6	1.2±5.9	2.5±28.2	30.3±27.5	121.6±445.0	53.5±114.0
H_2*' 3*	58.9±57.0	40.3±35.5	91.6±109.6	6.0±5.9	16.6±28.2	44.7±27.5	266.3±445.0	95.8±114.0
H_2*' 4*	46.4±57.0	20.3±35.5	66.4±109.6	0.5±5.9	11.6±28.2	55.8±27.5*	302.8±445.0	126.4±114.0
h^2	-0.7±41.8	37.2±26.0	155.5±80.5	5.6±4.3	4.7±20.7	37.0±20.2	-0.8±326.6	53.1±83.7
E	0.3±2.6	0.3±1.6	0.3±5.0	0.3±0.3	0.3±1.3	0.3±1.2	0.3±20.1	0.3±5.2
F mean	15.3±17.3	21.8±10.4*	81.3±33.2*	-3.2±1.8	25.7±8.6*	1.8±8.3	-16.8±134.8	81.4±34.6*
F' mean	17.7±17.9	-3.2±10.7	62.9±34.4	-2±1.8	28.9±8.9*	6.5±8.6	22.1±139.6	30.8±35.8
H_2 *mean*	43.7±37.5	27.3±22.5	86.0±72.2	2.3±3.9	9.5±18.6	42.0±18.1*	235.3±293.1	86.2±75.1

Chl: Chlorophyll content, HD: Heading date, PHT: Plant height, SN: Number of spikes, TKW: Thousand-kernel weight, SW: Spikes weight, GN: Number of grains per spike, BIO: Biomass. *: Estimate of the components significant at 5% probability when *t* value equals or exceeds 1.67.

average degree of dominance $(H_1/D)^{1/2}$, was greater than unity, suggesting over-dominance in both parent groups (Table 6). The proportion of dominant genes with positive or negative effects in the parents $H_2/4H_1$ was lower than 0.25 in both groups of parents, assuming unequal distribution of dominant genes with positive or negative effects (Table 6). This result was confirmed by the dominance-recessive ratio K_D/K_R which estimated the proportion between dominant and recessive genes, indicating the prevalence of dominant alleles in both parental groups. The direction of dominance $(K^+ - K^-)^2/K$ had a value close to zero, revealing the occurrence of bidirectional dominance (Table 6). According to Viana *et al.* (1999), $(K^+ - K^-)^2/K$ value would it be close to zero when the frequencies of the dominant genes with positive and negative effects were similar.

Table 6. Estimates of genetic parameters in both groups of parents for the different plant traits studied in the partial diallel mating system.

Genetic parameter	Chl	HD	PHT	SN	TKW	SW	GN	BIO
$H_2/4H_1$ (G_1)	0.20	0.14	0.23	0.44	0.09	0.17	0.24	0.16
$H_2/4H_1$ (G_2)	0.08	0.17	0.20	0.07	0.03	0.19	0.12	0.15
$(H_1/D_1)^{1/2}$ (G_1)	2.71	3.22	1.56	4.82	3.49	2.02	3.03	2.72
$(H_1/D_2)^{1/2}$ (G_2)	1.67	1.36	0.49	0.87	1.28	3.61	1.88	1.39
K_D/K_R (G_1)	1.61	3.30	1.55	-0.04	4.13	1.11	0.88	2.49
K_D/K_R (G_2)	1.44	0.77	2.70	0.26	3.68	1.26	1.15	1.80
$(K^+ - K^-)^2/K$	-0.03	1.11	0.91	0.63	0.80	1.17	0.00	0.55
h^2/H_2	0.02	1.36	1.81	2.43	0.49	0.88	0.01	0.61
h^2_{ns}	0.25	0.52	0.97	0.13	0.31	0.21	0.20	0.52

Chl: Chlorophyll content, HD: Heading date, PHT: Plant height, SN: Number of spike, TKW: Thousand-kernel weight, SW: Spikes weight, GN: Number of grains per spike, BIO: Biomass.

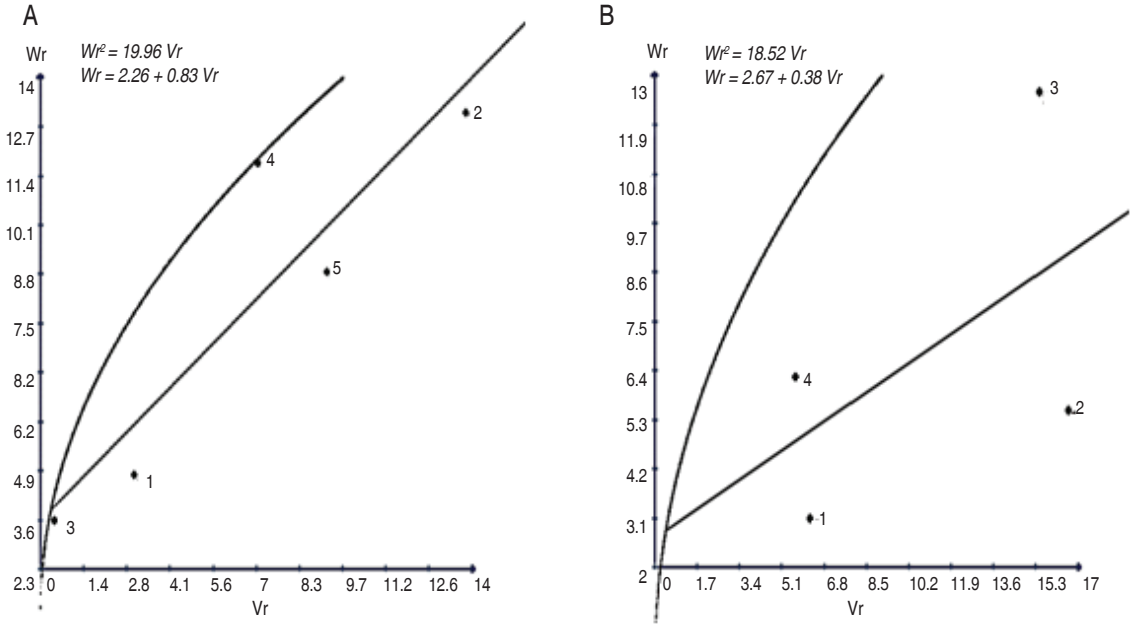

Figure 1. Regression of *Wr* on *Vr* graphs for Chl in G_1 (A) and G_2 (B) parental groups.

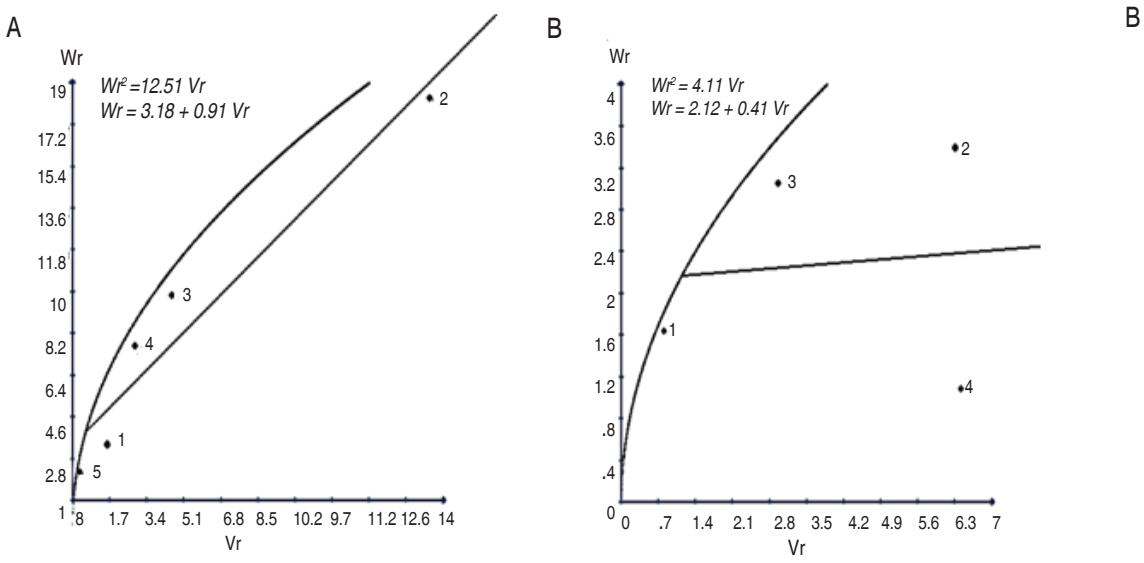

Figure 2. Regression of *Wr* on *Vr* graphs for HD in G_1 (A) and G_2 (B) parental groups.

The graphical analysis based on the regression of *Wr* on *Vr* (Figures 1, 2, 3, 4, 5, 6, 7 and 8) revealed that the parents $Acsad_{899}$ and Hidhab, with the highest number of recessive alleles, had also the highest values for chlorophyll content in group 1 and group 2, respectively (Table 3). For HD, the results show that the components associated with additive effects (D_2 and D_3) were more relevant than those associated with dominance effects (H_1, H_2 and h^2) at 5% probability (Table 5). Even though D_1 was not significant for group 1, the joint assessment (D_3) proved the occurrence of additive gene effects for this trait. Considering the two parental groups, the covariance of additive and dominance effect *F* was important in the first group, suggesting the prevalence of dominant alleles in this group.

The parents $Acsad_{901}$, $Acsad_{1135}$, $Acsad_{1069}$ and Ain Abid had the highest number of dominant alleles, while $Acsad_{899}$ had the highest frequency of recessive alleles (Table 5). There was asymmetric distribution of favourable and unfavourable alleles in the parents under study. This result was confirmed by the K_D/K_R ratio (Table 6). $(H_1/D)^{1/2}$ estimates were 3.22 and 1.36, respectively for group 1 and group 2. This result shows the existence of over dominance among the alleles in the control of this trait (Table 6). The $(K^+ - K^-)^2/K$ values showed evidence of unidirectional dominance (Table 6).

For PHT, the components associated with the additive effects were predominant in relation to those associated with the dominance effects (Table 5). The estimate of (D_1 - D_2) was lower than zero, proving greater variability in group 2. Over-dominance was evidenced in the expression of plant height in group 1, while partial dominance was present in group 2 (Table 6). Average value of the allelic frequency products $H_2/4H_1$ was lower than 0.25 in both groups of parents, suggesting unequal distribution of dominant and recessive alleles (Table 6). The ratio K_D/K_R indicated that both groups of parents carry more dominant alleles. Dominance acted in the direction of increasing value plant height. Additionally, the individual estimates (Table 3) in relation to the graphical analysis (Figure 3), suggested that the parents $Acsad_{1135}$, $Acsad_{1069}$, Ain Abid and Mahon-Demias had the highest number of dominant alleles.

The components (D_2 and D_3) for SN were significant at 5% probability, indicating a greater importance of additive gene effects in the determination of this trait. Over-dominance was involved in the genetic control of this trait in the first group, whereas partial dominance controlled this trait in group 2. The ratio K_D/K_R, estimating the proportion between dominant and recessive genes, indicated that more recessive alleles were present in both parental groups (Table 6). Group 1 showed symmetric distribution of the alleles with favourable and unfavourable effects in the parents (Table 6), but the $H_2/4H_1$ estimate was probably biased, since the maximum parametric value expected was 0.25. However, group 2

illustrated the occurrence of asymmetry distribution, its estimate was 0.07. Mean values analysis indicated that $Acsad_{1135}$ had the highest average among the parents of group 1, while Mahon-Demias, in group 2, recorded the highest value. These two parents carried also the highest number of recessive alleles (Table 5). This result indicates that high SN values are determined by recessive genetic factors.

TKW additive genetic components (D_1, D_2 and D_3) were positive and significant at 5% probability, D_2 was greater than D_1 ($D_1 < D_2$), indicating more genetic variability

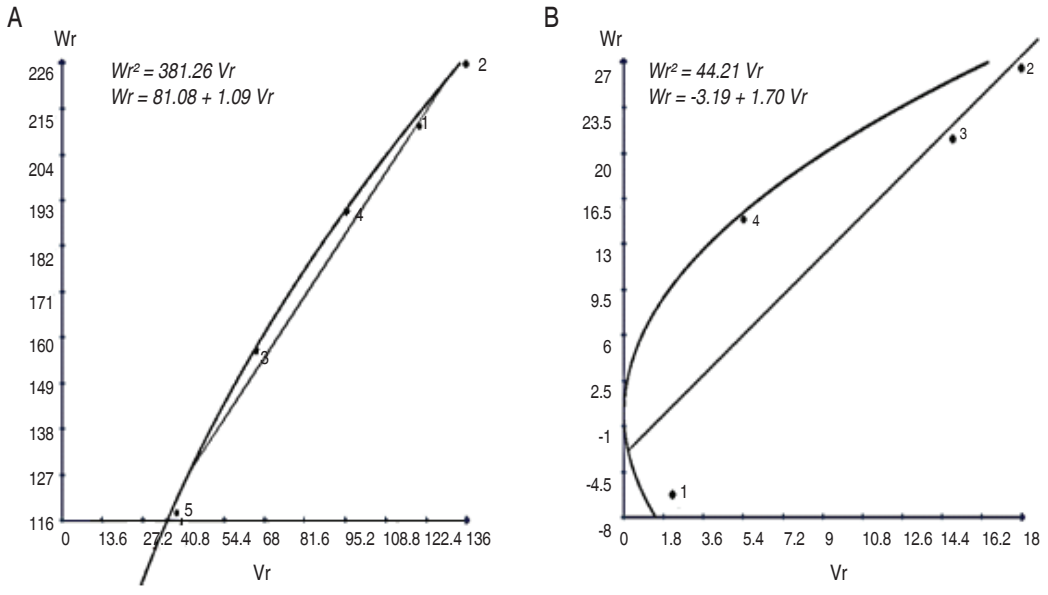

Figure 3. Regression of *Wr* on *Vr* graphs for PHT in G_1 (A) and G_2 (B) parental groups.

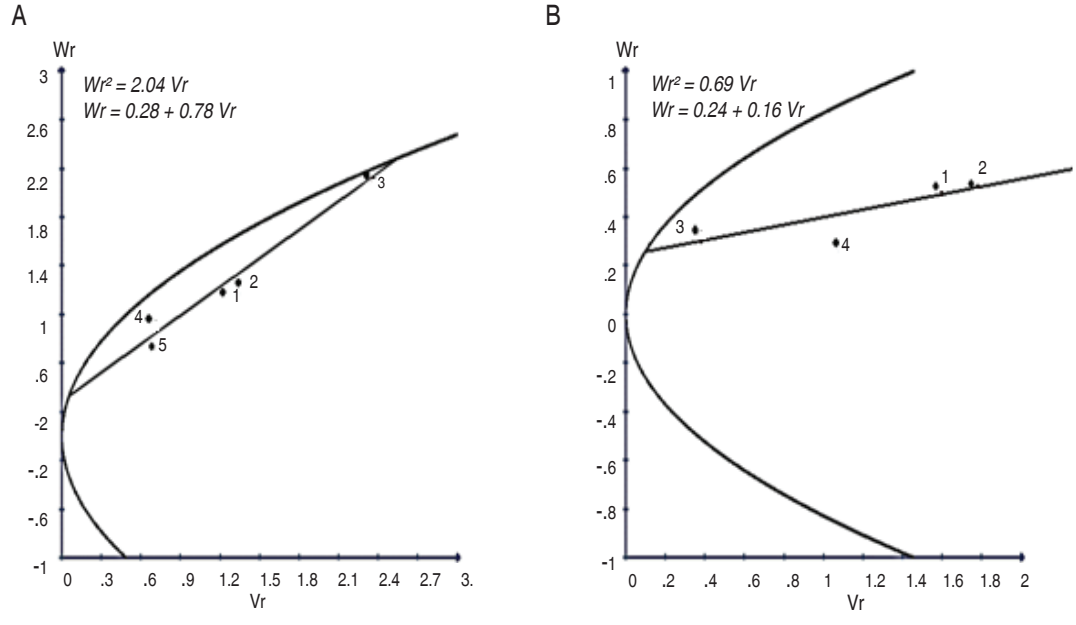

Figure 4. Regression of *Wr* on *Vr* graphs for SN in G_1 (A) and G_2 (B) parental groups.

in group 2 (Table 5). Nevertheless, only H_1 from the parameters related to dominance effects, was significant, suggesting the presence of both additive and dominance effects in the determination of this trait in group 1. These results were supported by the positive and significant values of *F* component (Table 5). The average degree

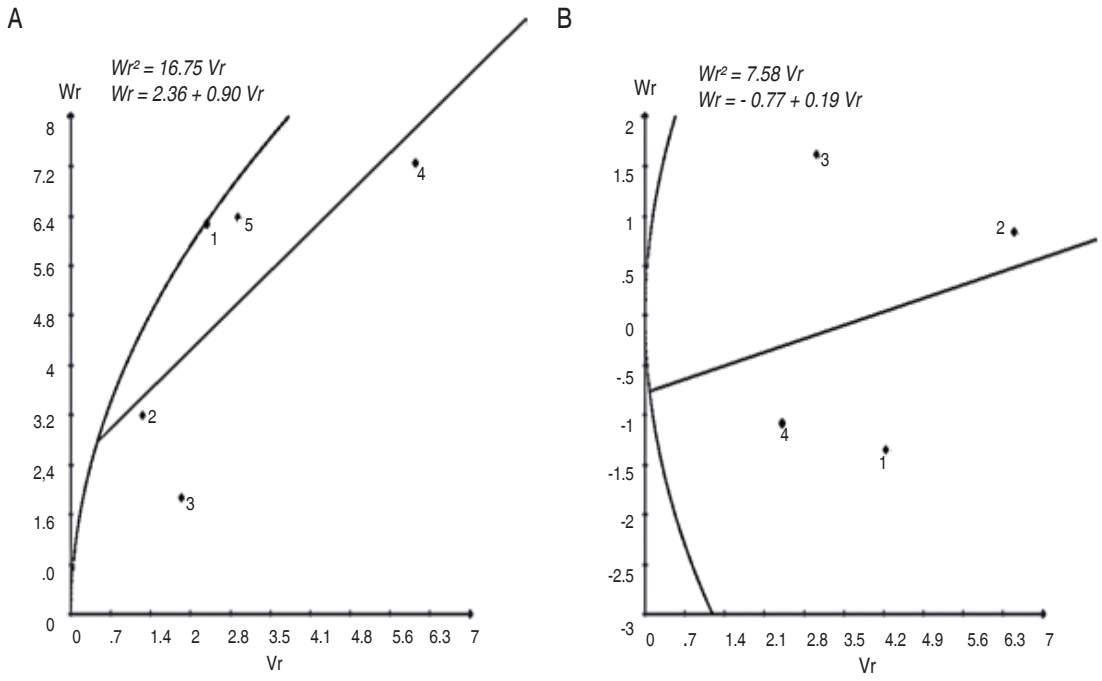

Figure 5. Regression of *Wr* on *Vr* graphs for TKW in G_1 (A) and G_2 (B) parental groups.

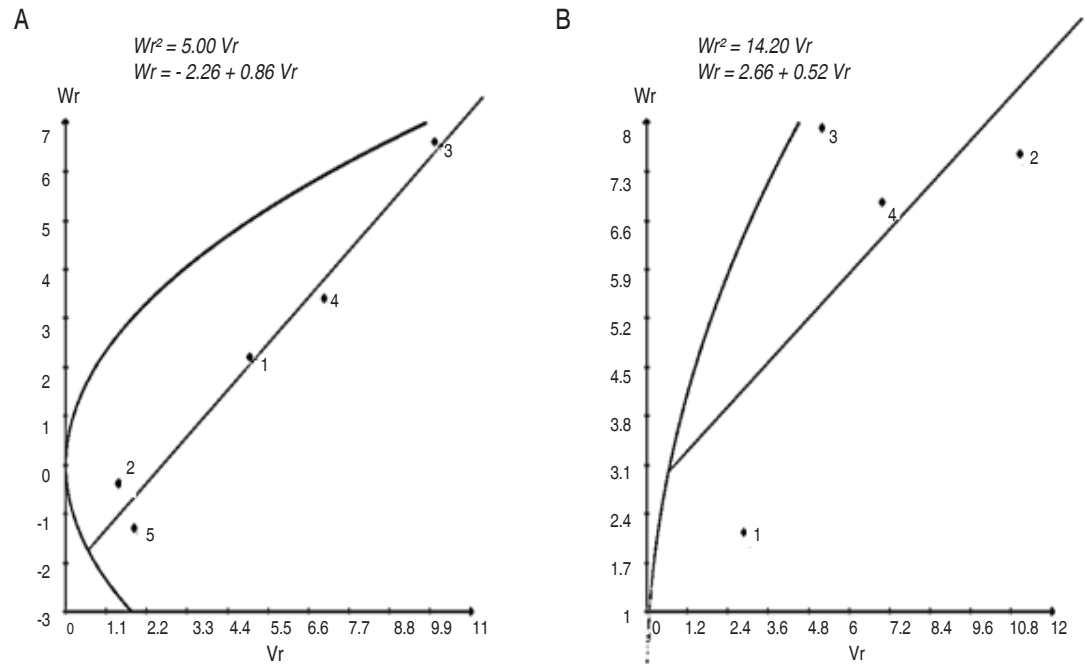

Figure 6. Regression of *Wr* on *Vr* graphs for SW in G_1 (A) and G_2 (B) parental groups

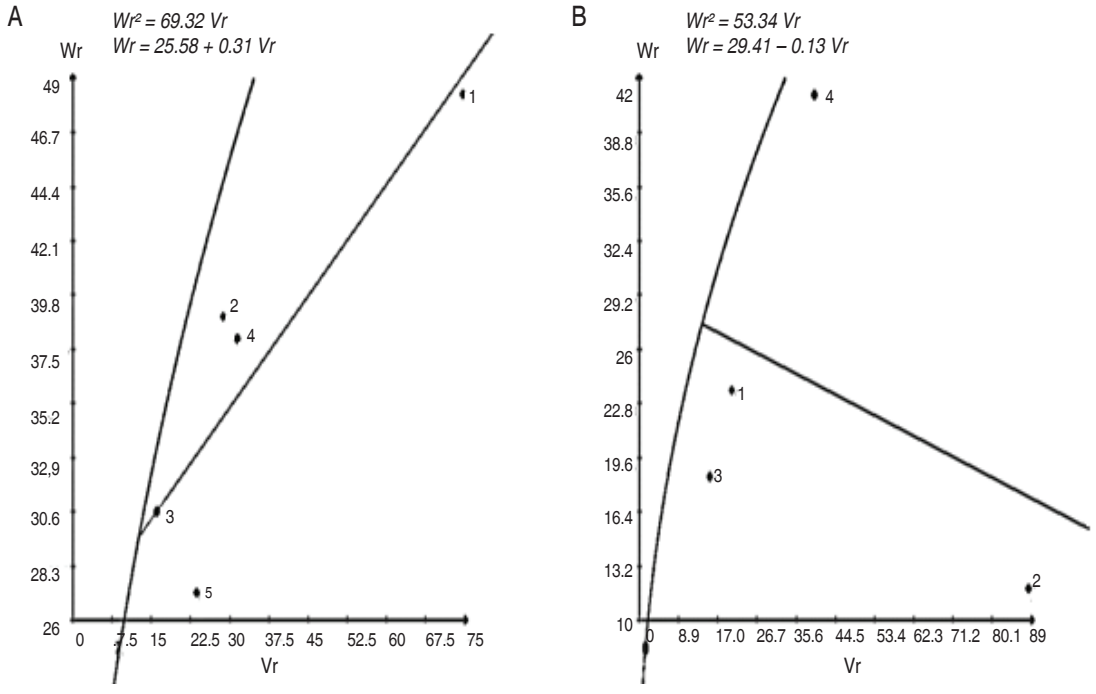

Figure 7. Regression of *Wr* on *Vr* graphs for GN in G_1 (A) and G_2 (B) parental groups.

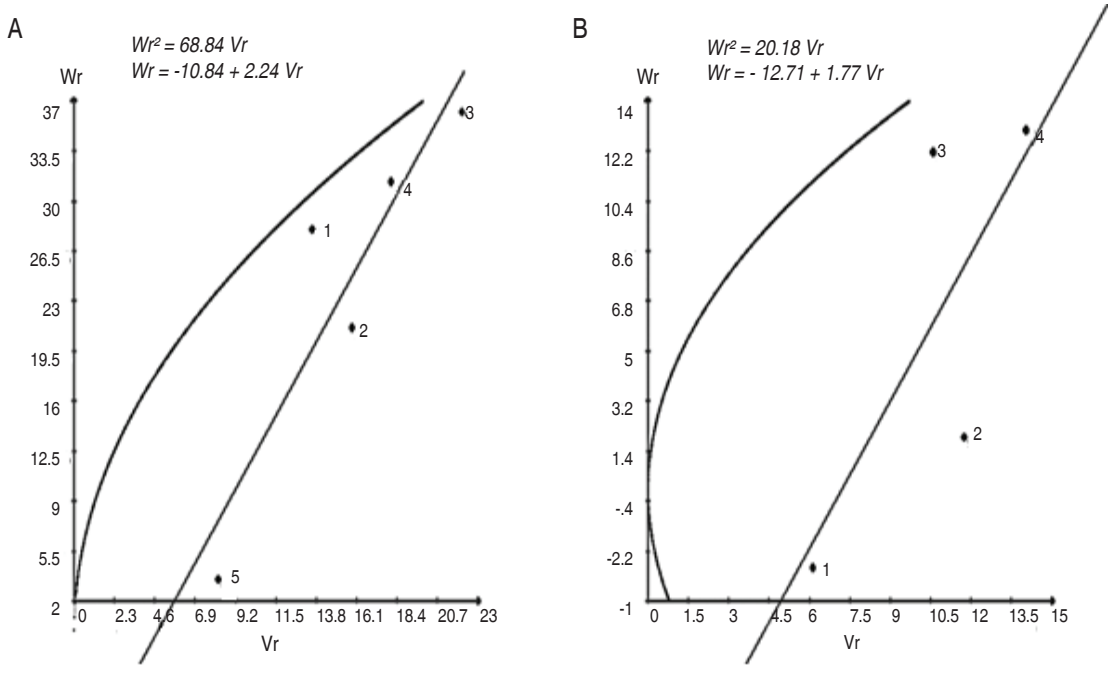

Figure 8. Regression of Wr on Vr graphs for BIO in G_1 (A) and G_2 (B) parental groups.

of dominance took a value greater than one, suggesting over-dominance in both parental groups (Table 6). Mean value of the allelic frequency products $H_2/4H_1$ was close to zero in both groups, suggesting unbalanced distribution of dominant genes with positive or negative effects in the parents under study (Table 6). This was confirmed

by the K_D/K_R ratio, which showed the preponderance of dominant alleles in both parental groups. Dominance was unidirectional for this trait and acted in the direction of increased value (Table 6).

The diallel analysis revealed significant role of additive and dominant genetic effect in the inheritance of SW (Table 5). Relative magnitude of dominant components (H_1 and H_2) were higher than additive component (D_1, D_2 and D_3), suggesting the preponderance of dominant gene effects controlling the inheritance of this trait. In addition, unequal H_1 and H_2 genetic component ($H_1 < H_2$), indicated that positive alleles are not proportional to negative alleles at all loci, among parents (Table 5). Positive and significance H_2 component estimates were determined for $Acsad_{1135}$ and Hidhab, showing evidence of dominance for spikes weight in these parents. *F* parameter exhibited positive and significant estimates for $Acsad_{899}$, Ain Abid and Mahon-Demias revealing the predominance of dominant alleles. These three parents recorded the highest values for SW. Therefore, selection of dominant alleles will improve this trait. The genetic factors that determine SW trait exhibited over-dominance for both groups of parents, as indicated by $(H_1/D)^{1/2}$ estimates (Table 6). The gene frequency seemed to be unequal as the range of the $H_2/4H_1$ component were less than 0.25 in both groups of parents. The estimates of the consistency of expression of the degree of dominance across all segregating loci K_D/K_R indicated over-dominance level over all loci.

The components of additive effects (D_1 and D_2) predominated the dominance effects for the GN trait, suggesting that genes controlling this trait acted additively. The difference (D_1 - D_2) was negative, attesting greater variability in group 2 (Table 5). Absence of dominance in the genetic control of GN is also suggested by the non-significant estimates of the component *F*, at 5% probability (Table 5). Value of $H_2/4H_1$ ratio was close to 0.25 in group 1, denoting equality of distribution of increasing and decreasing alleles. However, unequal gene frequency was observed in group 2 (Table 6). The K_D/K_R ratio indicated predominance of recessive genes in group 1 and dominant alleles in group 2 (Table 6). Over-dominance effect was apparent in the control of GN, the dominance was bidirectional and acted toward increased values of this trait, as shown by the $(K^+ - K^-)^2/K$ estimate (Table 6).

Estimation of genetic components of variation for BIO trait revealed significant additive gene effects (Table 5). Distribution of array points (Figure 8) depicted that the genotypes Ain Abid (group 1) and Mahon-Demias (group2) contained maximum dominant alleles while $Acsad_{1135}$ and El-Wifak being farthest from the origin hold the least dominant genes. Average degree of dominance in both parental groups (2.72 and 1.39, respectively) depicted over-dominance for this trait (Table 6). As the $H_2/4H_1$ deviated from its expected value of 0.25, therefore, the gene distribution was asymmetrical. The K_D/K_R ratio estimates suggested that more dominant alleles were present in the parents and dominance acted in the direction of increasing value of this trait (Table 6).

The environmental component *E* was not significant for all the traits under study (Table 5), indicating that these characters were not affected by environmental variations. The lack of significance of the statistic h^2 was found for all the traits (Table 5), suggesting that pedigree selection could be rewarding for these traits (Ali *et al.*, 2008). The h^2/H_2 measuring the number of groups of genes which control the traits suggested that there were one, two or more pairs of genes affecting the inheritance of these (Table 6). These results indicated that there has been at least one genetic group involved in the genetic control of the traits under study. Heritability is an important genetic parameter in crop breeding. It provides information about traits transmissibility from parents to their progeny, and how this is affected by genetic and environmental factors.

High narrow sense heritability h^2_{ns} was observed for PHT and intermediate values were recorded for HD, TKW and BIO, indicating that selection to improve these traits would be effective. Narrow sense heritability for Chl, SN, SW and GN was low due to the dominance gene effects involved in the genetic control of these traits. These results suggested that delaying selection to improve these traits would be more effective.

Genetic components of variations for HD, PHT, SN, GN and BIO revealed that only additive gene effects were significant in both groups of parents. Thus, improvement of these traits by selection could be done in early generations. Genetic components of variation for Chl, TKW and SW

showed that both additive and dominance variations were significant. However, dominant components were preponderant to additive components for these traits. Similar findings were reported by Farooq *et al.* (2011). $H_2/4H_1$ ratio values, for all traits under study in both groups except for SN and GN in group 1, indicated unequal distribution of positive and negative alleles among the parents. These results were in accordance with those previously reported by Yao *et al.* (2014) and Afridi *et al.* (2017). Except for PHT and SN in group 2, average degree of dominance $(H_1/D)^{1/2}$ for all the traits suggested the presence of over-dominance. Shehzad *et al.* (2015) reported over dominance gene action for most of the investigated traits a 5 x 5 complete diallel. Additive type of gene action with partial dominance for plant height was reported by Ojaghi *et al.* (2010) and for the number of spikes per plant by Kaukab *et al.* (2014). Significant and positive K_D/K_R ratio values signified the important role of dominant genes for most of the traits.

The findings of Akram *et al.* (2008) are in accordance with the results of the present study. Non-significant and positive value of h^2 indicated un-important role of net dominant effect due to heterozygous loci in the expression of these traits. High to moderate narrow sense heritability estimates were recorded, in this study, for PHT, HD, TKW and BIO indicating large additive proportion in the total genetic variation. High to moderate heritability values were also reported for number of days to 50% flowering, plant height and 1000-kernel weight by Fikre *et al.* (2015). Low narrow sense heritability estimates were found, in this study, for Chl, SN, SW and GN. Ketata *et al.* (1976) and Hassan *et al.* (2013) also reported low heritability due to the presence of dominance effects for yield related traits in wheat. Increased values of HD, PHT, SW and BIO were determined by dominant genetic factors, whereas, Chl and SN traits were governed by recessive genetic factors. Besides, the placement of array points indicated that parental genotypes Ain Abid and Mahon-Demias had the maximum dominant genes, while $Acsad_{899}$, $Acsad_{1135}$ and Rmada extreme recessive genes for most of the traits by considering both groups of parents. The h^2/H_2 ratio showed that PHT and SN might be controlled by two and four groups of dominant genes, respectively; while Chl, HD, TKW, GN and BIO might be controlled by one group of genes. In their study, Yao *et al.* (2011) reported that wheat traits were controlled by one to four groups of dominant factors.

CONCLUSIONS

Based on these results, it can be stated that enough genetic variation existed among the studied genotypes for most of the studied traits in both parental groups, with greater variability in group 2. Additive and non-additive gene effects were involved in the expression of all traits. Average value of the allelic frequency products suggested unequal distribution of dominant and recessive alleles for most of traits. This result was confirmed by the significant values of *F* component. Moreover, the K_D/K_R ratio indicated that more dominant alleles were present in parents belonging to group 1 than those of group 2. Dominance acted in the direction of increasing value for HD, PHT, SN, TKW, SW and BIO but was bi-directional for Chl and GN as the genetic parameter $(K^+ - K^-)^2/K$ that estimates the direction of dominance had a value close to zero for these traits. Additive gene effects with high heritability estimate suggested that PHT could be improved effectively through early generation selection, while the dominance gene effects along with low heritability estimates for the remaining traits favour delayed stage plant selection. Breeders in Algeria are concentrating their efforts to improve the yield potential of wheat to meet the future goals by developing new varieties with desirable genetic background. They are making a lot of attention to generate information of how gene action is important in a wheat breeding program, because knowledge in this field is helpful in deciding breeding procedures to be adopted for the improvement of those characters including yield.

REFERENCES

Afridi K, Khan NU, Mohammad F, Shah SJA, Gul S, Khalil IA, Sajjad M, Ali S, Ali I and Khan SM. 2017. Inheritance pattern of earliness and yield traits in half diallel crosses of spring wheat. Canadian Journal of Plant Science (*In press*). doi:10.1139/cjps-2016-0309

Akram Z, Ajmal SU, Munir M and Shabir G. 2008. Genetic determination of yield related attributes in bread wheat. Sarhad Journal of Agriculture 24(3): 431–438.

Ali MA, Khan IA, Awan SI, Ali S and Niaz S. 2008. Genetics of fibre quality traits in cotton (*Gossypium hirsutum* L.). Australian Journal of Crop Science 2(1): 10–17.

Ali MA and Awan SI. 2009. Inheritance pattern of seed and lint traits in cotton (*Gossypium hirsutum*). International Journal of Agriculture and Biology 11(1): 44–48.

Cruz CD, Regazzi AJ and Carneiro PCS. 2004. Modelos Biométricos Aplicados ao Melhoramento Genético, Thirth edition. Universidade Federal de Viçosa, Viçosa. 480 p.

Cruz CD. 2013. Genes: a software package for analysis in experimental statistics. Acta Scientiarum Agronomy 35(3): 271–276. doi: 10.4025/actasciagron.v35i3.21251

Falconer DS and Mackay TFC. 1996. Introduction to Quantitative Genetics, Fourth edition, Longman, Essex, UK. 464 p.

Food and Agriculture Organization. 2016. FAOSTAT database. http://faostat.fao.org/beta/en/

Farooq J, Khaliq I, Kashif M, Ali Q and Mahpara S. 2011. Genetic analysis of relative cell injury percentage and some yield contributing traits in wheat under normal and heat stress conditions. Chilean Journal of Agricultural Research 71(4): 511–520. doi: 10.4067/s0718-58392011000400003

Fellahi Z, Hannachi A, Bouzerzour H and Boutekrabt A. 2013. Line × Tester Mating Design Analysis for Grain Yield and Yield Related Traits in Bread Wheat (*Triticum aestivum* L.). International Journal of Agronomy, 2013, Article ID 201851, 9 p. doi: 10.1155/2013/201851

Fikre G, Alamerew S and Tadesse Z. 2015. Genetic Variability Studies in Bread Wheat (*Triticum Aestivum* L.) Genotypes at Kulumsa Agricultural Research Center, South East Ethiopia. Journal of Biology, Agriculture and Healthcare 5(7): 89–98.

Fronza V, Vello NA and Camargo LEA. 2004. Genetic analysis of soybean resistance to *Fusarium solani* f. sp. *glycines*. Genetics and Molecular Biology 27(3): 400–408. doi: 10.1590/s1415-47572004000300016

Gardner CO and Eberhart SA. 1966. Analysis and interpretation of the variety cross diallel and related populations. Biometrics 22(3): 439–452. doi: 10.2307/2528181

Griffing B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences 9(4): 463–493. doi: 10.1071/bi9560463

Hannachi A, Fellahi Z, Bouzerzour H and Boutekrabt A. 2013. Diallel-cross analysis of grain yield and stress tolerance-related traits under semi-arid conditions in Durum wheat (*Triticum durum* Desf.). Electronic Journal of Plant Breeding 4(1): 1027–1033.

Hassan MS, El-Said RAR and Abd-El-Haleem SHM. 2013. Estimation of heritability and variance components for some quantitative traits in bread wheat (*Triticum aestivum* L.). World Applied Sciences Journal 27(8): 944–949. doi: 10.5829/idosi.wasj.2013.27.08.13710

Hayman BI. 1954. The theory and analysis of diallel crosses. Genetics 39(6): 789–809.

Kaukab S, Saeed MS and ur Rehman A. 2014. Genetic analysis for yield and some yield traits in spring wheat. Universal Journal of Agricultural Research 2(7): 272–277. doi: 10.13189/ujar.2014.020707

Ketata H, Edwards LH and Smith EL. 1976. Inheritance of eight agronomic characters in a winter wheat cross. Crop Science 16(1): 19–22. doi: 10.2135/cropsci1976.0011183x001600010005x

Kribaa M, Hallaire V, Curmi P and Lahmar R. 2001. Effect of various cultivation methods on the structure and hydraulic properties of a soil in semi-arid climate. Soil and Tillage Research 60(1-2): 43–53. doi.org/10.1016/s0167-1987(01)00171-4

Mahmood T, Turner M, Stoddard FL and Javed MA. 2004. Genetic analysis of quantitative traits in rice (*Oryza sativa* L.) exposed to salinity. Crop and Pasture Science 55(11): 1173–1181. doi: 10.1071/ar03200

Mather K and Jinks JL. 2013. Introduction to biometrical genetics, Chapman and Hall Ltd., London. doi: 10.1002/bimj.4710260111

Mumtaz A, Zafar F, Saifulmalook and Shehzad A. 2015. A Review on Mating Designs. Nature and Science 13(2): 98–105. doi: 10.7537/marsnsj130215.15

Nazir A, khaliq I, Farooq J, Mahmood K, Mahmood A, Hussain M and Shahid M. 2014. Pattern of inheritance in some yield related parameters in spring wheat (*Triticum aestivum* L.). American Journal of Biology and Life Sciences 2(6): 180–186.

Ojaghi J, Salayeva S and Eshghi R. 2010. Inheritance pattern of important quantitative traits in bread wheat (*Triticum aestivum* L.). World applied Science Journal 11(6): 711–717.

Rashid MAR, Khan AS and Iftikhar R. 2012. Genetic studies for yield and yield related parameters in bread wheat. American-Eurasian Journal of Agricultural & Environmental Sciences 12: 1579–1583.

Saad FF, Abo-Hegazy SRE, EL-Sayed EAM and Suleiman HS. 2010. Heterosis and combining ability for yield and its components in diallel crosses among seven bread wheat genotypes. Egyptian Journal of Plant Breeding 14(3): 7–22.

Scott AJ and Knott MA. 1974. A cluster analysis method for grouping means in the analysis of variance. Biometric 30(3): 507–512. doi: 10.2307/2529204

Shehzad M, Hussain SB, Qureshi MK, Akbar M, Javed M, Imran HM and Manzoor SA. 2015. Diallel cross analysis of plesiomorphic traits in *Triticum aestivum* L. genotypes. Genetics and Molecular Research 14(4): 13485–13495. doi: 10.4238/2015.october.28.9

Viana JMS, Cruz CD and Cardoso AA. 1999. Theory and analysis of partial diallel crosses. Genetics and Molecular Biology 22(4): 591–599. doi: 10.1590/s1415-47571999000400021

Viana JMS, Cruz CD, Cardoso AA. and Regazzi AJ. 2000. Analysis of variance of partial diallel tables. Genetics and Molecular Biology 23(1): 229–234. doi: 10.1590/s1415-47572000000100040

Viana JMS, Cruz CD and Cardoso AA. 2001. Theory and analysis of partial diallel crosses. Parents and F_2 generations. Acta Scientiarum 23(2): 627–634.

Wilson ND, Weibel DE and McNew RW. 1978. Diallel analyses of grain yield, percent protein, and protein yield in grain sorghum. Crop Science 18(3): 491–495. doi: 10.2135/cropsci1978.0011183x001800030035x

Yao JB, Ma HX, Ren LJ, Zhang PP, Yang XM, Yao GC, Zhang P and Zhou MP. 2011. Genetic analysis of plant height and its components in diallel crosses of bread wheat (*Triticum aestivum* L.). Australian Journal of Crop Science 5(11): 1408–1418.

Yao J, Yang X, Zhou M, Yang D and Ma H. 2014. Inheritance of grain yield and its correlation with yield components in bread wheat (*Triticum aestivum* L.). Turkish Journal of Field Crops 19(2): 169–174. doi: 10.17557/tjfc.30098

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Revista Facultad Nacional de Agronomía

UNIVERSIDAD NACIONAL DE COLOMBIA

Evaluation of TRMM satellite rainfall estimates (algorithms 3B42 V7 & RT) over the Santo Antônio county (Goiás, Brazil)

Evaluación de las estimaciones de precipitaciones por satélite TRMM (algoritmos 3B42 V7 y RT) en Santo Antônio (Goiás, Brasil)

doi: 10.15446/rfna.v70n3.61805

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ABSTRACT

The rainfall has a direct influence on the agricultural productivity, being indispensable the knowledge of its spatiotemporal behavior in order to establish trends that will assist in the management of water resources, agricultural planning, hydrological monitoring and prevention of natural disasters. Thus, this work aimed to evaluate the accuracy of the TRMM satellite precipitation estimates in relation to the gauge-recorded precipitation. For this, the rainfall data from the weather station located in the municipality of Santo Antônio de Goiás-GO were used, being compared to the TRMM satellite datasets, especially, the algorithms 3B42 Version 7 (V7) and Real Time (RT), during the period from January 1998 to October 2015. The comparison of the TRMM satellite data showed that the ten-day and monthly precipitation records of the 3B42 V7 algorithm showed correlation values of 0.69 and 0.65, respectively, during the rainy season; in the dry season, the correlations were of 0.80 and 0.73. The ten-day concordance index ranged from 0.68 to 0.98 and the monthly concordance index ranged from 0.83 to 0.99. The algorithm 3B42 RT presented lower statistical results when compared to the 3B42 V7. The satellite precipitation estimates showed both trends of over estimation and underestimation; however, the satellite data can help research in the absence of information on the rainfall in the region.

Keywords:
Precipitation
Remote sensing
Uncertainty quantification
TRMM

RESUMEN

La precipitación tiene una influencia directa en la productividad agrícola, siendo indispensable el conocimiento de su comportamiento espacio-temporal para establecer tendencias que ayuden en la gestión de los recursos hídricos, la planificación agrícola, el monitoreo hidrológico y la prevención de desastres naturales. Por lo tanto, este trabajo tuvo como objetivo evaluar la exactitud de las estimaciones de precipitación de satélites de TRMM en relación con la precipitación registrada. Para ello, se utilizaron los datos pluviométricos de la estación meteorológica del municipio de Santo Antônio de Goiás - GO, comparándolos con los conjuntos de datos de satélites TRMM, especialmente los algoritmos 3B42 Versión 7 (V7) y Real Time (RT), durante el período de enero de 1998 a octubre de 2015. La comparación de los datos de satélite TRMM mostró que los registros de precipitación de diez días y mensuales del algoritmo 3B42 V7 presentaron valores de correlación de 0,69 y 0,65, respectivamente, durante la temporada de lluvias. En la estación seca, las correlaciones fueron de 0,80 y 0,73. El índice de concordancia de diez días osciló entre 0,68 y 0,98 y el índice de concordancia mensual osciló entre 0,83 y 0,99. El algoritmo 3B42 RT presentó resultados estadísticos más bajos en comparación con el 3B42 V7. Las estimaciones de la precipitación por satélite mostraron tanto las tendencias de sobreestimación como de subestimación; sin embargo, los datos satelitales pueden ayudar a la investigación en ausencia de información sobre las lluvias en la región.

Palabras clave:
Precipitación
Sensoriamento remoto
Exactitud
TRMM

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Received: December 31, 2016; Accepted: Abril 21, 2017
Rev.Fac.Nac.Agron. 70(3): 8251-8261. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

The rainfall has a direct influence on the agricultural productivity, being indispensable the knowledge of its spatiotemporal behavior in order to establish trends that will assist in the management of water resources, agricultural planning, hydrological monitoring and prevention of natural disasters (Baú *et al*., 2013).

According to Blain (2010), climate trends are characterized by a significant change in the average climate element during the historical series in question. The precipitation regime over the different regions of South America are related to distinct factors from local to large scales (Reboita *et al*. 2010). The rainfall distribution and amount are also affected by the presence of the phenomena El Niño and La Niña (Berlato and Fontana, 2003).

To obtain the precipitation measurements, rain gauges or pluviographs are used, however, in large territorial extensions such as Brazil, the distribution of rain gauge stations does not cover the whole territory; in addition, isolated rainfall occurring in areas of a watershed may not be counted in the nearest rain gauge station (Franchito *et al*., 2009).

According to the World Meteorological Organization (WMO), rain gauge stations have a representative observation of 100 km^2 coverage radius, however, in small-scale studies or local applications related to agriculture, the rain gauge station coverage range is 10 km^2 (WMO, 2008).

The state of Goiás, in turn, has a conventional and automated monitoring network of 104 rain gauge stations of the National Water Agency (ANA, for its Portuguese acronym) and 48 stations of the National Meteorological Institute (INMET, for its Portuguese acronym) to an area of 340,111,376 km^2 land area (IBGE, 2016). With the low density of weather stations, one of the possibilities to supply this information is through the use of satellite precipitation estimates datasets.

Although the satellite data are estimation and also subject to a variable magnitude of errors depending on the used sensor, region under investigation and other factors, the estimates can be used since they have two advantages compared to rain gauge stations: (i) higher achievement rate and ease of availability of information, mainly targeting the use in alert systems and flood control; (ii) production of information in the form of a spatial field of precipitation covering large areas (Paz and Collischonn, 2011).

In 1997, through a partnership between National Aeronautics e Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), the Tropical Rainfall Measuring Mission (TRMM) satellite was built and launched, which was able to get rainfall data in the tropical regions of the planet, especially through the use of passive and active microwaves (Kummerow *et al*., 1998). Among the main advantages of using precipitation data obtained by the TRMM satellite are its spatial and temporal resolutions, for instance the 3B42 algorithm with 0.25° by 0.25° for each 3 hours, covering 50°N to 50°S for 1998-present and freely available to the public (for more details access: http://trmm.gsfc.nasa.gov/).

Several studies, with the objective of evaluating the performance of TRMM satellite precipitation estimates, compared to in-situ observations, were performed over different regions of the globe such as Adler *et al*. (2001), Fisher (2004), Layberry *et al*. (2006), Sapiano and Arkin (2009) and Salio *et al*. (2014). In general, studies indicate that such performance varies according to the region and its rainfall regimes. Certain studies point to an overestimation of the precipitation coming from the TRMM satellite, specifically the algorithm 3B42, compared to the observed rain gauges measurements, such as Li *et. al*. (2014) in the Poyang Lake basin which is located in the middle of the Yangtze River in China; Almazroui (2011) in Saudi Arabia and Behrangi *et al*. (2011) in the Siloam River basin south of Siloam Springs, Arkansas. Others report an underestimate, such as Chen *et al*. (2013) over Taiwan Island; Dinku *et al*. (2007) over Ethiopia in the Horn Africa and part of Colombia in South America.

Notwithstanding, further studies are needed to assess the quality and the limitation of precipitation data from satellites, aiming to distinguish and quantify their uncertainties for proper application of these products to each study area (Kummerow *et al*., 2000; Kurtzman *et al*., 2009; Karaseva *et al*., 2011).

Taking into account that the precipitation is a climatic element of high variability and that in Santo Antônio de Goiás, the performance of several research is focused on the rural development through the EMBRAPA - Rice

and Beans unit, this study aimed to evaluate the climatic rainfall seasonality as well as the accuracy of TRMM satellite precipitation estimates in relation to the gauge-based rainfall measurements for the Santo Antônio de Goiás-GO county.

MATERIALS AND METHODS

The study was conducted in Santo Antônio de Goiás - GO. According to Köppen, the climate is Aw, tropical of savanna, megathermal. The rain regime is well defined in the rainy (October to April) and dry (May to September) seasons, with an annual average of 1498 mm (Silva *et al.*, 2014). Daily rainfall data were obtained from the pluviometric station of the Brazilian Agricultural Research Corporation - (EMBRAPA - Rice and Beans) located in Santo Antônio de Goiás - GO, with latitude of 16°28'00" (S), longitude of 49°17'00" (W) and altitude of 823 m.

For the seasonal distribution precipitation analysis at the Santo Antônio de Goiás city, a historical series of precipitation was used from 01/01/1983 to 12/31/2015, where the confidence intervals were calculated with 95% probability.

The TRMM satellite rainfall estimates were obtained through the Interactive Online Visualization and analysis Interface (Giovanni, https://giovanni.sci.gsfc.nasa.gov/giovanni) platform. Daily data from the 3B42 Version 7 (V7) and Real Time (RT) were acquired. The data from the 3B42 V7 algorithm are available since January, 1998, and from the 3B42 RT, since March, 2000. Thus, two distinct periods of evaluations were adopted: i) from January, 1998 to October, 2015 for the algorithm 3B42 V7, and ii) from March, 2000 to October, 2015 for the algorithm 3B42 RT.

The comparison of punctual gauge-based precipitation measurements (Po: observations) with the TRMM satellite precipitation estimates (Pe: estimated), at daily temporal resolutions were transformed into total decennial, monthly, and annual, in order to intercompare the distinct products (Pe vs. Po) in quantifying the precipitation under those accumulated temporal scales.

In order to verify the performance of the satellites estimates, the Pearson coefficient, r (Equation 1) is calculated. The r measures the degree of correlation and ranges between -1 and 1, which 1 means a perfect positive correlation between the two variables and when -1, means a perfect negative correlation between the two variables, that is, if one increases the other always decreases and when 0 means that the two variables do not depend linearly on each other.

$$r = \frac{\sum (P_i - \overline{P}) - (O_i - \overline{O})}{\sqrt{\sum (P_i - \overline{P})^2 \sum (O_i - \overline{O})^2}} \qquad [1]$$

To quantify the magnitude of the uncertainties in the satellite estimates compared to the observed, the Root Mean Square Error (RMSE) represented by equation 2 was used.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \qquad [2]$$

The accuracy is related to the distancing of the estimated values in relation to the observed and was given statistically by the concordance index "d" proposed by Willmott *et al.* (1985). Their values range from zero (no agreement), to 1 (for perfect agreement). The “d” index is given by equation 3:

$$d = 1 - \left[\frac{\sum (Pi - Oi)2}{\sum ([PI - O] + [Oi - \bar{O}])^2} \right] \qquad [3]$$

Where: P_i is the TRMM satellite rainfall estimation (mm) at time interval i; O_i = observed precipitation (mm) over a given time interval i; N = number of data analyzed; $\overline{P}$ = TRMM satellite precipitation estimation average (mm); and $\overline{O}$ is the gauge-based precipitation average (mm).

According to Camargo and Sentelhas (1997), the following statistical indicators to correlate the estimated values with those measured were considered: accuracy - Willmott "d" index and confidence or performance.

The "c" index is computed according to equation 4:

$$c = r \cdot d \qquad [4]$$

According to the value found in equation 4, they are classified according to Table 1.

Table 1. Performance classification of the estimation of agricultural productivity methods by the "c" index. Source: Camargo and Sentelhas (1997).

"c" Values	Performance
>0.85	Optimum
0.76 a 0.85	Very good
0.66 a 0.75	Good
0.61 a 0.65	Reasonable
0.51 a 0.60	Affordable
0.41 a 0.50	Worst
≤ 0.40	Terrible

RESULTS AND DISCUSSION

Figure 1 shows the variation in the annual rainfall in the region of Santo Antônio de Goiás from 1983 to 2015. Analyzing the time series occurred between 1983 and 2015 with the estimated annual average rainfall of 1498 mm, it is clear that only in seven years there were rainfall indices approaching the climatological normal. Precipitation was below the average for 15 years and above the average for 10 years. These oscillations occurring in the annual precipitation in the region may be associated with the El Niño-Southern Oscillation (ENSO), an atmospheric-oceanic phenomenon of large scale, characterized by anomalies in the surface temperature (SST) in the equatorial Pacific Ocean. During the negative phase (La Niña), the rainfall pattern are generally below the climatological normal, and in the positive phase (El Niño), they are usually higher than the normal (Grimm *et al*., 1998). The year with the highest accumulated rainfall was 2009 (1978 mm) and the driest year was 2007, with 1018 mm. However, the higher annual total precipitation variability was observed between 2002 and 2015.

Figure 2 shows the annual cycle of precipitation between 1998 and 2015 recorded in the rain gauge, estimated by the 3B42 V7 and RT algorithms for the period from 1998-2015 and 2000-2015, respectively, as well as the annual cycle of precipitation for the period from 1983 to 2015. The satellite precipitation estimates (3B42 V7 and RT) presented a similar behavior compared to the gauged precipitation, clearly identifying the rainy and dry periods at the study location. The annual cycle of precipitation from 1998 to 2015 was 4.1% above the climatological

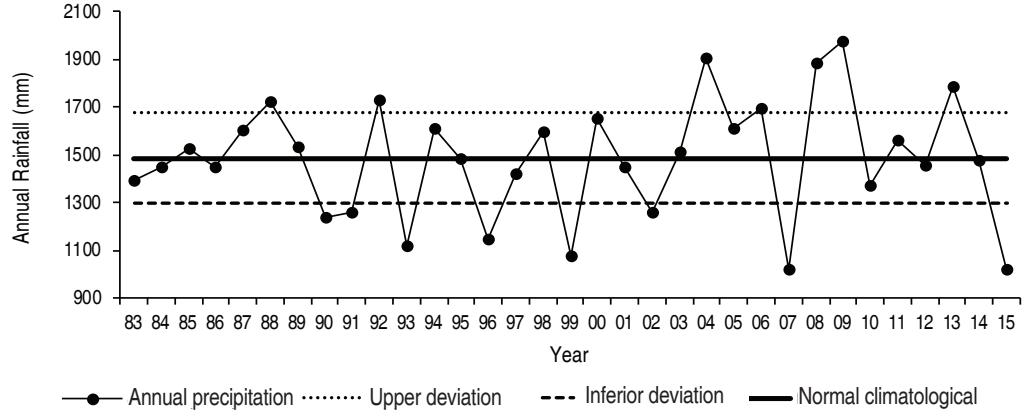

Figure 1. Annual rainfall Variability and its minimum and maximum confidence intervals at Santo Antônio de Goiás count, during the period from 1983 to 2015

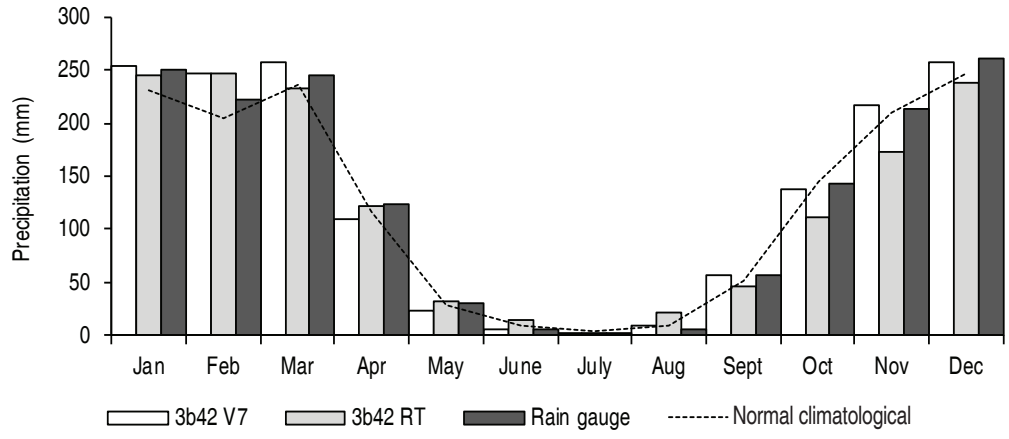

Figure 2. Annual comparison of rainfall for the period between 1998 and 2015, observed in the pluviometric station, estimated by satellite and the climatological normal.

normal. The 3B42 V7 (3B42 RT) precipitation estimates presented higher (lower) monthly totals at about 5.3% (0.5%) compared to the climatological normal.

Seasonally, the 3B42 V7 algorithm overestimated at around 1.5% during the rainy season and underestimated at around 3.7% during the dry compared to the monthly mean observed precipitation. On the other hand, the 3B42 RT algorithm underestimated 6% in the rainy season and overestimated 12.64% in the dry period.

The months of June, September and October presented an index c with performance classified by Camargo and Sentelhas (1997), as very good. The months of January, February, April, May, July and December were classified as good and March as median. The performance during November and August were classified as Affordable and Terrible, respectively. Table 2 shows the results also showed that the 3B42 RT algorithm and the gauged precipitation obtained a high and significant correlation coefficient (at around 0.88) with the indexes of performance classified as very good, good and medium from January to June and for September, October and December. Only in the months of July, August and November the precipitation estimates were lower, with values around 0.15, 0.28 and 0.14, respectively.

Table 2. Statistical analysis of the monthly annual precipitation observed in the rain gauge station against the precipitation estimates from the 3B42 V7 and RT algorithms for the period from January 1998 to December 2015 and from January 2000 to December 2015, respectively.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3B42 V7 r	0.72	0.68	0.63	0.76	0.71	0.84	0.88	0.68	0.86	0.79	0.55	0.70
3B42 RT r	0.74	0.87	0.57	0.75	0.55	0.68	0.22	0.38	0.88	0.88	0.15	0.55
3B42 V7 RMSE	3.79	26.66	25.75	6.82	7.46	0.84	1.09	5.05	0.37	10.31	7.06	6.52
3B42 RT RMSE	4.22	28.19	14.15	1.80	2.06	8.97	0.21	16.75	11.69	33.35	42.33	25.12
3B42 V7 d	0.99	0.98	0.98	0.99	0.93	0.97	0.86	0.39	0.99	0.99	0.98	0.98
3B42 RT d	0.99	0.97	0.97	0.99	0.98	0.92	0.70	0.75	0.95	0.94	0.96	0.97
3B42 V7 c	0.71	0.66	0.61	0.75	0.66	0.81	0.75	0.26	0.85	0.78	0.53	0.68
3B42 RT c	0.73	0.84	0.55	0.74	0.53	0.62	0.15	0.28	0.83	0.82	0.14	0.53

Figure 3 shows the monthly histograms of the observed rainfall in contrast with the estimated by the 3B42 V7 algorithm for the period from January 1998 to December 2015. During the rainy season from October to April, the 3B42 V7 algorithm overestimates at around 3.5% the observed precipitation. In this period, the correlation coefficient recorded an average value of 0.55 to 0.76, RMSE of 6.52 to 26.66 mm and concordance index of 0.98 to 0.99. In the dry season, during the months from May to September, the 3B42 V7 algorithm underestimates the precipitation at around 2.84% compared to the rain gauge. The correlation coefficient in this period had an average value of 0.68 and 0.88. The RMSE ranged from 0.84 to 7.46 mm and concordance index presented satisfactory values along the year, except for August, which showed a concordance index of 0.55.

These results according with Collischonn *et al*. (2007), who evaluated the 3B42 algorithm over the Paraguay River basin and found correlation coefficient ranging from 0.25 to 0.64, considered acceptable by the authors. The study also showed that there is a tendency for the satellite to overestimate precipitation by around 8%. Pereira *et al*. (2013) showed values 9% higher than the TRMM satellite estimates in the central region of Brazil.

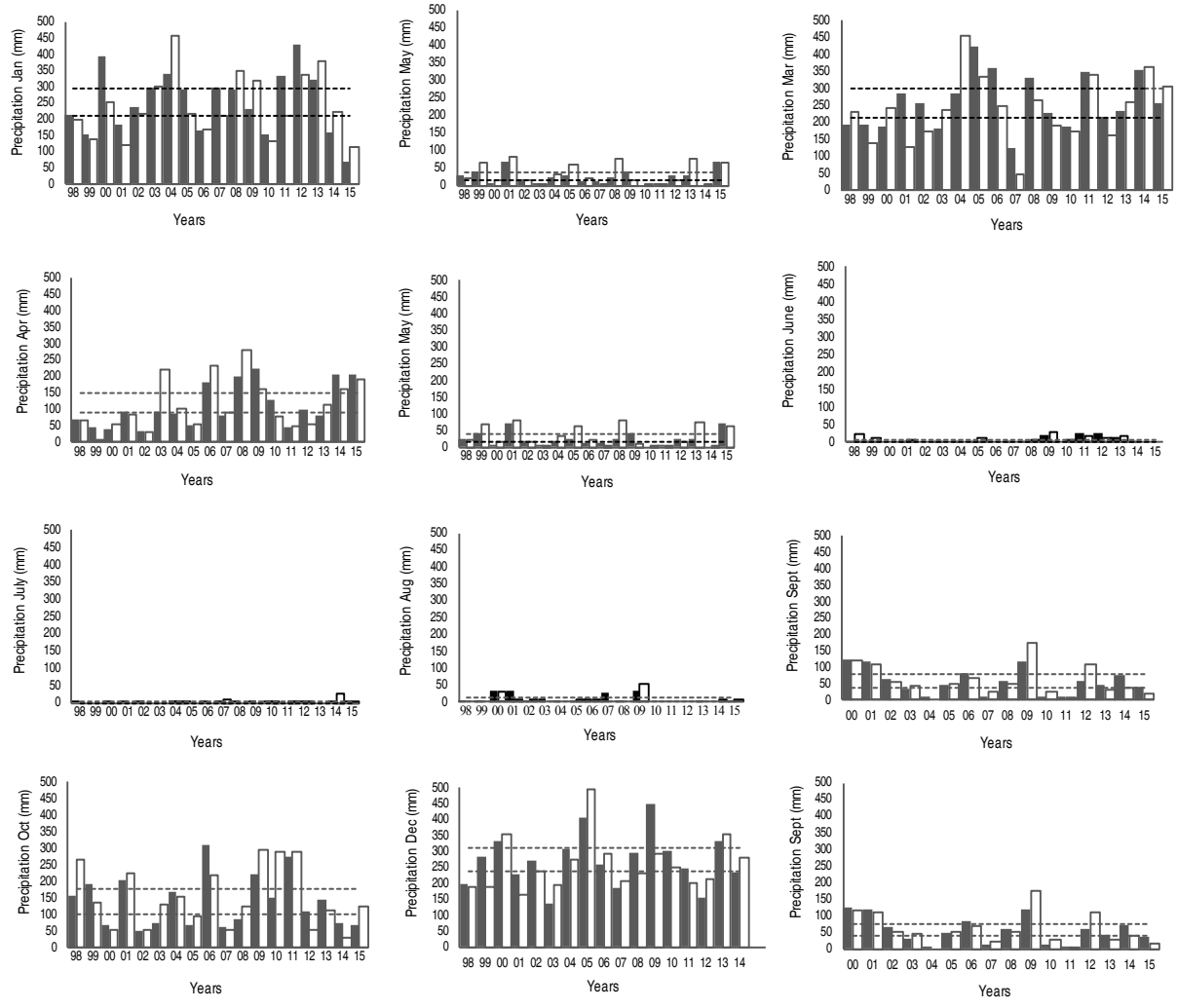

Figure 3. Comparison between the monthly rainfall estimated by the 3B42 V7 algorithm versus the recorded in the rain gauge, during the period from January, 1998 to December, 2015. Dashed lines indicate the maximum and minimum limits of precipitation

Figure 4 shows the rainfall histograms obtained by the algorithm 3B42 RT compared with the rain gauge station. The algorithm Real Time presented precipitation estimates 3.9% lower in the rainy season, with RMSE of 21.31 mm, 0.64 correlation and concordance index of 0.98. In the dry season, precipitation estimates overestimated by 14.47%. On the other hand, during the dry season, the precipitation estimation indicated lower values of performance between the months of July and August (Table 3).

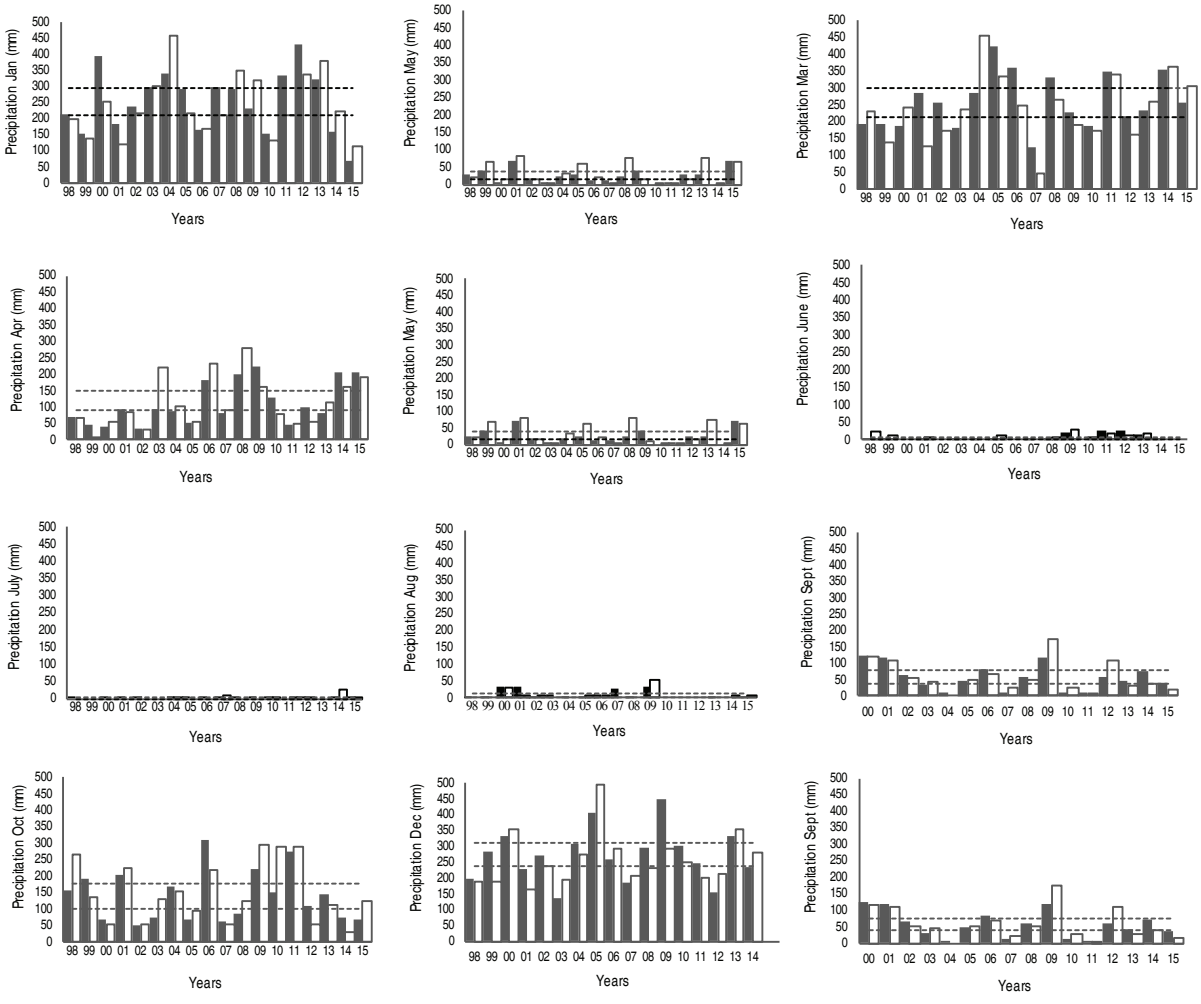

Figure 4. Same as Figure 3, but for the 3B42 RT algorithm and for the period from January, 2000 to December, 2015.

Figure 5 shows the scatter plot of the ten-day precipitation with confidence intervals at 95%. In the rainy season, only the month of February presented data within the confidence interval; in the months of October, November, December, January, March and April, the precipitation estimated by the algorithm 3B42 V7 overestimated the values by 4%. The correlation coefficient presented results between 0.50 and 0.71 and median performance classification except in the month of December, which presented values of 0.49.

The average correlation of the ten-day precipitation in the rainy season was 0.65, RMSE of 0.07 mm and concordance index of 0.98. In the dry season, the satellite underestimated the precipitation by 8.69%, the average correlation was of around 0.73, RMSE of 0.01 mm and 0.68 concordance index. However, according to Nobrega, *et al*. (2008) and Woldemeskel, *et al*. (2013), indicate that correlation indexes between 0.5 and 0.8 could be classified as good results.

Table 3. Statistical analysis of the monthly time precipitation observed in the rain gauge station against the precipitation estimates from the 3B42 V7 and RT algorithms for the period from January 1998 to December 2015 and from January 2000 to December 2015, respectively.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3B42 V7 r	0.72	0.68	0.63	0.76	0.71	0.84	0.88	0.68	0.86	0.79	0.55	0.70
3B42 RT r	0.74	0.87	0.57	0.75	0.55	0.68	0.32	0.38	0.88	0.85	0.35	0.55
3B42 V7 RMSE	3.79	26.66	25.75	6.82	7.46	0.84	1.09	5.05	0.37	10.31	7.06	6.52
3B42 RT RMSE	4.22	28.19	14.15	1.80	2.06	8.97	0.21	16.75	11.69	33.35	42.33	25.12
3B42 V7 d	0.99	0.98	0.98	0.99	0.93	0.97	0.86	0.55	0.99	0.99	0.99	0.99
3B42 RT d	0.99	0.98	0.99	0.99	0.99	0.85	0.80	0.60	0.95	0.94	0.60	0.89
3B42 V7 c	0.71	0.66	0.61	0.75	0.66	0.81	0.75	0.37	0.85	0.78	0.54	0.69
3B42 RT c	0.73	0.85	0.56	0.74	0.54	0.57	0.25	0.22	0.82	0.79	0.21	0.48

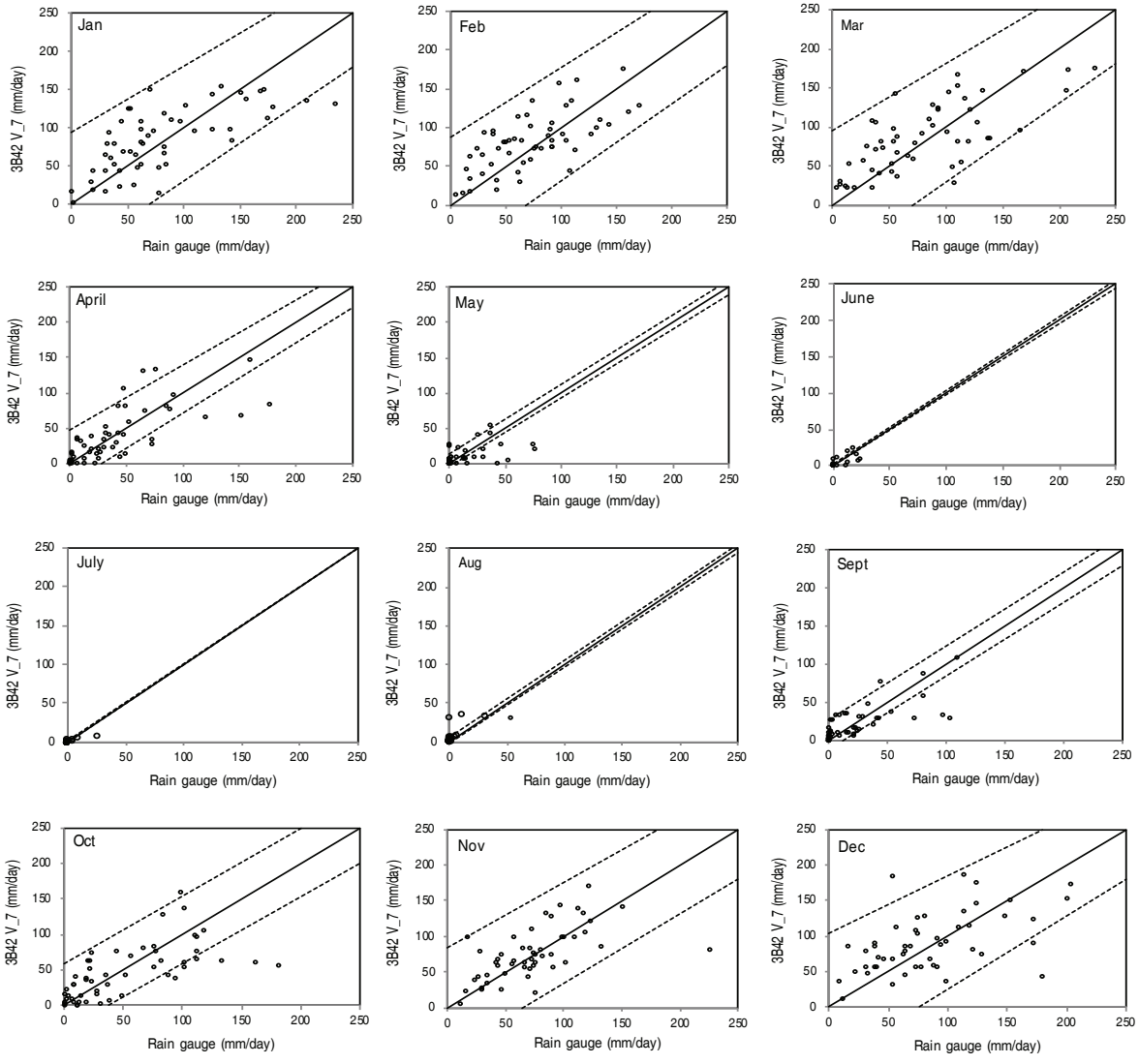

Figure 5. Scatter plot between the ten-day observed precipitation against the 3B42 V7 precipitation estimates by, from January 1998 to December 2015.

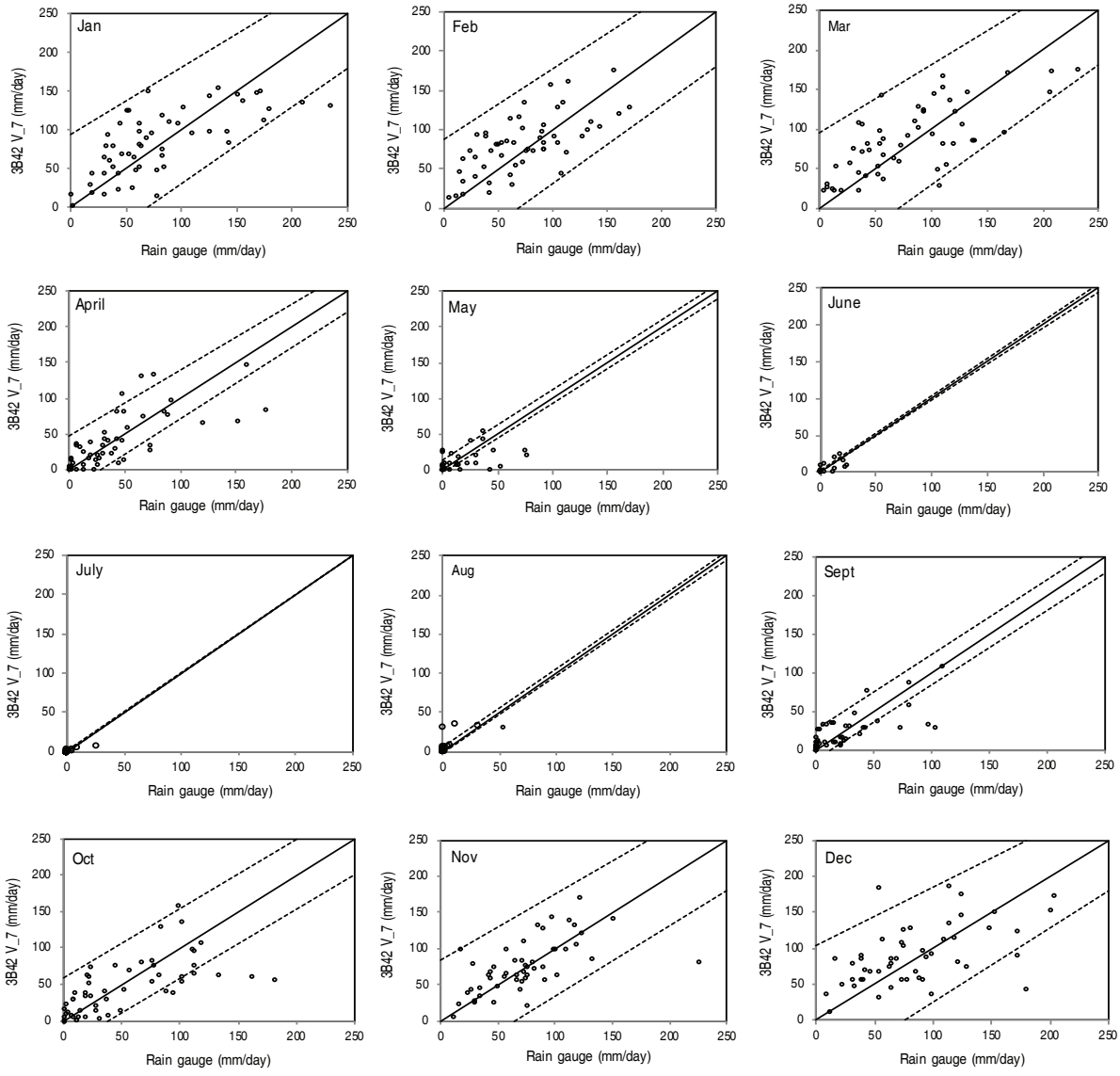

Figure 6. Scatter plot between the ten-day observed precipitation against the 3B42 RT precipitation estimates by, from January 1998 to December 2015

In the rainy season, the satellite precipitation estimates underestimated in 5.54% in relation to the precipitation registered in the rainy season. The correlation index ranged from 0.42 to 0.76, RMSE 0.03 to 0.23. In this period the agreement index of the precipitation estimate ranged from 0.86 to 0.99. However, during the months of November and December, the performance was relatively week, with values around 0.49 and 0.39. In the dry season, the rainfall was overestimated by 9.31%, with a correlation of around 0.37 to 0.80, RMSE of 0.001 to 0.10 mm and concordance index of 0.14 to 0.96. Lastly, in the dry period, the precipitation was overestimated by 9.31%. Satisfactory statistical results were found in April and September months, with values around 0.76 and 0.80. During the months of May to August the algorithm 3B42 RT did not show favorable results, for instance r presented values of 0.52 and 0.47, respectively (Table 4). The RMSE values found in this study were very similar to those of Dinku *et al*. (2007) in Ethiopia, where the relative RMSE was around 25%.

Table 4. Statistical analysis of the decendial time precipitation observed in the rain gauge station against the precipitation estimates from the 3B42 V7 and RT algorithms for the period from January 1998 to December 2015 and from January 2000 to December 2015, respectively.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3B42 V7 r	0.70	0.67	0.71	0.73	0.56	0.74	0.88	0.73	0.75	0.66	0.61	0.50
3B42 RT r	0.75	0.77	0.65	0.76	0.52	0.73	0.37	0.47	0.80	0.71	0.57	0.42
3B42 V7 RMSE	0.08	0.15	0.11	0.02	0.04	0.003	0.005	0.02	0.02	0.07	0.07	0.05
3B42 RT RMSE	0.03	0.16	0.04	0.04	0.001	0.04	0.015	0.10	0.08	0.23	0.31	0.11
3B42 V7 d	0.99	0.98	0.99	0.99	0.94	0.99	0.089	0.50	0.99	0.99	0.99	0.99
3B42 RT d	0.96	0.97	0.95	0.99	0.96	0.14	0.87	0.35	0.92	0.91	0.86	0.95
3B42 V7 c	0.63	0.65	0.70	0.72	0.52	0.73	0.78	0.36	0.74	0.65	0.60	0.49
3B42 RT c	0.72	0.74	0.61	0.75	0.49	0.10	0.32	0.16	0.73	0.64	0.49	0.39

CONCLUSIONS

This work evaluated the performance of TRMM satellite precipitation estimates, from 3B42 V7 and RT algorithms against the gauge-based precipitation as a reference located a Santo Antônio de Goiás, GO. Initially, a general investigation of the interannual precipitation regime from 1983-2015 was performed. Secondly, the period from 1998-2015 (2000-2015) was taken for the 3B42 V7 (3B42 RT) performance evaluations.

The performance of 3B42 V7 and RT algorithms against to the measured rainfall showed that the algorithm 3B42 V7 presented higher reliability statistical skills than the 3B42 RT algorithm.

On an annual, monthly and decennial time scales, an overestimation of the satellite precipitation estimates from 3B42 V7 algorithm were observed during the rainy season, where the precipitation estimates showed a greater proximity indexes on annual scale. In the dry period, the precipitation estimates obtained by 3B42 V7 were below than observed at the rain gauge. The monthly scale presented the lowest value of underestimations. Although the satellite precipitation showed both overestimate and underestimate trends, a good agreement in represent the precipitation regime at different time scales were observed. In addition, the satellite data showed to be a good complementary data source for agricultural applications with a lack of surface precipitation measurements over the region.

REFERENCES

Adler RF, Kidd C, Petty G, Morissey M, Goodman HM. 2001. Intercomparison of global precipitation products: the third precipitation intercomparison project (PIP-3). Bulletin of American Meteorological Society 82(7): 1377–1396. doi: 10.1175/1520-0477(2001)082<1377:IOGPPT>2.3.CO;2

Almazroui M. 2011. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009. Atmosphere Research 99(3-4): 400–414. doi: 10.1016/j.atmosres.2010.11.006

Baú AL, Azevedo CAV, Bresolin AA. 2013.Modelagem da precipitação pluvial diária intra-anual da Bacia Hidrográfica Paraná III associada aos eventos ENOS. En Revista Brasileira de Engenharia Agrícola e Ambiental, http://www.agriambi.com.br/revista/v17n08/v17n08a13.pdf; consulta: enero 2016.

Behrangi A, Khakbaz B, Jaw TC, Agha Kouchak A, Hsu K, Sorooshiam S. 2011. Hydrologic evaluation of satellite precipitation products over a mid-size basin. Journal of Hydrology 397(3-4): 225–237.doi: 10.1016/j.jhydrol.2010.11.043

Berlato MA and Fontana DC. 2003. El Niño e La Niña: impactos no clima, na vegetação e na agricultura do Rio Grande do Sul. Aplicações de previsões climáticas na agricultura. UFRGS, Porto Alegre. 110 p.

Blain GC. 2010. Séries anuais de temperatura máxima média do ar no estado de São Paulo: Variações e tendências climáticas. En: Revista Brasileira de Meteorologiahttp://www.scielo.br/pdf/rbmet/v25n1/v25n1a10; consulta: enero 2016.

Camargo AP and Sentelhas PC. 1997. Avaliação do desempenho de diferentes métodos de estimativas da evapotranspiração potencial no Estado de São Paulo, Brasil.Revista Brasileira de Agrometeorologia 11(6): 585 – 593. doi: 10.1590/S1415-43662007000600006

Chen S, Hong Y, Cao Q, Kirstetter P, Gouorley JJ, Qi Y, Zhang J, Howard K, Hu J, Wang J. 2013. Performance evaluation of radar and satellite rainfalls for Typhoon Morakot over Taiwan: Are remote-sensing products ready for gauge denial scenario of extreme events? Journal Hydrology 506: 4–13. doi: 10.1016/j.jhydrol.2012.12.026

Collischonn B, Allasua D, Collischonn W and Tucci CEM. 2007. Desempenho do satélite TRMM na estimativa de precipitação sobre a bacia do Paraguai superior. En: Revista Brasileira de Cartografia.http://

www.lsie.unb.br/rbc/index.php?journal=rbc&page=article&op=view302 consulta: Enero 2016.

Dinku T, Ceccato P, Grover-Kopec E, Lemma M, Connor SJ and Ropelewski CF. 2007. Validation of satellite rainfall products over East Africa's complex topography. International Journal of Remote Sensing 28(7): 1503-1526. doi: 10.1080/01431160600954688

Fisher BL. 2004. Climatological validation of TRMM TMI and PR monthly rain products over Oklahoma. Journal of Applied Meteorology 43: 519–535. doi: 10.1175/1520-0450(2004)043<0519:CVOTTA>2.0.CO;2

Franchito SH, Rao VH, Vasques AC, Santo, CME, Conforte JC. 2009. Validation of TRMM precipitation radar monthly rainfall estimates over Brazil. Journal of Geophysical Reserch 114: D02105. doi: 10.1029/2007JD009580.

Grimm A, Ferraz SET, Gomes J. 1998. Precipitation anomalies in Southern Brazil associated with Niño and La Niña events. Journal Climate (11): 2863-2880. doi*:* /10.1175/1520-0442(1998)011<2863:PAISBA>2.0.CO;2

BGE - Instituto Brasileiro de Geografia e Estatística. 2016. Estados. En: http://www.ibge.gov.br/estadosat/perfil.php?sigla=go. consulta: enero 2016.

Karaseva M, Prakash S, Gairola R. 2011.Validation of high-resolution TRMM-3B43 precipitation product using rain gauge measurements over Kyrgyzstan. Theoretical and Applied Climatology 108:147. doi: 10.1007/s00704-011-0509-6

Kummerow C, Barnes W, Kozu T, Shiue J and Simpson J. 1998. The Tropical Rainfall Measuring Mission (TRMM) Sensor Package. Journal of Atmospheric and Oceanic Technology 15(3): 809–817. doi: 10.1175/1520-0426(1998)0152.0.CO;2.

Kummerow C, Simpson J, Thiele O. 2000. The status of the Tropical Rainfall Measuring Mission (TRMM) after two years in orbit. Journal of Applied Meteorology 39: 1965-1982. doi: 10.1175/1520-0450(2001)040<1965:TSOTTR>2.0.CO;2

Kurtzman D, Navon S, Morin E. 2009. Improving interpolation of daily precipitation for hydrologic modelling: Spatial patterns of preferred interpolators. Hydrological Processes 23: 3281–3291. doi: 10.1002/hyp.7442

Layberry R, Kniveton DR, Todd MC, Kidd C, Bellerby TJ. 2006. Daily precipitation over southern Africa: a new resource for climate studies. Journal of Hydrometeorology 7: 149-159. doi: 10.1175/JHM477.1

Li X, Zhang Q, Xu C. 2014. Assessing the performance of satellite-based precipitation products and its dependence on topography over Poyang Lake Basin. Theoretical and Applied Climatology 115: 713-729. doi: 10.1007/s00704-013-0917-x

Nóbrega R S, Souza E P, Galvíncio J D. 2008. Análise da estimativa de precipitação do TRMM em uma sub-bacia da Amazônia Ocidental. En: Revista Geografia. https://periodicos.ufpe.br/revistas/geografia/article/viewFile/9041/8984; consulta: enero 2016.

Paz AR, Collischonn W. 2011. Avaliação de estimativas de campos de precipitação para modelagem hidrológica distribuída. En: Revista Brasileira de Meteorologia. http://www.scielo.br/pdf/rbmet/v26n1/a10v26n1.pdf;consulta: enero 2016.

Reboita MS, Gan MA, Rocha RP da, Ambrizzi T. 2010. Regimes de Precipitação na América do Sul: Uma revisão bibliográfica. En: Revista Brasileira de Meteorologia. http://www.scielo.br/pdf/rbmet/v25n2/a04v25n2.pdf; consulta: enero 2016.

Salio P, Hobouchian MP, García SY and Vila D. 2014. Evaluation of High-Resolution Satellite Precipitation Estimates over Southern South America using a Dense Rain Gauge Network. Atmospheric Research 116: 146-161. doi: 10.1016/j.atmosres.2014.11.017

Sapiano M and Arkin P. 2009. An intercomparison and validation of high-resolution satellite precipitation estimates with 3-hourly gauge data. Journal Hydrometeorology 10(1): 149–166. doi: 10.1175/2008JHM1052.1

Silva SC da, Heinemann AB, Paz RLF da, Amorim A de O. 2014. Informações meteorológicas para pesquisa e planejamento agrícola, referentes ao município de Santo Antônio de Goiás, GO. Embrapa Arroz e Feijão, documentos, Santo Antônio de Goiás. 298 p.

Willmott CJ, Ackleson SG, Davis RE, Feddema JJ, Klink KM, Legates DR, O'Donnell J and Rowe CM. 1985. Statistics for the Evaluation and Comparison of Models. Journal of Geophysical Research. 90(C5): 8995-9005. doi: 10.1029/JC090iC05p08995.

Woldemeskel FM, Sivakumar B and Sharma A. 2013. Merging gauge and satellite rainfall with specification of associated uncertainty across Australia. Journal of Hydrology 499: 167-176. doi: 10.1016/j.jhydrol.2013.06.039

WMO. 2008. Guide to Meteorological Instruments and Methods of Observation. 7th edition. World Meteorological Organization 8, Geneva Switzerland.

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Insecticide effect of leaf extracts from *Schinus molle* on larvae of *Gonipterus platensis*

UNIVERSIDAD NACIONAL DE COLOMBIA

Efecto insecticida de extractos de hojas de *Schinus molle* en larvas de *Gonipterus platensis*

doi: 10.15446/rfna.v70n3.58272

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Keywords:
Schinus molle
Gonipterus platensis
Botanical insecticides
Integrated pest management

ABSTRACT

The insecticide effect of new and mature leaf extracts obtained with ethanol and water from *Schinus molle* L. (Anacardiaceae) were evaluated at 0.5 - 3.4% w/v and 0.5 - 4.8% w/v, respectively, onto larvae third instar of *Gonipterus platensis* Marelli (Coleoptera: Curculionidae), an important defoliating pest on eucalypt (*Eucalyptus* spp., Myrtaceae) plantations. The extracts were applied to eucalypt leaves that were given as food to the larvae, and their effects were determined by determining mortality and the LC_{50} and LT_{50} by Probit analysis on the larvae. Both extracts were effectives, especially those from new leaves; the ethanol extract from them caused the greatest mortality. The highest concentrations of the water and ethanol extracts (3.4 and 4.8% w/v, respectively) caused average mortality of 100 and 88.9% with new leaf extracts, and 94.7 and 86.4% with mature ones, respectively. The insecticide effectiveness 6 d after treatment in decreasing order were: new leaves-ethanol (LC_{50} = 0.79% w/v), new leaves-water (LC_{50}= 2.08% w/v), mature leaves-ethanol (LC_{50}=0.63% w/v) mature leaves-water (LC_{50}=12.01% w/v). The LT_{50} at 1.7% w/v was 5.2 d in new leaves-ethanol. These results of the insecticide effect on *G. platensis* larvae allow to consider the leaf extracts from *S. molle* an interesting alternative as a bioinsecticide source for an integrated pest management system of this pest

Palabras claves:
Schinus molle
Gonipterus platensis
Insecticidas botánicos
Manejo integrado de plagas

RESUMEN

Se evaluaron extractos insecticidas etanólicos y acuosos obtenidos desde hojas jóvenes y maduras de *Schinus molle* L. (Anacardiaceae), en concentraciones de 0,5 a 3,4% p/v y 0,5 a 4,8% p/v, respectivamente, sobre larvas de tercer estadio de *Gonipterus platensis* (Coleoptera: Curculionidae), importante plaga defoliadora de eucaliptos (*Eucalyptus* spp., Myrtaceae). Los extractos se aplicaron sobre hojas de eucalipto como alimento para las larvas, y su efectividad se determinó a través de la mortalidad y la determinación mediante análisis Probit de la concentración y tiempo letal (CL_{50} y TL_{50}, respectivamente). Ambos extractos fueron eficaces contra las larvas, especialmente aquellos obtenidos de hojas jóvenes; el extracto etanólico de estas mismas hojas causó la mayor mortalidad. Con las mayores concentraciones de los extractos en etanol (3,4% p/v) y agua (4,8% p/v) se obtuvieron mortalidades promedio de 100 y 88,9% con hojas jóvenes, y 94,7 y 86,4% con hojas maduras, respectivamente. El orden decreciente de la efectividad insecticida de los extractos de hojas y solvente fue: hojas joven-etanol (CL_{50}= 0,79% p/v), hojas joven-agua (CL_{50}= 2,08% p/v), hojas maduras-etanol (CL_{50}= 2,63% p/v) y hojas maduras-agua (CL_{50}= 12,01% p/v) a seis días después de la aplicación de los extractos. El TL_{50} fue 5,2 días a la concentración de extractos de hojas nuevas en etanol de 1,7%p/v. Las propiedades insecticidas de los extractos de hojas de *S. molle* sobre las larvas de *G. scutellatus* permiten considerar a esta planta una alternativa interesante como fuente bioinsecticida para el sistema de manejo integrado de esta plaga.

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Received: August 30, 2016; Accepted: April 21, 2017
Rev.Fac.Nac.Agron 70(3): 8263-8270. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

Gonipterus platensis Marelli (formerly *G. scutellatus* Gyllenhal) (Col.: Curculionidae) is distributed worldwide, feeding both as larvae and adults on eucalypt leaves, causing defoliation and stopping growth (Mapondera *et al.,* 2012). The damage affects mainly the upper third of the tree, particularly on the new leaves of the upper part of the canopy. This pest may present 2-4 cycles a year (Muñoz *et al*., 2003; Alvarado and Sartori, 2006; Elgueta, 2010). In Chile, it has become an important forest pest because of the large eucalypt plantations, where it has caused economic losses to producers (Alvarado and Sartori, 2006).

The first and second stage larvae damage the leaf epidermis at both sides, and at the third and fourth stages they consume all the lamina. The adults feed at the leaf borders, where they leave a characteristic serrate border (Muñoz *et al*., 2003; Alzugaray *et al*., 2004; Sartori, 2006).

The use of chemical insecticides is an important tool on pest control, but they have also negative effect, like the development of pest and disease resistance, the appearance of new pests, the reduction of beneficial fauna, and contamination of the environment and feeding crops (Silva *et al*., 2002; Montesino, 2009). The use of plant extracts appears as an alternative to chemical treatments, as they are healthier and ecologically acceptable (Silva *et al*., 2002; Millán, 2008).

The plants are important sources of chemical molecules, and they have envolved for million years developing defense mechanisms to reduce insect damage (Regnault-Roger *et al*., 2004; Montesino, 2009). The plants synthesize secondary metabolites, natural products that do not participate directly in processes essential for growth, development and reproduction, but are determinant in plant resistance against insect damage or adverse factors like herbivore consumption, infection by microorganisms or competition for light, water or soil, among others (Sepúlveda *et al*., 2003; Ávalos and Pérez-Urria, 2009; Montesino, 2009).

The Bolivian pepper tree *Schinus molle* L. (Anacardiaceae), a Peruvian tree common in the Andes region of South America, has been efficacious as bioinsecticide (Ferrero *et al*., 2007; Werdin *et al*., 2008; Fuentes *et al*., 2010). This ever green tree with leaves rich in essential oils may reach up to 15 m high (Donoso, 2006). Some of its major secondary metabolites are tannins, alcaloids, flavonoids, saponins, sterols, terpenes, gums, resins, and essential oils, present mainly in its fruit and foliage (Ferrero *et al.,* 2006*,* 2007; Alba *et al*., 2009).

Other studies demonstrate the insecticide effect of the essential oils in *S. molle* leaves and fruit. For example, Deveci *et al*. (2010) determined the antimicrobial activity and repellence effect of the essential oil and the hexane extracts from the leaves and fruit of *S. molle* on *Blatta orientalis*, and on 9 bacteria strains. Also, Werdin *et al.* (2008) evaluated the insecticide effect of essential oils on leaves and fruit of *S. molle* on nymphs II of *Nezara viridula* L. (Hem.: Pentatomidae), a soybean pest. At the greatest concentrations (88 and 176 µg mL^{-1}) they obtained at 48 h a mortality >95%, while the least concentrations (11 and 22 µg mL^{-1}) caused >70% mortality.

Benzi *et al.* (2009) evaluated the repellence and fumigant action of essential oils from *S. molle* leaves and fruit on the rice weevil, *Sitophilus oryzae* L. (Col.: Curculionidae). The essential oil from the leaves caused repellence at 24 h at 0.04 and 0.4% w/v, but those from the fruit had no effect.

The insecticide effect of new and mature leaf ethanol and water extracts of *S. molle* were evaluated on larvae of *G. platensis* in laboratory bioassay tests, to contribute to integrated management of this pest.

MATERIALS AND METHODS

The larvae of *G. platensis* were collected in October 2011 at a five years old *E. globulus* plantation in the Metropolitan Region, Chile (33°47'41''S; 71°30'12''W), that were taken in cloth bags to the Forest Entomology Laboratory, where they were set in Petri dishes underlined with slightly wet filter paper, and provided daily with fresh eucalypt leaves.

In the bioassays, one kg of new and mature *S. molle* leaves were used, collected at random from adult trees at the College of Forestry and Nature Conservation Sciences, University of Chile, Santiago, during the fall and winter of 2011.

To prepare the extracts the leaflets were taken from the central leaf vein, weighed fresh and then dried at 37 °C in a Memmert® 854 (Schwabach, Germany) forced air

oven until constant weight at 60 h on a Shimadzu ELBL 3000 balance. Then the dry leaflets were grinded with an Ufesa® MC 0360 knife mill. The dust obtained was mixed with water or 96 % w/v ethanol, shaking 18 h on a Heidolph® MR 3001K magnetic stirrer (Schwabach, Germany), and was heated at 37 °C during the first hour. Then, the mixes were filtered with paper, and set 15 min in a centrifugue (HN-S, USA), to obtain the base extracts. To determine the concentrations of those base extracts, a small volume of them were dried and the concentrations of total solids in % w/v were obtained by weight difference. The solutions used were prepared by serial dilution of the leaf extracts (Huerta *et al*., 2010).

The bioassays had experiment units with five third instar larvae of *G. platensis* in plastic containers lined with slightly wet filter paper and fresh and clean eucalypt leaves, at room temperature (19±2 °C). The treatment was standardized at 60 s immersion of eucalypt leaves in the extracts. These leaves were maintained for two d on exposure to the third stage larvae then every two d were changed to fresh leaves without extract until completing 10 d (Huerta *et al*., 2010).

The efficacy of the leaf extracts were evaluated by determining daily mortality with the extracts and concentrations. The results with the extracts from new and mature leaves were analyzed separately, using bifactorial anovas with two solvents x five concentrations, including controls with only the solvents, with five replicates. The results were normalized by Bliss [arcsen $\sqrt{X}$ (% adult mortality/100)] prior to the analyses, to stabilize the error of the variance. Significant differences between treatments were separate with Tukey ($P \leq 0.05$) tests. Mortality percentages were corrected by Abbott's (1925) formula to eliminate natural mortality in the controls, particularly from the toxic effect of ethanol. The LC_{50}, and the $LT_{50\text{-}95}$, were obtained in Probit analyses of separate bioassays (Thrones *et al*., 1995).

RESULTS AND DISCUSSION

Evaluation of mortality

The larval mortality of *G. platensis* obtained with the ethanol extract from new *S. molle* leaves was greater that with the water extract. The statistical analysis indicated significant differences between the treatments and their respective controls. The least mortality obtained was >33%, with the least concentration (0.5% w/v). The greatest final mortality (100%) occurred with the ethanol extract from new leaves at the greatest concentration (3.4% w/v), at the 10 d evaluation (Table 1, Figure 1).

Table 1. Mortality (%) of *G. platensis* larvae by effect of the ethanol and water extracts from new and mature leaves of *S. molle* at 10 d.

	Concentrations of the extracts (%w/v) from new leaves				
Solvents	0.0 (controls)	0.5	0.8	1.7	3.4
Ethanol	32.0 ± 4.9 a (0.0)	64.0 ± 7.5 b (47.1)	76.0 ± 7.5 b (64.7)	84.0 ± 4.0 bc (76.5)	100.0 ± 0.0 c (100)
Water	28.0 ± 4.9 a (0.0)	52.0 ± 4.9 ab (33.3)	72.0 ± 10.2 bc (61.1)	80.0 ± 6.3 bc (72.2)	92.0 ± 8.0 c (88.9)
	Concentrations of the extracts (%w/v) from mature leaves				
	0.0 (controls)	0.5	1.2	1.7	4.8
Ethanol	24.0 ± 4.0 a (0.0)	60.0 ± 11.0 b (47.4)	72.0 ± 12.0 bc (63.2)	84.0 ± 4.5 bc (78.9)	96.0 ± 4.0 c (94.7)
Water	12.0 ± 4.9 a (0.0)	44.0 ± 4.0 b (36.4)	60.0 ± 6.3 bc (54.5)	76.0 ± 7.5 cd (72.7)	88.0 ± 8.0 d (86.4)

Mortality values in parenthesis corrected by Schneider-Orelli´s (1947) formula. Means in a line with different letters are significantly different, according to Tukey ($P \leq 0.05$) tests.

The bioassay with the ethanol extract from mature *S. molle* leaves yielded a minimum larval mean mortality of 47.4% at the least concentration (0.5% w/v). The maximum mortality at 10 d for both bioassays occurred with the greatest concentrations, 1.7 and 4.8% w/v (Table 1, Figure 1). The mortality levels obtained with the ethanol and water extracts from new leaves were greater than those from mature foliage. The larvae that consumed leaves treated with the ethanol extract from new leaves at the maximum concentration (3.4% w/v) presented 100% mortality.

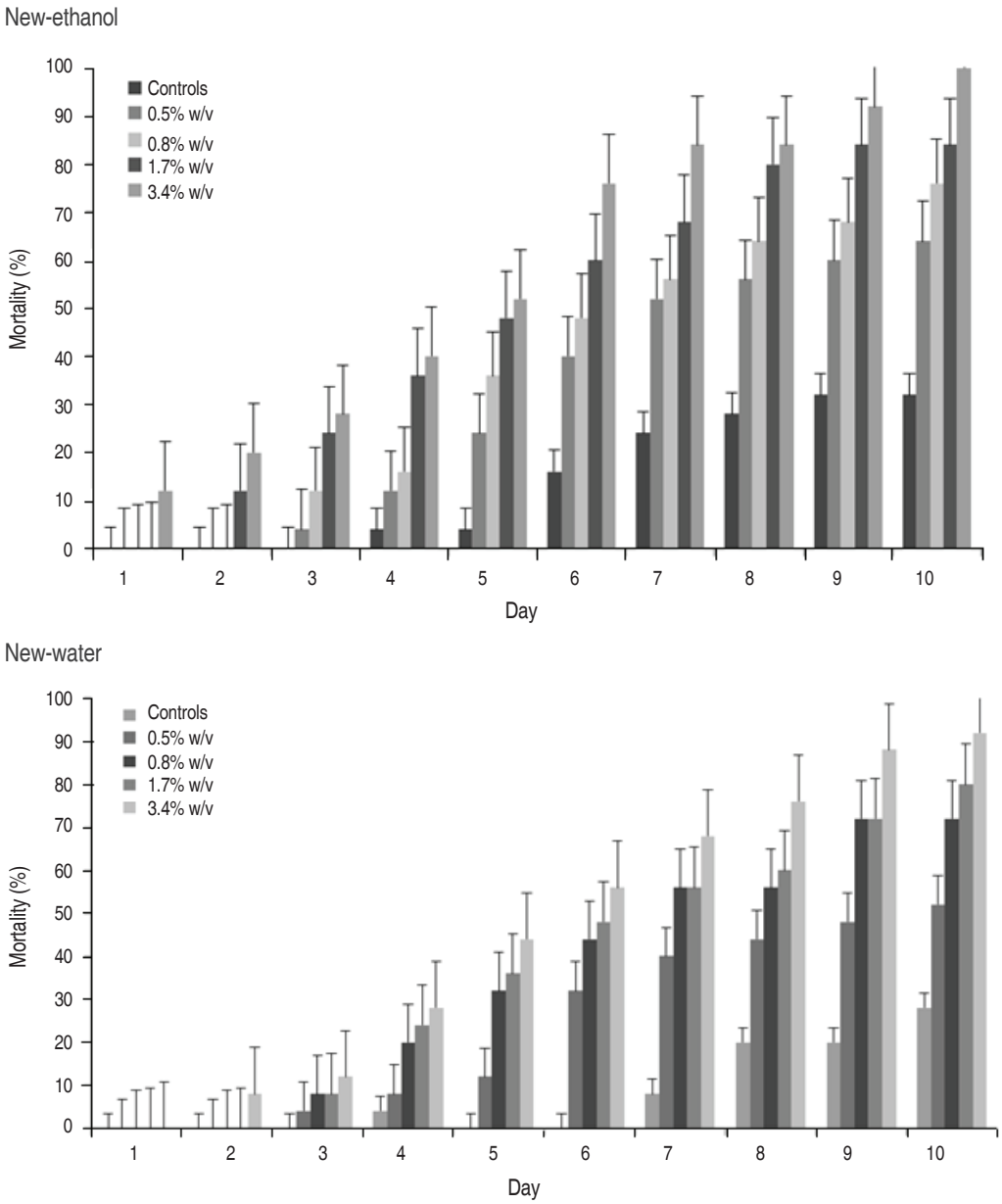

Figure 1. Mortality means (%) of larvae of *G. platensis* exposed to ethanol and water extracts of new *S. molle* leaves.

It is noteworthy to see that mortality at the two greatest concentrations evaluated in each bioassay was >72%, which demonstrates the insecticide value of both extracts (Table 1). The results obtained with the extract from mature foliage are presented in Table 1 and Figure 2.

Insecticide effectiveness

The results of the Probit analyses indicated a greater insecticide effect of the ethanol tan the water extracts on the larvae of *G. platensis*. The least LC_{50} was 0.79% w/v with the ethanol extract from new leaves at day six (Table 2). The extracts from new *S. molle* foliage caused greater effects than those of mature leaves on mortality of *G. platensis* larvae. The least lethal time (TL_{50}) at 1.7% w/v was 5.2 d with the ethanol extract from new leaves, while the greatest lethal time was 8.4 d with the water extract from mature foliage (Table 2).

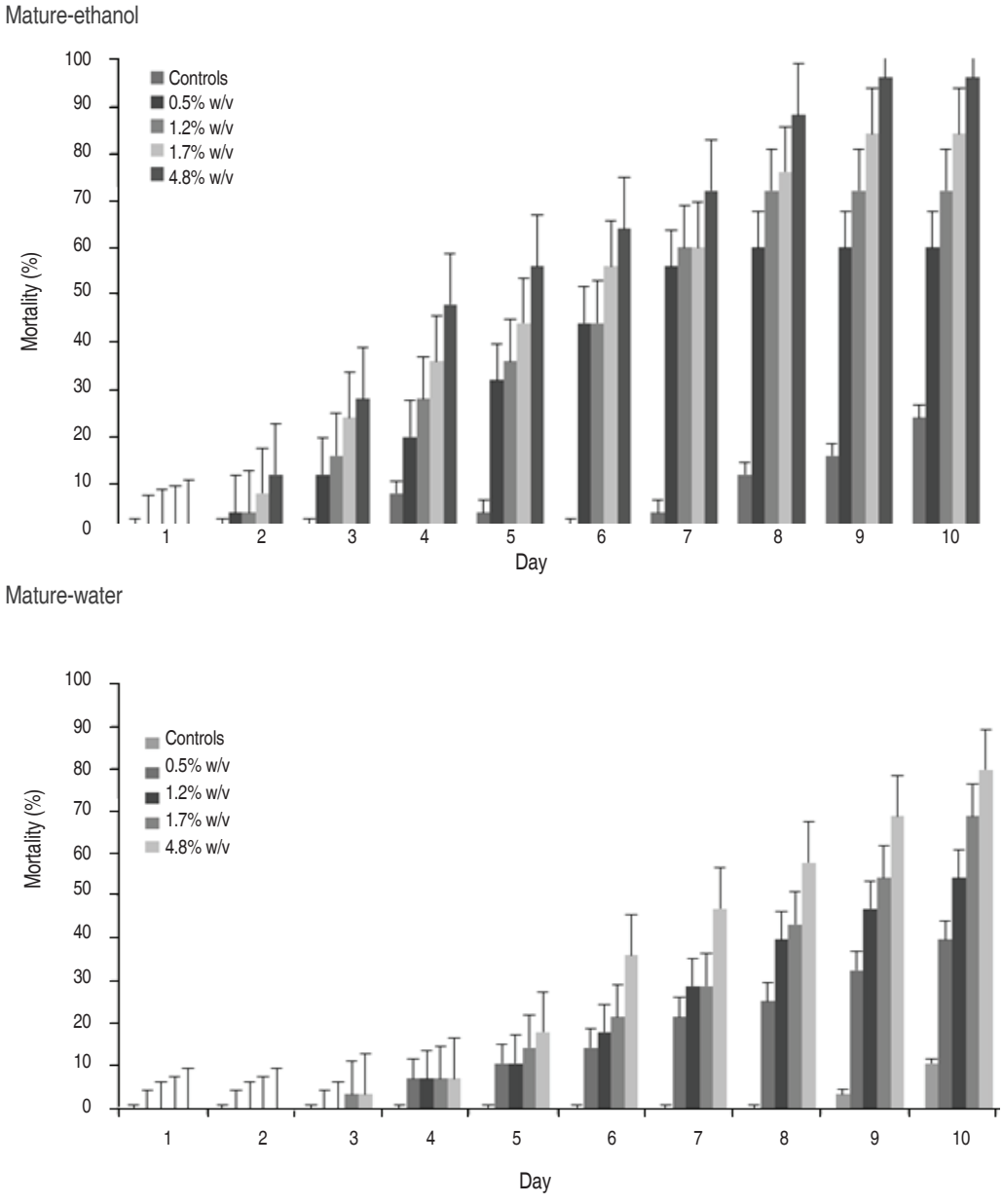

Figure 2. Mortality means (%) of larvae of *G. platensis* exposed to ethanol and water extracts of mature *S. molle* leaves.

The effectiveness of *S. molle* as botanical insecticide has been demonstrated in various studies on several pests. For example, Huerta *et al.* (2010) evaluated the toxicity of ethanol and water extracts of mature *S. molle* leaves onto adults of *Xantogaleruca luteola* Müller (Col.: Chrysomelidae), a defoliating pest of elm trees (*Ulmus* spp., Ulmaceae), at 2.0 to 4.7% w/v with ethanol and 2.5 to 5.6% w/v with water, and achieved mortality from 73.6 to 100% and 15.3 to 27.8 %, respectively. Chiffelle *et al*. (2013) analyzed the toxicity of ethanol and water extracts from new and mature *S. molle* leaves on third stadium *X. luteola* larvae, at 0.5 to 4.3% w/v for the ethanol and water extracts from new leaves, and 0.7 to 5.9% w/v and 0.5 to 4.3% w/v for mature leaves, respectively. Average mortality occurred with the greatest concentrations in ethanol and water: 89.2 and 67.4% from new leaves, and 78.4 and 62.8% from mature ones, respectively. In both studies the greatest

Table 2. Insecticide effectiveness (LC_{50} and LT_{50-95} at 1.9% w/v) on larvae of *G. platensis* of the leaf extracts from *S. molle*.

Leaf stages	Solvents	Days	Slopes (mean± SE)	LC_{50} (% w/v)	X^2
New	Ethanol	4	15.23 ± 2.86	5.42	5.69
		5	12.30 ± 4.47	2.33	2.22
		6	17.52 ± 3.47	0.79	4.49
	Water	5	9.41 ± 4.41	7.29	1.53
		6	11.13 ± 2.20	2.08	1.67
Mature	Ethanol	5	10.97 ± 7.53	4.46	2.00
		6	10.03 ± 7.21	2.63	1.50
	Water	6	10.65 ± 1.99	12.11	3.32
		7	11.73 ± 3.11	5.82	1.81
		8	15.72 ± 1.76	1.49	3.90
		LT_{50} (days)	LT_{95} (days)	Slopes (mean± SE)	X^2
New	Ethanol	5.2	9.6	0.2 ± 0.7	5.20
	Water	6.8	11.4	9.8 ± 0.8	6.50
Mature	Ethanol	6.7	11.7	9.0 ± 1.0	10.33
	Water	8.4	13.4	9.0 ± 1.3	9.22

The X^2 values calculated for the LC_{50} and LT_{50-95} were smaller than those in the table (df 3; $P \leq 0.05 = 7.8147$, and df 4; $P \leq 0.05 = 9.4877$), thus the Probit model was adjusted to the bioassay results. ± standard deviation.

mortality occurred with the ethanol extract from new leaves, similarly to our results herein.

Iannacone and Lamas (2003) evaluated the insecticide effect of water, hexane y acetone extracts at 10% w/v from *S. molle* leaves on larvae and adults of the potato moth *Phthorimaea operculella* Zeller (Lep.: Gelechiidae). For the larvae the solutions were added to the diet, and caused 90.4, 49.2 and 88.1% mortality, respectively. Those results are similar to *G. scutellatus* larval mortality obtained with the water extracts from new and mature leaves were 92% at 3.7% w/v, and 88% at 3.3% w/v, respectively.

Chiffelle *et al.* (2013) obtained a LC_{50} for *X. luteola* larvae with the ethanol extract from new *S. molle* leaves, of 1.28% w/v at seven d. This result is different to ours, where the LC_{50} was 0.79% and occurred at six d. Thus, the larvae of *G. platensis* are more susceptible than those of *X. luteola* to the extracts from *S. molle* leaves.

Also, Huerta *et al.* (2010) obtained with the ethanol extract from *S. molle* leaves a LC_{50} for *X. luteola* adults of 1.88 and 0.19% w/v at two and eight d, while that with the water extract was 8.52 and 4.06% w/v at four and eight d, respectively. This indicates that the adults of *X. luteola* are more sensible to the larvae of *G. platensis* to the extracts from the leaves of *S. molle*.

Descamps *et al.* (2008) evaluated the contact toxicity of ethanol and hexane extracts from *S. molle* leaves and fruit on larvae and adult *Tribolium castaneum* Herbst. (Col.: Tenebrionidae), at 6.8 and 4.8 % w/v of the extracts, respectively. A LC_{50} at 72 h for the foliage and fruit ethanol extracts were 13 and 29 µg $larva^{-1}$, and 11 y 17 µg $adult^{-1}$, respectively. The ethanol extract from the leaves was more effective than that from the fruit.

Iannacone and Alvariño (2010) evaluated the ecotoxicological effects of water extracts from *S. molle* leaves onto four controllers of crop pest in Perú.

Concentrations of 1.5, 2.5, 5.0, 10.0, and 20.0% w/v obtained at 48 h a LC_{50} of 3.7% for larvae of the neuropterans (Chrysopidae) *Ceraeochrysa cincta* (Schneider), 32.2% for larvae of *Chrysoperla asoralis* (Bank), 40.9% for adults of *Telenomus remus* Nixon (Hym.: Scelionidae), and 14.2% for adults of *Orius insidiosus* Say (Hem.: Anthocoridae). The third instar larvae of *G. platensis*, both the aqueous extracts of new and mature leaves, are more sensitive than the biological controllers evaluated, given that the LC_{50} 7.29% w/v to five d in new leaves and LC_{50} 12 % w/ v to six d in mature leaves.

CONCLUSIONS

The extracts from new and mature *S. molle* leaves were efficacious as bioinsecticides on *G. platensis* larvae, which were more susceptible to the extracts from new over mature leaves. The ethanol extract from *S. molle* new leaves caused at 3.4% w/v the greatest larval mortality (100%). The least LC_{50} (0.79% w/v) of *G. platensis* larvae occurred with the ethanol extract from new leaves, at day six, and also the least LT_{50} (5.2 d) at 1.7% w/v with the same extract. Our results of the insecticide properties of *S. molle* leaf extracts on *G. platensis* larvae allow to consider this tree an interesting alternative for a bioinsecticide to be used for integrated management of this pest.

REFERENCES

Alba A, Bonilla P y Arroyo J. 2009. Actividad cicatrizante de una pomada con aceite esencial de *Schinus molle* L. "molle" en ganado vacuno con heridas infectadas y en ratones. Ciencia e Investigación Agraria 12(1): 29-36.

Alvarado A y Sartori A. 2006. *Gonipterus scutellatus* Gyllenhal (Coleoptera: Curculionidae), "Gorgojo del eucalipto". Corporación Nacional Forestal. Santiago, Chile. Nota Técnica 24(47): 1-8.

Alzugaray R, Landeras E y Braña M. 2004. Evolución y situación de *Gonipterus scutellatus* Gyll. y su parásito *Anaphes nitens* Hubber en el Principado de Asturias durante los años 2001 y 2002. Boletín de Sanidad Vegetal, Plagas 30: 331-338.

Ávalos A y Pérez-Urria E. 2009. Metabolismo secundario de plantas. Reduca (Biología), Serie Fisiología Vegetal 2(3): 119-123.

Benzi V, Stefanazzi N and Ferrero A. 2009. Biological activity of essential oils from leaves and fruits of pepper tree (*Schinus molle* L.) to control rice weevil (*Sitophilus oryzae* L.). Chilean Journal Agricultural Research 69(2): 154-159. doi: 10.4067/s0718-58392009000200004

Chiffelle I, Huerta A, Celis M and Araya JE. 2013. Proximal analysis and insecticidal effects of extracts from pepper tree (*Schinus molle*) leaves on elm leaf beetle (*Xanthogaleruca luteola*) larvae. Industrial Crops and Products 43: 523-528. doi: 10.1016/j.indcrop.2012.07.062

Descamps L, Stefanazzi C y Sánchez A. 2008. Actividad biológica de extractos vegetales de *Schinus molle* var. *areira* (Anacardiaceae) en *Tribolium castaneum* Herbst. (Insecta, Coleoptera, Tenebrionidae), plaga de grano almacenado. Boletín de Sanidad Vegetal, Plagas 34: 595-605.

Deveci O, Sukan A, Tuzun N and Hames E. 2010. Chemical composition, repellent and antimicrobial activity of *Schinus molle* L. Journal of Medicinal Plants Research 4(21): 2211-2216.

Donoso C. 2006. Las especies arbóreas de los bosques templados de Chile y Argentina. Autoecología. Editorial Masisa Cuneo, Valdivia, Chile. 678 p.

Elgueta M. 2010. *Gonipterus scutellatus* El "gorgojo del eucalipto" (Coleoptera: Curculionidae) en Chile. *In*: Lanfranco, D. y C. Ruiz (eds.). Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia, Chile. pp. 425-442.

Ferrero A, Werdin J and Sánchez C. 2006. Biological activity of *Schinus molle* on *Triatoma infestans*. Fitoterapia 77(5): 381-383. doi: 10.1016/j.fitote.2006.03.004

Ferrero A, Sánchez C, Werdin J and Alzogaray A. 2007. Repellence and toxicity of *Schinus molle* extracts on *Blattella germanica*. Fitoterapia 78(4): 311-314. doi: 10.1016/j.fitote.2006.11.021

Fuertes C, Jurado B, Gordillo G, Negrón L, Núñez E, Esteban M y Távara A. 2010. Estudio integral de plantas biocidas del algodonero. Ciencia e Investigación Agraria 13(1): 34-41.

Huerta A, Chiffelle I, Puga K, Azúa F and Araya J. 2010. Toxicity and repellence of aqueous and ethanolic extracts from *Schinus molle* on elm leaf beetle *Xanthogaleruca luteola*. Crop Protection 29: 1118-1123. doi: 10.1016/j.cropro.2010.04.010

Iannacone J y Alvariño L. 2010. Toxicidad de *Schinus molle* L. (Anacardiaceae) a cuatro controladores biológicos de plagas agrícolas en el Perú. Acta Zoológica Mexicana 26(3): 603-615.

Iannacone J y Lamas G. 2003. Efecto insecticida de cuatro extractos botánicos y del cartap sobre la polilla de la papa *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), en el Perú. Entomotropica 18(2): 95-105.

Mapondera TS, Burgess T, Matsuki M and Oberprieler RG. 2012. Identification and molecular phylogenetics of the cryptic species of the *Gonipterus scutellatus* complex (Coleotera: Curculionidae: Gonipterini). Austral Entomology 51(3): 175-188. doi: 10.1111/j.1440-6055.2011.00853.x

Millán C. 2008. Las plantas: una opción saludable para el control de plagas. RAPAL, Uruguay. 99 p.

Montesino M. 2009. Insecticidas botánicos como alternativa para el manejo de plagas en sistemas agroforestales. Agricultura Orgánica 1: 24-26.

Muñoz C, Pérez V, Cobos P, Hernández R y Sánchez G. 2003. Sanidad Forestal. Guía de imágenes de plagas, enfermedades y otros agentes presentes en los bosques. Mundiprensa, Madrid, España. 576 p.

Regnault-Roger C, Philogène B y Vincent C. 2004. Biopesticidas de origen vegetal. Mundiprensa. Madrid, España. 325 p.

Sartori A. 2006. Ficha insectos. Agentes de daño en plantaciones y bosque nativo. *Gonipterus scutellatus* Gyllenhal (Coleoptera: Curculionidae), "gorgojo del eucalipto". Chile Forestal 322: 43-44.

Schneider-Orelli O. 1947. Entomoligisches Praktikum-Eifurung in die land- um forstwirtschafliche insektenkude. Sauerlander & Co., Aarau, Germany. 523 p.

Sepúlveda G, Porta-Ducoing H y Rocha-Sosa M. 2003. La participación de los metabolitos secundarios en la defensa de las

plantas. Revista Mexicana de Fitopatología 21(3): 355-363.

Silva G, Lagunes A, Rodríguez J y Rodríguez D. 2002. Insecticidas vegetales: una vieja y nueva alternativa para el manejo de plagas. Manejo Integrado de Plagas y Agroecología (Costa Rica) 66: 4-12.

Throne J, Weaver D, Chew V and Baker J. 1995. Probit analysis of correlated data: multiple observations over time at one concentration. Journal Economic Entomology 88(5): 1510-1512. doi: 10.1093/jee/88.5.1510

Werdin J, Ferrero A y Murray A. 2008. Bioactividad de aceites esenciales de *Schinus molle* var. *areira* (Anacardiaceae) en ninfas II de *Nezara viridula* (Hemiptera: Pentatomidae). Boletín de Sanidad Vegetal, Plagas 34: 367-375.

Research article

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Revista Facultad Nacional de Agronomía

Effect of a low rank coal inoculated with coal solubilizing bacteria for the rehabilitation of a saline-sodic soil in field conditions

Efecto de un carbón de bajo rango inoculado con bacterias solubilizadoras de carbón para la rehabilitación de un suelo salino-sódico en condiciones de campo

doi: 10.15446/rfna.v70n3.62478

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ABSTRACT

The aim of this research was to evaluate changes to several chemical, biological and physical properties of a Salidic Calciustolls, in response to enhancement by treatment with low rank coal (LRC) and coal solubilizing bacteria (CSB) -*Bacillus mycoides, Microbacterium* sp and *Acinetobacter baumannii*- that release humified organic matter (HOM) through biotransformation of the coal. Under field conditions, 5 m^2 plots were treated with the addition of LRC at a dose of 5 kg m^2 and an inoculum of CSB in a suspension of $1x10^8$ bacteria mL^{-1} at a dose of 100 mL m^{-2}. Soil respiration, microbiological activity, lignin peroxidase (LiP), manganese peroxidase (MnP) and laccase (Lac) enzyme activities were quantified. The variables associated with saline-sodic soils - pH, electrical conductivity (EC), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), cation exchange capacity (CEC) were measured every two months bulk density (BD) was determined sixth months after the start of the experiment. The LRC application contributed to the decrease of EC, SAR and ESP, but pH levels did not change significantly. Additionally, no significant changes were found in the BD, however the treatment increased the respiration and microbiological activity of soil, stimulated LiP, MnP and Lac enzyme activity, and increased soil CEC. These results suggest the possibility of using the LRC as an HOM source for the rehabilitation of degraded saline soils - a common problem in soils of the Cesar River Valley (Colombia) and in the dry lands of the Colombian Caribbean influenced by open-pit coal mining.

Keywords:
Lignite
Humic substances
Biotransformation of coal
Soil salinity

RESUMEN

El objetivo de esta investigación fue evaluar cambios en algunas propiedades químicas, biológicas y físicas, en respuesta mejorada por el tratamiento con carbón de bajo rango (CBR) tipo lignito y bacterias solubilizadoras de carbón (BSC) -*Bacillus mycoides*, *Microbacterium* sp y *Acinetobacter baumannii*- que liberan materia orgánica humificada (MOH) mediante la biotransformación de este carbón. En condiciones de campo, se trataron parcelas de 5 m^2 con la adición de CBR a una dosis de 5 kg de CBR m^{-2} y un inóculo de las BSC en una suspensión de $1x10^8$ bacterias mL^{-1} en una dosis de 100 mL m^{-2}. Se determinaron la respiración del suelo, la actividad microbiológica, la actividad de las enzimas lignino peroxidasa (LiP), manganeso peroxidasa (MnP) y lacasas (Lac). Las variables asociadas a la salinidad sódica del suelo: pH, la conductividad eléctrica (CE), la razón de absorción de sodio (RAS), el porcentaje de sodio intercambiables (PSI), la capacidad de intercambio catiónico (CIC) se midieron cada dos meses, mientras que la densidad aparente (Da) se determinó seis meses después de haber iniciado el experimento. La aplicación de CBR contribuyó a la disminución de la CE, RAS y PSI, pero los niveles de pH no presentaron cambios significativos. Adicionalmente, no se evidenciaron cambios significativos en la Da, sin embargo el tratamiento logró incrementar la respiración y la actividad microbiológica del suelo, estimuló la actividad de las enzimas LiP, MnP y Lac, y aumento la CIC del suelo. Estos resultados sugieren la posibilidad de utilizar el CBR como fuente de MOH para la rehabilitación de suelos salinos degradados, un problema común en los suelos del Valle del Río Cesar (Colombia) y en las tierras secas del caribe colombiano influenciadas por la minería del carbón a cielo abierto.

Palabras clave:
Lignito
Sustancias húmicas
Biotransformación del carbón
Salinidad de suelos

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Received: February 6, 2017; Accepted: April 19, 2017
Rev.Fac.Nac.Agron. 8271-8283. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

Currently, soil salinization is an environmental factor of worldwide concern, it has been estimated that 20% of total cultivated and 33% of irrigated soils are affected by high salinity (Shrivastava, 2015). There are around 800 million hectares on the planet affected by salts; of these, 397 million are due to salinity problems and 434 million are affected by conditions associated with sodicity (Munns, 2005; FAO, 2005). The high salt concentrations affect plant growth and crop production by limiting their ability to uptake water and nutrients (Abdul-Qados, 2011), and also contribute to soil degradation processes by increasing the dispersion of aggregates, compaction and soil erosion.

The main source of salt in soils comes from the weathering and erosion of rocks and primary minerals formed *in situ* or transported by water or wind. The main causes that generate salinization processes are: irrigation with saline water, groundwater level, evapotranspiration, water percolation through salt materials and seawater intrusion (Metternich, 2003). However, the dynamics of salts are so high that they cannot always be directly associated with the materials that precede the soils, but must take into account climatic, topographical, hydrological and anthropic factors (Gómez, 2004).

In sodic and saline-sodic soils, gypsum ($CaSO_4 2H_2O$) is the most commonly used amendment to maintain soil electrolyte levels that improve its physical and hydraulic properties (Wong *et al*., 2009). The combined application of gypsum-sulfur-compost has also been used, but in most cases has been decreasing due to the high costs of sulfur to farmers. Also the use of new technologies such as biofertilizers (beneficial bacteria, fungi and mycorrhiza), biopolymers and electromagnetism that stimulate microbial activity considerably, improve the soils physical properties affected by salinity due a reduction in compaction and improvements in long-term soil structure (Zúniga *et al*., 2011).

The addition of humidified organic matter (HOM) to soil has been frequently used to contribute to the rehabilitation of degraded lands (Ros *et al*., 2003), due to various studies that have demonstrated the positive effect of the HOM on soil properties (Khaled and Fawy, 2011). This has allowed HOM be recognized as fundamental to the performance of fertilization, crop productivity, soil degradation and erosion reduction, as well as the mitigation of soil desertification; because it improves soil structure and aggregation, hydraulic conductivity, promotes high levels of nutrient retention and increases cation exchange capacity (CEC) (Tejada and González, 2007; Sharif, 2002; Hernández, 2000). Several authors have incorporated different wastes and biosolids composted from green residues, vinasse (produced in sugar mills and with California red worms), among others, as amendments to soils affected by sodicity, favorably influencing some physical, chemical and biological properties of the soil , contributing to an increase in carbon immobilized by microorganisms and microbiological activity and plant growth (Duran *et al*., 2000, Gasca *et al*., 2011, Wang *et al*., 2014, Mogollón-Sandoval *et al*., 2015, Gutierrez *et al.,* 2016). Therefore, the application of organic amendments is an alternative for conditioning soil with these characteristics.

The low rank coals (LRC) such as lignite have a soft, friable consistency, opaque appearance, humidity of 30-45 %, high ash content, low fixed carbon content (low energy content) (Word of coal, 2005) and are considered by-products of open pit mining. LRC asunderstood by its low degree of carbonification is a great source of humic substances (HS) (Peña-Méndez, 2005; Gianoulli *et al*., 2009) and also has high contents of elements that stimulate microbial growth and development (Hölker *et al*., 2002; Tao *et al*., 2009), and, through different mechanisms, its macrostructureallows the release of HS (Peña-Méndez, 2005). Consequently, LRC could be used as an organic amendment for the management of degraded soils (Senesi *et al*., 1996; Chassapis and Roulia, 2008). Among the microorganisms that have the ability to solubilize LRC to generate substances with similar characteristics to HS obtained from LRC by chemical extraction (Filip and Kubát, 2001) are bacteria isolated from coal samples; some genera and species of *Escherichia freundii*, *Pseudomonas rathonis*, *Pseudomonas fluorescens*, *Streptomyces setoni*, *Pseudomonas putida*, *Bacillus* sp., *Staphylococcus*, *Rhodococcus* and others (Laborda *et al*., 1997; Machnikowska *et al*., 2002; Pokorný *et al*., 2005; Valero *et al*., 2014; David *et al*., 2017) have been reported.

In a study conducted by Valero *et al*. (2014), three new LRC biotransformers were reported: *Bacillus mycoides*,

Acinetobacter baumannii and *Microbacterium* sp.; these were isolated from environmental samples with coal residues, with the ability to solubilize LRC, producing up to 300 mg L^{-1} of HS in liquid medium. Subsequently Cubillos-Hinojosa *et al.* (2015) conducted a study where the LRC inoculated with coal solubilizing bacteria (CSB) were evaluated under greenhouse conditions as an organic amendment for a saline-sodic soil and it was found that the effect of the addition of LRC on the biological and chemical properties is greater when applied in conjunction with CSB. The application of LRC 1% and CSB in the Salidic Calciustolls soil promoted short-term biological activity, which was reflected in an increase in soil respiration, hydrolytic enzyme activity in fluorescein diacetate (FDA), ligninolytic enzyme [lignin peroxidase (LiP) and lacsases (Lac) activity associated with LRC biotransformation], and increased cation exchange capacity (CEC). The treatments of saline-sodic soil with LRC and CSB also generated short-term favorable changes in the chemical variables associated with sodium salinity in soil, and showed a decrease in electrical conductivity (EC), sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP).

In order to give continuity to the experiment conducted by Cubillos *et al.* (2015) under greenhouse conditions, an experiment was proposed under field conditions with the objective of evaluating the effect of the application of LRC and CSB on several chemical, biological and physical properties of a Salidic Calciustolls soil as a strategy to exploit the use of LRC as a source of humified organic matter (HOM) and CSB as an accelerating agent in the release of HOM from coal, allowing it to mitigate and/or rehabilitate soils with salinity problems, considered a common problem in the soils of the "Cesar" Department, located in an area under the influence of open-pit coal mining in the dry region of the Colombian Caribbean.

MATERIALS AND METHODS

This research was conducted in soil classified by Cubillos (2014) taxonomically as Salidic Calciustolls, which showed the following diagnostic characteristics: mollic epipedon, calcic horizon, base saturation in the profile> 50%, EC> 4, ESP> 15%. At these conditions the soil shows problems of degradation by salinization. This soil is located in the lower part of the alluvial fan of Cesar River Valley (Colombia), near the largest coal mining activity in Colombia. Geographically it is located at latitude 23°55'66" N, longitude 73°13'47" W. The area corresponds to tropical dry forest, according to Holdridge classification with an average temperature of 28.4 °C, an altitude of 169 m, annual rainfall of 970 mm and relative humidity between 56-74%. The climate is warm and very dry (IDEAM, 2014).

Low rank coal (LRC) samples

In this experiment, the same sample of a lignite type of low rank coal (LRC) was collected and used in the study by Cubillos-Hinojosa *et al.* (2015) under greenhouse conditions. It was sieved to obtain particles with a diameter of less than 300 µm, before being added to the soil. The characteristics of this LRC were determined in previous research by Valero *et al.* (2014) and showed a humidity of 28.44%, 11.12% ash, 47.79% volatile substances, a calorific value of 4781 kcal kg^{-1}, 41.09% fixed carbon, and 0.13% S. These characteristics correspond to lignite type LRC due to its high moisture content and volatile materials, and a calorific value lower than 6390 kcal kg^{-1}. The content of C, H, O and N elements in the LRC was 46.04%, 3.26%, 42.95% and 1.38% respectively and the ash minerals were found in values of Fe_2O_3 4.24%, CaO 69.3%, MnO_2 0.14%, MgO 9.37%, SrO 0.89%, K_2O 0.05%, and BaO 0.08%. The content of humic substances (HS) was 45% in extractable NaOH (0.5 N), total humic extract 32.91%, humic acid (HA) carbon 24.31%, and fulvic acid (FA) carbon 8.6%. The risk of toxicity from heavy metals in the LRC applied in the soil was considered low and negligible, because the content of As, Co, Pb, V, Cu, Zn, Ni, Cr, B, Mo and Cd [applying the standard methods of the American Section of the International Association for the Testing of Materials (ASTM)], were found in amounts of 0.71, 2.31, 1.73, 1.66, 0.55, 22.43, 3.35, 2.4, 15.11, 2.52 and 0.08 ppm of each metal, respectively.

Coal solubilizing bacteria (CSB)

In this experiment, the same coal solubilizing bacteria (CSB) evaluated in the greenhouse study by Cubillos-Hinojosa *et al.* (2015) were used. These bacteria (*Bacillus mycoides*, *Acinetobacter baumannii* and *Microbacterium* sp.) had been isolated in a previous study by Valero *et al.* (2012), from the rhizosphere of plants present in the area of accumulation of coal sediments, sediments from the washing of coal and LRC respectively. The CSB were reported by Valero *et al.,* (2011) for the ability to solubilize LRC in solid medium and liquid releasing humified organic matter (HOM).

These bacteria were conserved in the strains bank of the research group in Agricultural and Environmental Microbiology of the Popular University of Cesar (Colombia), and the inoculum of each of the bacteria were reactivated and prepared in a concentration of 1 x 10^8 bacteria mL^{-1} following the methodology used by Cubillos-Hinojosa *et al.* (2015). A pool (mixture of the three CSB) was also prepared at a concentration of 1 x 10^8 bacteria mL^{-1}.

The field conditions trial

The area delimited to develop the experiment was prepared by passing a rigid chisel that would break the compacted soil layers as well as subsequently applied irrigation to generate the same moisture conditions.

The experiment was conducted with randomized complete block design with three repetitions per treatment; the experimental unit consisted of a plot of 5 m^{-2} each separated 2 m from the adjacent plot with a 50 cm high barrier to reduce cross-contamination between treatments by surface flow or wind. In all treatments, the LRC incorporation was performed at a dose of 5 kg m^{-2} and each bacterial inoculum (*B. mycoides, A. baumannii* and *Microbacterium* sp.) separately, and the bacterial pool (mix of three CSB) was applied at the rate of 100 mL m^{-2} in the concentration of 1x10^8 bacteria mL^{-1} (Table 1).

Table 1. Treatments used in the field conditions trial.

Treatments	Name	Description
1	C-BM	LRC + *Bacillus mycoides*
2	C-M	LRC + *Microbacterium* sp
3	C-AB	LRC + *Acinetobacter baumannii*
4	C-P	LRC + Pool
5	C	LRC
6	Control	Absolute control

C coal, LRC low rank coal, BM *Bacillus mycoides*, M *Microbacterium* sp., AB *Acinetobacter baumannii*, Pool (P): mixture of three CSB.

The LRC and CSB were mixed with the topsoil to -20 cm depth and star grass (*Cynodon plectostachium*), adapated to saline-sodic conditions (Más and García-Molinari, 2006), which was previously established in the soil, as a vegetation cover, as well as stimulator of biological activity in the rhizosphere used in all plots.

After two, four and six months of treatments had been applied, soil samples were taken from each plot from 0 to -20 cm depth in order to determine the respiration and microbiological activity of the soil, as well as the activity of lignin peroxidase (LiP), manganese peroxidase (MnP), and laccase (Lac) enzymes (associated with the solubilization of LRC) and the variables associated with sodic salinity: pH, electrical conductivity (EC), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), and cation exchange capacity (CEC). Bulk density was determined only six months after treatments were applied.

In each plot soil respiration was determined with the closed incubation technique proposed by Celis *et al.* (2009) with some modifications, - installing an incubation chamber with NaOH (Cubillos-Hinojosa *et al.*, 2015) and after 24 h, the amount of CO_2 released from the samples was calculated (Alef, 1995). The soil microbiological activity was determined by the hydrolysis of fluorescein diacetate (FDA) method proposed by Schnürer and Rosswall, (1982) with some modifications for the soil samples (Adam and Duncan, 2001; Greena *et al.*, 2006). The fluorescein produced by FDA hydrolysis was calculated in mg kg^{-1} of soil per hour (Alvear *et al.*, 2007).

The activity of the enzymes associated with the solubilization of coal LiP and Lac were determined following the protocol used by Cubillos-Hinojosa *et al.* (2015), while the MnP enzyme was determined following the method of Paszcznsky *et al.* (1986), where an enzymatic unit was defined as the Mn amount of enzyme required to oxidize 1 µmol of Mn^{2+} to Mn^{3+} in one minute.

The chemical properties of soil: pH, EC, SAR, ESP and CEC were determined according to the protocols of the soil

laboratory of the Agustin Codazzi Geographic Institute, which are based on Soil Survey Laboratory Methods of the US Department of Agriculture (Burt, 2004) in a saturation paste, and bulk density was performed by the cylinder method.

Statistical analysis

The data were submitted to analysis of variance, significant minimum differences and in some cases, the average Dunnett's test was applied by performing a previous analysis of the of the data normality parameters. Additionally, the data corresponding to the last sampling (sixth month) were submitted to Categorical Principal Components Analysis (CATPCA), using the statistical analysis program SPSS version 18 to determine the association between all variables.

RESULTS AND DISCUSSION

Soil respiration

After two months of soil treatment, an increase in soil respiration was found with significant differences ($P<0.05$) compared to the control in the C-AB, C-BM and C-P treatments. Additionally, it was also observed that C-M and C treatments showed a tendency to increase soil respiration above the control (Figure 1).

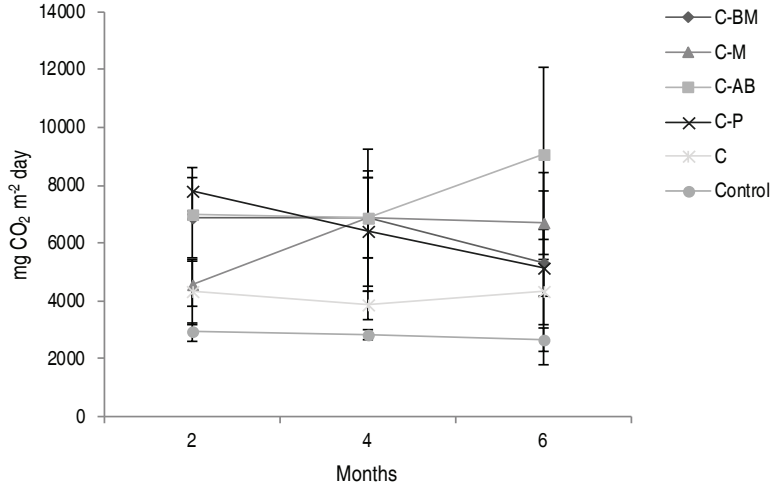

Figure 1. Salidic calciustolls soil respiration after treatment with LRC and CSB in field conditions.
C coal (low rank coal), BM *Bacillus mycoides*, M *Microbacterium* sp, AB *Acinetobacter baumannii*, P mixture of three CSB.

The addition of *B. mycoides, A. baumanii, Microbacterium* sp. and the pool of three BSC in conjunction with LRC stimulated the early activity of soil respiration. This result might indicate the possible microbial activity on the LRC or the stimulation of general soil microbial activity of the soil by LRC influence, due to the possible release of HOM mediated by the CSB that have been reported for their ability to solubilize LRC (Valero *et al.*, 2014). The HOM contribute to soil conditioning, aggregate stability of soil (Piccolo and Mbagwu, 1999) and have been used as a coadjuvant in post-mining soil recovery processes (Christanis *et al.*, 2006; Valero, 2013; Valero *et al.*, 2016).

In the fourth month post-treatment the soil respiration remained constant in C-AB, C-BM treatments, increased in treatment C-M but decreased in C-P. However, all treatments present significant differences with respect to the control. In the sixth month only C-P and C-BM treatments managed to maintain and increase soil respiration, while C-P and C-BM treatments began to decrease in soil respiration but maintained differences with respect to the control. This decrease is probably due to intense microbial activity on the LRC at the beginning with a gradual decrease over time.It is also possible that the native soil microorganism have had some activity on the LRC, as this has been described in long term studies of lignite waste incorporation in the organic matter cycle for the rehabilitation of post mining soil (Rumpel and Kogel-Knabner, 2002).

In addition, these results are consistent with those found by Cubillos-Hinojosa *et al.*, 2015 in a previous experiment

under greenhouse conditions, where the addition of LRC 1% in conjunction with CSB increased Salidic Calciustolls soil respiration, showing in field studies (Figure 1) a greater effect when the LRC was applied in conjunction with *A. baumanii* (C-AB treatment), and also showed significant differences with respect to the other treatments and the control. This could occur by the mechanisms and time of solubilization of coal used by the bacteria, indicating a possible effect by the release of HS contributing to the formation of soil aggregates (Piccolo, 2002), which could be influencing the increase in soil respiration.

In the case of treatment C where only LRC was added, there was an increase in soil respiration without the addition of CSB and despite being lower than the other treatments, significant differences from the control were shown. This indicates that LRC, due to its physical properties (high surface area and porosity), stimulates moisture (Levine *et al.*, 1982), which favors the microbial growth present in the LRC and the soil, reflected in the increase in soil respiration. These results agree with those reported by Cubillos-Hinojosa *et al.* (2015) when adding LRC 1% in a saline-sodic soil under greenhouse conditions and also by Valero *et al.* (2016) for treating edaphic materials with LRC, where increases in soil respiration without CSB application were observed.

Therefore, the results suggest that the incorporation of LRC as a source of HOM stimulates short-term saline-sodic soil respiration, showing a larger increase when performed in conjunction with CSB, mainly with *A. baumanii*.

Microbiological activity

The results show that after two months of the LRC and CSB application, all treatments showed an increase in the amount of hydrolyzed FDA, which indicate an increase in microbial enzymatic activity in the soil with significant differences ($P<0.05$) compared to the control, presenting a greater increase in the C-P, C-M, C-BM and C-AB treatments respectively (Table 2).

Table 2. Microbiological activity of the Salidic Calciustolls soil post-treatment with LRC and CSB in field conditions.

Treatments	Fluorescein produced (mg kg soil^{-1} h^{-1})		
	2 month	4 month	6 month
C-BM	133.8 ± 0.57	130 ± 3.9	113.4 ± 1.7
C-M	141.3 ± 2.3	127.7 ± 2.2	119.4 ± 3.5
C-AB	127.7 ± 4.3	108 ± 7.4	97.9 ± 10
C-P	147.7 ± 2.2	129.7 ± 3.5	127.2 ± 4
C	102.6 ± 3.3	99.8 ± 0.3	92.4 ± 1.3
Control	92.1 ± 6.8	90.9 ± 6.5	91.7 ± 7

C coal (low rank coal), BM *Bacillus mycoides*, M *Microbacterium* sp, AB *Acinetobacter baumannii*, P mixture of three CSB.

The microbiological activity of soil includes all metabolic reactions, cellular interactions and biochemical processes mediated by soil microorganisms (Siqueira *et al.*, 1994). The FDA hydrolysis technique allows to measurement of the enzymatic activity of microbial populations, although it is not specific because of sensitivity to the activity of other enzymes such as lipases, esterases and proteases. However, this technique can provide information on estimating changes in microbiological activity (Greena *et al.*, 2006), in the saline-sodic soil caused by the addition of LRC and CSB, and because this parameter has been used in several studies as an indicator of soil quality in degraded areas under rehabilitation. In this sense the results suggest that the microbiological activity is stimulated early with the addition of LRC, obtaining a greater increase when LRC is applied in conjunction with CSB. This suggests that the solubilization of LRC by these bacteria result in the release of HS (Valero *et al.*, 2014) that can be used by the native soil and are present in the LRC microorganism, favoring microbiological activity. In addition, these results are similar to those obtained in a previous trial under greenhouse conditions, where an increase in microbiological activity was observed in C-P, C-M, C-BM and C-AB treatments (Cubillos *et al.*, 2015).

Valero *et al.* (2016) found a stimulus of microbiological activity in the soil in the treatment of edaphic materials (soil materials removed during the pre-mining phase of coal) with LRC and CSB, but its effect was independent of the conjoined addition with CSB.

From the fourth to the sixth post-treatment months a decreasing trend in microbiological activity in all treatments was observed, however all treatments maintained microbiological activity above the control except C treatment. This is possibly due to LRC consumption as a substrate by the microorganisms present as in the same LRC as by the native soil microbiota. These results are similar to those obtained in the previous study under greenhouse conditions by Cubillos-Hinojosa *et al.* (2015).

LiP, MnP and Lac enzyme activity

In Figure 2, an early increase is evident in the activity of lignin peroxidase (LiP) and manganese peroxidase (MnP) enzymes in saline-sodic soil after two months of treatment with LRC and CSB. This is possibly due to the LRC properties, characterized by the presence of element that favor the microbial nutrition and development of CSB (Cubillos-Hinojosa *et al.,* 2015). However, LiP and MnP activity cannot be attributed to the effect of the application of CSB, because peroxidase enzyme activities

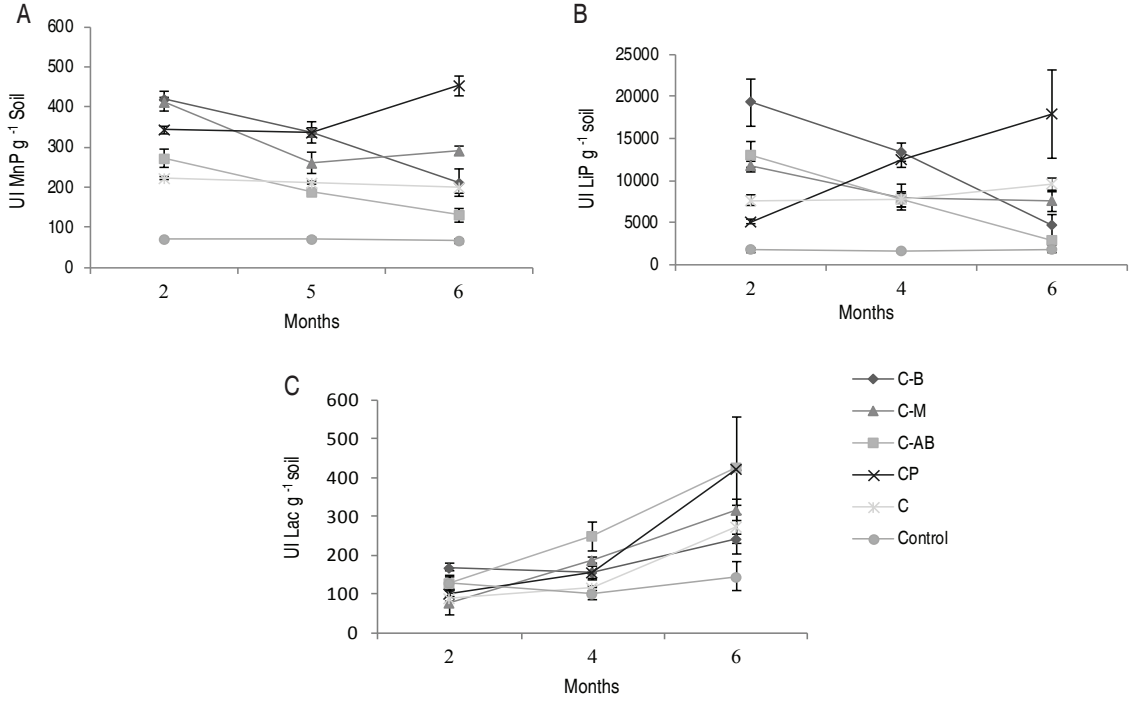

Figure 2. Activity of enzymes associated with coal solubilization in the treatment of Salidic calciustolls soil with LRC and CSB under field conditions. A. Lignin peroxidase (LiP), B. Manganese peroxidase (MnP) and C. Laccases (Lac).
C coal (low rank coal), BM *Bacillus* mycoides, M *Microbacterium* sp., AB *Acinetobacter baumannii*, P mixture of three CSB.

are not known (LiP and MnP) in bacteria. Therefore, this ligninolytic activity may be being performed by fungi found in the microhabitat formed in the porous spaces of the LRC or by native fungi inthe saline-sodic soil. These microorganisms may be being induced to generate LiP and MnP extracellular enzymes that biotransform LRC as described by Fakoussa and Hofrichter (1999).

The activation of ligninolytic enzymes allow fungi to depolymerize the components of the mobile phase of coal, which it is a material of plant origin with a structure very similar to lignin, containing organic matter such as carbon and energy for their metabolism. Also in the process of coal biotransformation some elements important for microbial nutrition such as nitrogen, sulfur and iron can be

available. All these phenomena could have been favoring the colonization and growth of inoculated CSB, the native microorganisms of the LRC, and native microorganism of saline-sodic soil, contributing to increase of microbiological activity as described above.

Figure 2B shows that at 4 and 6 months post-treatment of saline-sodic soil with LRC and CSB, the LiP activity was reduced in most treatments and this is probably due to the fact that some microorganisms can induce MnP activity (Figure 2A) and inhibit LiP activity, this phenomenon of enzymatic regulation has been described in studies of the biotransformation of lignin and coal by Hofrichter and Fritsche (1996).

In all treatments, increases in the activity of Lac enzymes were observed in the fourth and sixth month after soil treatment with LRC and CSB, showing significant differences (P<0.05) with respect to the control treatment. The results suggest that the application of C-AB stimulates Lac activity, showing better results in the fourth and sixth month post-treatment with significant differences (P<0.05) compared to the control (Figure 2C), followed by treatment C-P that showed the greatest long-term increase (6 months post-treatment) in Lac activity. Meanwhile, considering that some bacteria have been reported with Lac activity (Madhavi and Lele, 2009; Diamantidis *et al*., 2000) and as the CSB inoculated into the saline-sodic soil biotransform LRC, the results show evidence that CSB had Lac activity, especially *A. baumanni*, although it can also be associated with bacteria and fungi native to the LRC used in the experiment or native microorganism in soil.

Chemical variables associated with sodium soil salinity

During the 6 months of the experiment, no significant changes in the pH (P<0.05) were generated according to Dunnett's comparison test (Table 3). After two months post-treatment of saline-sodic soil with the LRC and CSB, the EC of soil decreased in all treatments, showing

Table 3. Chemical variables associated with sodic salinity in Salidic Calciustulls soil post-treatment with LRC and CSB under field conditions

Treatments	pH			EC (dS m^{-1})		
	Months					
	2	4	6	2	4	6
C-BM	10.0 ± 0.1	9.9 ± 0.0	9.8 ± 0.2	5.3 ± 0.9	5.2 ± 0.7	5.5 ± 0.0
C-M	9.8 ± 0.4	9.8 ± 0.3	9.8 ± 0.1	5.1 ± 0.6	5.1 ± 0.5	5.5 ± 0.8
C-AB	9.5 ± 0.2	9.8 ± 0.2	9.7 ± 0.1	4.3 ± 1.1	4.8 ± 0.9	5.1 ± 0.3
C-P	9.8 ± 0.2	9.8 ± 0.1	9.8 ± 0.1	3.8 ± 0.7	4.4 ± 0.5	5.2 ± 0.7
C	9.6 ± 0.2	9.7 ± 0.1	9.8 ± 0.0	4.2 ± 0.2	4.5 ± 0.0	4.8 ± 0.1
Control	10.0 ± 0.0	10.3 ± 0.11	10.4 ± 0.0	7.9 ± 0.0	7.9 ± 0.0	7.9 ± 0.1
Treatments	SAR (mmol dm^{-3})			ESP (%)		
	Months					
	2	4	6	2	4	6
C-BM	21.6 ± 0.9	21.6 ± 0.3	32.2 ± 0.5	32.3 ± 5.9	37.3 ± 2.8	59.9 ± 1.1
C-M	34.2 ± 1.1	34.2 ± 0.4	35.1 ± 8.4	37.3 ± 0.6	37.3 ± 1.3	55.8 ± 0.7
C-AB	23.0 ± 1.8	23.0 ± 2.9	46.5 ± 3.1	33.6 ± 19.8	33.6 ± 19.5	50.5 ± 18.4
C-P	22.4 ± 8.2	26.3 ± 8.2	44.4 ± 4.6	55.5 ± 3.1	55.5 ± 3.4	58.7 ± 3
C	24.4 ± 3.3	24.4 ± 2.0	31.5 ± 3.2	46.0 ± 13.8	46.0 ± 12.7	59.5 ± 12.5
Control	56.8 ± 0.5	56.8 ± 0.5	56.8 ± 0.3	61.2 ± 1.7	61.2 ± 0.3	61.2 ± 0.7

C coal (low rank coal), BM *Bacillus mycoides*, M *Microbacterium* sp, AB *Acinetobacter baumannii*, P mixture of three CSB, ± SD Standard deviation, EC electrical conductivity, SAR sodium adsorption ratio, ESP exchangeable sodium percentage.

significant differences (P<0.05) in some treatments (C-P, C, C-AB, C-M and C-BM) with respect to the control. In the fourth month, the results showed that only the C-P, C, and C-AB treatments maintained significant differences with respect to the control, and in the sixth month a greater decrease in soil EC was found when treated only with LRC compared to the control by significant differences (P<0.05). Therefore, the addition of LRC alone or in conjunction with the CSB inoculum have an effect on the EC of saline-sodic soil, and agrees with that found by Vance *et al.* (1998), that when applying organic matter with gypsum on the surface of a Natrixeralf soil managed to decrease the EC compared to an untreated control soil.

The SAR and ESP showed significant changes in all treatments by the addition of LRC and CSB in saline-sodic soil. A decrease was observed after the start of the experiment over the 6 months for the SAR, while the ESP showed a decrease in the second and fourth month, with a greater decrease in the C-AB treatment. Also it was evidenced that when the saline-sodic soil is treated with only LRC a greater decrease in the SAR is obtained, while in a study conducted by Gasca *et al.* (2011) where organic matter such as vinasse was applied to treat a soil with salinity problems, it did not show changes in SAR and PSI.

In response to the application of LRC and CSB in the saline-sodic soil the CEC increased in the short-term in all treatments and continuously increased during the experiment showing significant differences (P<0.05) compared to the control. This allows the demonstration of the effect of the LRC as a source of HOM that favorably stimulates the CEC (Table 4) and can be explained because the LRC has a high CEC and its application in the soil favors the growth of native soil microorganism and the application of the CSB can solubilize it and give rise to the release of HS which act as polyelectrolytes that stimulate the CEC (Janos *et al.*, 2011).

Table 4. CEC in Salidic Calciustolls soil after being treated with LRC and CSB under field conditions.

Treatments	CEC ($cmol_{(+)}$ kg^{-1})		
	Month		
	2	4	6
C-BM	9.1 ± 1.0	9.2 ± 0.6	9.1 ± 0.5
C-M	9.4 ± 1.3	9.3 ± 0.7	9.1 ± 0.7
C-AB	9.0 ± 1.2	9.0 ± 1.2	9.0 ± 0.8
C-P	9.4 ± 0.3	9.3 ± 0.3	9.1 ± 0.5
C	9.5 ± 0.4	9.2 ± 0.4	9.1 ± 0.3
Control	7.4 ± 1.1	7.4 ± 0.0	7.4 ± 0.4

C coal (low rank coal), BM *Bacillus mycoides*, M *Microbacterium* sp., AB *Acinetobacter baumannii*, P mixture of three CSB, CEC cation exchange capacity.

Bulk density (BD)

At the sixth month post-treatment mark of saline-sodic soil with LRC and CSB, no changes in any of the treatments compared to the control (P<0.05) were observed, where the BD was 1.62 g cm^{-3}. These results are similar to those obtained by Valero (2013) when treating a soil at the start of post-mining rehabilitation in field conditions with LRC and BSC, where no significant differences regarding the control were found. Therefore, these results suggest that the effect that LRC and BSC could have on BD should be considered in the long term.

Categorical principal components analysis

Figure 3 shows the categorical principal components analysis (CATPCA) that was performed to establish the association between the evaluated variables in the sixth month post-treatment of saline-sodic soil with LRC and CSB. The CATPCA explained 57% of the variability of the data in two dimensions: 39% in dimension 1 and 18% in dimension 2 (Table 5). The most influential variables in dimension 1 were LRC, activity of the enzymes LiP, MNP and Lac, soil respiration, pH, EC, CEC and BD of soil, while in dimension 2 it was the Pool of the three CSB and ESP (Table 6).

Table 5. Summary table of the model in CATPCA.

Dimension	Cronbach's Alpha	Variance accounted for	
		Total (Eigenvalue)	% of Variance
1	0.896	6.262	39.138
2	0.685	2.801	17.508
Total	0.949 (a)	9.063	56.646

Table 6. Saturation in components in CATPCA.

Variables	Dimension	
	1	2
C	-0.821	-0.160
C-BM	0.061	-0.067
C-M	-0.036	-0.503
C-AB	-0.518	-0.456
C-P	-0.467	0.832
Microbiological activity	-0.434	0.310
LiP	-0.700	0.567
MnP	-0.797	0.529
Lac	-0.666	-0.026
Respiration	-0.636	-0.451
pH	0.865	-0.215
EC	0.701	0.206
SAR	0.599	0.088
ESP	0.276	0.667
CEC	-0.685	-0.306
BD	0.890	0.284

C coal (low rank coal); BM *Bacillus mycoides*; M *Microbacterium* sp.; AB *Acinetobacter baumannii*; P mixture of three CSB; EC electrical conductivity; SAR sodium adsorption ratio; ESP exchangeable sodium percentage; CEC cation exchange capacity; BD bulk density.

In Figure 3. an association between the following groups of variables was observed: (1) The activity of the enzymes LiP and MnP, microbiological activity and the pool of the three CSB, indicating that the application of the pool of CSB favors the joint expression of peroxidase ligninolytic enzymes and is reflected in the increase in microbiological activity as described above. This is possible because the CSB can biotransform the LRC resulting in the release of HS that might stimulate the activity of native soil microorganisms or LRC companion microorganisms. (2) The activity of the enzymes Lac, LRC, CEC, soil respiration and *A. baumannii* inoculation- This association demonstrates that the LRC application in conjunction with *A. baumannii* favors soil respiration and production of Lac enzymes, which are

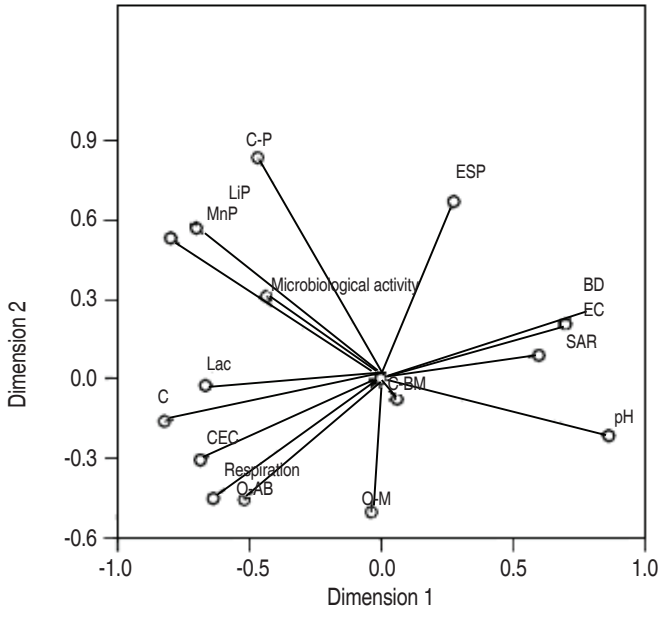

Figure 3. Association analysis of the variables evaluated in a Salidic Calciustolls soil after sixth months post-treatment with LRC and CSB in field conditions.
C coal (low rank coal); BM *Bacillus mycoides*; M *Microbacterium* sp; AB *Acinetobacter baumannii*; P mixture of three CSB; EC electrical conductivity; SAR sodium adsorption ratio; ESP exchangeable sodium percentage; CEC cation exchange capacity; BD bulk density.

generated by bacteria and it is possible that this activity is being performed by *A. baumanni* because it has the ability to biotransform LRC. The LRC favors the CEC, which in itself has a high CEC, due to the presence of phenolic and carboxylic groups (Janos *et al*., 2011). (3) The correlation between BD and the salinity parameters EC, SAR, and pH, indicating that the salinity negatively influenced BD.

CONCLUSIONS

The incorporation of LRC and CSB in the Salidic Calciustolls soil in field conditions favorably influences some chemical and biological properties. This is reflected in a decrease in EC, SAR and ESP, and in an increase of microbiological activity, soil respiration and CEC. The activity of ligninolytic peroxidase enzymes of the native microorganism present in LRC and soil are also favored.

The application of LRC as a source of HOM and CSB in the Salidic Calciustolls soil generates a positive effect on chemical and biological soil properties in the short-term when LRC is added in conjunction with CSB, mainly with *A. baumannii*.

ACKNOWLEDGEMENTS

The authors wish to thanks the Centro Biotecnológico del Caribe of Servicio Nacional de Aprendizaje (SENA) in Colombia for allowing the development of this research and the research group Microbiología Agricola y Ambiental (MAGYA) of Universidad Popular del Cesar in Colombia for technical support.

REFERENCES

Abdul-Qados AMS. 2011. Effect of salt stress on plant growth and metabolism of bean plant Vicia faba (L.). Journal of the Saudi Society of Agricultural Sciences 10(1): 7-15. doi: 10.1016/j.jssas.2010.06.002

Adam G and Duncan H. 2001. Development of a sensitive and rapid method for the measurement of total microbial activity using fluorescein diacetate (FDA) in a range of soils. Soil Biology and Biochemistry 33(7-8): 943–951. doi: 10.1016/s0038-0717(00)00244-3

Alef K. 1995. Dehydrogenase activity. pp. 228–231. In: Alef K and Nannipieri P. (eds). Methods on Applied Soil Microbiology and Biogeochemistry. Academic Press, London.

Alvear M, Urra C, Huaiquilao R, Astorga M y Reyes F. 2007. Actividades biológicas y estabilidad de agregados en un suelo del bosque templado Chileno bajo dos etapas sucesionales y cambios estacionales. Revista de la Ciencia del Suelo y Nutrición Vegetal 7(3): 38–50. doi: 10.4067/S0718-27912007000300004

Bourbonnais R, Paice MG, Reid ID, Lanthier P and Yaguchi M. 1995. Lignin oxidation by laccase isozymes from trametes versicolor and role of the mediator 2,29-azinobis(3-ethylbenzthiazoline-6-sulfonate) in Kraft Lignin Depolymerization. Applied Environmental Microbiology 61(5): 1876–80.

Burt R. 2004. Soil Survey Laboratory Methods. United States Department of Agriculture, Natural Resources Conservation Service, Natural Soil Survey Center, Lincoln, Nebraska. 503 p.

Celis J, Sandoval M y Zagal E. 2009. Actividad respiratoria de microorganismos en un suelo patagónico enmendado con lodos salmonícolas. Archivos de Medicina Veterinaria 41(3): 275-279. doi: 10.4067/s0301-732x2009000300013

Chassapis K and Roulia M. 2008. Evaluation of low-rank coals as raw material for Fe and Ca organomineral fertilizer using a new EDXRF method. International Journal of Coal Geology 75(3): 185-188. doi: 10.1016/j.coal.2008.04.006

Christanis K, Giannouli A, Kalaitzidis S, Katzur J, Böcker Land Petrakis G. 2006. Application of soil-improving media produced on lignite-basis on the rehabilitation of post-mining sites. Mineral Wealth 140: 43–55.

Cubillos J. 2014. Efecto de la aplicación de bacterias productoras de sustancias húmicas mediante la biosolubilización de carbón de bajo rango en un suelo salino-sódico en el Valle del Cesar. Tesis Magister en Ciencias Agrarias. Facultad de Ciencias Agrarias. Universidad Nacional de Colombia, Medellín. 56 p.

Cubillos-Hinojosa JG, Valero NO and Melgarejo LM. 2015. Assessment of a low rank coal inoculated with coal solubilizing bacteria as an organic amendment for a saline-sodic soil. Chemical and Biological Technologies in Agriculture 2(21). doi: 10.1186/s40538-015-0048-y

David Y, Baylon MG, Pamidimarri SDVN, Baritugo KA, Chae CG, Kim YJ, and Park SJ. 2017. Screening of microorganisms able to degrade low-rank coal in aerobic conditions: Potential coal biosolubilization mediators from coal to biochemicals. Biotechnology and Bioprocess Engineering 22(2): 178–185. doi: 10.1007/s12257-016-0263-9

Diamantidis G, Effosse A, Potier P and Bally R. 2000. Purification and characterization of the first bacterial laccase in rhizospheric bacterium, *Azospirillum lipoferum*. Soil Biology and Biochemistry 32(7): 919–927. doi: 10.1016/s0038-0717(99)00221-7

Duran R, Garcia J y Amaya R. 2000. Evaluación de varias enmiendas para la corrección de suelos sódicos en el Valle del Cesar. Revista Suelos Ecuatoriares 30(1): 21-28.

Fakoussa RM and Hofrichter M. 1999. Biotechnology and microbiology of coal degradation. Applied Microbiology Biotechnology 52(1): 25–40. doi: 10.1007/s002530051483

FAO. 2005. Global network on integrated soil management for sustainable use of salt-affected soils. FAO, Rome, Italy: Land and Plant Nutrition Management Service. http://www.fao.org/ag/agl/agll/spush.

Filip Z and Kubát J. 2001. Microbial utilization and transformation of humic substances extracted from soils of long-term field experiments. European Journal of Soil Biology 37(3): 167–174. doi: 10.1016/s1164-5563(01)01080-9

Gasca C, Menjivar JC, Torrente-Trujillo A. 2011. Cambios en el porcentaje de sodio intercambiable (PSI) y la relación de adsorción de sodio (RAS) de un suelo y su influencia en la actividad y biomasa microbiana. Acta Agronómica 60(1): 27–38.

Giannoulli A, Stavros K, Siavalas G, Chatziapostolou A, Christanis K, Papazisimou S, Papanicolaou C and Foscolos A. 2009. Evaluation of Greek low-rank coals as potential raw material for the production of soil amendments and organic fertilizers. International Journal of Coal Geology 77(3–4): 383–393. doi: 10.1016/j.coal.2008.07.008

Greena VS, Stottb DE and Diacka M. 2006.Assay for fluorescein diacetate hydrolytic activity: optimization for soil samples. Soil Biology and Biochemistry 38(4): 693–701. doi: 10.1016/j.soilbio.2005.06.020

Gómez D. 2004. Recuperación de espacios degradados. Ediciones Mundiprensa, Madrid, España. 585 p.

Gutiérrez MA, Zúñiga O, Ospina-Salazar D. 2016. Effect of three biowastes on the productivity potential of a sodic soil. Agronomía Colombiana 34(2): 250.

Hernández O. 2000. Uso de métodos químicos y biológicos como mejoradores de la conductividad hidráulica de un suelo salino sódico. Tesis Doctorado en Ciencias. Facultad de Ciencias Biológicas y Agropecuarias. Universidad de Colima. Tecomán, México. 126 p.

Hofrichter Mand Fritsche W. 1996. Depolymerization of low-rank coal by extracellular fungal enzyme systems. I. Screening for low rank coal depolymerizing activities. Applied Microbiology Biotechnology 46(3): 220–225.

Hölker U, Schmiers H, Grobe S, Winkerhofer M, Polzakiewicz M, Ludwig S, Dohse J and Hofer M. 2002. Solubilization of low-rank coal by *Trichoderma atroviridae*: evidence for the involvement of hydrolytic and oxidative enzymes by using 14C-labelled lignite. Journal of Industrial Microbiology and Biotechnology 28(4): 207–212. doi: 10.1038/sj/jim/7000232

Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia, IDEAM. (2014). Características climatológicas de ciudades principales y municipios turísticos. Recuperado de http://www.ideam.gov.co/documents/21021/21789/1Sitios+turisticos2.pdf/cd4106e9- d608-4c29-91cc-16bee9151ddd#page28

Janos P, Závodská L, Lesný J, Kříženecká S, Synek V, Hejda S and Kub M. 2011. Young brown coals for environmental applications: composition, acid-base, ionexchange, and sorption properties of selected Central European coals. pp. 71–90. In: Stewart J (ed.). Coal extraction. Nova Science Publishers, New York.

Khaled H and Fawy H. 2011. Effect of different levels of humic acids on the nutrient content, plant growth, and soil properties under conditions of salinity. Soil and Water Research 6(1): 21–29.

Laborda F, Fernandez M, Luna Nand Monistrol IF. 1997. Study of the mechanisms by which microorganisms solubililize and/or liquefy Spanish coals. Fuel Processing Technology 52(1): 95–107. doi: 10.1016/s0378-3820(97)00019-2

Levine DG, Schlosberg RH and Silbernagel BG. 1982. Understanding the chemistry and physics of coal structure (A Review). Proceeding of the National Academy of Sciences 79(10): 3365–3370. doi: 10.1073/pnas.79.10.3365

Machnikowska H, Pawelec Kand Podgorska A. 2002. Microbial degradation of low rank coals. Fuel Processing Technology 77–78: 17–23. doi: 10.1016/s0378-3820(02)00064-4

Madhavi V and Lele SS. 2009. Laccase: properties and applications. BioResources 4(4): 1694–1717.

Más EG and García-Molinari O. 2006. Guía ilustrada de yerbas comunes en Puerto Rico. University of Puerto Rico and USDA-NRCS. 303 p.

Munns, R. 2005. Genes and salt tolerance: ringing them together. New Phytologist 167(3): 645-663. doi: 10.1111/j.1469-8137.2005.01487.x

Peña-Mendéz EM, Havel J and Patocka J. 2005. Humic substances - compounds of still unknown structure: applications in agriculture, industry, environment and biomedicine. Journal of Applied Biomedicine 3: 13–24.

Piccolo A. 2001. The supramolecular structure of humic substances. Soil Science 166(11): 810–832.

Piccolo A. 2002. The supramolecular structure of humic substances: a novel understanding of humus chemistry and implications in soil science. Advances in Agronomy 57–134. doi: 10.1016/s0065-2113(02)75003-7

Piccolo A and Mbagwu JSC. 1999. Role of hydrophobic components of soil organic matter on soil aggregate stability. Soil Science Society of America Journal 63(6): 1801. doi: 10.2136/sssaj1999.6361801x

Pokorný R, Olejníková P, Balog M, Zifcak P, Holker U, Janssen M and Varecka L. 2005. Characterization of microorganisms isolated from lignite excavated from the Záhorie coal mine (southwestern Slovakia). Research in Microbiology 156(9): 932–943. doi: 10.1016/j.resmic.2005.04.010

Ros M. 2003. Soil microbial activity after restoration of a semiarid soil by organic amendments. Soil Biology and Biochemistry 35(3): 463-469. doi: 10.1016/s0038-0717(02)00298-5

Rumpel C and Kogel-Knabner I. 2002. The role of lignite in the carbon cycle of lignite - containing mine soils: evidence from carbon mineralization and humic acid extractions. Organic Geochemestry 33(3): 393–399. doi: 10.1016/s0146-6380(01)00169-3

Schnürer J and Rosswall T. 1982. Fluorescein diacetate hydrolysis as a measure of total microbial activity in soil and litter. Applied and Environmental Microbiology 43(6): 1256–1261.

Senesi M, Miano TM and Brunetti G. 1996. Humic-like substances in organic amendments and effects on native soil humic substances. pp. 531–594 In: Piccolo A (ed.). Humic substances in terrestrial ecosystems. Elsevier, USA.

Sharif M. 2002. Effect of lignite coal derived humic acid on growth and yield of wheat and maize in alkaline soil. Thesis Doctor of Philosophy in Soil and Environmental Sciences. Faculty of Crop Production Sciences. Agricultural University, Peshawar, Pakistan.

Shrivastava P and Kumar R. 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences 22(2): 123–131. doi: 10.1016/j.sjbs.2014.12.001

Siqueira JO, Moreira FM de S, Grisi BM, Hungria M and Araujo RS.1994. Microrganismos e processos biológicos do solo: perspectiva ambiental. EMRAPA-SPI. Brasília, p. 7-81.

Tao XX, Pan LY, Shi KY, Chen H, Ying S Dand Luo ZF. 2009. Bio-solubilization of Chinese lignite I: extra-cellular protein analysis. Mining Science and Technology (China) 19(3): 358–62. doi: 10.1016/s1674-5264(09)60067-3

Tejada M and González JL. 2007. Influence of organic amendments on soil structure and soil loss under simulated rain. Soil and Tillage Research 93(1): 197–205. doi: 10.1016/j.still.2006.04.002

Vance WH, Tisdell JM and McKenzie BM. 1998. Residual effects of surface application of organic matter and calcium salts on the sub-soil of a red–brown earth. Australian Journal of Experimental Agriculture 38(6): 595. doi:10.1071/ea97102

Valero N. 2013. Transformación microbiana de carbón de bajo rango para inducir cambios en las propiedades del suelo. Tesis Doctorado en Ciencias Agropecuarias. Facultad de Agronomía. Universidad Nacional de Colombia, Bogotá. 121 p.

Valero N, Beleño J y Mancilla S. 2011. Biotransformación de carbón de bajo rango por bacterias aisladas de microhábitats influenciados por residuos de carbón. Revista Colombiana de Biotecnología 13(1): 58–65.

Valero N, Gómez L, Pantoja M and Ramírez R. 2014. Production of humic substances through coal-solubilizing bacteria. Brazilian Journal of Microbiology 45(3): 911–918. doi: 10.1590/s1517-83822014000300021

Valero N, Rodríguez LN, Mancilla S y Contreras L. 2012. Obtención de bacterias biotransformadoras de carbón de bajo rango a partir de microhábitats con presencia de residuos carbonosos. Acta Biológica Colombiana 17(2): 335–48.

Wang L, Sun X, Li S, Zhang T, Zhang W and Zhai P. 2014. Application of Organic Amendments to a Coastal Saline Soil in North China: Effects on Soil Physical and Chemical Properties and Tree Growth. PLoS ONE 9(2) e89185. doi: 10.1371/journal.pone.0089185

World Coal Institute. 2005. The coal resource, a comprehensive overview of coal. WCI, London. 44 p.

Wong VNL, Dalal RC and Greene RSB. 2009. Carbon dynamics of sodic and saline soils following gypsum and organic material additions: A laboratory incubation. Applied Soil Ecology 41(1): 29-40. doi: 10.1016/j.apsoil.2008.08.006

Zúñiga O, Osorio J, Cuero R y Peña J. 2011. Evaluación de tecnologías para la recuperación de suelos degradados por salinidad. Revista Facultad Nacional de Agronomía 64(1): 5769 – 5779.

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Effect of magnesium silicate in cv. 'ICA Cerinza' common bean (*Phaseolus vulgaris* L.) under field conditions

Efecto del silicato de magnesio en frijol común (*Phaseolus vulgaris* L.) cv. 'ICA Cerinza' bajo condiciones de campo

doi: 10.15446/rfna.v70n3.62679

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ABSTRACT

The bean crop is very important in Colombia, being a generator of income and employment; and furthermore very important within the diet of the population due to its high protein content. Currently, bean production is not sufficient to meet the demand in the country, because of phytosanitary problems, scarce replacement of varieties and inappropriate handling of mineral nutrition of cultivars. Nowadays, the use of products for soils rich in silicon represents an alternative for production increase, because they contribute markedly in nutritional dynamics. So, the purpose of this research was to assess the effect of magnesium silicate on the physiological behavior of 'ICA Cerinza' bean cultivar under agro-ecological conditions in Tunja (Boyacá, Colombia). For that, a completely random design with four treatments each was used, corresponding to increasing doses of magnesium silicate (0, 300, 600 y 900 kg ha^{-1}) with four replications. The total chlorophyll content, leaf area, leaf thickness, fresh and dry mass, yield components, silicon and phosphorus leaf content were evaluated. Statistical differences between treatments ($P \leq 0.05$) were found in all variables tested. The application of increasing doses of magnesium silicate showed a positive effect, being the treatment of 900 kg ha^{-1} which presented the best results. This indicates that the contribution of silicon as a beneficial element that can submit a favorable response to physiological level in crops which do not use bio-accumulators. However, this response can be linked to agro-ecological conditions, the type of product and also the dose used.

Keywords:
Silicon
Leguminous vegetable
Beneficial element
Nutritional dynamics
Amendment

RESUMEN

El cultivo de frijol es muy importante en Colombia siendo un generador de ingresos y empleo; sumado a su importancia dentro de la dieta de la población debido a su alto contenido de proteínas. Actualmente en el país es insuficiente la producción de fríjol para abastecer la demanda, esto debido a problemas de tipo fitosanitario, escaso recambio de variedades y manejo inadecuado de la nutrición mineral de los cultivares. En la actualidad el uso enmiendas ricas en silicio (Si) representan una alternativa en el incremento de la producción, ya que estas contribuyen de manera notoria en la dinámica nutricional. Por tanto, el objetivo de esta investigación fue el de evaluar el efecto del silicato de magnesio sobre el comportamiento fisiológico del cultivar de frijol 'ICA Cerinza' bajo condiciones agroecológicas del municipio de Tunja-Boyacá. Para ello, se empleó un Diseño Completamente al Azar con cuatro tratamientos correspondientes a dosis crecientes de silicato de magnesio (0, 300, 600 y 900 kg ha^{-1}) con cuatro replicaciones. Se evaluó el contenido total de clorofilas, área foliar, grosor de hoja, masa fresca y seca, componentes de rendimiento, contenido foliar de silicio y fósforo. Se presentaron diferencias estadísticas entre tratamientos ($P \leq 0{,}05$) para todas variables. La aplicación de dosis crecientes de silicato de magnesio mostro un efecto positivo, siendo el tratamiento de 900 kg ha^{-1} el que presentó los mejores resultados, lo anterior indica que el aporte de silicio como elemento benéfico puede presentar una respuesta a nivel fisiológico favorable en cultivos no bio-acumuladores de este elemento. Sin embargo, esta respuesta puede estar ligada a las condiciones agroecológicas, al tipo de fuente empleada y la dosis utilizada.

Palabras clave:
Silicio
Leguminosa
Elemento benéfico
Dinámica nutricional
Enmienda

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Received: February 15, 2017; Accepted: June 12, 2017
Rev.Fac.Nac.Agron. 70(3): 8285-8293. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

The common bean (*Phaseolus vulgaris* L.) is one of the most important crops in many parts of the country, providing income, rural employment and a basic product in the diet of the Colombian population due to its high content of proteins and minerals; in this way, helping to improve the poor diet of the rural population (Arias *et al*., 2007) coming mostly from smallholdings production systems (Ruiz and Rincón, 2000). However, bean production in Colombia is insufficient to meet demand; therefore, imports came from countries like Peru, Argentina, Bolivia, China, Venezuela and Ecuador (FENALCE, 2015). This is because of phytosanitary problems, scarcity in the delivery of new varieties and an inappropriate management of mineral nutrition.

The application of macronutrients and micronutrients for obtaining highly productive and healthy crops, has been widely documented (Marschner, 2012). However, nowadays, elements like silicon (Si), the second most abundant element in soil after Oxygen (Liang *et al.,* 2007; Epstein, 2009), present in silicate minerals (Silicon oxide) and aluminosilicates, representing 90% of all the terrestrial minerals (Datnoff *et al.,* 2007), it's not considered as essential but beneficial in some major crops like rice, being an element which contributes significantly to productivity (Fageria *et al.,* 1997) and healthy crops, because it promotes the synthesis of low molecular weight metabolites with anti-fungal activity like phytoalexins (Fawe *et al.,* 1998). It also generates an increased growth in plants under biotic and abiotic stress conditions (Rodrigues *et al*., 2003; Ma, 2004) and decreases the oxidative stress caused by heavy metal toxicity (Qinghua *et al.,* 2005).

Nowadays, its beneficial effects have been studied on the growth and development of many plants, particularly Poaceae and some Cyperaceae (Richmond and Sussman, 2003), with the application of mineral sources, especially magnesium silicates or calcium (Álvarez and Osorio, 2014). Likewise, the research should be focused on crops needed for global food security to ensure an increase in their production and observe their beneficial effects with regard to disease control, different types of stress, and mitigation of heavy metals (Epstein, 1999).

Silicon is absorbed by the roots in the form of H_4SiO_4 and is transported by the apoplast into the xylem and the aerial part of plants, to be accumulated in epidermal cells (Mitani and Ma, 2005). Under field conditions, it can stimulate growth and productivity, because it increases the availability of elements like P, Ca, Mg, K y B, countering antagonistic effects generated in soils with high saturation of Al and Fe (Epstein and Bloom, 2005). One of the most important effects in the application of silicate fertilizers is to improve the availability of phosphorus in the soil and benefit the absorption of the same by cultivated plants, and, as a result, the yield of crops, resulting in their most obvious and valuable effects in tropical soils where phosphorus fixation limits the effectiveness of fertilizers (Álvarez and Osorio, 2014).

It is known that silica gel is deposited between the cell walls of plants and contributes to beneficial effects of the element (Álvarez and Osorio, 2014), forming a double cuticular layer to protect and mechanically reinforce all plants. For this reason, in many countries fertilizers are applied consistently with silicon to increase the productivity and the sustainability of crops (Snyder *et al.,* 2007).

With this in mind, the purpose of this research was to evaluate the effect of silicon application in increasing doses using magnesium silicate as a source on the growth and production of cv.'ICA Cerinza' (*Phaseolus vulgaris* L.) common bean under agro ecological conditions in Tunja–Boyacá.

MATERIALS AND METHODS

The research was made under field conditions from October, 2015 to January, 2016 at the "La Maria" farm located at the UPTC in Tunja-Boyacá with coordinates 5°32'25"N 73°21'41"O and a height of 2691 msnm. The climate conditions during the development of the experiment were as follows: Average temperature 13.9°C, relative humidity 70% and an average monthly precipitation of 81.7 mm.

Before the sowing, we made a physicochemical analysis of the soil (Table 1). The analysis in vegetal tissue of phosphorus were realized according to NTC 234, and silicon through technique of atomic emission spectroscopy, internal methodology. The measurement of growth and production variables was made in the Laboratory of Plant Physiology at the UPTC.

Table 1. Physicochemical properties of soil used in the experiment.

Property	Value
pH	5.53
MO (%)	0.99
P Bray II (mg kg^{-1})	22.7
Ca ($cmol_c$ kg^{-1})	11.35
Mg ($cmol_c$ kg^{-1})	3.6
K ($cmol_c$ kg^{-1})	1.88
Na ($cmol_c$ kg^{-1})	0.75
Fe (mg kg^{-1})	94
Cu (mg kg^{-1})	1.28
Zn (mg kg^{-1})	10.6
Mn (mg kg^{-1})	28.79
Depth (cm)	0-30
Sand (%)	28.88
Silt (%)	45.12
Clay (%)	26
Texture	Loam
CE (dS m^{-1})	0.63

We used a completely random design, with 4 treatments: T1: treatment control (without application); T2: 300 kg ha^{-1}; T3: 600 kg ha^{-1} y T4: 900 kg ha^{-1} using Silimag 30-30 Rio Claro® as a source (magnesium silicate MgO-30%; SiO_2-30%). Each treatment was replicated 4 times, for a total of 16 experimental units.

Each experimental units corresponded to a plot with dimensions 1.4 x 2 m, for an area of 2.8 m^2, the sowing was made with a row spacing of 0.6 m and 0.3 m between plants with a density of 55,555 plants ha^{-1}, placing 2 grains per site, and then, to perform a thinning and having a total of 18 plants per plot. To make the variables measurement, 10 plants were selected from the central furrows to avoid the edge plot effect. We used the cultivar 'ICA Cerinza' common bean type shrubby seed, well-adapted to the area and with an average yield of 1.6 t ha^{-1} (FENALCE, 2015).

The application of magnesium silicate was made at the moment of sowing. The fertilization was performed according to the results of the soil analysis obtained one month after sowing. Sprinkler irrigation was applied according the needs of crop, an application of phytosanitary control based on monitoring, and control products of anthracnose and leaf-miners.

Physiological and growth variables evaluated were: Total chlorophyll with a Minolta clorofilometer SPAD 502, taking a total of 10 measurements per plant; sheet thickness with a Mitutoyo digital calibrator precision ± 0.05 mm, leaf area with a CCI-202 meter, fresh and dry weights on an electronic Acculab VIC 612 balance of 0.01 g precision and dried in a Memmert drying oven at 70 °C during 48 h; the P content in plant tissues was performed by the method of calcination at 600 °C, acid digestion and valuation by visible spectrophotometry and the Silicon content was made by closed wet digestion via a microwave oven, quantification by atomic-absorption flame technique. According to the yield, we measured variables such us: number of pods per plant, number of grains per pod, weight of 100 grains to 14% humidity balanced in the Motomco Moisture meter model 919 from the seed laboratory at FENALCE and yield in kg ha^{-1}.

Data obtained were tested for normality and homogeneity of variance by Shapiro-Wilk y Levene testing respectively. Testing the cases, we made the variance analysis, the

variables which show statistical differences were tested for comparison means of Tukey ($P \leq 0.05$). The analysis was made with the statistical program SAS v.9.2e SAS Institute Inc., Cary, NC.

RESULTS AND DISCUSSION

Variables of leaf thickness, fresh and dry mass of shoot and root showed significant differences between treatments ($P \leq 0.05$), we observed that the higher values were the result of applying 900 kg ha^{-1} of magnesium silicate and the lower values were in plants without any application (Table 2). This is due possibly, to the Silicon accumulation in the cell walls and intracellular spaces of leaves and root cells (Epstein, 1994), forming a silicon–cellulose membrane which can be associated with pectin and calcium ions (Snyder *et al.,* 2007). Even though the concentration of silicon in plants varies considerably between species of 0.1% to 10% dry weight (Ma *et al.,* 2011).

Table 2. Effect of different doses of magnesium silicate on physiological variables in bean.

Treatments (kg ha^{-1})	LT (mm)	APFW (g)	APDW (g)	RFW (g)	RDW (g)	LA (cm^2)
Control	0.35 ± 0.002 d	109.08 ± 2.43 c	32.82 ± 0.32 c	3.15 ± 0.4 b	0.45 ± 0.03 c	866.68 ± 7.86 c
300	0.40 ± 0.002 c	145.84 ± 3.44 b	46.21 ± 0.72 b	3.60 ± 0.27 ab	0.55 ± 0.007 bc	895.94 ± 7.39 c
600	0.42 ± 0.002 b	164.29 ± 12.7 b	50.98 ± 4.42 b	3.91 ± 0.25 ab	0.88 ± 0.15 ab	1045.64 ± 14.94 b
900	0.57 ± 0.005 a	335.79 ± 8.77 a	99.07 ± 2.63 a	4.69 ± 0.36 a	1.00 ± 0.07 a	1287.52 ± 65.91 a

LT: Leaf thickness APFW: Aerial part fresh weight; APDW: Aerial part dry weight RFW: Root fresh weight; RDW: Root dry weight; LA: Leaf area. Averages with different letters in the same column indicate a significant difference according to the Tukey Test ($P \leq 0.05$).

Hernández (2002) and Tahir *et al.* (2010) indicate that the application of silicon helps the root development system and a significant increase in biomass in plants exposed to salt stress. It is shown that silicon can be accumulated in the epidermal root cells (Epstein, 1994). This is associated with the results obtained in this research in which an increasing of mass and leaf thickness was an effect of applying edaphic magnesium silicate.

Meanwhile the leaf area showed significant differences between treatments according to the Tukey Test ($P \leq 0.05$). The treatment of 900 kg ha^{-1} of magnesium silicate presented the higher value to the leaf area with 1287.52 ± 65.91cm^2. It showed significant differences versus other treatments; meanwhile, the treatment without any application showed the lower value with 866.68 ± 7.86 cm^2 (Table 2). It is reported that the application of edaphic silicon has a positive effect on the growth of plants, because there is an increasing in the leaf area, shoot growth, dry biomass and yield (Gevrek *et al*., 2012; Tavares *et al*., 2012). On the other hand, Nwudo and Huerta (2008) indicate that the addition of silicon at 20 days old stimulated the growth of rice plants and inhibits the negative effect of cadmium. According to Liu *et al.* (2014), the application of silicon increases the photosynthesis rate in sorghum because of the development of the leaf area. Haghighi and Pessarakli (2013) observed that the silicon improved the photochemical efficiency of leaf in *S. lycopersicum* plants, under conditions of salt stress.

According to Epstein (1999), the silicon absorbed is transferred from roots to the aerial part of the plant through the transpiration stream via xylem, but being inside the plant the phytoliths, which are microscopic mineral particles formed when the silicon is inside and around the cells of the epidermal tissue and in the cell walls remain insoluble until the plant residues return to the soil and begin to decompose (Álvarez and Osorio, 2014). The silicon deposited on the leaf blade allows the silica bodies to act as a window to ease the light transmission to the mesophyll photosynthetic tissue, hypotheses still to be tested (Ma and Takahashi, 2002), easing the transmission of light to leaves. The photosynthesis process will help generate more energy to the plant, increasing its productivity.

The content of total chlorophyll showed statistical differences between the doses used from week eight after sowing

(Figure 1). The treatment of 900 kg ha^{-1} of magnesium silicate presented the higher value of total chlorophyll (SPAD) during the greater part of the experiment. The accumulation of silicon in the cell walls and intercellular spaces can protect and inhibit morphological and anatomical alterations of the photosynthetic apparatus, of which pigments like chlorophylls make an important part, due to the role of activation of the defense system of the plant (Adrees *et al.,* 2015).

According Shekari *et al.* (2015) silicon helps the photosynthetic rate, which is directly linked to the content of chlorophyll in leaves. Qinghua *et al.* (2005), indicate to be an excess of micronutrients such as magnesium biosynthesis is inhibited in the chlorophyll and it causes a decrease in the photosynthesis rate, effects that can be fixed with the application of silicon. Mihaličová *et al.* (2014) report the positive effects of silicon in the formation of chlorophyll in corn.

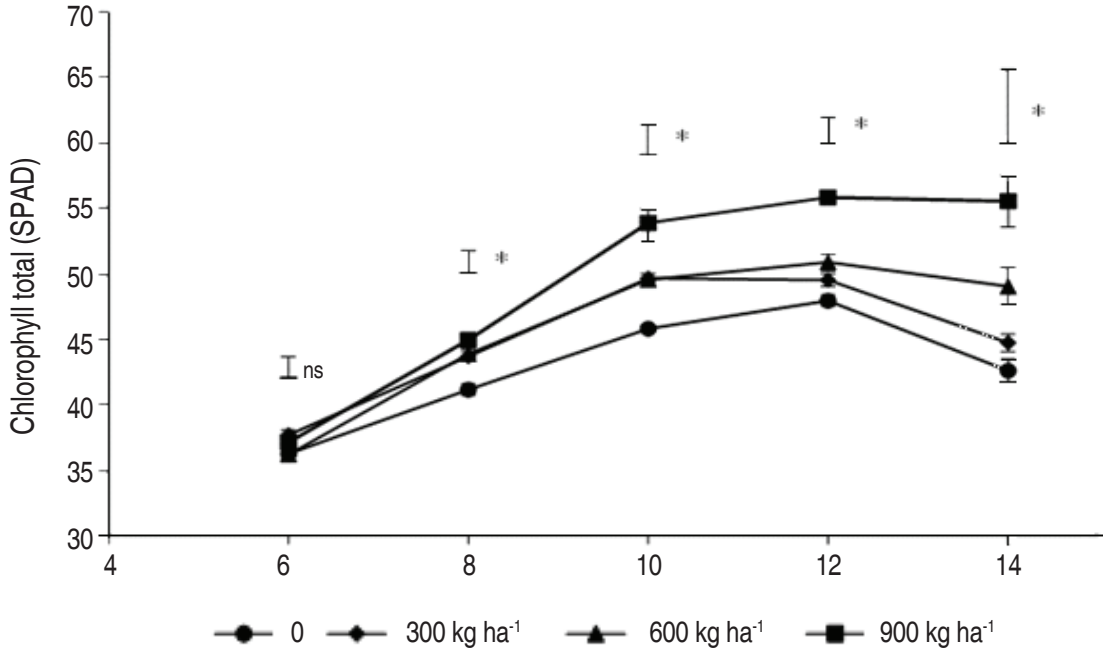

Figure 1. Behavior of the total chlorophyll in cv. 'ICA Cerinza' (*Phaseolus vulgaris* L.) common bean under different doses of magnesium silicate. Vertical bars on treatments indicate standard error (n=4). Bars on the sampling points indicate the minimum significant difference in each sampling point according to the Tukey Test ($P \leq 0.05$), ns: no statistical difference, *: Significant differences.

Adatia and Besford (1986) indicate that silicon is presented in the chlorophyll in high concentrations per unit area of leaf tissue, representing a positive impact in the plant tolerance with low or high levels of light, making its use more efficient.

In corn silicon improves the levels of chlorophyll in plants under water stress compared with plants without any application (Kaya *et al.,* 2006). The results obtained in this research show that the application of increasing doses of magnesium silicon enhance the content of chlorophyll in the cv. 'ICA Cerinza' common bean crop, generating a contribution of silicon and magnesium, both, important components of chlorophyll.

The variables number of pods per plant and grains per pod showed significant differences between treatments ($P \leq 0.05$) (Figure 2). The application of 900 kg ha^{-1} of magnesium silicate resulted in a greater number of pods per plant with a value of 18.25 ± 0.75. The lower value was in the treatment control with 12 ± 0.4 pods per plant. The number of grains per pod showed statistical differences between the control treatment and the other treatments with the application of magnesium silicate, the higher value was observed in the treatment without any application with 3.43 ± 0.09 and the lower value was the treatment of 900 kg ha^{-1} with 3 ± 0.05 grains per pod without significant differences between treatments 2 and 3 (Figure 2). As was mentioned before,

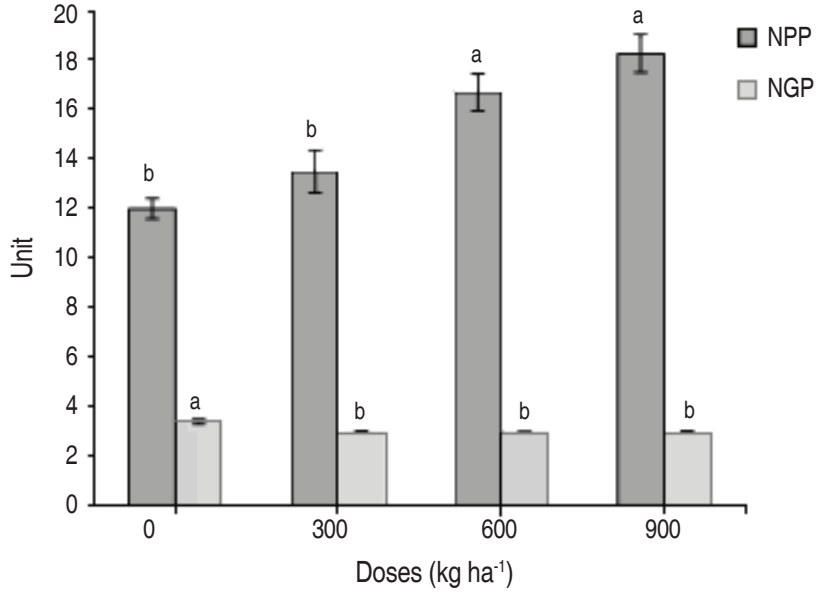

Figure 2. NVP: Number of pods per plant, NGP: Number of grains per pod in cv. 'ICA Cerinza' (*Phaseolus vulgaris* L.) common bean under different doses of magnesium silicate. Treatments followed by different letters show significant differences according to the Tukey Test ($P \leq 0.05$), vertical bars indicate standard error (n=4).

the magnesium silicate generated greater vegetative plant growth, seeing this reflected in the high number of reproductive structures; however, as Delgado *et al*. (2013) said, there is a negative correlation between the number of pods/plant and the number of grains/pod, it correlates the results obtained before.

Research made in citric fruits showed that silicified fertilization accelerates their growth and increases maturation and quantity. (Álvarez and Osorio, 2014). In gramineous, the number of tillers is an indicator of productivity, due to the relation that exists between this and the biomass per unit of area; in rice, a considerable increase in the number of pods per plant has been demonstrated, this is possible because of improvement in the nutritional dynamics that allowed the absorption of some nutrients like P, Ca and the contribution of Mg and Si, which generates an increase in the photosynthesis rate and yield.

There were some significant differences between treatments in the weight variables of 100 grains (P100) and yield ($P \leq 0.05$) (Figure 3). The higher values were in the treatment 900 kg ha^{-1} with a P100 of 70.36±1.09 g and a yield of 2139.1±59.35 kg ha^{-1}. The treatment without any application showed the lower value with a P100 of 63.11 ± 0.73 g and a yield of 1445.5 ± 58.93 kg ha^{-1} (Figure 3 A y 3 B). We could observe that the increasing doses of magnesium silicate affect the yield of the bean crop, as it increased by 47%; this is possibly due to the accumulation of this element in the epidermal cells of the grain.

According to Hernández (2002) and Quero (2008), the silicon is essential for tomato and cucumber crops; this is also found in oat, barley and bean seeds in concentrations of 4.25; 2.42; and 1.20 g kg^{-1} dry mass respectively. In the chili crops, the production and quality of the harvest increased with the application of fertilizers, irrigation water and other elements rich in silicon (Quero, 2008).

The role of silicon in plant metabolism has got great attention (Kaya *et al.,* 2006). The silicon has many functions like the stimulation of photosynthesis, increasing the strength of tissues and reducing the rate of transpiration, functions that help increase the production of dry mass and the resistance of plants to physical, chemical and biological stress (Álvarez and Osorio, 2014). It's important to know that silicon can be utilized in metabolic,

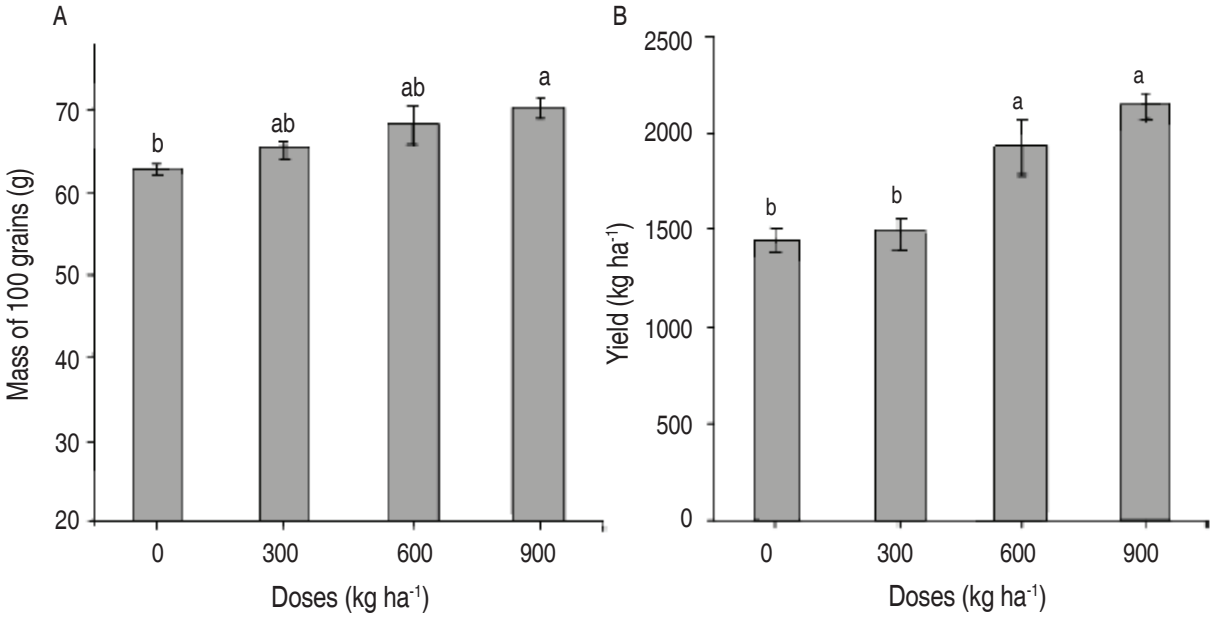

Figure 3. A. Mass of 100 grains at 14 % of humidity; B. Yield in kg ha^{-1} in beans (*Phaseolus vulgaris* L.) cv. 'ICA Cerinza', under different doses of magnesium silicate. Treatments followed by different letters show significant differences according to the Tukey Test ($P \leq 0.05$), vertical bars indicate standard error (n=4).

physiological and/ or structural activities in higher plants, mainly when they are exposed to biotic and abiotic stress (Liang *et al.,* 2007).

According to Álvarez and Osorio (2014), one of the most important effects in the application of silicate fertilizers is to improve the availability of phosphorus in the soil, thus, improving its absorption by the cultivated plants, and, of course, the yield of crops. In the variables of silicon and phosphorus concentration at plant tissue levels (leaves), there were significant statistical differences (Figure 4). For the concentration of silicon, the higher value used a dose 900 kg ha^{-1} of magnesium silicate with 2013±27.26 mg L^{-1}, without any statistical difference with treatment 3, but similar to treatments 1 and 2. For the variable of phosphorus concentration in a tissue, there were no statistical differences between the treatments with application of magnesium silicate, but they were related to the treatment control. The highest concentration of phosphorus was for treatment 2 with a value of 0.22±0.002%. The application of 300 kg ha^{-1} of magnesium silicate generated an increase in phosphorus absorption and its accumulation in tissue (leaves); similar results were obtained with the application of treatments 600 and 900 kg ha^{-1}.

Roy *et al.* (1971) found that applying calcium silicate (500 mg kg^{-1} of silicon) in four tropical soils, significantly reduced the phosphorus fixation of the soil. This beneficial effect of silicon makes that the quantity of soluble phosphorus greater, reducing the application of phosphorus fertilizers and the prices of production. According to the same author, the application of phosphorus on tropical soils can be reduced with the application of calcium silicate and lime at the same time.

According to the species, plants accumulate an amount of silicon in their tissues, mainly Poaceae which accumulate a higher content of this element and dicotyledonous species, which do not greatly benefit from silicon; so, highly silicate fertilizers will provide a greater absorption of this element, showing its beneficial effects in plants.

It has been reported that in tomato crops the most accumulation of silicon is found in roots and not in stems, a typical effect in plants which do not accumulate silicon (Menzies *et al.,* 1991). In the bean leaves, a concentration that varies from 0.14% silicon without any application of silicified source to 0.2% of silicon in treatments with application of magnesium silicate was

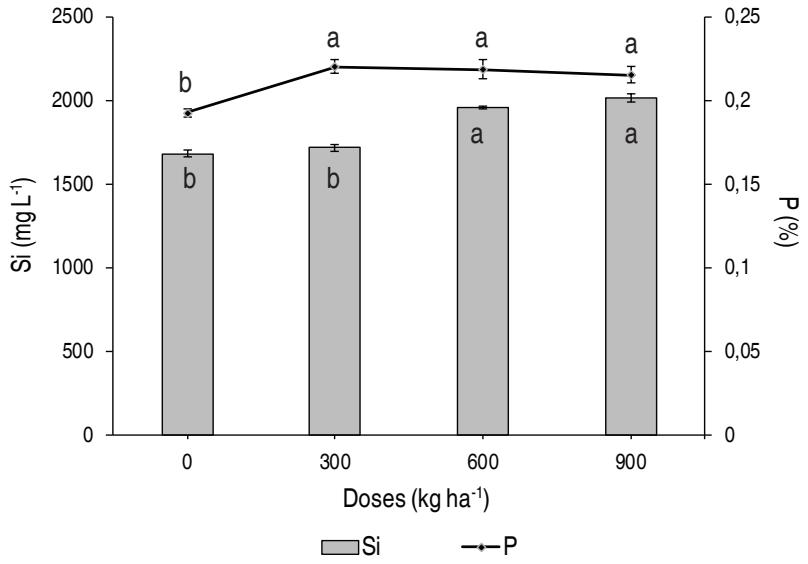

Figure 4. Concentration of phosphorus (mg kg^{-1}) in plant tissue (leaves) and silicon (mg kg^{-1}) in cv. 'ICA Cerinza' (*Phaseolus vulgaris* L.) common bean under different doses of magnesium silicate. Bars indicate concentration of Si and dispersion line a concentration of P. Treatments followed by different letters show significant differences according to the Tukey Test ($P \leq 0.05$), vertical bars indicate standard error (n=4).

found; it allows to catalog the bean cv 'ICA Cerinza' as a species which does not accumulate silicate, but in which it has important benefits, because of a significant increase in the growth variables and in the yield components. Therefore, the application of magnesium silicon has become an important alternative at the level of nutritional dynamics for plants which do not accumulate of silicon like the common bean.

CONCLUSIONS

The application of increasing doses of magnesium silicate significantly helped the growth variables and the yield components, because the productivity increased by 47% per hectare. The application of magnesium silicate helped to improve the absorption of phosphorus and increased the concentration of silicon in leaves, indicating that the product used did not have a high bio-accumulation of silicon, but on the contrary, had a beneficial effect.

ACKNOWLEDGMENTS

This research was carried out with the support of Cales and Calcareous Derivatives Rio Claro Naranjo and Compañía S C A and the Pedagogical and Technological University of Colombia (UPTC) Tunja.

REFERENCES

Adatia M and Besford R. 1986. The effects of silicon on cucumber plants grown in recirculating nutrient solution. Annals of Botany 58: 343-351. doi: 10.1093/oxfordjournals.aob.a087212.

Adrees M, Ali S, Rizwan M, Zia-ur-Rehman M, Ibrahim M, Abbas F, Farid M, Qayyum M and Irshad M. 2015. Mechanisms of silicon-mediated alleviation of heavy metal toxicity in plants: A review. Ecotoxicology and Environmental Safety 119: 186–197. doi: 10.1016/j.ecoenv.2015.05.011.

Álvarez C and Osorio W. 2014. Silicio Agronómicamente esencial. Mejisulfatos S.A.S., Itagüí, Colombia y Universidad Nacional de Colombia, Medellín, Colombia. 108 p.

Arias JH, Jaramillo M and Rengifo T. 2007. Manual Técnico: Buenas Prácticas Agrícolas (BPA) en la producción de fríjol voluble. CORPOICA – MANA – FAO. C.I. La Selva, Medellín. 168 p.

Datnoff L, Rodrigues F and Seebold K. 2007. Silicon and Plant Disease. pp.233-246. In Datnoff L, Elmer W and Huber DM (eds.). Mineral nutrition and plant disease. The American Phytopathological Society, St. Paul, MN.

Delgado, H, Pinzón E.H, Blair M, y Izquierdo P.C. 2013. Evaluación de líneas de fríjol (*Phaseolus vulgaris* L.) de retrocruce avanzado entre una accesión silvestre y radical cerinza. Revista U.D.C.A Actualidad & Divulgación Científica 16(1): 79-86.

Epstein E. 1994. The anomaly of silicon in plant biology. Proceedings of the National Academy of Sciences 91: 11-17.

Epstein E. 1999. Silicon. Annual Review of Plant Physiology and Plant Molecular Biology 50: 641-664. doi: 10.1146/annurev.arplant.50.1.641.

Epstein E. 2009. Silicon: its manifold roles in plants. Annals of Applied Biology 155: 155–160. doi:10.1111/j.1744-7348.2009.00343.x.

Epstein E and Bloom A. 2005. Mineral nutrition of plants, principles and perspectives. Second edition. Sinauer Associates, Sunderland. 400 p.

Fageria NK, Baligar VC and Jones CH. 1997. The role of essential nutrients on plant diseases. Growth and mineral nutrition of field crops. Marcel Dekker Inc., New York. 199-218p.

Fawe A, Abou-Zaid M, Menzies JG and Belanger RR. 1998. Silicon-mediated accumulation of flavonoid phytoalexins in cucumber. Phytopathology 88: 396-40. doi: 10.1094/PHYTO.1998.88.5.396.

Federación Nacional de Cultivadores de Cereales y Leguminosas (FENALCE). 2015. Área, producción y rendimiento cereal y leguminosas 2014 B. http://www.fenalce.org/nueva/plantillas/arch_down_load/APR_2014_B.pdf; consulta: Febrero 2016.

Gevrek MN, Atasoy GD and Yigit A. 2012. Growth and yield response of rice (*Oryza sativa* L.) to different seed coating agents. International Journal of Agriculture and Biology 14: 826–830.

Haghighi M and Pessarakli M. 2013. Influence of silicon and nano-silicon on salinity tolerance of cherrytomatoes (*Solanum lycopersicum* L.) at early growth stage. Scientia Horticulturae 161: 111–117. doi: 10.1016/j.scienta.2013.06.034

Hernández GR. 2002. Nutrición mineral de las plantas. Facultad de Ciencias Forestales y Ambientales. Universidad de los Andes-Mérida, Venezuela. En www.forest.ula.ve/-rubenhg, consulta: febrero 2016.

Kaya C, Tuna L and Higgs D. 2006. Effect of Silicon on Plant Growth and Mineral Nutrition of Maize Grown Under Water-Stress Conditions. Journal of Plant Nutrition 29(8): 1469-1480. doi: 10.1080/01904160600837238.

Liang Y, Sun W, Zhu Y and Christie G. 2007. Mechanisms of silicon mediated alleviation of abiotic stresses in higher plants: a review. Environmental Pollution 147(2): 422–428. doi: 10.1016/j.envpol.2006.06.008

Liu P, Yin L, Wang S, Zhang M, Deng X, Zhang S and Tanaka K. 2014. Enhanced root hydraulic conductance by aquaporin regulation accounts for silicon alleviated salt-induced osmotic stress in *Sorghum bicolor* L. Environmental and Experimental Botany 111: 42–51. doi: 10.1016/j.envexpbot.2014.10.006.

Ma J and Takahashi E. 2002. Soil, Fertilizer, and Plant Silicon Research in Japan. First edition. Elsevier, Amsterdam. 281 p.

Ma J, Yamaji N and Mitani-Ueno N. 2011. Transport of silicon from roots to panicles in plants. Review. Proceedings of the Japan Academy. Series B, Physical and biological sciences 87(7): 377-385. doi: 10.2183/pjab.87.377.

Ma JF. 2004. Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Journal Soil Science and Plant Nutrition 50(1): 11–18. doi: 10.1080/00380768.2004.10408447.

Marschner, P. 2012. Mineral nutrition of higher plants. 3nd. Edition. Elsevier. Oxford, UK. 645 p.

Menzies JG, Ehret DL, Glass AD, Helmer T, Koch C and Seywerd F. 1991. Effects of soluble silicon on the parasitic fitness of *Sphaerotheca fuliginea* on *Cucumis sativus*. Phytopathology 81: 84-88.

Mihaličová S, Ducaiova Z, Maslanakova I and Backor M. 2014. Effect of silicon on growth, photosynthesis, oxidative status and phenolic compounds of maize (*Zea mays* L.) grown in cadmium excess. Water, Air, & Soil Pollution 225: 1–11. Doi: 10.1007/s11270-014-2056-0.

Mitani N and Ma JF. 2005. Uptake system of silicon in different plant species. Journal Experimental Botany 56: 1255–1261. doi: 10.1093/jxb/eri121.

Nwugo C and Huerta A. 2008. Effects of silicon nutrition on cadmium uptake, growth and photosynthesis of rice plants exposed to low-level cadmium. Plant Soil 311: 73–86.

Qinghua S, Zhiyi B, Zhujun Z, Yong H, Qiongqiu Q and Jingquan Y. 2005. Silicon-mediated alleviation of Mn toxicity in *Cucumis sativus* in relation to activities of superoxide dismutase and ascorbate peroxidase. Phytochemistry 66: 1551–1559. doi:10.1016/j.phytochem.2005.05.006.

Quero E. 2008. Silicio en la producción de chile. La biosilicificacion: Proceso biológico fundamental en la productividad vegetal. De riego: Protección y Nutrición de Hortalizas y Frutas 39: 72-76.

Richmond KE and Sussman M. 2003. Got silicon? The non-essential beneficial plant nutrient. Current Opinion in Plant Biology 6: 268–272. doi: 10.1016/S1369-5266(03)00041-4.

Roy A, Ali MV, Fox R and Silva J. 1971. Influence of calcium silicate on phosphate solubility and availability in Hawaiian Latosols. pp.757–765 In: Proceedings of the International Symposium on Soil fertility Evaluation, vol. 1, New Delhi, 815 p.

Rodrigues FA, Vale FCR, Korndorfer GH, Prabhu AS, Datnoff LE, Oliveira AMA and Zambolim L. 2003. Influence of silicon on sheath blight of rice in Brazil. Crop Protection 22: 23–29. doi: 10.1016/S0261-2194(02)00084-4.

Ruiz R and Rincón O. 2000. Cultivo de Maíz y Frijol. Temas de Orientación Agropecuaria. Tercera Edición. Bogotá-Colombia. 181 p.

Shekari F, Abbasi A and Mustafavi S. 2015. Effect of silicon and selenium on enzymatic changes and productivity of dill in saline condition. Journal of the Saudi Society of Agricultural Sciences. 1-8. doi: 10.1016/j.jssas.2015.11.006.

Snyder GH, Matichenkov VV, Datnoff LE. 2006. Silicon. pp 551–568. In: Barker A, Pilbeam D (eds.). Handbook of plant nutrition. Taylor and Frances, Boca Raton. 773 p.

Tahir M, Rahmatullah A, Aziz T and Ashraf M. 2010. Wheat genotypes differed significantly in their response to silicon nutrition under salinity stress. Journal Plant Nutrition 33: 1658–1671. doi: 10.1080/01904167.2010.496889.

Tavares LC, Rufino CA, Dorr CA, Barros AS and Peske ST. 2012. Performance of lowland rice seeds coated with dolomitic limestone and aluminum silicate. Revista Brasileira de Sementes 34: 202–211. doi: 10.1590/S0101-31222012000200003.

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Actions for the participative rehabilitation of the National Monument Forest of Stone "Isabel Rubio"

UNIVERSIDAD NACIONAL DE COLOMBIA

Acciones participativas para la rehabilitación del monumento nacional bosque de piedra "Isabel Rubio"

doi: 10.15446/rfna.v70n3.66326

Barbarita Mitjans Moreno[1]* and Joel Pacheco Escobar[1]

ABSTRACT

This work was carried out in the Monumento Nacional Bosque de Piedra "Isabel Rubio" in Guane municipality, Pinar del Río province, Cuba. It was aimed at proposing the participatory actions that contribute to mitigate the process of degradation in this ecosystem. Social information was collected for this purpose. The methods used were Participatory Rapid Diagnosis, Participative Action Research, as well as the Participative Scientific Observation. The techniques used for the collection of information were: semi-structured interview and participant observation. Significant results in this study include the following. It was found that among the causes that contribute to the degradation of the ecosystem are: logging of species of high commercial value, burning of the tropical karstic forests, construction of roads and insufficient knowledge local players have in relation to the patrimonial and natural values of the monument in the area under study. The consequences of these human actions were also identified and an action plan based on four lines of work (rehabilitation, training, integration and promotion) was designed including real community participation in solving problems in relation to this heritage. It is concluded that the causes of the ecosystem deterioration are related to the anthropic action from negative positions, thus the participation of local players from a committed perspective for rehabilitation process is necessary.

Keywords:
Action plan
Participation
Rehabilitation
National monument

RESUMEN

El presente trabajo se realizó en el Monumento Nacional Bosque de Piedra "Isabel Rubio", municipio Guane, provincia Pinar del Río, Cuba. Tuvo como objetivo proponer acciones participativas que contribuyeran a mitigar el proceso de degradación en ese ecosistema. Para ello se recogió información social. Los métodos utilizados fueron el Diagnóstico Rápido Participativo, la Investigación Acción Participativa y la Observación Científica Participativa. Las técnicas usadas para la recogida de información fueron: la entrevista semi-estructurada y la observación participante. Como resultados importantes se encontró que entre las causas que contribuyen en la degradación del ecosistema se encuentran: tala de especies de alto valor comercial, quema del bosque kárstico tropical, construcción de caminos y un insuficiente conocimiento por parte de los actores locales colindantes acerca de los valores patrimoniales y naturales del área de estudio. También se identificaron las consecuencias de estas acciones antrópicas y se diseñó un plan de acción que se fundamenta en cuatro líneas de trabajo (rehabilitación, capacitación, integración y promoción) con la idea base de la participación real de la comunidad en la solución de los problemas presentes en este patrimonio. Así, se concluye que las causas del deterioro del ecosistema están relacionadas con la acción antrópica desde posiciones negativas, por lo que se precisa de la participación de los actores locales desde una perspectiva comprometida y participativa para su rehabilitación.

Palabras clave:
Plan de acción
Participación
Rehabilitación
Monumento nacional

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Received: December 11, 2016; Accepted: March 24, 2017
Rev.Fac.Nac.Agron. 70(3): 8295-8301. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

The neglect of the environment and the mistreatment of men over their natural resources and sources have become one of the greatest problems in the contemporary world and a concern for politicians, environmentalists, ecologists, non-governmental organizations and scientific institutions around the world (Mitjans, 2012).

Mountains are among the more vulnerable or fragile, within ecosystems, to the changes that man or other natural agents can provoke according to (Rivera, 2010). In these there is a great diversity of plants, some of them registered in catalogues and studies carried out by specialists and others that perhaps are ignored by man or insufficiently studied, without ending up verifying their true importance for the humanity development.The present research is carried out in the "Isabel Rubio" Stone Forest (hereafter referred to as IRSF), which is constituted by limestone rocks, of which hundreds of mini tropical karstic forests have been chiseled that surpass 10 meters in height (CITMA, 2004). These formations, which mark the western end of the great *Sierra de los Órganos*, are considered the most picturesque in Cuba.

Nevertheless, there are critical processes at the ecosystem level that influence the stability of its flora, fauna and soil, which ultimately affect the well-being of the neighboring local players. Among these processes are: indiscriminate logging, introduction of exotic species, fires and road building caused by social indiscipline of some residents adjoining the area. There is evidence that problems such as these can be overcome through rehabilitation with the participation of local players (Mitjans *et al.,* 2013).

The above-mentioned authors affirm that this commitment requires community participation, since ecological rehabilitation requires a restoration of the spirit and a change of attitude towards what are the ecosystems, so as not to damage them and restore what has been degraded. On the other hand Rodríguez (2003) stated: *"communities must be adequately educated in the knowledge of the ecosystem and the positive or negative influence they can exert on this ..."*

Several researchers converge on this topic from the creation of participative processes to conduce the emergence of a popular critical conscience to understand the social practice as an inseparable unit of reflection and action; such is the case of the works of some authors like Rodríguez (2003), Valdés *et al*. (2008), FAO (2010), Mitjans (2012) and Marzin *et al.* (2014), which offer a current and deep focus on the community work from the participation and the social self-management, in agricultural and forest processes.

The rehabilitation, planning and administration of the natural resources require not only a physical space to be executed but also a true and effective participation of the involved local players. Thus, a development model is required to improve the relationship between man and the natural resources (Andino *et al*., 2006).

According to the FAO (2010) the forest sector in Latin America has focused more on the perception of society regarding forests, from which important changes have been experienced during the last years, with a growing emphasis on the environment, social, and cultural values. Molina *et al.* (2011) demonstrated that in protected areas, better protection and conservation results have been obtained when adjacent communities have participated. Furthermore, they have been able to explain the conflicts on degradation causes, the forests management and their relationship with the local players in studies from the resident's perception.

Therefore, it is necessary to elaborate action plans, strategies, and programs for the ecosystems forest management to educate the people involved to maximize their intellectual and spiritual capabilities from a participatory perspective, creating a commitment with the environment.

Taking into account the arguments presented above, the objective of this work is to propose participatory actions that contribute to mitigate the progressive deterioration of the existing flora in the IRSF National Monument. For this purpose the following hypothesis is formulated: if the causes that affect the degradation of the existing flora in the IRSF are known, as well as the theoretical fundamentals that support the restoration of forest ecosystems with the community participation, then it will be possible to propose participatory actions for contributing to mitigate the degradation of this ecosystem.

MATERIALS AND METHODS

Characterization of the study area

The study area covers 136.6 ha and is located at the western end of the Sierra de los Órganos, bordering the Cuyaguateje river and the popular councils Isabel Rubio and Molina in Guane, Pinar del Río province, Cuba.

Vegetation and fauna

The predominant vegetation is of mesophyll semideciduous forest, with *Gerascantus gerascantoides* L., *Cedrela odorata* L., *Guarea guidonia* L. and *Guazuma ulmifolia* Lam. The fauna represents a high degree of endemism and biodiversity conditioned by its geological evolution. This has also contributed to the existence of very numerous groups such as: arachnids, reptiles, mollusks, butterflies, birds and in smaller number small mammals.

Size and type of sampling

A total of 42 local players was interviewed from the intentional sampling: 10 direct predators, 22 adjacent to the area and 10 decision makers (officials from the State Forestry Service, Ranger Corps, CITMA Delegate, directors of the Macurije Integral Forestry Company, Community and Local Industries, the presidents of the Municipal Committee of Heritage and the People’s Council of Isabel Rubio, an engineer from the Forestry Company and a sociologist from the Municipal University Headquarters also contributed in the research).

The determination of the sample size for the research was according to the procedures presented by Calero (1978) for social studies in finite populations, during the estimation of a proportion, with a confidence level (1-) of 95%, a level of significance (α) of 5%, with a critical value (Z) of 1.96, a positive variability (p) of 0.95 and a negative variability (q) of 0.05, assuming a maximum permissible error (E) of 0.05.

$$n = \frac{Z^2 p\, q\, N}{N E^2 + Z^2 p\, q}$$

Where:

n = sample size.
Z = level of confidence.
p = positive variability.
q = negative variability.
N = Size of the population
E = maximum permissible error

Methods used

The qualitative research methodology was predominantly used in this work and it was focused on the understanding of the facts, trying to identify the different perspectives that occur in the social reality from the descriptions of the social players themselves.

Qualitative research is directed throughout its development. It does not intend to enumerate or measure events, rather it is a question of interpreting what is posed by local players and generally does not use statistical instruments (Salgado and Santos, 2009).

The methods used were Rapid Participatory Diagnosis (RPD) and Participatory Action Research (PAR). In order to collect the information, the semi-structured interview and the simple and participant observation were used; exchange workshops were carried out to corroborate the results of the interview. Field trips were conducted with the neighboring players to identify the species that have been introduced into the area.

The RPD is used to know and evaluate the existing problems and opportunities in a community and at the same time to plan ideas for the solution of those problems. According to Gomes *et al.* (2001), Rapid Participatory Diagnosis (RPD) is one of the most used approaches to enable the direct participation of the population in the generation and analysis of the information collected.

During the diagnosis, participatory techniques were used, stimulating the interest of local actors in solving problems; among them the most commonly used was the Rapid Rural Appraisal (RRA), which allows field technicians to collect and analyze information on natural and human ecosystems, promote the participation of local people in forest management, and increase the capability of local people to manage their own problems, according to the criteria of Jackson and Ingles (2004). Invasive species were classified according to the criteria of Oviedo *et al.* (2012) and Regalado *et al.* (2012).

RESULTS AND DISCUSSION

Causes of forest deterioration

Exploitation of marble stone. Among the obtained results in the interview it is one of the main causes that affect the deterioration of the ecosystem, since the

marble stones are extracted by applying fire, leading to the collapse of mini tropical karstic forests and consequently the associated vegetation. The 66.6% (28/42) of respondents stated it. In this case, it coincides with Bruzón *et al.* (2008) who argued that this action is one of the human activities that most affect natural ecosystems.

Ovens to produce marble paint. 11 marble paint ovens were identified throughout the area, whose objective is the production of paint for trade inside and outside the municipality. Of the residents interviewed, 88% (34/42) assert that ovens favor respiratory diseases and destroy the scenic beauty of the place; those who denied this claim were coincidently detractors of this ecosystem.

*Access ways and paths***.** Roads and paths have been built by people who illegally enter the Monument for the extraction and transfer of marble stones and wood of species for commercial purposes. The main species include *Gerascantus gerascantoides, Cedrela odorata* and *Guazuma ulmifolia*. This illegal entry of offenders reaches to the extent that they are making roads to extract and transfer the stones, eliminate the present plants. Unfortunately, native species often do not recover because they can be completely extinguished. In this sense, there is a coincidence with Ramírez *et al.* (2001) who argued that the opening of roads, paths and felling of the forest to build roads not only implies a reduction of the density of trees, but drastically changes in floristic composition, including precious wood species, among others.

In the exchange workshops, 91% (20/22) of the 22 neighboring local actors assert the above, while at the same time warn that there are hardly any timber species of economic value with commercial dimensions, which shows that there is degradation of the ecosystem.
*Solid waste dumping***.** This is another problem that affects the deterioration of this ecosystem, hindering the natural development of different heliophill species that try to colonize a place, since some people from the nearest community have used it as a landfill; depositing solid residues such as plastic and sawdust, which hinders the germination of pioneering and colonizing plants, a negative issue for the conservation of forest structure patterns, what could be directly observed in the area and verified with the adjacent residents, out of which 43% of the interviewees assert that it is the place where the majority of them deposit the solid residuals. In this regard, Sierra (2006) showed that sawdust and nylon cause dissolved oxygen deficiency, hindering the development and establishment of plant and animal species.

*Insufficient knowledge of local stakeholders about the need to care for this heritage***.** The dependency ratio of this community with the site has contributed to the destruction of a large part of its resources, due to the insufficient real participation of the local players in the search for solutions to their problems; insufficient knowledge about the importance of its assets and the advantages that derive from its management; insufficient integration between institutions and community; poor management of environmental management; insufficient mastery of participatory approaches to heritage management and prejudices about the community's ability to protect its environment, are evidence of this and was corroborated through observation, exchange workshops and interviews. Out of the 42 interviewees, 64% (27/42) assert the above.

During this research the community players recognized the need to prioritize, rescue, and systematize the traditional knowledge of local players who have lived adjacent to this site, as well as carry out educational work to enrich the knowledge related to the conservation of this forest heritage. In this regard Mitjans (2012) stated *"one of the causes of greater incidence in the deterioration of forests has been the lack of knowledge of the residents on the future consequences of their deterioration, for humanity and nature".*

Another example of this ignorance is presented in the results obtained from the interviews. Of the 42 local actors interviewed, 38 (90%) did not know the heritage values that identify it as National Monument, an exceptional category assigned by the unequalled beauty and natural values.

The introduction of exotic species. 16 species have been introduced to the area, which coincide to be invasive (Table 1). The 62% (26/42) of the respondents identified these species, also raised that in the last two decades, there has been a significant increase in the volume of evidence on the harmful effect of biological invasions and

also on the global interest of the scientific community for this problem.

Effects produced by anthropogenic actions

In recent years the harmful effects of man on forest ecosystems as well as the inclusion of invasive plant species have been widely recognized. Local, regional, national and global programs have been developed to curb their proliferation and mitigate their present and future impacts (Vilamajó *et al*., 2002).

Table 1. List of invasive species identified in the IRFS.

No.	Scientific name	Family	Origin
1	*Caesalpinia violacea* (Mill.) Standl.	Caesalpiniaceae	Mexico
2	*Cocos nucifera* L	Arecaceae	Africa
3	*Cordia obliqua* Willd.	Boraginaceae	India
4	*Delonix regia* (Bojer ex Hook.) Raf	Caesalpiniaceae	Madagascar
5	*Dichrostachy scinerea* L.	Mimosaceae	Africa
6	*Eucaliptus citriodora*	Myrtaceaea	Australia
7	*Ficuscras sinervia* Willd.	Moraceae	Unknown
8	*Hura crepitan* L.	Euphorbiaceae	Tropical America
9	*Leucaena leucocephala* (Lam.) de Wit.	Mimosaceae	Tropical America
10	*Melia azedarach* L.	Meliaceae	Pakistan
11	*Melicoccus bijugatus Jacq.*	Sapindaceae	America
12	*Mimosa pigra* L.	Mimosaceae	Pantropical
13	*Samanea saman* (Jacq.) Merill.	Mimosaceae	South America
14	*Sterculia apetala* (Jacq.) H. Karst.	Ustercliaceae	Tropical America
15	*Terminalia catappa* L.	Combretaceae	Asia
16	*Albizia lebbeck* (L.) Benth.	Mimosaceae	Asia

Coinciding with Álvarez (2005), the effects caused by anthropic pressure, if not controlled, can lead to the loss of biodiversity, among the most relevant found effects are: destruction of wildlife habitats, landscape modification, deforestation, environmental contamination and burning of marble, introduction of exotic and invasive species, this could be verified in the area through tours with the players involved.

These effects have conditioned the continuous loss of the constituent elements of the natural ecosystem, in terms of their structure and composition, due to the anthropic disturbances which can affect the loss of biodiversity. In this sense, there is a coincidence with Álvarez (2005) who argued that degraded or disturbed forests are those that have modified their structure, operation and capacity to provide services and products. Rosete *et al.* (2011) stated that invasive plants such as *Dicrostachys cinerea* have devastating effects on the structure, balance, dynamics and health of the forests. This specie was observed during the tour in several places in the study area.

Plan of action for the participative rehabilitation of the National Monument Forest of Stone "Isabel Rubio"

Actions to encourage the rehabilitation of the forest

- Select possible seed stands for nurseries to plant production.
- Establish the perimeter fence to limit the entry of detractors to the area.
- Establish a micro nursery in the adjacent community to the IRSF.
- Reforesting by using native species seedlings produced in the nursery.
- Perform by enrichment works with native species throughout the area.

- Perform an inventory of the existing flora.
- Develop a management plan that guarantees the protection and conservation of the IRSF.

Actions to upgrade the local actors adjoining the Monument

- Provide upgrading courses on the importance and care of the IRSF assets.
- Provide an environmental education course on waste pollution issues.
- Video debate about tropical karstic forests formations and National Monuments.
- Conduct exchange workshops to socialize the experiences of community leaders who are better trained in the subject.
- Make a catalogue that provides information about the heritage values of the Stone Forest.

Actions to achieve the integration of the neighboring actors

- Conduct conversations with representatives of the institutions and organizations involved, in order to reflect and assess the need for coherent articulation and integration for the rehabilitation of the IRSF.
- Propose tasks where it is possible, to carry out integration actions (participatory rehabilitation, voluntary works for the collection of residuals).
- Involve all local players and decision-makers in the decision-making of the tasks.

Actions to promote the natural values of the IRSF

- Elaborate and distribute brochures with topics related to the IRSF.
- Disseminate information by the local radio, on the tasks that are done for the rehabilitation of the National Monument.
- Make signs and posters with various advertisements on the conservation of the IRSF.
- Launch competitions with various topics on the natural resources of the IRSF, in schools of different teachings.
- Make a logo that identifies the place, to promote the project and the National Monument.

CONCLUSIONS

The ecosystem deterioration causes are related to the negative positions from anthropogenic actions, so a rehabilitation process is necessary from a committed participatory perspective by the local players.

The proposed action plan is focused on the people, their experiences and knowledge; it is projected to get the goals from their joint achievements, as well as on an active and conscious participation in the elaboration and execution of activities to favor the socio-environmental transformation by the community.

REFERENCES

Álvarez C. 2005. Perturbación, fragmentación y destrucción de bosques. Memorias (CD) del Curso de Restauración Ambiental INECOL. 15 p.

Andino J, Campos JJ and Villalobo R. 2006. Manejo de recursos naturales a partir de servicios ambientales prioritarios en la cuenca del lago Yojoa, Honduras. Revista Recursos Naturales y Ambiente. (48): 47-56.

Bruzón N, Herrero G, Matos A and Salazar R. 2008. Estudio ambiental para la planificación integral de la rehabilitación minera, la empresa niquelífera "René Ramos Latour". Revista Anuario. 1-18.

Calero A. 1978. Técnica de muestreo. Editorial Pueblo y Educación, La Habana. 514 p.

CITMA. 2004. Expediente del Monumento Nacional Bosque de Piedra Isabel Rubio. La Habana. 6 p.

FAO 2010. La estrategia de la FAO para los bosques y el sector forestal. Roma. 9 p. Disponible en: http://www.fao.org/docrep/012/al043s/al043s00.pdf. Consultado marzo 2010.

Gomes M, Souza A and Carvalho R. 2001. Diagnóstico Rápido Participativo (DRP) como mitigador de impactos socioeconômicos negativos em empreendimentos agropecuários. pp. 63-78. In: BROSE, M. (ed.). Metodologia participativa: uma introdução a 29 instrumentos. Tomo Editorial, Porto Alegre.

Jackson WJ and Ingles AW. 2004.Técnicas Participativas para Actividades Forestales Comunitarias: Manual de Campo. UICN, Gland, Suiza y Cambridge, RU y Fondo Mundial para la Naturaleza, Gland, Suiza, XII. 128 pp. ISBN: 2-8317-0557-6.

Marzin J, Benoit S, López TV, Cid G, Peláez O, Almaguer N, Herrera JA and Rose M. 2014. Herramientas metodológicas para una extensión agraria generalista, sistémica y participativa. Primera edición. Editora Agroecológica, 150 p. ISBN: 978-959-7210-70-2.

Mitjans B. 2012. Rehabilitación del bosque de ribera del río Cuyaguateje, en su curso medio. Estrategia participativa para su implementación. Tesis (en opción al grado científico de Doctor en Ciencias Forestales). Universidad de Pinar del Río. 100 p.

Mitjans B, González E, González M and Pérez J. 2013. Restauración participativa del Monumento Nacional Bosque de Piedra Isabel Rubio. Revista Cubana de Ciencias Forestales 1(1): 52-64 ISSN 2310-3469.

Molina Y, Sosa A, Santos W, Hechavarría O y Arcos M. 2011. Percepción ambiental por los actores sociales de la reserva ecológica el gigante. En: Memorias del 5to Congreso Forestal. (5: 2011: Palacio de las Convenciones, 25-29 abril: La Habana). ISBN 0138-6441. 10 p.

Oviedo R *et al.* 2012. Lista Nacional de especies de plantas invasoras y potencialmente invasoras en la República de Cuba - 2011. Boletín sobre conservación de plantas del jardín Botánico de Cuba Bissea 6 (número especial 1): 22-119. ISSN1998-4197.

Ramírez MN, González EM and Williams LG. 2001. Anthropogenic disturbance and tree diversity in Montane Rain Forests in Chiapas, Mexico. Forest Ecology and Management. 154(1,2): 311-326. doi: 10.1016/S0378-1127(00)00639-3

Regalado L, González-Oliva L, Fuentes I and Oviedo R. 2012. Las plantas invasoras. Introducción a los conceptos básicos. Boletín sobre conservación de plantas del jardín Botánico de Cuba. Bissea. 6 (Número especial 1): 2-21. ISSN 1998-4197

Rivera C. 2010. Estrategia de conservación para las especies *Pera oppositifolia* Griseb. Y *Juglans jamaicensis* sub sp. *insularis* (Griseb.) H. Schaarschm., en el Valle de San Andrés, municipio La Palma, Pinar del Río. Tesis de Doctorado en Ciencias Forestales. Universidad de Pinar del Río/Universidad de Alicante. 137 p.

Rodríguez G. 2003. Bases para el manejo sostenible de un bosque de manglar en estado de deterioro, sector Coloma-Las Canas de la Provincia de Pinar del Río. Tesis de Doctorado en Ciencias Ecológicas Universidad de Pinar del Río/Universidad de Alicante. 176 p.

Rosete S, Pérez J, Sánchez O and Rosa R. 2011. Bosques de Cuba. Instituto de Ecología y Sistemática (CITMA), Ministerio de la Agricultura (MINAGRI), Ministerio de Educación Superior (MES) y Ministerio del Interior (MININT), La Habana. 241 p.

Salgado A and Santos V. 2009. Metodología cualitativa: es posible adecuar las técnicas de colecta de datos a los contextos vividos en el campo? p. 12. En: Memorias VII Congreso Sociedad Brasileña de Economía, Administración y Sociología Rural. Porto Alegre, Brasil.

Sierra R. 2006. Fitorremediación de un suelo contaminado con plomo por actividad industrial. Trabajo de Grado. Ingeniero Agrícola y Ambiental. Universidad Autónoma Agraria “Antonio Narro”. México. 51 p.

Valdés O, García JM, Ramos P y Rodríguez M. 2008. Educación protección ambiental y prevención de desastres: Escuela, familias y comunidad. Editorial Pueblo y Educación. ISBN: 978-959-18-0404-4. 128 p.

Vilamajó D, Vales M, Capote R, Salabarría D and Menéndez L. 2002. Estrategia Nacional para la Diversidad Biológica y Plan de Acción en la República de Cuba. IES, CITMA, UNEP y CENBIO. 88 p.

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Revista Facultad Nacional de Agronomía

Agroindustrial performance of sugarcane varieties for panela in Antioquia, Colombia

UNIVERSIDAD NACIONAL DE COLOMBIA

Desempeño agroindustrial de variedades de caña de azúcar para panela en Antioquia, Colombia

doi: 10.15446/rfna.v70n3.66329

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ABSTRACT

In the municipality of San Carlos the panela agroindustry is the most important agricultural sector, in the economic, in the generation of employment and in food security. The varieties of sugar cane obtained by Cenicaña represent alternatives of competitiveness and productivity for the Colombian panelero sector. The present research evaluated agronomically and in yield in a Cimpa sugar mill type, ten varieties of sugar cane, in two localities of the municipality of San Carlos, Antioquia, in a design of complete blocks at random, with two replicates. In four rows of six meters in length, 10 buds were sown by furrow. With an average of three cutting cycles, the variables studied were tons of cane per hectare, tons of panela per hectare, industrial yield (%) and industrial quality. The varieties CC 93-4418, CC 93-3817, CC 93-3895 and CC 92-2154 exceeded in 40, 34, 30 and 21 tons of cane and 7, 6, 5 and 5 tons of panela, respectively, to the yields obtained by the control Co 421. The industrial yield fluctuated between 11 and 13%, the control was 12%. These four varieties have good characteristics of pH, concentration of soluble solids, saccharose and reducing sugars. These results are replicable and acceptable for most of the producing areas of the department of Antioquia.

Keywords:
Cane yield
Panela yield
Saccharose
Soluble solids
Quality

RESUMEN

En el municipio de San Carlos la agroindustria panelera es el sector agrícola más importante, en lo económico, en la generación de empleo y en la seguridad alimentaria. Las variedades de caña de azúcar obtenidas por Cenicaña representan alternativas de competitividad y productividad para el sector panelero de Colombia. La presente investigación evaluó agronómicamente y en rendimiento en trapiche tipo Cimpa, diez variedades de caña, en dos localidades del municipio de San Carlos, Antioquia, en un diseño de bloques completos al azar, con dos repeticiones. En cuatro surcos de seis metros de largo, se sembraron 10 yemas por surco. Con un promedio de tres ciclos de corte, las variables estudiadas fueron, toneladas de caña por hectárea, toneladas de panela por hectárea, rendimiento industrial (%) y calidad industrial. Las variedades CC 93-4418, CC 93-3817, CC 93-3895 y CC 92-2154 superaron en 40, 34, 30 y 21 toneladas de caña y 7, 6, 5 y 5 toneladas de panela, respectivamente, a los rendimientos obtenidos por el testigo Co 421. Los rendimientos industriales fluctuaron entre 11 y 13%, el testigo fue del 12%. Estas cuatro variedades presentan buenas características de pH, concentración de solidos solubles, sacarosa y azucares reductores. Estos resultados son replicables y asumibles para la mayoría de las de zonas productoras del departamento de Antioquia.

Palabras clave:
Rendimiento de caña
Rendimiento de panela
Sacarosa
Sólidos solubles
Calidad

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Received: January 11, 2017; Accepted: May 2, 2017
Rev.Fac.Nac.Agron. 70(3): 8303-8310. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

The first worldwide producer of panela is the country of India, which represents 56% of the total production; in second place is Colombia, with 15%. Burma (Myanmar), Brazil and China, followed in importance. In Latin America, the main producers are Colombia, Brazil, Honduras, Mexico, Peru and Venezuela (Rodríguez, 2014).

The cultivation of sugarcane is an agricultural activity of great socio-economic importance in the world. Sugarcane in Colombia has an area of 484,559 ha, of which 45% (218,000 ha) is dedicated to the production of sugar and ethanol and the remaining 55% (266,559 ha), to the panela production (Murcia and Ramírez, 2017). Within permanent crops, sugarcane ranks second in extension, after coffee (Minagricultura, 2004). Panela production is one of the main agricultural activities of the Colombian economy (Ramírez, 2017) among other reasons, because of its significant participation in the gross domestic product (GDP), about 7.3% of the agricultural sector, because it is a source of income for more than 70,000 families of producers and for the generation of rural employment, linking close to 350,000 people (Dane, 2016).

According to DANE (2016), in Colombia was sown 167,711 ha of cane and its production in panela was estimated at 990,908 tons. The panela is characterized by its high concentration of sugars, mineral content and traces of vitamins (Hernández *et al*., 2002). For Kumar and Tiwari (2006) it is an integral sugar, not refined and without chemical additives, that has a great nutritive and medicinal value.

The genetic improvement of sugarcane for panelera agroindustry is oriented to the substitution of genetic materials with low productive potential, through the introduction and evaluation of high yielding varieties and good agroindustrial performance, adaptable to the management conditions of the panela zones (Insuasty *et al*., 2003). The new varieties of sugar cane are produced in the country by el Centro de Investigación de la Caña de Azúcar de Colombia-Cenicaña in the department of Valle del Cauca, with the purpose of increasing the production of cane and sugar (Cassalett *et al*., 1995). These varieties could be good for the production of panela, but when they are planted in different agroecological zones, in soils of low fertility, less luminosity, greater precipitation and height above sea level, among others, they cannot adapt and therefore, their production is lower than that obtained at the place of origin. Because of the sugar content in the cane at the beginning of the harvest has low values, it is convenient to have varieties with high content and early accumulation of saccharose (Cox *et al*., 1990; Singh and Singh, 2004; Wagih *et al*., 2004).

The productivity of cane crops in the municipality of San Carlos is very low (30 to 50 t ha^{-1}), compared to the national yield in 2014, of approximately 113 t ha^{-1} (López JG, 2017, comunicación personal). This is due to the use of low-yielding varieties, low planting densities, lack of adequate renovation and fertilization programs, and the use of cutting by pick out, among others. Therefore, the objective of this research was to evaluate, agronomically and industrially, ten varieties of sugar cane for panela produced by Cenicaña, from the series 85, 92 and 93, using as a control the local variety Co-421.

MATERIALS AND METHODS

The study was carried out in the sugarcane production area of the municipality of San Carlos (Antioquia), in two localities (El Paraguas and La Cabaña), at a height between 800-950 masl, with an average temperature of 22.5 °C, precipitation of 4000 to 5000 mm per year, relative humidity of 85%, average solar brightness of 4.3 h d^{-1} (IDEAM station Nº 23085220. Average 2010-2014).

The soils where the tests were sown, showed Ar and FArA textures, extremely acidic, with low contents of organic matter (OM), low P availability, low in K, Ca, Mg, S, Zn, B, Cu and rich in Fe and with medium contents of Al (Table 1). In general terms they are soils of low fertility.

Two plots were established where the following varieties were evaluated: CC 85-92, CC 92-2188, CC 92-2154, CC 93-4418, CC 93- 3895, CC 85-47, CC 85-57, CC 92-2198, CC 93-3817, CC 84-75 and as control the variety Co-421. The asexual seed (stems) used was divided into pieces of four buds and planted at the bottom of the furrow at a density of ten buds per linear meter, with a furrow length of six m and a furrow distance of 1.4 m, four furrows of six m long; the effective area was 604.8 m^2 corresponding to each experimental plot.

Table 1. Chemical characteristics of the soils where the variety tests were established in the municipality of San Carlos (2014).

Locality	pH	OM	Al	Ca	Mg	K	P	S	Fe	Cu	Mn	Zn	B
		%	($cmol_c\ kg^{-1}$)				($mg\ kg^{-1}$)						
El Paraguas	4.4	5.3	1.6	0.7	0.1	0.07	5	5	226	1	6	1	0.12
La cabaña	5.0	6.3	1	1.1	0.2	0.13	10	3	226	2	4	1	0.10

pH in water (1:1); soil organic matter (SOM), Walkley and Black; Al, 1 *M* KCl; Ca, Mg, K and Na, 1 *M* ammonium acetate; P, Bray II; S, 0.008 *M* calcium phosphate; Fe, Mn, Cu and Zn, Olsen-EDTA; B, hot water.

Variables to evaluate

The variables studied were tons of cane per hectare (TCH), tons of panela per hectare (TPH), industrial yield (%) and industrial quality represented in total soluble solids (°Brix), pH, saccharose (%), reducing sugars (%), phosphates (ppm) and purity (%). In addition, the sanitary behavior of diseases of economic importance such as ring spot (*Leptosphaeria sacchari* van B), yellow freckle (*Mycovellosiella kopkey* Kruger), brown rust and virus, were recorded.

Plant height or stem length (m). Five stems per experimental unit (EU) were randomly picked from each variety and the length at harvest, was measured from the plant neck to the first visible ligule, using a non-destructive method.

Stem diameter (cm). From each variety were taken five random stems per EU at which the diameter was measured at harvest, using a micrometric calibrator, using a non-destructive method.

Population of stems (bunchig). The number of stems present in five linear meters in each variety was counted at harvest.

Overturning (%). The percentage of stems that showed overturning with respect to the total of the population of the EU of each variety was determined. This measurement was made at the time of harvest.

Physicochemical analysis. The content of total sugars was measured from twelve months after sowing and after each month, until reaching the appropriate maturity index for harvest (cutting time), in 10 stems per replicate, of each variety. For this analysis samples of panela (3 units of 170 g each) were weighed in a digital analytical balance (Mettler Toledo model AB204-S/ FACT, 0.1 mg precision), with samples of raw juices of cane (200 mL per variety); the soluble solids were determined with a digital refractometer (Anton Paar ref. Abbemat 300, 0.01 °Brix, precision). The percentage ratio between saccharose in juice and °Brix is known as juice purity. The apparent content of saccharaose, expressed as a percentage by weight and determined by a polarimetric method, is called "pol" (Larrahondo, 1995).

For the analysis of pH, saccharose (%), reducing sugars (%), purity (%) and humidity (%), the following equipment was used: a Schott potentiometer model CG842 precision 0,01; Spectrophotometer (Thermo Scientific model Evolution 201, precision 1.0 nm); A Atago polarimeter model OSK 6544, with an accuracy of 0.1 deg. (SI Analytics GMBH model SLR, speed range of rotation of the agitator 100-1,100 rpm, temperature regulation 25-200 °C ± 3 °C). Drying stove for dry matter obtaining (Thelco model 17, series 21AG-6, temperature range 30-225 °C). For these analyzes, 15 kg of cane per EU (per treatment and per repetition) were taken.

Experimental design

An experimental design of a randomized complete blocks, with two replications per locality, was carried out for each variety. The analysis of combined variance and the Duncan's mean test with a significance level of 5% was performed to detect differences in mean between treatments. An average of three cut cycles was obtained for each variable, using the statistical program MSTATC.

RESULTS AND DISCUSSION

Cane and panela production

According to the results contained in Table 2, it was observed that for the variables TCH and TPH, there were significant differences ($P \leq 0.05$) between the materials. The varieties that stood out for TCH were CC 93-4418 and CC 93-3895, with 138.9 and 128.4 t ha^{-1}, respectively, followed by varieties CC 92-2154 and CC 92-2198 with 119.0 t ha^{-1}; the control Co-421 was exceeded by the variety CC 93-4418 at 40.4 t ha^{-1}. These data are similar to those found by Ramírez *et al.* (2014) in Guepsa, Santander with varieties of series CC 92 and 93.

Table 2. Tons of cane and panela per hectare and average yield of three cuts of the variety test, located in the municipality of San Carlos, Antioquia. 2014.

Variety	TCH	TPH	Industrial yield (%)
CC 93-4418	138.9 a*	18.1 a*	13.0 a*
CC 93-3895	128.4 a	15.4 ab	12.2 ab
CC 85-57	90.1 c	11.8 bcd	12.4 ab
CC 92-2198	119.8 ab	15.4 ab	12.8 a
CC 85-47	87.1 c	11.2 bcd	12.3 ab
CC 92-2154	119.1 ab	15.2 abc	12.8 a
CC 92-2188	93.5 bc	11.6 bcd	12.4 ab
CC 84-75	99.8 bc	12.5 bcd	12.4 ab
Co 421(T)	98.5 bc	11.7 bcd	12.0 ab
CC 85-92	90.6 c	10.7 d	11.7 b
CC 93-3817	132.2 a	16.8 ab	12.7 a

TCH: Tons of cane per hectare. TPH: Tons of panela per hectare.
* Values in the same column with different letters are statistically different (Duncan's test $P \leq 0.05$).

The stems population per ha at harvest, ranged from 61,613 to 90,354 units, with the variety CC 93-4418 being the most productive, with a difference over the control of 16,043 units, followed by the variety CC 92-21188 with a difference of 4564 units, since the control only produced 74,307 units; similar data and in some cases higher than those found by Ramírez *et al.* (2014), in a variety test in Santander. All the varieties exceeded in thickness to the control, being the material CC 92-2198 the one of thicker stem, but with smaller production of stems; the CC variety 93-4418 (Table 3) is followed in its order and with good stems production and thickness.

The varieties CC 93-3817, CC 93-4418 and CC 93-3895 showed lower percentages of overturning than the control, with a reduction of 33%, 31% and 22%, respectively. As a negative aspect it was observed that the materials CC 85-57 and CC 92-2154, showed flowering percentages of 87 and 44%, respectively, with the control, which did not flower; it is estimated that outstanding genotype should not present blooms higher than 20% (López, 2015)(Table 3).

The severity levels of the evaluated diseases (ring spot, yellow spot, rust and virus), in the three evaluation cycles showed an incidence ranging from 1 to 3, which is considered low.

Physicochemical characterization of juices and panela

The maturity index (MI) in all the varieties was less than 1, except for the control that was superior; according to Duran and Zapata (1992), a variety of cane is considered

mature if the MI is between 0.95 and 1, over-ripening greater than 1 and immature lower than 0.95, indicating that all materials were in optimal conditions for their harvest (Table 4).

Table 3. Results of agronomic evaluations to the harvest of three cuts, in the variety test, located in the municipality of San Carlos, Antioquia. 2014.

Variety	Stems	Plant height	Stem diameter	Internode lenght	Bloom	Overturning
	ha	(m)	(cm)		(%)	
CC 93-4418	90,354 a*	2.37 b*	3.02 a	7.95 c*	1.25 a*	5.83 b*
CC 93-3895	81,450 a	2.43 b	2.86 b	7.95 c	5.16 a	14.16 b
CC 85-57	62,142 bc	2.45 b	2.88 b	12.35 a	86.75 c	11.66 b
CC 92-2198	69,347 ab	2.47 b	3.06 a	10.09 b	16.25 b	12.33 b
CC 85-47	61,613 bc	2.33 b	3.00 ab	10.53 b	20.08 b	35.44 a
CC 92-2154	70,140 ab	2.45 b	3.05 a	9.07 bc	43.58 ab	15.00 b
CC 92-2188	87,105 a	2.28 c	2.74 b	9.32 bc	2.50 ab	20.83 a
CC 84-75	80,260 a	2.57 ab	2.72 b	9.43 ab	0.0 ab	26.66 a
Co 421(T)	82,541 a	2.67 a	2.60 c	11.90 a	0.0 ab	37.08 a
CC 85-92	74,307 ab	2.46 ab	2.73 b	10.80 ab	4.41 ab	32.91 a
CC 93-3817	83,412 a	2.28 bc	3.01 a	7.33 c	0.0 ab	3.73 b

***** Values in the same column with different letters are statistically different (Duncan's test $P \leq 0.05$).

Table 4. Average results of evaluation of physiological maturity measured in ºBrix to the harvest, of three cuts of the test of varieties of cane, located in the municipality of San Carlos, Antioquia. 2014.

Variety	Basal °Brix	Apical °Brix	M.I.
CC 93-4418	20.97 a*	20.62 a*	0.98*
CC 93-3895	21.53 a	20.17 a	0.93
CC 85-57	20.73 a	20.26 a	0.98
CC 92-2198	20.00 b	19.87 a	0.99
CC 85-47	20.29 a	20.27 a	0.99
CC 92-2154	21.60 a	20.84 a	0.96
CC 92-2188	20.79 a	19.65 a	0.95
CC 84-75	21.20 a	20.46 a	0.97
Co 421(T)	19.59 b	19.81 a	1.01
CC 85-92	20.23 b	19.80 a	0.98
CC 93-3817	21.46 a	20.76 a	0.97

M.I.: Maturity Index: Apical °Brix /Basal °Brix.

***** Values in the same column with different letters are statistically different (Duncan's test $P \leq 0.05$).

In the juice of the cane are dispersed multiple substances, in addition to saccharose and reducing sugars; the proportion of these substances differs with each variety (Zossi *et al*., 2011). In the juice, soluble solids content or °Brix ranged from 19.70 for the CC 92-2154 variety and 21.60 for the CC 93-4418. According to Larrahondo (1995) and Duran and Zapata (1992), °Brix of juices should normally fluctuate between 16 and 24, a range in which the varieties evaluated in this study were found, standing out the materials CC 93-4418, CC 92 2188, CC 93-3895 and CC 93-3817 (Table 5); According to Duran and Zapata (1992) these are cataloged as ripe canes.

Corpoica (2007) has established minimum and maximum pH values that determine the quality of sugarcane juices to obtain panela with good commercial characteristics; the values found in this study fluctuated between 5.1 and 5.6, indicating that the materials are in the recommended range. The variety with the highest values of pH was CC 92-2198 (5.6) and the lowest one was CC 85-57 (5.1); the average value was 5.41 (Table 5). The results obtained in this study were different to those reported for the other panela areas of Santander, which fluctuated between 5.0 and 5.2 (Table 5). Saccharose Pol (%) in all varieties presented appropriate values, since contents below of 18% can be considered low (Ramírez *et al*., 2104). The varieties CC 93-3817 and CC 93-3895, with values of 18.6% and 18.5%, respectively, were higher than the control, which only reached 17.1% (Table 5).

Table 5. Average values of industrial quality in cane juice at harvest, of three cuts in the varieties assay.

Variety	°Brix	pH	Saccharose Pol	Reducing sugars	Phosphates	Purity
	(%)		(%)		(ppm)	(%)
CC 93-4418	21.6	5.4	17.4	3.0	90	80.6
CC 92-2198	20.0	5.6	17.2	2.4	92	86.0
CC 85-92	19.5	5.3	16.6	2.4	93	85.0
CC 92-2154	19.7	5.3	16.2	2.8	94	82.2
CC 92 2188	21.4	5.4	18.3	1.9	81	85.6
CC 93-3895	21.4	5.5	18.5	2.9	97	86.4
CC 85-57	20.0	5.1	17.3	2.1	51	86.5
CC 85-47	20.4	5.4	16.5	2.7	89	80.1
CC 93-3817	20.7	5.5	18.6	1.9	101	89.9
CC 84-75	19.9	5.4	16.9	2.6	95	84.9
Co 421(T)	20.2	5.5	17.1	2.1	85	84.7

Purity= (Saccharose Pol / °Brix)*100

Among the simplest sugars are glucose and fructose (reducing sugars), which exist in the juice of ripe canes in a concentration between 1% and 5%. The quality of raw sugar and other products - such as the color and grain (hardness) of the panela - depends in part on the proportion of these reducing sugars, which when increased by deterioration or lack of maturation of the plant, can produce increases in color and defective grain in the panela (Clarke *et al*., 1986). The reducing sugars in this study fluctuated between 1.9 and 3.0% (Table 5), which were within the values reported by Clarke *et al*. (1986); however, Corpoica (2007) suggests a range between 0.5 and 1.7%, indicating that the values found in this case are means.

The plots were fertilized in each cut with 1 t ha^{-1} of dolomitic lime and organic matter, 112 kg ha^{-1} of nitrogen, phosphorus and potassium, and triple 15 plus 20 kg ha^{-1} of minor elements. In spite of that, phosphates (P_2O_5) were low in all varieties, with the highest amount

of CC 93-3817 with 101 ppm (Table 5), since, according to Corpoica (2007), the ranges of juice must be between 100 and 700 ppm; low values produce panela with dark colorations. It is important to clarify that the soils tested were very low in P (<10 mg kg^{-1}).

The purity of the juices in most varieties presented values higher than 80%, where the highest was CC 93-3817 with 89.9% (Table 5); according to Corpoica (2007) purity ranges must be between 82 and 95%.

Corpoica (2007) at the Experimental Station Cimpa, established the ranges of physical-chemical parameters that determine the quality of the panela. In this sense, the content of soluble solids or °Brix, for the variety CC 93-3895 was 78 and 70 for the control. According to the same authors, °Brix of the juices, should normally fluctuate between 89 and 95, range in which the varieties evaluated in this study were found, standing out the materials CC 93-3895, CC 84-75 and CC 92 2188 (Table 6).

On the other hand, the minimum and maximum values of pH, recommended by Corpoica (2007), are between 5.5 and 6.5; the values found in this study fluctuated between 5.5 and 6.3, with the exception of CC 85-57 with a pH of 5.3, indicating that most materials are in the recommended range. The variety with the highest pH value was CC 92-2154 (6.6) and the lowest was CC 85-57 (5.3) (Table 6); the average value was 5.7. These data are similar to those reported by Ramírez *et al*. (2014) in Santander and correspond to those mentioned by the Ministry of Social Protection (2006), established for panela of 5.5 to 6.5.

The values of Saccharose Pol (%) (Table 6) in all materials were adequate for panela, since according to the Ministry of Social Protection (2006), the maximum value that this product must fulfill, as a quality standard, is 83%. The varieties CC 93-3895 and CC 84-75, with values of 78% and 76%, respectively, are outstanding. The final product (panela) of each variety, due to its physical and chemical characteristics, is considered of very good quality.

Reducing sugars in all varieties were high, since the range recommended by Corpoica (2007) is between 5.0 and 14%. The variety CC 93-3895 showed the lowest percentage of reducing sugars and the control, the maximum (Table 6).

The phosphate content of the panela was high in most varieties, with the highest content being CC 92-2154 (652 ppm) and the lowest CC 85-57 (267 ppm).

Table 6. Average values of industrial quality in panela at harvest, of three cuts in the varieties assay.

Variety	°Brix (%)	pH	Saccharose Pol (%)	Reducing sugars (%)	Phosphates (ppm)	Moisture (%)
CC 93-4418	93.1	5.7	73.4	15.1	437	7.2
CC 92-2198	92.4	5.7	72.5	15.6	513	7.9
CC 85-92	93.6	5.5	71.3	16.9	649	6.8
CC 92-2154	92.8	6.6	72.4	16.5	652	7.5
CC 92 2188	93.5	5.7	74.8	15.4	377	6.8
CC 93-3895	94.4	5.8	78.0	13.1	340	5.9
CC 85-57	93.8	5.3	71.8	18.2	267	6.4
CC 85-47	92.7	5.6	73.3	17.4	489	7.6
CC 93-3817	92.7	5.6	73.5	16.9	504	7.6
CC 84-75	92.8	5.7	76.0	14.9	581	7.4
Co 421 (T)	92.8	5.6	70.0	19.0	585	7.2

Phosphates are important in the nutritional value of the panela. Moisture percentages were found at the appropriate levels and fluctuated between 4.6 and 7.5% and should be lower than 9%. High percentages reduce panela useful life (Table 6).

CONCLUSIONS

With this study, an advance in the selection of sugarcane varieties for the panelera areas of Antioquia was made; the monitoring of these materials allowed the identification of varieties with potential from the agronomic and industrial view, for the soil and climate conditions of the area of study and are CC 93-4418, CC 93-3895, CC 93-3817 and CC 92-2198, far exceeding the Co 421 control in yield of TCH and TPH.

In this evaluation the outstanding variety was CC 93-4418, both in the agronomic and industrial aspect, being a good material to be recommended for panela production in similar regions. These varieties of sugar cane for panela are of paramount importance for programs of adaptation and evaluation for other panelera departmental zones.

ACKNOWLEDGEMENTS

The authors thank to the farmer José de Los Santos Aristizábal, owner of the farm “La Sucesión” in the village of El Paraguas, and the municipality of San Carlos, owner of the farm “La chirria”, in the village of La Cabaña.

REFERENCES

Cassalett C, Torres J e Isaacs C (eds.). 1995. El cultivo de la caña en la zona azucarera de Colombia. Cenicaña, Cali. 280 p.

Clarke MA, Blanco RS and Godshall MA. 1986. Colorant in raw sugars. Proceedings. International Society. Sugar Cane Technology. (ISSCT) 2: 670-682.

Corporación Colombiana de Investigación Agropecuaria (CORPOICA). 2007. Guía tecnológica para el manejo integral del sistema productivo de la caña panelera. Produmedios, Bogotá DC. 152 p.

Cox MC, Hogarth DM and Mullins RT. 1990. Clonal evaluation of early sugar content. Proceedings Australian Society of Sugar Cane Technologists. 12: 90-98.

Departamento Administrativo Nacional de Estadística (DANE). 2016. Boletín Técnico Encuesta Nacional Agropecuaria. (ENO) 2015 Bogotá. 25 p.

Duran N y Zapata G. 1992. Convenio de investigación y divulgación para el mejoramiento de la industria panelera. CIMPA - ICA, Barbosa Santander. p. 18.

Hernández E, Amaya F, Galeano V, Ramírez F y Cortés R. 2002. Alternativas tecnológicas para la producción de caña panelera. INIA-DAINCO, Táchira, Venezuela. 169 p.

Insuasty O, Manrique E y Palacio C. 2003. Catálogo de variedades de caña para la producción de panela en la Hoya del río Suárez. Corpoica, Barbosa, Santander. 56 p.

Kumar A and Tiwari G. 2006. Effect of shape and size on convective mass transfer coefficient during greenhouse drying (GHD) of jaggery. Journal of Food Engineering, 73: 121-134. doi: 10.1016/j.jfoodeng.2005.01.011

Larrahondo JE. 1995. Calidad de la caña de azúcar. pp. 337-354. En: CENICAÑA. El cultivo de la caña en la zona azucarera de Colombia. Cenicaña, Cali. 280 p.

López JG. 2015. Manejo agronómico del cultivo de la caña de azúcar para panela en Antioquia. Corpoica, Bogotá, Colombia. 100 p.

Ministerio de Agricultura y Desarrollo Rural. 2004. Observatorio Agrocadenas Colombia. Costos de producción de caña de azúcar en Colombia. Documento de trabajo Nº 47. Bogotá. Colombia.

Ministerio de la Protección Social. 2006. Reglamento técnico sobre los requisitos sanitarios que se deben cumplir en la producción y comercialización de la panela para consumo humano. Resolución 779 de 2006. Bogotá, República de Colombia. 4 p.

Murcia-Pardo ML y Ramírez-Durán J. 2017. Reconversión del sistema regional de producción de caña para la agroindustria panelera en Boyacá y Santander. Corpoica Ciencia Tecnología Agropecuaria 18(1): 75-87. doi: 10.21930/rcta.vol18_num1_art:559

Ramírez JG. 2017. Characterization of traditional production systems of sugarcane for panela and some prospects for improving their sustainability. Revista Facultad Nacional de Agronomia. 70(1): 8045-8055. doi: 10.15446/rfna.v70n1.61763

Ramírez J, Insuasty O y Viveros C. 2014. Comportamiento agroindustrial de diez variedades de caña de azúcar para producción de panela en Santander, Colombia. Corpoica Ciencia Tecnología Agropecuaria 15(2) 183-195. ISSN 0122-8706

Rodríguez GB. 2014. La agroindustria panelera en cifras. Ficha Técnica. Corpoica - Corporación Colombiana de Investigación Agropecuaria, Bogotá, Colombia.

Singh RK and Singh SB. 2004. Breeding strategies for commercially elite early maturing varieties of sugarcane (*Saccharum* species Complex). Sugar Technology 6: 89-92.

Wagih ME, Ala A and Musa Y. 2004. Evaluation of sugarcane varieties for maturity earliness and selection for efficient sugar accumulation. Sugar Technology 6: 297-304.

Zossi BS, Cárdenas GJ, Sorol N y Sastre M. 2011. Influencia de compuestos azúcares y no azúcares en la calidad industrial de caña de azúcar en Tucumán. R. Argentina: caña verde y quemada (Parte 2). Revista Industrial y Agrícola de Tucumán 88(1): 13-21.

Research article

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Revista Facultad Nacional de Agronomía

Evaluation of bioactive compounds with functional interest from yellow pitahaya (*Selenicereus megalanthus* Haw)

Evaluación de componentes bioactivos con interés funcional a partir de pitahaya amarilla (*Selenicereus megalanthus* Haw)

doi: 10.15446/rfna.v70n3.66330

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ABSTRACT

Yellow Pitahaya (YP) is an exotic fruit, cataloged by Colombia International Corporation as a promising fruit to export, due to its sensorial and organoleptic attributes. In addition, this fruit has been associated with the control of constipation, and benefits for health because of its content of antioxidants. Therefore, the purpose of this work was to determine its chemical and biocompounds present in stem, peel, seed, and pulp of yellow pitahaya. The polyphenols were determined with the Folin-Ciocalteu method; the vitamin C content was determined using 2-nitroaniline; the antioxidant capacity was found with the ABTS and DPPH methods; and the peristalsis acceleration by measuring feces in biomodels (golden hamster) fed with various parts of this fruit. The results proved that the fruit composition varies according to its part. It is noteworthy that all parts of the fruit contain bioactive compounds in various proportions; the highest concentration of vitamin C, polyphenols and antioxidant capacity (AC) were found in the seed (22.08 mg ascorbic acid per g dry matter, 1580 mg gallic acid per 100 g dry matter, 79.2 ± 0.2% ABTS, respectively) and peel (20.615 mg ascorbic acid per g dry matter, 1333.33 mg gallic acid per 100 g dry matter, 66.2 ± 0.8% ABTS, respectively); regarding the peristalsis acceleration, the fecal production increased with the consumption of the seeds. Consequently, result showed that yellow pitahaya could be an alternative of a promising product due to its composition, and content of bioactive components of functional interest.

Keywords:
Antioxidants
Bioproducts
Constipation
Peristalsis
Polyphenols

RESUMEN

La pitahaya amarilla es una fruta exótica, catalogada por la Corporación Internacional Colombiana como una fruta promisoria para la exportación, debido a sus atributos sensoriales y organolépticos. Además, esta fruta ha sido asociada al control del estreñimiento, y con beneficios para la salud, gracias a su contenido de antioxidantes. Por consiguiente, el propósito de este trabajo fue evaluar las propiedades químicas y los biocomponentes presentes en tallo, cáscara, semilla y pulpa de pitahaya amarilla. La determinación de polifenoles se realizó siguiendo el método de Folin-Ciocalteu; el contenido de vitamina C por el método de 2-nitroanilina; la capacidad antioxidante se determinó por los métodos ABTS y DPPH; y la aceleración del peristaltismo mediante la medición de heces en biomodelos (hámsteres dorados), alimentados con diferentes partes de esta fruta. Los resultados demostraron que la composición de la fruta varía de acuerdo a sus partes. Es de destacar que todas las partes de la fruta contienen compuestos bioactivos en diferentes concentraciones; la concentración más alta de vitamina C, polifenoles y capacidad antioxidante se encontró en la semilla (22,08 mg ácido ascórbico por g materia seca, 1580 mg ácido gálico por 100 g materia seca, 79,2 ± 0,2% ABTS, respectivamente) y cáscara (20,615 mg ácido ascórbico por g materia seca, 1333,33 mg ácido gálico por 100 g materia seca, 66,2 ± 0,8% ABTS, respectivamente); respecto a la aceleración del peristaltismo, la producción de heces incrementó al consumir semillas de pitahaya. De acuerdo a lo anterior, se concluye que la pitahaya amarilla podría ser una alternativa de un producto promisorio, debido a su composición y contenido de compuestos bioactivos de interés funcional.

Palabras clave:
Antioxidantes
Bioproductos
Estreñimiento
Peristaltismo
Polifenoles

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Received: June 24, 2016; Accepted: January 15, 2017
Rev.Fac.Nac.Agron. 70(3): 8311-8318. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

In the last decade the world trend toward consumption of food with additional benefits as well as their nutrients (Bello, 2000) has increased because they have the ability to prevent and cure certain diseases (Dembitsky *et al.,* 2011), and are associated with the consumers desire for a better quality of life (Diplock *et al*., 1999). This type of food is named *functional foods* and are defined as those of vegetal or animal origin that when consumed in daily diet provide biocompounds, which cause therapeutic effects in the body, resulting in benefit for health (Roberfroid, 1999). A functional food may be then a natural one or modified to influence health through addition or modification of any specific component (Howlett, 2008). According to the above, this type of food provide specific effects related to particular components (Labrecque and Doyon, 2008). Some of such components and benefits contained in these foods are polyphenols, vitamin C, antioxidant capacity (AC), and peristalsis acceleration.

Polyphenols are generally found in all vegetal origin foods and form a wide group of substances that include families of compounds with various structures which have the same characteristic of including in their structure various benzenic groups substituted by hydroxylic functions (Peris *et al*., 1995), they have antioxidant and antimutagenic properties; delay senescence, anticancer, and antimicrobial (Zloch, 1996). These compounds inhibit oxidation of β-carotenes catalyzed by myoglobin and those produced by Fe-ascorbic acid system (Rice-Evans *et al*., 1996). In addition, vitamin C improves endothelial dysfunction (May, 2000), by stabilizing tetrahydrobiopterin, a cofactor of oxide nitric synthase endothelial enzyme by increasing nitric oxide availability (Huang *et al*., 2000; Li and Schellhorn, 2007). Vitamin C, likewise, prevents apoptosis of the endothelial cells by intracellularly inhibiting caspase-9 (tumor inhibiting proteins), and the endothelial ET-1 function (endotheline) and preventing IL-6 release (interleucin-6) (Böhm *et al*., 2007; Dhar-Mascareño *et al*., 2005).

Taking into account the above reported effects, yellow pitahaya (YP) (*Selenicereus megalanthus* Haw*)* may be considered as a source of functional biocompounds, because its peel and even its stem are used to obtain benefits for health (CCI, 2006), and its components include polyphenols (Wu *et al*., 2006), vitamin C (Serna Cock *et al*., 2013), among other. Wu *et al*. (2006) evaluated the polyphenols content and the antioxidant activity of red pitahaya, in addition to its anti-proliferating activity in melanoma cancer cells, finding a high content of these compounds and inhibition of growth of such cells. In addition, YP has effects on peristalsis acceleration (Parra Yambay, 2010) associated with constipation decrease, which is the cause of multiple medical consultations (Fleming and Wade, 2010). Traditionally, the amount of carbohydrate available for colonic bacterial fermentation is determined by the amount of dietary fibre present in foods. However, some of the 'available carbohydrate' (i.e., "available" for small intestinal absorption: total carbohydrate minus dietary fibre) in many foods may escape digestion in the small intestine in appreciable amounts and become available for fermentation by the colonic micro flora (Huebner *et al*., 2007; Greger, 1999) cited by (Mohd *et al*., 2014).

This fruit is mainly produced in tropical and subtropical countries with a dry climate and 18 – 28 °C temperature; it has very specific features such as its exuberant yellow thorny peel, and white pulp with many small seeds (Nerd *et al*., 2002); it has been considered by Colombia International corporation – CCI as a promising fruit for export due to its sales price and exotic features (Mosquera *et al*., 2011). In the world 1083 hectares are cultivated, of which 827 are in Colombia (76.4%), 100 ha in Israel (9.2%), Brazil participates with 3.2% and Ecuador with 1.9%, other countries participate with 9.3% (Betancourt *et al*., 2010). In addition, Colombia participates with 43.7% of the international exportations (Mosquera *et al*., 2011). According to the above mentioned, the purpose of this investigation was to establish chemical and functional characteristics in the various parts of YP, in ripeness state 6, third quality, in order to determine its possible use in the production of functional food. For such purpose, an empirical-analytical research was carried out using experimental units, (YP), provided by the society of producers of yellow pitahaya – Asoppitaya (Colombia).

MATERIALS AND METHODS

Fruit samples

The research was performed using third quality YP (*Selenicereus magalanthus* Haw), in ripeness state 6 (ICONTEC, 1996), from the state of Valle del Cauca, provided by the society of producers of yellow pitahaya –Asoppitaya. The external appearance of the fruit pieces was analyzed; however, fruit pieces affected by mechanical damage or fungi, which constitute third category, were used.

Fruit pieces were cleaned and disinfected, starting by washing them with tap water, using a soft brush to remove thorns from the peel; then they were disinfected by immersion for 10 minutes into a solution with a concentration of 2.5 mL L^{-1} of citrosan (Diken International, Mexico).

The stem, the peel, the pulp and seeds were manually separated; each part was separately dried with hot air (Binder, USA) at 45 °C for 24 hours. The dry products were pulverized in a blade grinder, and stored in high density polyethylene bags at room conditions (58% HR, 20.5 °C y 3300 lux), for later use in the determination of functional properties.

Chemical analysis

The total soluble solids (TSS), pH and the total titratable acidity (TTA) were determined in the homogenized and filtrated juice extracted from various parts of the pitahaya. The TSS were estimated by using a refractometer (ABBE DR-A1, Atago, Bellevue, Washington), following the AOAC 932.12 method. The pH was estimated with the potentiometric method, using a pH-meter (Hanna Instruments). The TTA was found by using AOAC 942.15A official method, by means of an acid-base titration using a solution of NaOH 0.1N until a pH of 8.1 was reached; acidity was expressed as percentage of citric acid.

Preparation of antioxidant and polyphenol extracts

The extracts were obtained parting from the four parts of YP: pulp, seed, peel, and stem, following the methodology reported by Jara-Palacios *et al.* (2014), with modifications. 25 mL of ethanol were taken at 80%, and 5 g of dry sample; the mixture was stirred for one hour at 1.26 g in a shaker; then centrifuged for 25 minutes in a centrifuge (Vebmlw T51, USA); the three supernatants were separated, and the process was repeated for three times. The three supernatants were mixed and stored in amber bottles for the later quantification of total polyphenols, vitamin C and AC.

Total polyphenol and vitamin C content

The total polyphenols were quantified with the Folin-Ciocalteu method (Jara-Palacios *et al.*, 2014). 0.25 mL of extract, 0.25 mL of reagent Folin-Ciocalteu (Merck, Colombia), and 3.25 mL of 20% sodium carbonate were used. The mixture was shaked for 90 minutes at 1.26 g, and stored for two hours in dark condition for subsequent determination of polyphenols by spectrophotometry using a Genesys 10 UV-vis HP spectrophotometer (Thermoscientific, USA) at a wavelength of 765 nm. The results were expressed in mg of galic acid (GAE per 100 g of dry sample). Vitamin C was determined with the colorimetric method of the 2-nitrianilin (Bernal, 1993).

Antioxidant capacity

The antioxidant ability was determined by two methods ABTS (acid 2,2'-azino-bis 3-ethylbenzotiazolin-6-sulphonic) and DPPH (2,2-difenil-1-picril hydrazilo) based on the electron transference method, which involves a redox reaction with the oxidant as an indicator of the endpoint of recation (Tovar-del Río, 2013). An $ABTS^{\bullet+}$ radical cation was produced which directly produced a green-blue ABTS chromophore through the reaction between $ABTS^{\bullet+}$ and potasium persulfate, which presents a maximum absorption at 734 nm. The $ABTS^{\bullet+}$ radical cation was produced from a reaction between a solution 7mM of ABTS with potassium persulfate (2.45 mM). The mixture was taken into darkness for 16 hours, then it was diluted by using ethanol (Emsure® ACS, ISO, Reag. Ph. EUr) until achieving an absorbance of 0.715 $\pm$ 0.005 to 732 nm.

Then, 50 µL de $ABTS^{\bullet+}$ were taken and mixed with 1450 µL of the solution for analysis; the mixture was kept in darkness for 30 minutes to facilitate the reaction and then the absorbance was read at 732 nm in a Genesys 10 UV-vis HP spectrophotometer (Thermoscientific, USA). The addition of antioxidant caused a decoloration associated with inhibition of the radical in function of concentration and the time; reading was performed at constant time of reaction of 30 minutes. AC expressed on percentage was calculated through equation (1).

$$AC(\%) = \frac{A_{control} - A_{sample}}{A_{control}} * 100 \qquad (1)$$

Where:

AC = Antioxidant capacity expressed in percentage
$A_{control}$ = Absorbance of negative control (solution ABTS)
A_{sample} = Absorbance of the sample read at 732 nm

The measurement of AC by DPPH was performed based on the decoloration of the radical, absorbance was measured at 529 nm, and was determined with spectrophotometry, following the method reported by Geng *et al.* (2015), with

some modifications; 1.4 mg of DPPH reagent were used and it was dissolved in 70 mL of methanol until achieving an absorbance of 1.174 measured with a Genesys 10 UV-vis HP spectrophotometer (Thermoscientific, USA) at 529 nm. 2 and 0.5 mL of DPPH reactive and the sample respectively were taken and left in reaction for 30 minutes. AC was quantified similarly to the one reported for ABTS method following equation 1.

The antioxidant activity of extracts evaluated through the two methods (ABTS and DPPH), was expressed in AC in trolox equivalent (TEAC), which represents a trolox solution concentration with the same AC of free radicals as the extract. It was obtained based on the regression equation obtained from a standard curve with the antioxidant reference trolox (equation 2) (Tovar-del Río, 2013; Zhu *et al.*, 2015).

$$TEAC = 1.0645 * (AC\%) + 0.9323 \quad (2)$$

Peristalsis acceleration

Three-month-old golden hamsters with about 100.75 g were used to quantify the peristalsis acceleration. The biotypes were obtained from ICESI University (Colombia), and kept under controlled laboratory conditions of temperature (26 °C) and illumination cycles of 12 hours. The hamsters were fed with 10 $\pm$ 2 g of sunflower seeds and 70 mL of water approximately every day.

Four groups of 9 hamsters, including male and female, were organized; each group was assigned a part of the YP (seed, peel, stem and pulp), as a dietary complement. The parts of the YP were provided orally, which account for 30% of the daily feeding dose. Immediately after feeding the YP the biotypes were observed in their general aspect, checking health conditions, in compliance with legal rules (Salud, 1993).

The observed patterns were hair appearance, activity, weight, production and characteristics of fecal material, water amount, and consumed food. A numerical scale was applied based on feces consistence, as follows: 1 (Solid), 2 (Semi-solid), 3 (Liquid), and variation in feces production was calculated, by using equation 3.

$$\Delta Mf = Mf_i - Mf_f \quad (3)$$

Mf_i = Mass of initial feces
Mf_f = Mass of final feces

Statistical analysis and experimental design

A single factor design with 4 levels was used, the evaluated variable was a part of YP with four levels; stem, peel, pulp and seed. The effect of part of YP was determined by the analysis of variance (ANOVA) and mean comparisons with the Tuckey test at 5% probability using Stathgraphics® statistical program. All determinations were performed in triplicate.

RESULTS AND DISCUSSION

Chemical analysis

The pH, total soluble solids (TSS), and total titratable acidity (TTA) of stem, peel, pulp and seed of YP are presented in Table 1. The variations of pH for the various parts of YP, are seen here due to the effect of the part of the fruit, which is higher in the peel (P<0.05); Rodriguez *et al.* (2005) found that YP in ripeness state 3 has a pH of 4.7, which changes to pH 5.1 during refrigerated and non-refrigerated storage. In a mixture of seeds and pulp of YP under refrigerated storage a pH between 4.1 and 4.8 is reported, with an increase during storage (Serna *et al.*, 2013). The peel of the fruit shows a higher pH which may be associated with a different composition regarding the fruit. These results are correlated with the total titratable acidity, expressed in the percentage of citric acid, since values of a higher pH for the peel show a lower degree of acidity (lower TTA); this case is contrary to the pH in the pulp which is lower and indicates higher amount of acids. TTA values are lower than those reported by Serna *et al.* (2012, 2013) in YP in ripeness state 3; the difference may be caused by the metabolism of organic acids (Davies and Maw, 1972) which are consumed in oxidating reactions during senescence (Neves *et al.*, 2008). Regarding TSS, the values were higher in the pulp, followed by those in the seed, and the lowest ones were found in the peel of the fruit. Statistically significant difference was found between the pulp, seed and peel (P<0.05).

In the pulp of YP values of 17.7 °Brix were found, which are similar to those found in YP in ripeness state 3 after 27 days of refrigerated storage (Serna *et al.*, 2013); such difference may be explained by metabolism of the fruit, associated with the energy consumption in a form of ATP and other compounds to maintain homeostasis of the fruit (Lima *et al.*, 2011); the above include conversion of starch into glucose and fructose, and their use through metabolic routes such as substrate for respiration (Paliyath *et al.*, 2008).

Chemical composition of YP (TSS, TTA, pH), varies according to the part of the fruit. Nerd and Mizrahi (1999) reported difference in water content of the pulp and the peel of YP and, therefore, difference in dry matter.

Total polyphenol and vitamin C content

Experimental results of total polyphenols for each analyzed part of YP are presented in figure 1a. It may be observed that polyphenols content varied between 600 and 1580 mg GAE per 100 g dry matter, the higher content being in the seed, followed by the peel. Difference found was statistically significant (P<0.05).

The polyphenol content was found in all parts of analyzed YP; however, higher amount of this bio-compound was found in the seed (1580 mg GAE per 100 g dry matter), representing an important source of antioxidants.

As in the YP, other studies have reported the similar values of polyphenol, like apples *(Malys pumilla)* with 1600 to 1800 GAE per 100 g dry matter (Beltrán-Orozco *et al* 2009), and strawberry *(Fragaria ananassa)* with 1600 to 1800 GAE per 100 g dry matter (Beltrán-Orozco *et al*., 2009). In addition, Daza (2014) reports in the pulp of YP 77.6 ± mg GAE per 100 g dry matter; 102.0 ± mg GAE per 100 g dry matter in peel, and 202.7 ± 1.1 mg GAE per 100 g dry matter in seed (Daza, 2014), these values being lower than those found in this work.

The results of vitamin C for peel, pulp, seed and stem of YP are shown in Figure 1b. Significant difference between the parts of pitahaya were observed (P<0.05). The highest content of ascorbic acid was found in the seed (22.0881 mg Ascorbic Ac. per g dry matter). The results reported by Beltrán-Orozco *et al* (2009) showed that the content of ascorbic acid in YP is 17.04 ± 0.30 mg of Ascorbic acid per g dry matter; in red pitahaya, cherry and white pitahaya the values are, 10.25±0.25, 8.49 ± 0.25 and 14.56 ± 0.25 mg of Ascorbic acid per g dry matter respectively (Beltrán-Orozco *et al*., 2009). Muñoz-de-Chavez *et al*. (2002) reports that 100 g of eatable pulp of YP represents 21% of daily consumption of Vitamin C as recommended for adults (60 mg of Ascorbic Acid per g of dry matter).

Antioxidant capacity

The Table 1 shows the results of analysis of AC performed to the parts of YP (peel, pulp and seed). Highly significant

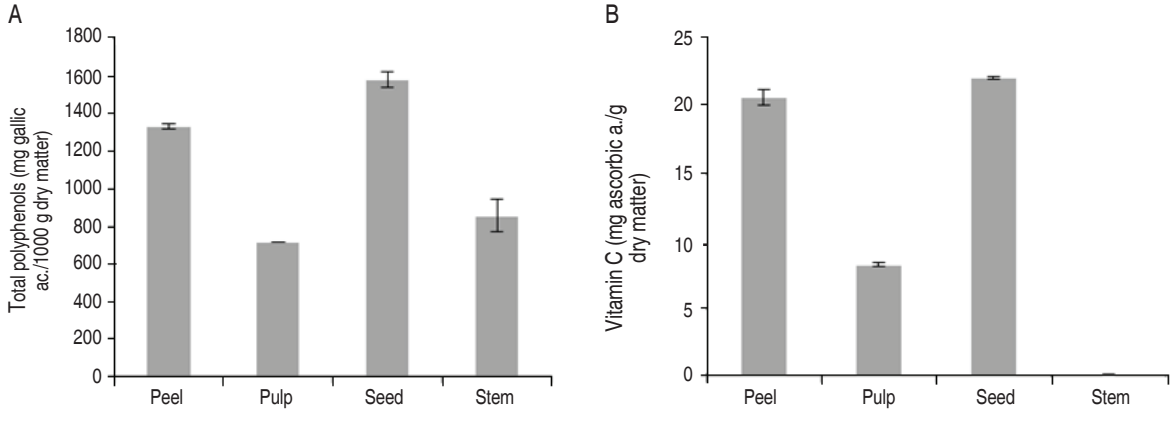

Figure 1. Bioactive compounds found in the parts of yellow pitahaya: A. Total polyphenols content. B. Vitamin C content

difference was obtained among analyzed parts (P<0.05). It may be observed that AC is higher than 62% for the various parts of YP. High values of AC are found in all parts of the fruit, however these values are higher in the seed, with values of 79.2 and 96% for tests with ABTS and DPPH, respectively. Ayala-Camarillo *et al*. (2008) reports the AC in yellow pitahaya of 58.96 ± 0.55.

Likewise, epidemiological studies have suggested that consumption of a diet rich in biocompounds such as polyphenols provides protection against cancer, diabetes, hypertension, cardiovascular diseases, aging, and other (Pandey and Rizvi, 2009). However, a daily recommended dose of consumption (RDC) for antioxidants has not been defined yet.

The results suggest that the YP is a source of health protection compounds, against free radicals reducing the risk of chronic diseases such as cancer (Ayala-Camarillo *et al.*, 2008).

Table 1. Chemical properties and biocompounds of yellow pitahaya.

Part of the fruit	pH	TSS (%)	TTA (%)	AC (ABTS)	TEAC (µM)	AC (DPPH)	TEAC (µM)
Pulp	4.48 ± 0.25[a]	17.67 ± 0.06[a]	0.20 ± 0.007[a]	63.3 ± 0.9%	91.38	85.0 ± 0.2%	68.30
Peel	5.31 ± 0.17[b]	3.87 ± 1.62[b]	0.08 ± 0.01[a]	66.2 ± 0.8%	66.99	62.1 ± 0.1%	71.35
Seed	4.82 ± 0.04[a]	4.9 ± 0.90[b]	0.10 ± 0.01[a]	79.2 ± 0.2%	103.08	96.0 ± 0.1%	85.20

TSS: Total soluble solids; TTA: Total titratable acidity; AC: Antioxidant capacity measured by ABTS and DPPH methods; TEAC: Trolox equivalent antioxidant capacity. The results are the average of three samples. Similar letters indicate that there are no differences statistically significant at significance level of 95%.

Acceleration ability of the peristalsis

A statistically significant difference is observed ($P<0.05$) between pitahaya samples; the seed is the part containing higher acceleration ability of the peristalsis by increasing 55% the amount of feces produced with respect to biomodels fed with a traditional diet (sunflower seed) (Table 2). Laxative ability was also found in pitahaya pulp and stem, otherwise the peel causes decrease of feces produced; therefore, its consumption is not considered suitable to stimulate feces production of the evaluated biomodels.

Regarding feces consistence, the consumption of the pulp and seed changes their appearance to a less solid behavior which could be related to easiness of expulsion; otherwise, the stem and the peel do not produce any changes which may reduce dehydration in the consumers.

Table 2. Acceleration ability of peristalsis of yellow pitahaya and appearance of feces according to treatment applied to biomodels.

Part of yellow pitahaya administered	Feces (g per day)	Increase of feces (%)	Feces appearance
Stem	0.35 ± 0.07	12.09[c]	Solid
Seed	0.49 ± 0.09	55.13[a]	Semisolid
Peel	0.31 ± 0.05	-1.71[d]	Solid
Pulp	0.43 ± 0.02	35.01[b]	Liquid
Sunflower seeds (Control)	0.32 ± 0.02	N/A	Solid

The pitahaya pulp consists of highly viscous carbohydrate fibers (cellulose, hemicellulose, fructooligosaccharides and simple sugars), vitamin C and minerals (Nur'aliaa *et al.*, 2010a) cited by (Dasaesamoh *et al.*, 2016). The oligosaccharides as reported by Dasaesamoh *et al.* (2016) are metabolized by intestinal microbiota and subsequently converted into short chain fatty acids: acetic acid, propionic, butyric acid, lactic acid and butyrate. Butyrate is responsible for some important functions in the intestinal epithelium, such as prevention of certain types of colitis (Scheppach, 1994, cited by Dasaesamoh *et al.*, 2016). In addition, the oligosaccharides present in pitahaya become substances that increase motility by reducing diseases such as colitis and irritable bowel syndrome (Dasaesamoh *et al.*, 2016).

Parra Yambay (2010) reported laxative properties of seed and stem of YP, with absence of liquid feces, therefore,

the authors recommend its use and incorporation to nutrition. The AC and laxative properties of parts of YP suggest that the seed could be an important source of biocompounds. Due to its high polyphenolic content, it is possible to conclude that the peel of YP could be a source of biocompounds for functional foods, as well as the seed, turning into an alternative for development products with add value.

CONCLUSION

Composition of YP varies in function of the part (stem, peel, pulp and seed), although there are bioactive compounds with a functional interest in all parts. The seed may be consumed as a potential alimentary additive. The peel could represent an alternative of use for this byproduct, due to its content of vitamin C and polyphenols that may be extracted and incorporated as functional ingredients to develop new food, for which purpose subsequent research is required.

ACKNOWLEDGEMENTS

The authors express their acknowledgement to the program Jóvenes Investigadores y Semillero de Investigación - Departamento Administrativo de Ciencia, Tecnología e Innovación – Colciencias, for funding this project.

REFERENCES

Association of Official Analytical Chemists – AOAC. 2005. Official methods of analysis of AOAC International (17th ed.). AOAC International, Gaithersburg.

Ayala-Camarillo K, Gallardo-Velázquez T and Beltrán-Orozco M. 2008. Determinación del contenido de fenoles totales y de la capacidad antioxidante de tres especies del fruto de la pitaya (*Stenocereus griseus* H.). En: Memorias V Congreso Internacional de Ingeniería Bioquímica, XVI Congreso Nacional de Ingeniería Bioquímica, VI Jornadas Científicas de Biomedicina y Biotecnología Molecular. Mexico, D.F.

Bello J. 2000. Alimentos con propiedades saludables especiales. pp. 343-356. En: Astiasarán I, Martínez J (eds.). Alimentos: composicion y propiedades McGraw-Hill/Interamericana, Madrid, España.

Beltrán-Orozco M, Oliva-Coba T and Gallardo-Velázquez T. 2009. Ascorbic acid, phenolic content, and antioxidant capacity of red, cherry, yellow and white types of pitaya cactus fruit (*Stenocereus stellatus Riccobono*). Agrociencia 43(2): 153-162.

Bernal I. 1993. Análisis de alimentos. Academia Colombiana de Ciencias Exactas, Físicas y Naturales, Bogotá. 313,p.

Böhm F, Settergren M and Pernow J. 2007. Vitamin C blocks vascular dysfunction and release of interleukin-6 induced by endothelin-1 in humans *in vivo*. Atherosclerosis 190(2): 408-415. doi: 10.1016/j.atherosclerosis.2006.02.018

Corporación Colombia Internacional, CCI. 2006. Perfil de producto, pitaya amarilla. Inteligencia de Mercados, Bogotá, 16 p.

Dasaesamoh R, Youravong W and Wichienchot S. 2016. Digestibility , fecal fermentation and anti-cancer of dragon fruit oligosaccharides. International Food Research Journal 23(6): 2581–2587.

Davies J and Maw G. 1972. Metabolism of citric and malic acids during ripening of tomato fruit. Journal of the Science of Food and Agriculture 23(8): 969-976. doi: 10.1002/jsfa.2740230808

Daza L. 2014. Evaluación de propiedades antioxidantes de parte comestible y no comestible de pitahaya, uchuva y mangostino. Biotecnología en el Sector Agropecuario y Agroindustrial 12(1): 98-105.

Dembitsky V, Poovarodom S, Leontowicz H, Leontowicz M, Vearasilp S, Trakhtenberg S and Gorinstein S. 2011. The multiple nutrition properties of some exotic fruits: biological activity and active metabolites. Food Research International 44(7): 1671-1701. doi: 10.1016/j.foodres.2011.03.003

Dhar-Mascareño M, Cárcamo J and Golde D. 2005. Hypoxia–reoxygenation-induced mitochondrial damage and apoptosis in human endothelial cells are inhibited by vitamin C. Free Radical Biology and Medicine 38(10): 1311-1322. doi: 10.1016/j.freeradbiomed.2005.01.017

Diplock A, Aggett P and Ashwell M. 1999. Scientific concepts of functional foods in Europe: Consensus document. British Journal of Nutrition 81(1): 1-27.

Fleming V and Wade W. 2010. A review of laxative therapies for treatment of chronic constipation in older adults. The American Journal of Geriatric Pharmacotherapy 8(6): 514-550. doi: 10.1016/S1543-5946(10)80003-0

Geng D, Chi X, Dong Q and Hu F. 2015. Antioxidants screening in Limonium aureum by optimized on-line HPLC–DPPH assay. Industrial Crops and Products 67: 492-497. doi: 10.1016/S1543-5946(10)80003-0

Howlett J. 2008. Functional foods: from science to health and claims. ILSI Europe, Brussels, Belgium 36 p.

Huang A, Vita J, Venema R and Keaney J. 2000. Ascorbic acid enhances endothelial nitric-oxide synthase activity by increasing intracellular tetrahydrobiopterin. Journal of Biological Chemistry 275(23): 17399-17406. doi: 10.1074/jbc.M002248200

Instituto Colombiano de Normas Técnicas y Certificaciones - ICONTEC. 1996. Norma técnica colombiana 3554: Frutas frescas, pitahaya amarilla. NTC, Bogotá, Colombia.

Jara-Palacios M, Hernanz D, González-Manzano S, Santos-Buelga C, Escudero-Gilete M and Heredia F. 2014. Detailed phenolic composition of white grape by-products by RRLC/MS and measurement of the antioxidant activity. Talanta 125: 51-57. doi.10.1016/j.talanta.2014.02.065

Labrecque J and Doyon M. 2008. Functional foods: a conceptual definition. British Food Journal 110(11): 1133-1149. doi: 10.1108/00070700810918036

Li Y and Schellhorn H. 2007. New developments and novel therapeutic perspectives for vitamin C. Journal of Nutrition 137(10): 2171-2184.

Lima F, Saavedra J, Marcos E and Kluge R. 2011. Pós-colheita de lichia 'Bengal' tratada com etileno e 1-metilciclopropeno. Ciência Rural 41(7): 1143-1149.

May J. 2000. How does ascorbic acid prevent endothelial dysfunction?. Free Radical Biology and Medicine 28(9): 1421-1429.

Ministerio de Salud. 1993. Título V. La investigación biomédica con animales. En: Resolución 008430 de 1993, El Ministerio, Bogotá.

Mohd Adzim R, Che Abdullah A and Abdul Manaf A. 2014. Isolation and characterization of oligosaccharides composition in organically grown red pitaya, white pitaya and papaya. International Journal of Pharmacy and Pharmaceutical Sciences 6 (Suppl. 2): 131–136.

Mosquera H, Betancourt B, Castellanos J and Perdomo L. 2011. Vigilancia Comercial de la cadena productiva de la pitaya amarilla. Cuadernos de Administración 27(45): 75-93.

Muñoz-de Chavez M, Ledesma Solano J, Chávez Villasana A. 2002. Tablas de valor nutritivo de alimentos: los alimentos y sus nutrientes. McGraw Hill Interamericana, México. 203 p.

Nerd A and Mizrahi Y. 1999. The effect of ripening stage on fruit quality after storage of yellow pitaya. Postharvest Biology and Technology 15(2): 99-105. doi: 10.1016/S0925-5214(98)00080-5

Nerd A, Tel-Zur N, Mizrahi Y. 2002. Fruits of vine and columnar cacti. Chapter 12. In: P.S. Nobel (ed.). Cacti: Biology and uses. University of California Press, Berkeley. 280 p.

Neves L, Moreno R, da Silva V, Lopes R and Ruffo S. 2008. Dano de frio em limas-ácidas Tahiti, colhidas em diferentes épocas e submetidas a tratamentos térmicos e bioquímicos. Revista Brasileira de Fruticultura 30(2): 377-384. doi: 10.1590/S0100-29452008000200019

Paliyath G, Murr D, Handa A and Lurie S. 2008. Postharvest biology and technology of fruits, vegetables and flowers. Wiley-Blackwell, New Delhi. 498 p.

Pandey K and Rizvi S. 2009. Plant polyphenols as dietary antioxidants in human health and disease. Oxidative Medicine and Cellular Longevity 2(5): 270-278. doi: 10.4161/oxim.2.5.9498

Parra Yambay M. 2010. Tamizaje fitoquímico y determinación de la actividad laxante de tallos y semillas de pitahaya (*Hylocereus triangularis*). Tesis de grado Bioquímico Farmacéutico. Facultad de Ciencias, Escuela Superior Politécnica de Chimborazo, Riobamba, Ecuador. 123 p.

Peris J, Stubing G and Vnaglosha B (eds.). 1995. Heterósidos, pp. 61-73. In: Fitoterapia aplicada. Primera edición, Editorial MICOF, Valencia, 1995. 678 p.

Roberfroid M. 1999. Concepts in functional foods: The case of inulin and oligofructose. Journal of Nutrition 129(7): 1398-1401.

Rice-Evans C, Miller N and Paganga G. 1996. Structure-antioxidant activity relationships of flavonoids and phenolic acids. Free Radical Biology and Medicine 20(7): 933-956. doi: 10.1016/0891-5849(95)02227-9

Rodríguez D, Patiño M, Diego M, Fischer G and Galvis J. 2005. Efecto de dos índices de madurez y dos temperaturas de almacenamiento sobre el comportamiento en poscosecha de la pitahaya amarilla (*Selenicereus megalanthus* Haw). Revista Facultad Nacional de Agronomía 58(2): 2837-2857.

Serna L, Torres L and Ayala A. 2012. Effect of pre- and postharvest application of 1-methylcyclopropene on the maturation of yellow pitahaya (*Selenicerus megalanthus* Haw). Vitae 19(1): 49-59.

Serna L, Torres L and Ayala A. 2013. Physical, chemical and sensory changes of refrigerated yellow pitahaya treated preharvest with 1-MCP. Dyna 80(178): 11-20.

Tovar-Del Río J. 2013. Determinación de la actividad antioxidante por DPPH y ABTS de 30 plantas recolectadas en la ecoregión cafetera. Trabajo de grado Químico Industrial. Facultad de Tecnología. Universidad Tecnológica de Pereira, Pereira. 150 p.

Wu L, Hsu H, Chen Y, Chiu C, Lin Y and Ho J. 2006. Antioxidant and antiproliferative activities of red pitaya. Food Chemistry 95(2): 319-327. doi: 10.1016/j.foodchem.2005.01.002

Zhu Q, Nakagawa T, Kishikawa A, Ohnuki K and Shimizu K. 2015. *In vitro* bioactivities and phytochemical profile of various parts of the strawberry (Fragaria × ananassa var. Amaou). Journal of Functional Foods 13: 38-49. doi: 10.1016/j.jff.2014.12.026

Zloch Z. 1996. The role of dietary plants polyphenols in health maintenance. US National Library of Medicine 135(3): 84-88.

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Revista Facultad Nacional de Agronomía

UNIVERSIDAD NACIONAL DE COLOMBIA

Economic viability of muskmelon cultivation in different planting spacing in Brazil central region

Viabilidad económica del cultivo de melón Cantaloupe en diferentes espaciamientos de plantación

doi: 10.15446/rfna.v70n3.62656

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ABSTRACT

Production diversification is one way to avoid losses due to market variations. Melons are among the species used for this purpose, however, little information is a limiting factor to production stimulation. The objective of this study was to estimate and evaluate the economic indicators of muskmelon (*Cucumis melo* L.) cultivation, defining the most appropriate plant spacing in the planting line. A randomized complete block design was used, with four replications of five treatments corresponding to planting spacing of 15, 25, 35, 45 and 55 cm. From the production data of each treatment, economic indicators related to costs and returns obtained with the melon crop were estimated. For the production of melons in a protected area of 300 m^2, a total operating cost of $ 440.02 per production cycle was obtained. This amount was constituted by investments in manual operations, inputs, other expenses and interest of cost, which had a participation of 60.60%, 31.78%, 4.62% and 3.00%. The highest values of the economic indicators and the lower equilibrium and productivity prices were obtained for melons spaced 55 cm. The cultivation of muskmelons spaced 55 cm in the planting lines provides greater economic gains for this culture. This species can be used by farmers as an alternative to crops commonly grown in systems protected environment, but continuing studies should be performed to allow greater financial performance by optimizing the production system.

Keywords:
Cucumis melo L.
Economic indicators
Production costs
Financial return
Noble melon

RESUMEN

La diversificación de la producción es una manera de evitar las pérdidas debido a las variaciones del mercado. Los melones se encuentran entre las especies utilizadas para este propósito, sin embargo, la poca información es un factor limitante para la estimulación de la producción. El objetivo de este estudio fue estimar y evaluar los indicadores económicos del cultivo del melón Cantaloupe (*Cucumis melo* L.), definiendo el espaciamiento más apropiado de la planta en la línea de plantación. Se utilizó un diseño de bloques completos al azar, con cuatro repeticiones de cinco tratamientos correspondientes a un espaciamiento de plantación de 15, 25, 35, 45 y 55 cm. A partir de los datos de producción de cada tratamiento, se estimaron los indicadores económicos relacionados con los costos y los retornos obtenidos con el cultivo de melón. Para la producción de melones en un área protegida de 300 m^2, se obtuvo un costo total de operación de $ 440.02 por ciclo de producción. Este monto fue constituido por inversiones en operaciones manuales, insumos, otros gastos e intereses de costo, que tuvieron una participación de 60,60%, 31,78%, 4,62% y 3,00%. Los valores más altos de los indicadores económicos y el menor precio de equilibrio y productividad se obtuvieron para los melones espaciados 55 cm. El cultivo de melones Cantaloupe espaciados 55 cm en las líneas de plantación proporciona mayores ganancias económicas para este cultivo. Esta especie puede ser utilizada por los agricultores como una alternativa a los cultivos que se cultivan comúnmente en sistemas de medio ambiente protegido, pero deben realizarse estudios continuos para permitir un mayor rendimiento financiero optimizando el sistema de producción.

Palabras clave:
Cucumis melo L.
Iindicadores económicos
Costos de producción
Rendimiento financiero
Melón

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Received: February 15, 2017; Accepted: April 26, 2017
Rev.Fac.Nac.Agron. 70(3): 8319-8325. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

The diversification of production in rural properties can be an important tool to alleviate losses caused by the fluctuation of prices paid to producers. In this sense, the production of melons has been pointed out as an alternative to the commonly used crops (Silva *et al*., 2014). In addition, the great diversity of marketable melon species makes possible the most appropriate choice according to the characteristics of each property and preferences of the consumer market.

The search for fruits with superior organoleptic characteristics has aroused interest in the production of fruits known as "nobles", popularly known as Japanese melon or Cantaloupe, which belong to the group of muskmelons (*Cucumis melo* var. *Reticulatus* Naud., Group Cantaloupensis). The attraction of the market is due to the marked aroma characteristics, pulp with differentiated coloration and higher soluble solids content compared to traditional melons (Medeiros *et al*., 2007).

Melon fruits have a growing acceptance in markets around the world. In twenty years, production has practically doubled, from 15.1 to 29.6 million t between 1994 and 2014, with China holding 50% of the total production (FAO, 2017). In Latin America about one million tons of melons are produced, of which approximately 50% are grown in an area equivalent to 22,000 ha in Brazil (FAO, 2017). In addition, the melon market is an important job generator for communities in productive areas, raising the quality of life of local people (Crisóstomo *et al*., 2008).

With an approximate production of 560,000 t, the Northeast region is the largest producer of melons in Brazil, corresponding to 95% of the national production (IBGE, 2016), although the crop is capable of production practically throughout the national territory. In order to meet national and international demand, there has been a significant increase in the production of melons in the last decade, from 350,000 t produced in 2003 to 590,000 t annually in 2014 (IBGE, 2016).

Despite the potential use of melon as an alternative to monoculture in rural properties throughout the country, research focuses on areas already explored with the species. The lack of technical information is a discouraging factor for producers from other regions, due to the lack of preparation of professionals who work in the field.

Obtaining economic indicators for the crop is another essential action, for which it is possible to pass to the producer information related to the investments and returns associated with the cultivation of a particular species. Through a set of information it is possible to plan the actions to be taken before, during and after the productive cycle. This information must be obtained through specific studies, which envisage the improvement of the productive technique together with the observation of the operational costs, since these factors are intrinsically connected.

Thus, the objective of this study was to estimate and evaluate the economic indicators of muskmelon cultivation, defining the planting spacing in the planting line that presents greater economic advantages.

MATERIALS AND METHODS

Plant material and growing conditions

The study was conducted in the city of Goiânia, State of Goiás, Brazil. The municipality is located in the central region of the Country, 16°40'S, 49°15'W and altitude of 750 m. It presents as average climatic indicators: annual precipitation of 1.575 mm and average monthly temperature of 22.9 °C, predominance of Aw climate, characterized by tropical climate with rainy season of October/April and a period with rainfall less than 100 mm monthly between May/September.

The soil present in the experimental area is classified as an Latossolo Vermelho (Santos *et al*., 2013) and presents the following chemical characteristics: O.M. = 0.7%; pH = 4.6; P (Mehlich) = 3.5 mg dm^{-3}; K = 131.0 mg dm^{-3}; Ca = 2.0 $cmol_c$ dm^{-3}; Mg = 0.81 $cmol_c$ dm^{-3}; H + Al = 2.5 $cmol_c$ dm^{-3}; Al = 0.0 $cmol_c$ dm^{-3}; CTC = 5.6 $cmol_c$ dm^{-3}; m = 0.0%; V = 55.7%.

The experiment was designed in randomized blocks with five treatments corresponding to five planting spacing (15, 25, 35, 45, 55 cm), with four replications. Each plot consisted of a line of 3.5 m in length and 0.7 m in width. To obtain the useful plot, the first and last plants of each plot were eliminated.

The climatic records of the temperature and humidity of the air that occurred during the conduction of the experiment were obtained from a climatic station located at the Agronomy School of the Federal University of Goiás, Goiânia, Brazil (Figure 1).

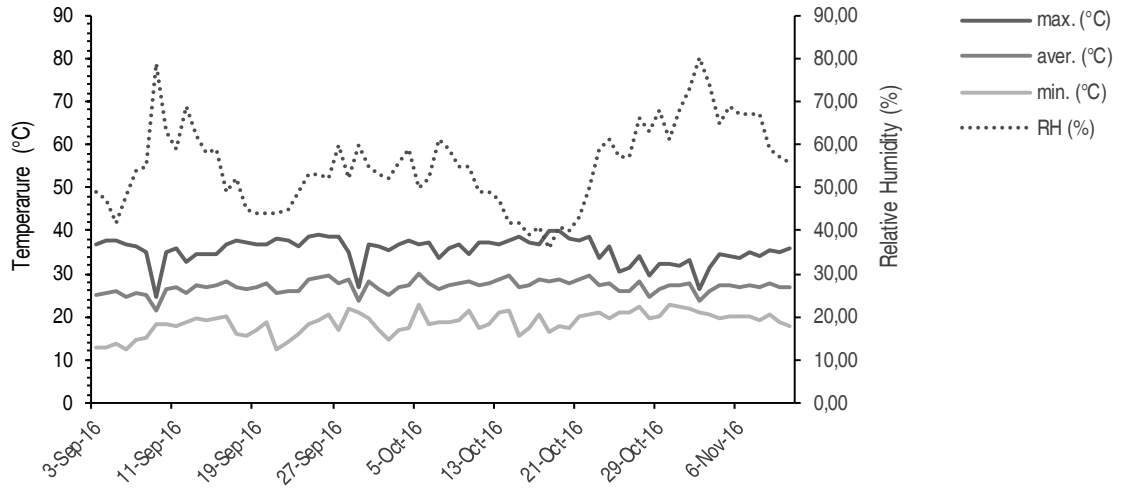

Figure 1. Summary of climatic conditions of relative air humidity and maximum, average and minimum temperature during the period of conduction of the study.

Ninety days before the installation of the experiment, the soil was corrected by applying a dose equivalent to 500 kg ha^{-1} of 100% ECCE dolomitic limestone ($CaCO_3$) in a haul distribution, followed by irrigation.

Plots were prepared with 50 cm wide than were fertilized, according to the recommendation in Bulletin 100 for the melon cultivation, and stirred for incorporation of the fertilizers. On the plots were distributed tapes suitable for irrigation, with drippers spaced 20 cm apart and "mulching" black and white in order to avoid the growth of spontaneous plants and excess water losses by evaporation. The irrigation was started soon after the assembly of the plots to allow the reaction of the elements incorporated into the soil.

The seedlings were obtained by sowing, on commercial substrate (Bioplant®) and earthworm humus (3:1), Cantaloupe melon seeds, Trinity cultivar. Thirty-five days after sowing, the seedlings were transplanted in the previously prepared plots. The conduction was vertically made by using plastic string attached to a 2.5 m high tensioned wire on the lines of planting.

Cover fertilization was carried out via fertigation at 33 and 54 days after transplanting, following the recommendations for the crop based on soil analysis. A control of whitefly and aphid with the use of insecticide based on thiamethoxam (250 g kg^{-1} of a.i.) was carried out, being applied at 14 and another at 52 days after transplanting of the seedlings. There was no need to apply fungicides or herbicides during cultivation.

The appearance of the crack in the insertion of the peduncle next to the fruit was defined as the harvesting point. The harvest was started at 63 days after transplanting and extended for six days until the fruits were harvested.

Economical analysis

In order to determine the production cost of a muskmelon production cycle, the total operational cost (TOC) structure proposed by Martin *et al*. (1998) was obtained by the sum of the expenses with interest of cost, depreciation, other expenses and the effective operating cost (EOC), which in turn is composed of the expenses of the operations and inputs used.

The economic analysis was made considering the different treatments as commercial crops. Considering the existence of structural elements such as greenhouse, irrigation system and other elements used by more than one productive cycle in the area of cultivation, in the present study the costs paid for the implantation of the same were disregarded.

In order to obtain the average prices received by the producers, the data contained in the website of the Center for Advanced Studies in Applied Economics (CEPEA, 2016) were taken into account. The average price of Cantaloupe

melon received by producers in the period from January to May 2016 was $9.03 per 10 kg box, for calculation purposes, the same was used in the present work.

Labor costs were calculated through the index generated by the need for manual operations for each operation, obtained in men/day (MD), then multiplied by the average value of labor force in the region in the year 2016 ($23.83). For inputs, the cost was calculated based on the average value of the product in the region and the amount of material used. A rate of 5% of total EOC expenses was considered for other expenses, while costing interest is assumed to be 6.5% per year over 50% of OEC (Martin *et al.*, 1998).

To determine the profitability of each treatment, a) gross revenue, obtained between the quantity produced (10 kg boxes) and the average price received by the producer in the period from January to May of 2016, were calculated (Martin *et al.*, 1998); B) operating profit, such as the difference between gross revenue and total operating cost; C) Profitability index, understood as the proportion of gross revenue that represents the final amount after covering the total operational cost of production; (D) Equilibrium price given at a given level of total operational cost of production as the minimum price required to be covered to cover the TOC, taking into account the average productivity obtained by the producer; E) Equilibrium productivity, given at a given level of total operational cost of production, as the minimum productivity required to cover the TOC. The amounts, when related to monetary amounts, were expressed in US dollars.

RESULTS AND DISCUSSION

For the production of muskmelons in a protected area of 300 m^2, a total operating cost of $440.02 was obtained per production cycle. This amount was comprised of investments in manual operations, inputs, other expenses and costing interest, which had a participation of 60.60%, 31.78%, 4.62% and 3.00%.

Expenditure on plant management, including mentoring, shedding lateral branches and fruit stewardship contributed most of the expenses related to the operations and also to the total operational cost (Table 1). The group of actions that compose this activity had a 67.19% share between the manual operations and 40.72% over the total operating cost.

Table 1. Estimated total operational cost for a muskmelon crop, spaced 55 cm between plants in a protected area of 300 m^2.

Description	Specification	Qty.	U.C. ($)	Cost ($)
A- Manual operations				
Soil prepare	Man/day	0.2	23.83	4.17
Seedling transplant	Man/day	0.8	23.83	16.67
Plant conduction	Man/day	8.6	23.83	179.17
Fertirrigation	Man/day	1.2	23.83	25.00
Pulverization	Man/day	0.2	23.83	4.17
Harvest	Man/day	1.8	23.83	37.50
Subtotal A ($)				266.67
B- Inputs				
B1 - Polietilen mulch				
Polietilen mulch	Coil (500 m)	0.32	130.95	41.91
B2 – Fertilizers				
Limestone	t	0.014	26.79	0.37
Single superphosphate (18% P_2O_5)	kg	2.40	0.39	0.96
KCl	kg	3.60	0.60	2.14
P fertilizer + micronutrients	kg	2.40	0.57	1.36
Ureia (45% N)	kg	2.40	0.61	1.46
B3 – Seeds				
Trinity cultivar	1000 seeds package	0.58	133.93	77.40
B4 – Pesticides				
Insecticide (2x)	100 g	1.68	8.46	14.21
Subtotal B ($)				139.82
Effective Operational Cost (A+B) ($)				406.49
C – Other expenses ($)				20.32
D - Costing Interest per year ($)				13.21
Total Operating Cost (A+B+C) ($)				440.02

Qty = Quantity; U.C = Unit Cost.

Among the inputs, the one that most charged the production of muskmelons in protected environment was the hybrid seed. The input stopped most of the expenses related to the preparation and maintenance for the correct development of the crop, with participation of 55.33%. In relation to the total operational cost, the acquisition of seeds represented a fraction of 17.59% of the final amount.

The different planting spacing of the muskmelon alter the total operational cost, mainly through the demand for labor to attend the activities of tutoring, pruning, among others, included in the item of plant management. Higher amounts of seeds, used to obtain larger plant stands, were the second factor to burden the activity due to the high value of the hybrid seeds.

There was a 265.12% increase in the need for labor and 267.24% in the number of seeds used for the treatment of smaller planting spacing between plants (Table 2). These increases in expenses culminated in a monetary difference of $1027.47 between treatments.

Table 2. Participation of the cost variation factors over the total operating cost for muskmelon cultivation in different planting spacing between plants in a protected area of 300 m^2.

Planting Spacing	Plant Conduction (Man/day)		Seed (1000 seeds package)		TOC increase (%)
	Quantity	($)	Quantity	($)	
15 cm	31.40	654.17	2.13	285.27	234.00
25 cm	25.80	537.50	1.28	171.43	181.00
35 cm	20.00	416.17	0.91	121.88	142.00
45 cm	14.20	295.83	0.64	85.71	110.00
55 cm	8.60	179.17	0.58	77.41	0.00

TOC = total operating cost.

The estimated gross revenues, considering the average price received by producers between January and June 2016 ($9.03 per 10 kg box), were positive for all evaluated treatments and varied in a decreasing $1769.17 to $872.12 for protected environment of 300 m^2 in the treatments with use of planting spacing of 15 to 55 cm, respectively.Despite the lower value of gross revenue found for the planting spacing of 55 cm, in this one was observed the highest operating profit (Table 3), corresponding to the net profit obtained by the producer. This is mainly due to lower labor and seed costs during the productive cycle combined with good productivity. At the same time, it is observed that the treatment provided higher profitability indices, following the trend of operating profit.

The lower operating profit and profitability index were obtained for the treatment of 45 cm between plants. In spite of the lower values of these indicators, obtained in

Table 3. Productivity and economic indicators obtained by cultivating the muskmelon in a protected environment of 300 m^2, as a function of planting spacing.

Planting spacing (cm)	Production (10 kg boxes)	Gross revenue	TOC	OP	PI (%)
			($)		
15	195.93	1769.17	1467.49	301.67	17.05
25	179.61	1621.85	1236.45	385.39	23.76
35	134.91	1218.24	1066.87	151.37	12.43
45	108.46	979.33	922.88	56.44	5.76
55	96.58	872.12	440.02	432.09	49.55

TOC = total operating cost; OP = operating profit; PI = profitability index.

the treatment with planting spacing of 45 cm, it is observed that all the treatments were able to profit after the payment of all the operational costs.

For species usually cultivated in protected environments, such as lettuce, it was observed that, even when operating profit was favored by the adoption of the intercropping system with cucumber (Silva *et al*., 2008) or tomato (Rezende *et al*., 2005), this economic indicator was much lower than that obtained in this work with melon cultivation. It was verified that all the treatments reached productivities greater than the equilibrium for the price received by the producer from January to May of 2016. However, the crop driving in planting spacing of 55 cm required less production to cover the total operating costs. In this way, the cultivation in planting spacing of 55 cm allows greater security to the producer against the variations in the prices paid for the product, since the equilibrium price obtained for this treatment was approximately 50% lower than the amount paid to the producers in the survey period ($9.03) (Table 4).

The cultivation of muskmelon presents good economic indicators, favoring the introduction of the crop in rotation with other species already exploited commercially. Compared to other cultivated species such as corn (Kaneko *et al*., 2016) and soybean (Vazquez *et al*., 2014), muskmelon cultivation generates an income of approximately 42 and 23 times higher, respectively, in a same productive area size.

Table 4. Production and equilibrium price obtained with the cultivation of muskmelon in a protected environment of 300 m^2, as a function of planting spacing.

Planting spacing	Equilibrium productivity (10 kg boxes)	Equilibrium price ($ per 10 kg boxes)
15 cm	162.52	7.49
25 cm	136.93	6.88
35 cm	118.93	7.91
45 cm	102.20	8.51
55 cm	48.73	4.56

The lack of interest of rural producers to seek new species options for inclusion in different production systems is a reflection of the low technical-scientific production in regions not recognized nationally or internationally as potential regions producing a given crop. In this context, the importance of the economic feasibility study, which determines the operational sustainability and the profitability for the rural worker, is inserted. Consequently, bringing solutions to increase productivity combined with lower operating costs in agriculture and reducing the risks of monetary loss in the face of market oscillations.

CONCLUSIONS

For the muskmelon crop, better economic indexes are obtained with a 55 cm planting spacing between plants, in the central region of Brazil. In addition, the cultivation of the melon in all the spacings studied generated positive economic indices. This species can be used by farmers as an alternative to crops commonly grown in protected environment systems but future studies should be done in order to enable a greater financial return by optimizing the melon production system.

ACKNOWLEDGEMENTS

Thanks to the Coordination of Improvement of Higher Education Personnel - CAPES for granting the scholarship to the first author.

REFERENCES

Crisóstomo JR, Miranda FR, Medeiros JF and Freitas JGA. 2008. Cadeia produtiva do melão no Brasil. Pp. 579-594. In: Albuquerque ACS and Silva AG (eds). Agricultura Tropical: quatro décadas de inovações tecnológicas, institucionais e políticas. Embrapa Informação Tecnológica, Brasília, D.F. 1337 p.

CEPEA - Centro de Estudos Avançados em Economia Aplicada. 2016. Melon. In: http://www.hfbrasil.org.br/br/estatistica/melao.aspx. accessed: July 2016.

FAO. 2017. Faostats: Crops. In: http://www.fao.org/faostat/en/#data/QC. accessed: May 2016.

IBGE - Instituto Brasileiro de Geografia e Estatística. 2016 Sistema IBGE de Recuperação Automática – SIDRA. In: http://www.sidra.ibge.gov.br. accessed: July 2016.

Kaneko FH, Sabundjian MT, Arf O, Leal AJF, Carneiro LF and Paulino HB. 2016. Análise econômica do milho em função da inoculação com *Azospirillum*, fontes e doses de N em cobertura. Revista Brasileira de Milho e Sorgo 14(1): 202-216. doi: 10.18512/1980-6477/rbms.v15n2p202-216

Martin NB, Serra R, Oliveira MDM, Ângelo JA and Okawa H. 1998. Sistema "CUSTAGRI": sistema integrado de custo agropecuário. Informações Econômicas, SP 28(1): 1-28.

Medeiros JD, Santos SCL, Câmara MJT and Negreiros MZ. 2007. Melon yield and fruit quality as influenced by soil coverages, agrotextile and irrigation depth in dry season. Horticultura Brasileira. 25(4): 538-543. doi: 10.1590/S0102-05362007000400009

Rezende BLA, Costa CC, Cecílio Filho AB and Martins MIEG. 2005. Custo de produção e rentabilidade da alface crespa, em ambiente protegido, em cultivo solteiro e consorciado com tomateiro, Jaboticabal, estado de São Paulo. Informações Econômicas 35(7): 42-50.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Cunha TJF and Oliveira JB. 2013. Sistema brasileiro de classificação de solos. Third edition. Embrapa, Brasília. 353 p.

Silva GS, Rezende BLA, Cecílio Filho ABC, Barros Júnior APB, Martins MIEG and Porto DRQ. 2008. Viabilidade econômica do cultivo da alface crespa em monocultura e em consórcio com pepino. Ciência e Agrotecnologia 32(5): 1516-1523.

Silva MC, Silva TJA, Bonfim-Silva EM and Farias LN. 2014. Productivity and quality characteristics of nitrogen and potassium fertilized net melon. Revista Brasileira de Engenharia Agrícola e Ambiental 18(6): 581-587. doi: 10.1590/S1415-43662014000600003

Vazquez GH, Peres AR and Tarsitano MAA. 2014. Reducing soybean plant population and effects on grain net economic return. Científica 42(2): 108-117.

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Revista Facultad Nacional de Agronomía

Characterization and typification of coffee production systems (*Coffea arabica* L.), Andes municipality

Caracterización y tipificación de sistemas de producción de café (*Coffea arabica* L.), municipio de Andes.

doi: 10.15446/rfna.v70n3.66332

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ABSTRACT

The Southwestern region of Antioquia has been characterized for being at the forefront of coffee production in Colombia, with a high diversity in production systems. The research was intended to characterize and typify 13 coffee production systems (*Coffea arabica* L.) in Andes Municipality (Antioquia) under several types of management. The methodology included the qualitative characterization of aspects such as socio-demography, environment, economics, and agriculture, followed by a classification. Statistical multiple-correspondence analyses were conducted and the cluster method was applied. Results on the evaluation of sizes show that concerning the socio-demographic dimension 100% coffee growers own the land, completed primary school, hold a property area between three and four hectares, and have over 20 years of experience in the field; with respect to the environmental dimension, 100% coffee growers have traditional benefits and their coffee is sundried, and between 46% and 69% of them used chemical fertilizers. In relation to the economic aspect, 77% of coffee growers market through unions and experience high production costs with no profit. Finally, concerning the agricultural aspect 100% of coffee growers prepare their soil with minimum farm work and purchase the seeds; 85% of them engage workforce; and 46% of them own low-quality soils and biodiversity. Typification showed that 47% of coffee growers resort to conventional systems (use of chemical products); 38% of them use Transition I systems (Rationalization of Synthetic Supplies); and only 15% of them use Transition II systems (Use of Organic Supplies).

Keywords:
Agroecology
Coffee-growing
Dimensions
Types of management

RESUMEN

La región del suroeste de Antioquia, se ha caracterizado por estar a la vanguardia en la producción de café en Colombia, con una alta diversidad de sistemas de producción. En la investigación, se caracterizaron y tipificaron 13 sistemas productores de café (*Coffea arabica* L.), bajo diferentes tipos de manejo, del municipio de Andes. La metodología consistió en la caracterización cualitativa de las dimensiones sociodemográfica, ambiental, económica y agrícola, seguido de una tipificación estratificada. Se realizaron análisis estadísticos de tipo factorial por correspondencia múltiple y el método del clúster. Los resultados destacan que en la dimensión sociodemográfica el 100% de los cafeteros son propietarios de la tierra, poseen formación primaria, presentan un área predial entre tres y cuatro hectáreas y poseen más de 20 años de experiencia. En la ambiental, el 100% poseen beneficios tradicionales con secado solar y entre el 46 y 69% utilizan agroquímicos. En la económica, el 77% de los cafeteros comercializan con las cooperativas y poseen altos costos de producción sin ganancias. Por último, en la agrícola el 100% preparan los suelos con labranza mínima, compran las semillas, el 85% contratan mano de obra y el 46% presentan baja calidad del suelo y de biodiversidad. La tipificación arrojó que el 47% de los cafeteros presentan sistemas convencionales (utilización de insumos químicos), el 38% son sistemas en Transición I (Racionalización de insumos sintéticos) y sólo el 15% poseen sistemas en Transición II (Utilización de insumos orgánicos).

Palabras clave:
Agroecología
Cafeteros
Dimensiones
Tipologías de manejo

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Received: February 21, 2017; Accepted: June 15, 2017
Rev.Fac.Nac.Agron. 70(3): 8327-8339. 2017 ISSN 0304-2847 / e-ISSN 2248-7026

Coffee is the second most important agricultural product marketed worldwide. Coffee is grown in over 70 countries around the world. During the last 20 years, coffee production has increased from 5.6 to 8.3 million tons per year due to the labor acting to countries such as Brazil, Vietnam, and Colombia (OIC, 2014).

The increase of coffee production has been directly associated to the increase on the use of soil worldwide (Jiménez *et al.,* 2012). The intensive use of soils results in the planet's loss of functional biodiversity of agricultural ecosystems year after year, all due to the technological package of the green revolution, deforestation, habitat destruction, pollution, introduction of exotic species, the strong climate change, and the development of an intensive conventional agriculture that impairs environmental natural resources (Altieri *et al*., 2012).

In coffee production systems in Colombia, environmental degradation generates a cost equivalent to 3.5% of the DGP and associated costs excel due to floods, landslides, and soil erosion (MA, 2014). In the department of Antioquia, 68% of coffee is grown in strongly huddled lines and directly exposed to sunlight under an intensive single-crop conventional management system is used with excessive use of chemical fertilizes (Arcila *et al.,* 2007).

In the municipality of Andes, the coffee cultivation settled down in the second half of the XIX century, as the main source of income for the 80% of the population. Andes represent the 24% of production in the total area of the territory. It covers 47,500 plots with 33,100 coffee growers, of which 68,300 of the cultivated areas correspond to the 60% of the total cultivated area in Antioquia. Therefore, the cultural identity of the local people is closely linked to the evolution and sustainability of the coffee production (FNC, 2014; Mejía, 2016).

The conventional management system that prevails in the region, results in contamination of water resources, death of animals, economic unbalance, and affects food security of most families; it furthers deteriorates life quality of the population (Altieri *et al.,* 2012). Additionally, this system directly impact human health through intoxication and respiratory, cardiovascular, and carcinogenic diseases (Paulo *et al*., 2013).

In order to drive productions towards sustainability (Altieri *et al.,* 2012), researchers, without causing negative environmental impact and keeping and increasing coffee production, quality of resources, and human welfare, propose that agricultural systems should be studies based on the grouping of sets according to their similarities, taking into account the diversity of structures, the functioning, and the dynamic of production units. In this manner, a classification of farm systems can be used as an attempt to know the dynamic of the agricultural development within a region (Escobar and Berdegué, 1990).

The farm classification system is required as a theoretical organization mechanism for the research on farm systems and as a communication tool which allows exchanging information among researchers, coffee growers, and extension agents. Different types of farm systems could exist within a coffee growing area. The result of a typology is always the effect of the criteria employed in the classification. An alternative classification method that is based on a solid conceptual framework and the application of multivariate techniques with principal components based on data collected through participative surveys to a stratified sample of production units constitutes an efficient choice for solving the problem (Escobar and Berdegué, 1990).

In coffee production systems from Latin America, characterization and classification have been performed through productive comparisons between conventional models and organic transition models, and the following aspects have been assessed: environment, biodiversity, management, soils, production, and the socioeconomic component as well (Vázquez *et al.,* 2014; Machado *et al.,* 2015; Nicholls *et al.,* 2016).

The research was conducted with the purpose of giving response to the following question: Could several types of coffee plantation management systems be assessed based on the characterization and classification of production systems at Santa Rita borough in Andes Municipality? Consequently, it will be possible rejecting or supporting the following hypothesis: If characterization and classification of systems are used, types of coffee management systems can be known under different socio-demographic, environmental, economic, and agricultural approaches. The study object of this research was to characterize and classify the coffee production systems at Santa Rita borough.

MATERIALS AND METHODS

The research proposal started in 2014 by means of a scientific event carried out in Universidad de Antioquia south-east campus, in Andes municipality. During the event, a research project entitled: "Participative Design for Conversion of Coffee Systems to Multidiverse Systems," was launched. 50% of participating coffee-producers expressed an interest to participate in the project and were consolidated through a work group.

Coffee-growing systems were submitted to different selection criteria (land size, land possession, production experience, formation degree, articulation production-trading, community share, water availability, presence of other productive activities and soil-climate factors), focused on property features, the producer, population and marketing, following Sarandon and Flores`s (2014) adapted methodologies. According to established criteria, there were 13 coffee-growing farms selected under different management types.

Study area

The study area is located in Andes Municipality (southwest of Antioquia; 05° 39' 29" latitude north and 75° 52' 51" longitude west), 121 km away from Medellin City (Colombia). The area shows a tropical warm wet climate, frequently observed in life zones of pre-mountain rainforests. The relief goes from slightly wavy to very steep; acute and rounded crests and peaks; generally long, straight, and convex slopes above 7%. In general, climate conditions show a mean bio-temperature between 18 °C and 24 °C and an average annual rainfall between 1000 and 2000 mm. The urban center is located next to a mountain stirrup falling from the west cordillera (PBOT, 2016).

All 13 systems selected are located at the following villages: San Gregorio, La Soledad, La Clara, and Egipto; all of them from Santa Rita village over an altitude strip between 1700 and 2000 m. According to USDA (2014), soils of coffee-growing systems have been developed from metamorphic, igneous and sedimentary rocks with volcanic ashes deposits. They exhibit a clay-like and sandy loamy soil in some cases with high content of minerals and a strongly acid pH. They are very deep with an organic superficial horizon, good drainage and low moisture retention. Also, the study systems belong to producers with more than 10 years in coffee- growing production, either by solar exposure or under shade associated to several species represented in the low, medium and high stratums.

Methodological design

The research methodology was started with the qualitative characterization of socio-demographic, environmental, economic, and agricultural aspects of 13 coffee growing systems. Then, a statistical classification of the systems was made and final description of components and interactions of classified typologies was conducted by applying the system approach.

Qualitative characterization of coffee growing systems

The qualitative characterization of aspects above (socio-demography, environment, economy, and agriculture) from coffee growing systems was made from a survey administered to the work team in Santa Rita village, following Sarandón and Flores (2014) adapted methodology. The three assessment ranges set indicate the following: (1) Low state; (2) Medium state for variables having three ranges and High for variables having only two ranges; and (3) High state (Table 1).

Qualitative assessments were performed in 2015 through several theoretical-practical workshops, employing a participation training process with producers from Santa Rita borough by adapting Brüschweiler and Rist methodology (2005).

In order to process the statistically collected information, the Multiple-Correspondence Analysis was used for each topic under study, corresponding to aspects such as socio-demography, environment, economy, and agriculture, relating to the management of the coffee growing system used by coffee growers. Additionally, the frequency distribution relating to each variable and modality associated to the same was found. The statistical packages SAS university edition (2016) and SPAD Version 3.5, were employed.

Classification of coffee growing systems

Classification of systems was performed by applying a cluster analysis from non-hierarchical agglomeration within a tree diagram and the same statistical package was used.

Table 1. Qualitative assessment of aspects in the coffee growing systems.

Socio-demography aspect			
Variables	**Assessment ranges**		
TT	Own (3)	Managed (2)	Rented (1)
GF	Primary (1)	Secondary (2)	University (3)
CF	1 to 3 (1)	4 to 6 (2)	> 6 (3)
AT	0 to 2 ha (1)	2 to 4 ha (2)	4 to 6 ha (3)
SP	Poor (1)	Fair (2)	Good (3)
EF	1 to 2 (1)	2 to 4 (2)	> 4 (3)
VA	Poor (1)	Fair (2)	Good (3)
AC	1 to 2 (1)	2 to 4 (2)	> 4 (3)
ATE	Yes (2)	No (1)	-
CEAT	1 to 2 (1)	2 to 4 (2)	> 4 (3)
I	Farm (3)	Other activity (1)	Both (2)
GO	None (1)	One (2)	Two or more (3)
AGU	Water supply system (2)	Source (3)	River or brook (1)
R	High slope (1)	Medium slope (2)	Low slope (3)
ACC	0 to 10 (1)	10 to 20 (2)	> 20 (3)
ASNM	From 1200 (1)	1200 to 1800 (3)	> 1800 (2)
Environmental aspect			
Variables	**Assessment ranges**		
SS	Yes (2)	No (1)	-
PSE	Yes (2)	No (1)	-
UH	Yes (1)	No (2)	-
UP	Yes (1)	No (2)	-
EPP	Yes (2)	No (1)	-
TB	Traditional (2)	Ecological (3)	Others (1)
RI	Yes (1)	No (2)	-
SCU	Free exposure (1)	Shade (2)	-
DS	Yes (1)	No (2)	-
Economic aspect			
Variables	**Assessment ranges**		
TC	Union (1)	Alternate markets (2)	Direct markets (3)
RTA	Costs > Sales (1)	Costs = Sales (2)	Costs < Sales (3)
RTO	< 2000 kg dpc/ha (1)	2000 to 3500 kg dpc/ha (2)	-
AE	Yes (2)	No (1)	
POLI	Yes (2)	No (1)	-
REP	Yes (2)	No (1)	-
BIOP	Yes (2)	No (1)	-
DC	Yes (2)	No (1)	-
TMO	Family-owned (3)	Rented (1)	Both (2)

Table 1. continuation

Agricultural aspect			
Variables	**Assessment ranges**		
BIO	High (3)	Medium (2)	Low (1)
NC	1 to 2 (1)	3 to 5 (2)	> 5 (3)
PO	1 to 2 (1)	3 to 5 (2)	> 5 (3)
AS	Yes (2)	No (1)	-
CS	High (3)	Medium (2)	Low (1)
TF	Chemical (1)	Organic (3)	Both (2)
MF	Yes (2)	No (1)	-
IB	> 5% (1)	0 to 2% (3)	2 to 5%(2)
NA	1 to 2 (1)	3 to 5 (2)	> 5 (3)
PS	Purchase (1)	Produced (2)	-
TL	Mínimum (2)	Intensive (1)	-
EGA	Yes (2)	No (1)	-
RP	Yes (2)	No (1)	-
RPR	Yes (2)	No (1)	-

Variables: TT- Tenure of the Land; GF- Degree of Education; CF- Family Members; AT- Total Area of Property; SP- Quality of Utilities; EF- Farm Employees; VA- Ways of Access; AC- Supplementary Activities; ATE- Technical Support; CEAT- Amount of Entities Providing Technical Support; I- Income; GO- Union Groups; AGU- Water Supply Sources; R- Farm Relief; ACC- Years Growing Coffee; ASNM- Meters Above Sea Level; SS- Use of Solar Dryer; PSE- Use of Septic Tank; UH- Use of Herbicides; UP- Use of Pesticides; EPP- Use of Personal Protection Equipment; TB- Type of Processing Plant; RI- Intoxication Risks; SCU- Plantation Systems; DS- Soil Degradation; TC- Type of Marketing; RTA- Profitability; RTO- Production; AE- Economic Support; BIO- Plant Biodiversity; NC- Number of Plantations; PO- Organic Practices; AS- Soil Analysis; CS- Soil Quality; TF- Type of Fertilizers; MF- Phytosanitary Management; IB- Borer Beetle Infestation Percentage; NA- Number of Animal Species; PS- Origin of Seed; TL- Type of Farm Work; EGA- Preparation of Germinators and Seedbeds; RP- Crop Pruning; RPR- Production Records; POLI- Multiple-Crops; REP- Allelopathic Plants; BIOP- Use of Bio-Preparations; DC- Use of Crop Wastes; TMO- Type of Workforce.

Description of typified systems

Description of systems was performed by applying the systems approach proposed by Hart (1979). Typologies were plotted with relevant components and interrelations. The main components evaluated corresponded to soil, plantation, animal, and pests. Then, mass and energy flowcharts were prepared on the following interrelations: soil-plantation; plantation-pests; plantation-weed; and plantation-infrastructure for each classified typology.

The approach of the system was applied in conjunction with the coffee growers during several visits to the properties, workshops, and training conducted throughout the research. During the process, producers appropriated the state of components that comprise their systems and showed them with illustrations. In order to support this process, quick evaluations on soil quality (physical, chemical, and biological properties) and plant and animal multifunctional biodiversity were conducted, for this purpose, different adjusted methodologies were used (Altieri and Nicholls, 2008; Vázquez *et al*., 2014).

RESULTS AND DISCUSSION

Qualitative characterization of coffee growing systems

Participation processes with the group subject matter of this research resulted in the appropriation of knowledge, techniques, and improvement of the participants' life conditions. Additionally, coffee growers showed motivation to implement agro-ecological practices intended to reach the balance of the agro-ecosystem pillars toward the search for sustainability and resilience of coffee plantations.

When the analysis of relative frequencies was made, associated to each modality corresponding to variables associated to the sociodemographic aspect, it was found that 100% of people subject to the survey owned the farms, completed primary education, and enjoy regular utilities, technical support was provided by UMATA, and systems were located between 1200 and 1800 m.

Additionally, 100% of coffee growers who owned their own farms performed supplementary activities which allowed them to financially sustain themselves and they have access to governmental bank loans. Other associated variables indicated that 53.9% of respondents were members of different organizations, and 53.8% expressed that they had regular ways of access. Relating to family composition, families consisted of four through six children. The area of properties showed the highest percentage with values ranging between three and four hectares; 69.2% of them extracted water from water springs, and 84.6% had over 20 years of experience in the field of coffee production.

Concerning the sociodemographic aspect, it was demonstrated that coffee growers having less than ten years of settling of coffee growing, had good ways of access, the slopes where they settled cultures were low, and the number of employees used for providing production services ranged between one and four. Coffee growers engaged four employees, and grew coffee at high slopes; water used was taken directly from the water supply system and had regular ways of access. Families showed a high number of children (above 6) and they took water especially from a brook or a river, and were located above 1800 m.

Sociodemographic results concerning the tenure of own land, access to financing sources, and sociodemographic characteristics of coffee growing families coincide with studies performed by Machado *et al*. (2015), and these aspects help decrease rural poverty and create neighborhood and cooperation networks that allow them to face together all critical moments that may arise.

Also, Gómez (2016) affirms that variables corresponding to type of property, ways of access, technical support provided, and topography of properties, assure production integrity and efficiency of the agricultural production systems, with an increase of plantation biodiversity higher than that of the systems that may be rented or only managed by third parties.

When environmental variables were assessed, it was found that 100% of coffee growers resort to sun to dry coffee and own a traditional processing system. 46.1% of them employ herbicides; 76.9% affirmed that they had been exposed to intoxication risks due to the use of herbicides and fungicides; 69.2% employ pesticides and only 15.4% of them use septic tanks. Over 60% of respondents affirmed that they had experienced degradation processes in their soils and that the plantation system employed was a free exposure system.

The multiple-correspondence analysis of the environmental aspect allowed determining (as similarities) that coffee growers who used herbicides owned degraded soils. On the one side, the ones who used shadow system for coffee plantations did not employ pesticides or herbicides and had not experienced intoxication or degradation problems in their soils. On the other side, producers who experienced intoxication affirmed that they used pesticides in the coffee plantation.

From the environmental point of view, results indicate that the highest percentage of coffee growers showed intoxication risks due to the excessive use of pesticides and herbicides. These results coincide with research works performed by Márquez (2013) where intensive systems characterize for the application of chemical products that result in chronic intoxication, residual character of plantations and soils, contamination of natural resources, and impairment of food security of both animals and coffee growers. The aggressive environmental impact shown by agro-ecosystems with crops directly exposed to sunlight was verified; the crops decrease the biological activity of soil and speed up the climate impact; different from the positive benefits provided by crops with diversified shadow, which regulate the microclimate, provide shelter and micro-habitats to natural enemies, and assure multi-diverse ecosystemic services. Many researchers demonstrated that in order to assure an agro-ecosystem free of hazardous organisms and with a high soil fertility, biodiversity and introduction of agro-ecological practices should be implemented in order to stimulate trophic networks through several interactions of the components (Vázquez *et al.,* 2014; Nicholls *et al.,* 2016).

After assessing the economic aspect, it was found that 76.9% of coffee growers marketed their products through cooperatives, while remaining 23.1% did it in alternate markets. 76.9% of them expressed that production costs were equal to the amount collected from the sale of the product. 61.5% of them affirmed that profit was below 2000 kg dpc/ha. Therefore, the correlation analysis on the economic aspect showed that coffee growers who made a direct sale affirmed that sales meet production costs, and this shows that, in general, there is not a strong relationship among the modalities associated to this aspect.

Concerning the economic results, coffee growers showed a significant interest in the equality between production costs and profits. These results indicate that the way of production is the main cause for the economic unbalance. Hence, the systems which exhibited the highest economic risk were the ones comprised by families who only have coffee associated to subsistence products and have a marketing channel; contrarily, coffee growers with more diversified systems have more sources of food and byproducts, an organic management, and different channels to sustain production and assure additional income. These results coincide with similar research works (Márquez, 2013; Machado *et al.,* 2015).

Finally, concerning the multiple correspondence analysis of the agricultural aspect, associated to the management of crops, it was found that the most common aspect noticed was that small coffee growers surveyed had a maximum of two crops, with a low-quality soil, affirming that 53.8% of their crops showed between 3% and 4% of Borer Beetle Infestation (*Hypothenemus hampei* Ferrari)

In general, 100% of coffee growers prepared soils with minimum farming work, purchase the seeds, own germinators and seedbeds, and carry out pruning. 84.6% engage workforce to perform productive activities and vegetal matter collected from crop wastes and cultural management is used to prepare different types of fertilizers. Only 7.7% of them use exclusively organic fertilizers. 15.4% of them keep records of their crops.

Hence, coffee growers exhibiting high levels of borer beetle in their coffee plantations get associated to systems having low-fertility soils. Besides, they do not use fertilizers, allelopathic plants or bio-preparations. Contrarily, it does occur in systems with low levels of borer beetle. It should be noticed that systems involving the use of chemicals do not use vegetal wastes.

These relationships involve two types of management for the coffee plantation: intensive systems that use the green revolution model with low vegetal biodiversity, low soil fertility, and sanitation of crops; on the other hand, systems with conservationist organic principles that improve physical, chemical, and biological properties of soil and increase vegetal biodiversity through the use of organic products (FNC, 2014) stand out.

Typification of coffee growing systems

Typification of coffee-growing systems showed a tree diagram with three types of management, where study coffee-growing systems are listed (Figure 1). Results by typology show that coffee productive systems in Colombia can be put into groups or sets according to their similarities concerning social, ecological, environmental, economic, technological, and agricultural management characteristics of the agro-ecosystem components. Also, the environment of systems, the development capacity, and soil-climate factors may influence on aspects that bring similarities to the systems. These parameters, that provide similarities among systems, are clearly seen with positive or negative aspects in the management of coffee crops, and can be analyzed under several conventional, traditional or organic approaches of coffee crops. These parameters have been analyzed and assessed by different authors in similar agro-ecosystem typification studies (Carvajal *et al.,* 2014; Gómez, 2016).

Description of typified systems

Typified systems are shown below through the approach of systems proposed by Hart (1979). Graphs were prepared with components corresponding to soil, crop, animal, pests and recycling, environment, inputs and outputs (Figure 2).

Systems shown in Typology I are characterized by a mandatory input of potentially toxic agricultural chemical fertilizers that, together with human resource and climate, assure excessive fertilization of coffee and subsistence products crops. Also, the permanent use of herbicides is observed in order to handle the invasive weeds that appear in the system. This intensive management of coffee crops allows the coffee growers to obtain dry parchment coffee and secondary agricultural products.

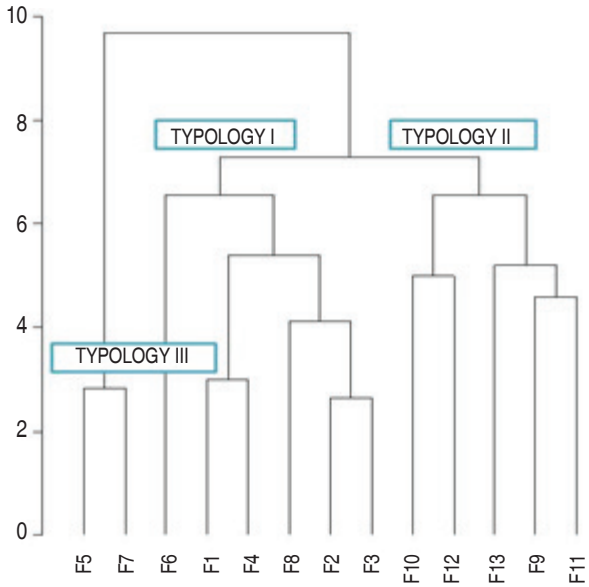

Figure 1. Cluster analysis of coffee growing systems.
Distribution of the systems according to cluster analysis: Typology I: F1 System: El Pedregal; F2 System: La Loma; F3 System: Esperanza J; F4 System: El Zapote; F6 System: Esperanza L; and F8 System: La Cumbre. Typology II: F9 System: San Juan; F10 System: La Isabela; F11 System: La Aurora; F12 System: El Progreso; and F13 System: La Quinta. Typology III: F5 System: La Cecilia; F7 System: La Dalia.

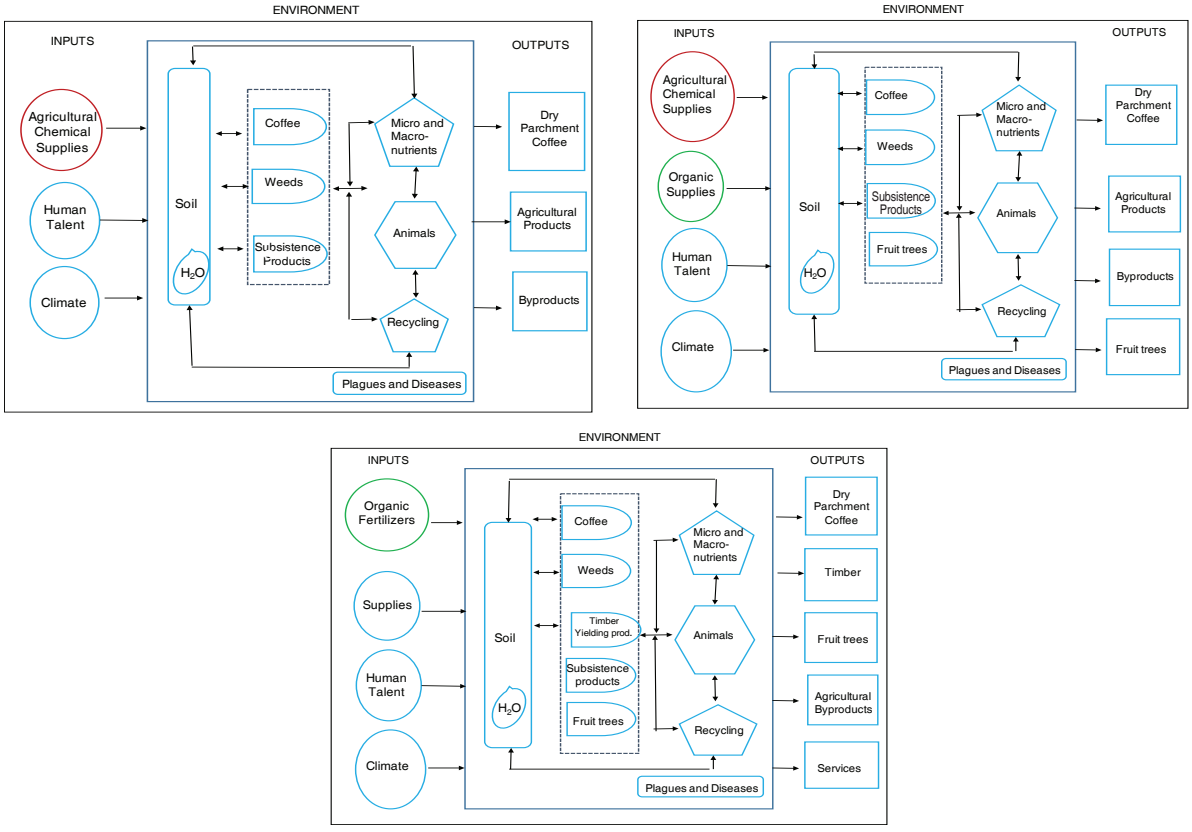

Figure 2. Diagrams on Typology I, II y III systems, respectively.

In Colombia, these results are reflected on the intensive modern coffee systems where the productive model based on synthetic products transforms quality of landscape, triggers alterations in ecological and climatic processes of the region, and decreases functional biodiversity of the agro-ecosystem (Rojas *et al.,* 2012).

These systems are characterized by the replacement of more diversified and heterogeneous ecosystems with homogeneous and regular ecosystems, which make of them systems more sensitive to erosive processes, contamination of water resources, and imminent attack of pests and diseases (Luna *et al.,* 2012).

Concerning Typology II, systems show the restricted use of agricultural chemical products and the employment of organic fertilizers as inputs. These inputs, together with the influence of soil and climate factors of the region and human resource, allow the system to create several interrelations between crops and weeds, recycling of nutrients, and management of pests of the agro-ecosystem. In his manner, parchment coffee, agricultural products, fruit crops, and byproducts are assured as outputs.

The traditional coffee production model expressed through these systems decreases the dependence on external supplies, thus reducing production costs and favoring conservation of natural resources of the farm, such as soil, water, and biodiversity (Guhl, 2009). Additionally, the presence of fruit trees brings a small percentage of shade to the crop, which regulates light intensity and decreases soil temperature, creating optimal conditions for the settlement of soil microbial populations and increasing fertility of soil (Bosselmann *et al.,* 2009).

Relating to Typology III, systems only employ organic products and apply agro-ecological practices which, combined with human talent and climatic conditions of the region, allow growers to plant coffee, timber-yielding species, fruit trees, food species, and non-competing weeds. This balance between soil fertility and management of pests and diseases provides timely outputs such as chemical-free dry parchment coffee and agricultural products and byproducts from food, fruit, and timber-yielding species. Coffee growing systems under these diversified shade characteristics result in conservation of vegetal and animal biodiversity, increase of beneficial insect populations, and outstand for their provision of environmental agro-ecosystem services to the communities (Moorhead *et al.,* 2010).

Several synergies and interactions taking place on the soil with the use of poly-cultivations and within the soil, with the increase of organic matter and the biological activity of the soil under this typology, offer resilience before climatic events, reestablish eroded soils, self-regulate populations of pests and diseases, and improve productivity and efficiency of systems. These results have been obtained from research works of different authors (Alvarado and Laura, 2013).

Components of the system by typology approach

Soil component. In coffee-growing systems, soils of Typologies II and III are characterized by a granular structure with high structural stability of aggregates, high porosity and permeability, receiving organic fertilizers such as vermicompost, rustic compost, bocashi, mineral mixes. This practice accounts for a higher percentage of organic matter, essential macro- and micro-nutrients, and biological activity; this improves physical properties of soil such as porosity, aeration, structural stability, infiltration, and humidity retention (Altieri and Nicholls, 2008; Cabrera, 2014).

When compared to freely exposed soils observed in Typology I, these present a compact structure with erosive processes, such as surface runoff, presence of ditches, localized mass movements. Also, there is low water storage capacity and low porosity and permeability. The content of organic matter and the biological activity result much lower, which unbalances the state of physical, chemical, and biological properties of the soil and brings severe erosive processes that affect growth and development of coffee growing (Nicholls *et al.,* 2016).

Vegetal component by stratum. Characterization of vegetal component was performed through low, medium, and high strata of the typified coffee growing systems (Table 2).

Vegetal biodiversity seen in systems under Typologies II and III offers optimum shade conditions and permanent contribution of dead leaves; this helps regulate soil and climate conditions of the crop, increases soil fertility, provides shelter and food for natural pest controllers,

and assures a more self-sustainable and resilient system over time (Vázquez *et al.,* 2014).

On the other hand, vegetal biodiversity of Typology I systems is scarce. This low vegetal coverage alters the balance of agro-ecosystem components, decreases natural fertility and water storage capacity in the soil, and this tends to speed up the hydrological erosive processes caused by surface runoff and ditches throughout the slope (PBOT, 2016). Weeds comprising the land become invasive species that compete with coffee for light, water, and nutrients. Soil biota that recycles nutrients starts decreasing and predatory insects and pests accelerate populations (Ospina, 2015; Socarrás, 2016).

Coffee (*Coffea arabica* L.) is the main agricultural product of the production systems studied. This cultivation is produced in Andes Municipality with a clean cup and acidy and body ranging from medium to high, under different management systems. The main varieties of coffee seen in the systems are Variety 2000, Catimor, Castillo, Caturro, Colombia, and Bourbon (Arcila *et al.,* 2007).

Table 2. Characterization of vegetal component.

Vegetal strata	Typologies		
	I	II	III
Low	Consisting of very competing weeds such as: Grass (*Cynodon dactylon*), cadillo (*Triumfetta semitriloba*), coquiyo (*Cyperus rotundus*), verdolaga (*Portulaca oleracea*), lengua de vaca (*Rumex obtusifolius*), pata de gallina (*Eleusine indica*), and pasto blanco (*Digitaria sanguinalis*).	Consisting of weeds such as: Grass (*Cynodon dactylon*) and pata de gallina (*Eleusine indica*). Other species such as carey (*Salix cordata*), maracuya (*Passiflora incarnata*), and weeds with flowers.	Consisting of medicinal species such as: sauco (*Sambucus nigra*), limoncillo (*Cymbopogon citratus*), sábila (*Aloe vera*), rosemary (*Rosmarinus officinalis*), salvia (*Salvia officinalis*), toronjil (*Melissa officinalis)*, basil *(Ocimum basilicum),* chili pepper (*Capsicum annuum*), and fruit trees such as pineapple (*Ananas comosus*), blackberry (*Morinda citrifolia*), granadilla (*Passiflora laurifolia*). All these vegetal species provide coverage to soil, serve as living barrier, regulate natural enemies, and associate with coffee in poly-plantations.
Medium	Coffee is produced in strongly tight lines directly exposed to sunlight. Subsistence species such as yucca (*Manihot esculenta*) and plantain (*Musa* sp.)	Coffee is produced directly exposed to sunlight and with species that provide slight shade. Subsistence species such as yucca (*Manihot esculenta*), corn (*Zea mays*), and plantain (*Musa* sp.)	Coffee is produced under shade. Subsistence species such as yucca (*Manihot esculenta*), corn (*Zea mays*), bean (*Phaseolus vulgaris*), and plantain (*Musa* sp.). Citric and fruit species such as lemon (*Citrus* sp.), orange (*Citrus sinensis*), tangerine (*Citrus tangerina*), guava (*Psidium guajava*), sugar cane (*Saccharum officinarum*), and higuerilla (*Ricinus communis*).
High	No high stratum.	Consisting of fruit species such as avocado (*Persea americana*) and mango (*Mangifera indica*).	Consisting of fruit species such as avocado (*Persea americana*) and mango (*Mangifera indica*); timber-yielding species such as nogal (*Cordia alliodora*), yarumo (*Cecropia peltata*), cedar (*Cedrela odorata*) and guamo (*Inga densiflora*).

Interrelations by management typologies: flowcharts on mass and energy

Interrelations of management typologies are shown below through different mass and energy flowcharts (Figure 3).

In the results of the interrelations by study systems, it was found that the Conventional and Transition I systems show similarities in the management of soil, cultivation, weeds, and plagues. Conventional systems are the most abundant in the country with modern

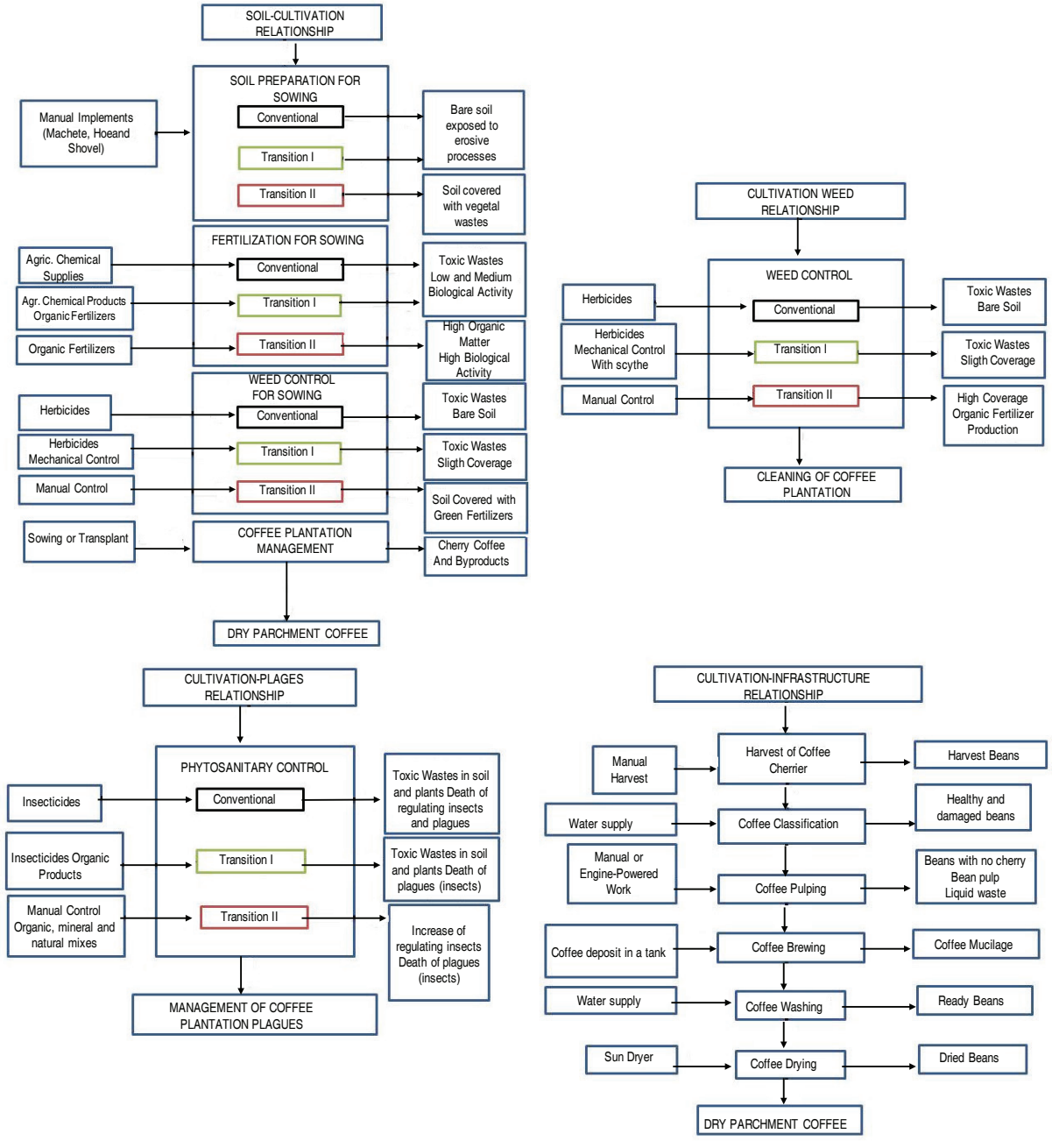

Figure 3. Flowcharts of interrelations: soil-cultivation; cultivation-weeds; cultivation-plagues; and cultivation-infrastructure by management typologies

methods designed and managed to increase coffee production at any environmental cost (Jiménez *et al.,* 2012). Transition I systems, located at the initial stage of the conversion process, are a little different from the conventional management, applying several practices that restrict the use of agrochemicals and introduce organic fertilizers; these changes stabilize physical and chemical properties of the soil and benefit the increase of vegetal and animal biodiversity (Vázquez *et al.,* 2014), while Transition II systems show specific qualities concerning interrelations; therefore, these are the most conserved and sustainable systems. Interrelations seen keep a balance between soil fertility and agroecological management of plagues, thus promoting integrity of coffee-growing agro-ecosystems that perform such practices (Nicholls *et al.,* 2016).

Finally, it should be noted that interrelations such as soil-cultivation, cultivation-weeds, cultivation-plagues, and cultivation-infrastructure constitute key processes to understand the coffee-growing systems. In this manner, coffee growers and their families recognize the principal aspects that offer them valuable contributions to approach the sustainable and resilient agro-ecological systems; they understand the main factors that may decrease coffee production and detract environmental, social, and financial value to current production systems. In general, orientation of interrelations to redesign the agro-ecosystem components will allow rescuing the ancestral knowledge coffee growers have and providing new knowledge and innovative tools to efficiently execute the process to redesign, manage, and conserve natural resources. Many researchers coincided in affirming that the settlement of interrelations is the ecological and functional basis of agro-ecosystems during the agro-ecological conversion process (Márquez, 2013).

CONCLUSIONS

In Santa Rita, a village of the Municipality of Andes, three types of coffee production systems were founded with characteristic that correspond to the highly intensive, in transition and organic systems. They are the Conventional, Transition I, and Transition II. The scientific contribution of this research has been centered on the development of a methodology that shows an integral vision of the coffee production systems. Additionally, it becomes a perfect tool for coffee growers, and researchers who wish to identify the main strengths and restrictions of the structure, and function of coffee-growing systems towards a sustainable production. The results of the characterization and typification showed the current state of the components of the coffee agroecosystems, and the necessity of the implementation of an agroecological building design that may be resilient over the time, for each management typology, increasing the coffee plantation productivity, improving the life quality, and reaching a balance between the agroecosystems bases.

ACKNOWLEDGMENTS

Authors would like to thank the financial support to the research project funded by CODI (COL0009556) – Universidad de Antioquia. They would also like to thank "Grupo de Investigación en Sistemas Agroambientales Sostenibles" and all coffee growers from communities settled at Santa Rita village in Andes municipality.

REFERENCES

Altieri MA y Nicholls CI. 2008. Sistema agroecológico rápido de evaluación de calidad de suelo y salud de cultivos en el agroecosistema de café. Universidad de California, Berkeley. pp. 1-16.

Altieri MA, Nicholls CI and Funes FM. 2012. The scaling up of agroecology: spreading the hope for food sovereignty and resiliency. A contribution to discussions at Río+20 on issues at the interface of hunger, agriculture, environment and social justice. SOCLA's Río+20 pp. 3-17.

Alvarado B y Laura S. 2013. Evaluación de la sustentabilidad de la producción orgánica el café a través de la medición de eficiencia económica con variables ambientales. Revista Natura and Economía 1(2): 91-110.

Arcila P, Farfán V, Moreno B, Salazar G e Hincapié G. 2007. Sistemas de producción de café en Colombia. Chinchiná, Cenicafé 10: 233-254.

Bosselmann A, Dons K, Oberthur T, Olsena C, Reabilda A and Usmac H. 2009. The influence of shade trees on coffee quality in small holder coffee agroforestry systems in Southern Colombia. Agriculture, Ecosystems and Environment 129: 253-260.

Brüschweiler S y Rist S. 2005. AIL- Apoyando Innovaciones Locales. Un instrumento para el fortalecimiento de innovaciones locales y la promoción del desarrollo rural sostenible. Experiencia de dos talleres pilotos de MASAL y CDE realizados en la provincia de Cuzco, Perú. Berna. 20 p.

Cabrera G. 2014. Manual práctico sobre la macrofauna edáfica como indicador biológico de la calidad del suelo, según resultados en Cuba. Fundación Rufford (RSGF, para la Conservación de la Naturaleza). 34 p.

Carvajal J, Méndez A, Piñeiros R, Mora J. 2014. Tipología de fincas, capital social y cobertura arbórea en el cañón de Anaime,

Tolima. Colombia. Agroforestería Neotropical 4: 43-47.

Escobar G y Berdegué J. 1990. Tipificación de sistemas de producción agrícola. Red Internacional de Metodología de Investigación de Sistemas de Producción (RIMISP), Santiago de Chile. ISBN: 956.7110-01-07. 284 p.

Federación Nacional de Cafeteros de Colombia - FNC. 2014. Ensayos sobre Economía Cafetera. Federación Nacional de Cafeteros de Colombia 27(30): 5-37.

Gómez LM. 2016. Estudio de la conversión agroecológica de sistemas agrícolas convencionales de frijol (*Phaseolus vulgaris* L.), en el municipio del Carmen de Víboral. Tesis Doctorado en Agroecología. Universidad de Antioquia, Medellín, Colombia. 124 p.

Guhl A. 2009. Café, bosques y certificación agrícola en Aratoca, Santander. Revista de Estudios Sociales 32: 114-125.

Hart RD.1979. Agroecosistemas, conceptos básicos. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba. Costa Rica. 211 p.

Jiménez A, Rivera L y Coopedota L. 2012. Sostenibilidad en el negocio del café: Coopedota y el camino hacia la carbono neutralidad. FOMIN-Coopedota R.L, San José, Costa Rica, 3-45.

Luna R, López M y Larios G. 2012. Sistemas de manejo en café (*Coffea arabica* L.) y su efecto en la fertilidad del suelo y el rendimiento del café oro, Masatepe, Masaya. Revista Científica La Calera 12(18): 29-36.

Ministerio del Ambiente y Desarrollo Sostenible - MA. 2014. Programa de las Naciones Unidas para el Desarrollo. Quinto Informe Nacional de Biodiversidad de Colombia ante el Convenio de Diversidad Biológica, MA, Bogotá, Colombia. 101 p.

Machado M, Nicholls C, Márquez S, Turbay S. 2015. Caracterización de nueve agroecosistemas de café de la cuenca del río Porce, Colombia, con un enfoque agroecológico. Idesia 1(33): 69-83.

Márquez SM. 2013. Riesgo ambiental por uso del clorpirifos en zonas de ganadería de leche y propuesta de conversión agroecológica, en San Pedro de los Milagros. Tesis Doctorado en Agroecología, Universidad de Antioquia, Medellín. 40 p.

Mejía JJA. 2016. Plan de desarrollo. Andes: Inclusión, Orden y Progreso Verde. Municipio de Andes, Antioquia 317: 17-108.

Moorhead LC, Philpott SM and Bichier P. 2010. Epiphyte biodiversity in the Coffee agricultural matrix: Canopy stratification and distance from forest fragments. Conservation Biology 24(3): 737-746.

Nicholls CI, Altieri MA, Vázquez L. 2016. Agroecology: Principles for the conversion and redesign of farming systems. Journal of Ecosystem and Ecography S5: 010. doi:10.4172/2157-7625.S5-010

Organización Internacional del Café - OIC. 2014. En: http://www.ico.org/botanical.asp; consulta: Abril 2014.

Ospina D. 2015. Diversidad genérica de hongos micorrízicos arbusculares (HMA) nativos en suelos de la alta guajira colombiana. Tesis de Grado en Biología. Instituto de Biología. Facultad de Ciencias Exactas y Naturales. Universidad de Antioquia, Medellín. 81 p.

Paulo L, Keila A, Iara L. 2013. Del monocultivo a la agroforestería: una oportunidad para la generación de ingresos y acceso a nuevos mercados con la producción agroforestal de café orgánico. Revista LEISA 29(2): 14-16.

PBOT, 2016. Plan básico de ordenamiento territorial del municipio de Andes. Temas: geomorfología, geografía y ecología, usos de la tierra, zonas de vida, tipos de suelos. En: http://www.andes-antioquia.gov.co/index.shtml; consulta: Marzo 2016.

Rojas A, Hartman K y Almonacid R. 2012. El impacto de la producción de café sobre la biodiversidad, la transformación del paisaje y las especies exóticas invasoras. Ambiente y Desarrollo 16(30): 93-104.

Sarandón S y Flores C. 2014. Agroecología: bases teóricas para el diseño y manejo de agroecosistemas sustentables. Facultad de Ciencias Agrarias y Forestales. Primera eidición. Universidad Nacional de La Plata, La Plata. ISBN 978-950-34-1107-0, pp.375-410.

Socarrás A. 2016. Variación de los componentes de la mesofauna edáfica en una finca con manejo agroecológico. Revista Pastos y Forrajes 39(1): 41-48.

United States Department of Agriculture - USDA. 2014. Keys to soil taxonomy. Twelfth Edition, NRCS-USDA, USA. 335 p.

Vázquez L, Matienzo Y, Griffon D. 2014. Diagnóstico participativo de la biodiversidad en fincas en transición agroecológica. Revista Fitosanidad 3: 5-10.

Research article

http://www.revistas.unal.edu.co/index.php/refame

Revista Facultad Nacional de Agronomía

Emission and fixation of greenhouse gases in potential specialty coffee production zones in Antioquia -Colombia

Emisión y fijación de gases efecto invernadero en zonas con potencial de producción de cafés especiales en Antioquia-Colombia

doi: 10.15446/rfna.v70n3.62639

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ABSTRACT

The aim of this work was to estimate the greenhouse gas (GHG) emission and fixation balance in potential specialty coffee production zones in the department of Antioquia, Colombia. It were used the Intergovernmental Panel on Climate Change – IPCC methods in this research. The results showed an average of 1.068 kg CO_2 fixed per kg of produced coffee cherry. The fixation and emission balance was positive for 0.271 kg CO_2e per kg of coffee cherry. The total GHG emission was 0.816 kg CO_2e per kg of coffee cherry. The emissions from loss of carbon from soil organic matter, organic matter incorporation and coffee leaf litter decomposition were 84.3% of total emissions, and the remaining 15.7% resulted from emissions from nitrogen fertilization. In the balance between emission and fixation in the evaluated zones, Giraldo´s center had the best at 0.5751 kilograms CO_2e per kg of coffee cherry.

Keywords:
Specialty coffee
Biomass
Greenhouse gases
Global warming
Methane.

RESUMEN

El objetivo de este trabajo fue estimar el balance de emisión y fijación de gases efecto invernadero (GEI) en núcleos potenciales de producción de cafés especiales en el Departamento de Antioquia – Colombia. Se utilizó la metodología recomendada por el Grupo Intergubernamental de Expertos sobre el Cambio Climático -IPCC en esta investigación. Los resultados muestran que se fijan en promedio 1.068 kg de CO_2e por kg café cereza producido. Se obtuvo un balance de fijación y emisión positivo de 0,271 kg de CO_2e por kg de café cereza. Las emisiones totales de GEI fueron de 0,816 kg de CO_2e por kg de café cereza. Las emisiones por pérdida de carbono de la materia orgánica del suelo en promedio en todos los núcleos evaluados, incorporación de materia orgánica y la descomposición de la hojarasca de café, fueron del 84,3% de las emisiones totales y el 15,7% restante correspondió a las emisiones por fertilización nitrogenada. En el balance de emisión y fijación de los núcleos evaluados, el de Giraldo fue el que mejor resultado obtuvo con 0,5751 kg de CO_2e por kg de café cereza.

Palabras claves:
Cafés especiales
Biomasa
Gases de efecto invernadero
Calentamiento global
Metano

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Received: February 14, 2017; Accepted: June 27, 2017
Rev.Fac.Nac.Agron 70(3): 8341- 8349. 2017
ISSN 0304-2847 / e-ISSN 2248-7026

Agriculture contributes heavily to greenhouse gases (GHG), mainly nitrous oxide, which results from the application of nitrogen-based fertilizers and manures (Rees *et al*., 2014). Likewise, Andrade *et al*. (2014) stated that agriculture is one of the most important sectors influencing climate change because it can act as net source of GHG; however, it can mitigate global warming.

Consequently, Colombia has developed some plans and policies that address climate change mitigation, identifying priority sectors with high GHG emission rates. A working group led by the Ministry of Environment and Sustainable Development has selected target areas for low emission development in agriculture, forestry, and land use sectors (AFOLU). These include reducing emissions from deforestation and forest degradation, oil palm, livestock, forestry, and fertilizers. In December 2015, the government of Colombia presented its Intended Nationally Determined Contributions, which include contributions from the AFOLU sector, at the Conference of the Parties in Paris (De Pinto *et al*., 2016).

Since coffee production plays an important role worldwide in sustaining millions of livelihoods around the world, it is critical to understand GHG emissions from coffee supply chains in order to evaluate options for climate change mitigation within the sector (Noponen *et al*., 2012), especially in Colombia, which is one of the largest coffee producers in the world.

The specialty coffee industry was born in North America, as a result of the decline in coffee quality offered by commercial roasters. It focuses on high quality and originality perception, defined by some industry agents as "good preparation of a single origin and distinct taste" (Ponte, 2004). They are coffees that come from a country, region or farm, with a number of unique qualities because they grow in special places, and are sold to the final consumers without being mixed with coffees of other qualities or origins (Organización Internacional del Café, 2014). They are valued by consumers for their consistent, verifiable and sustainable attributes, for which a higher price is paid to the producer. As an alternative and great possibility, Colombia has sought to join the green markets, and the way into these international markets is encouraging greater sustainable production. Colombia is the world's second-largest supplier of Fair Trade USA Certified coffee, the third-largest 4C coffee producer, the second-largest Rainforest coffee producer and the third-largest UTZ coffee producer. By 2013, over 184 thousand producers were reported, with verification and/or certifications of some type of sustainability protocol and, therefore, receive quality premiums, which increased by 7%. By 2014, according to the FNC figures of the Colombian coffee industry, production increased to 12.1 million bags, of which more than half of this export was value-added, corresponding to 3.2 and 2.5 million bags with added value and specialty coffees, respectively (Federación Nacional de Cafeteros de Colombia-FNC, 2014).

By 2014, different brands had incorporated new elements related to climate change into their checklists, based on measurements of (GHG), which obligates producer countries to have their GHG inventories, in order to make them more competitive and position them in the international market, giving added value to internal and external production, as is the case in Colombia.

Based on the above, this research aimed to estimate the balance between emission and fixation of GHG in the production process of coffee cherry (BefGHGcc). It was determined in carbon dioxide equivalent (CO_2e) per kg of coffee cherry produced on the different coffee farms, grouped by zones with potential for the production of specialty coffee in Antioquia - Colombia, one of the largest coffee producing departments in the country.

MATERIALS AND METHODS

This research was carried out based on the guidelines of the Intergovernmental Panel on Climate Change – IPCC (Eggleston *et al*., 2006) at a TIER 1 level, with a sample consisting of 30 representative coffee farms in different regions of the department of Antioquia-Colombia, which were grouped into four zones with specialty coffee production potential: Ciudad Bolívar, Giraldo, Urrao and El Retiro-La Ceja. In spite of the fact that the TIER 1 methodology was used according to IPCC, in order to reduce uncertainties, primary information was used in this research, such as organic matter, biomass volume, volume of the tree section, coffee cherry production, and annual amount of N applied to soils, among others.

Taking into account the fact that our systems of coffee production vary from farm to farm and type of shading, we aimed to quantify only the biomass fixation of coffee in relation to production, without taking into account the contribution of biomass generated by the different Agroforestry arrangements.

Some characteristics related to the crops of the farms within each center with specialty coffee production potential, such as agroecological zones, % of organic matter (MOc), and soil bulk, observed during the study period are shown in Table 1.

The estimation of GHG emission and fixation in the production of coffee in those locations with a potential for production of specialty coffee, was carried out until production of coffee cherry, since this is the more standardized step in the production process, and the post-harvest processing of specialty coffee tends to meet each customer's own guidelines to better support cup quality.

Table 1. Average characteristics of of the farms within each center.

Location	Farms per center	Altitude	MOc	Bulk density	Weighted age of coffee		Weighted planting density	Nitrogen-based fertilizer applications (kg per period)		
		(m)	(%)	(g/cm^3)	T1 (months)	T2	T1 – T2	N	P_2O_5	K_2O
Ciudad Bolívar	10	1765	16.2	0.94	39	46	5.299	7017	2587	7023
Giraldo	5	2017	9.5	1.18	48	50	5.930	842	144	686
La Ceja - El Retiro	5	1934	14.9	0.98	43	39	5.072	1542	254	1254
Urrao	10	2011	29.5	0.5	39	46	4.081	4156	1254	3863

Estimating the emission of CO_2e in the processes of coffee cherry production

An interview and some questionnaires were conducted on each farm to determine the volume of application of synthetic nitrogen fertilizers, amendments, organic matter as well as coffee cherry production, concerning the harvest period. CO_2e is equal to the production of N_2O in Global warming potential because of the greenhouse effect, N_2O with respect to CO_2 (GWP). The N_2O_{Direct} – N was estimated from the sum of two main contributions, nitrogen fertilization and joint contribution of N mineralization, related to the loss of C from soil organic matter, incorporation of organic matter and contribution of N from agricultural residues (coffee leaf litter) (Klein *et al.*, 2006):

$$N_2O - N = \left[\left(FSN + FON + FCR + FSOM + \left(CO_2 - C\ Emissions\right)\right) * EF_1\right] * GWP \quad (1)$$

Where:

N_2ODirect -N = annual direct emissions of N_2O-N produced from managed soils, kg N_2O-N year^{-1}

N_2O-Ncontribution N = annual direct emissions of N_2O-N produced by N inputs to managed soils, Kg N_2O-N year^{-1}

N_2O-NOS = annual direct emissions of N_2O-N from managed organic soils, kg N_2O-N year^{-1}

N_2O-N_{PRP} = annual direct releases of N_2O-N from urine and manure inputs to grazing lands, kg N_2O-N year^{-1}

In Equation 1, the terms N_2O-N_{OS} + N_2O-N_{Nprp} do not only take into account direct contributions (N_2O-$N_{N\ Contribution}$); therefore, Equation 2 and 3 were used after some mathematics arrangements to adjust to the coffee crop dynamics.

$$N_2O - N = \left[\left(FSN + FON + FCR + FSOM +\right) * EF_1\right] * GWP \quad (2)$$

Where:

N_2O–N = annual direct emissions of N_2O–N produced from managed soils, kg N_2O–N/period.

FSN = annual amount of N applied to soils in the form of synthetic fertilizer, kg N year^{-1}/period.

FON = annual amount of animal manure, compost, sewage sludge and other N inputs applied to soils by period.

FCR = annual amount of N in agricultural waste (aerial and underground), kg N/period.
FSOM = annual amount of N in mineral soils being mineralized, related to C loss from soil organic matter as a result of changes in land use or management, kg N/period.
CO_2 –C Emission = annual emissions of C by application of limes, kg C period.
EF1 = emission factor for N_2O emissions from N inputs, kg $(N_2O–N)^{-1}$ (kg N contribution)/period.

In this research, no emissions were found from the application of limes because there were no applications of calcium limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), which lead to CO_2 emissions since they are dissolved and release bicarbonate ($_2HCO_3^-$), which is converted to CO_2 and water (H_2O). The few applications made by the producers were from soluble sources of CaO, which do not contain inorganic carbon; therefore, they are not included in the calculations for the estimation of the CO_2 emissions from applications to the soil, as recommended by Klein *et al*. (2006).

Estimation of N_2O and CO_2e emission by application of synthetic nitrogen fertilizers to the soils, (FSN)

The nitrogen volume applied in the period (kg of N) was determined from equation 2 FSN, where total nitrogen fertilization contribution was established as follows:

$$FSN = \left(Kg\ N\ applied\right) * EF1 * MN_2O / MN_2 * GWP \quad (3)$$

Where:
FSN= Kg CO_2e (per contribution of $N)^{-1}$
EF1= 0.01
MN_2O/MN_2= 44/28 is the mass ratio of N_2O to N_2 molecules
GWP N_2O = 298. (Eggleston *et al*., 2006)

Estimation of N_2O and CO_2e emission related to C loss from organic matter of the soil, incorporation of organic matter and decomposition of litter. (FSOM, together with FON and FCR)

The FSOM was estimated from the soil calcination method of *loss on ignition*, (Zhang and Wang, 2014), which also quantified the FON and FCR in an indirect way. Two soil samples were taken at a depth of 20 cm per farm, 60 in total, at two different times, T1 and T2, in which the calcined organic matter (% MOc) was measured to obtain a single % MOc corresponding to the harvest period. A soil sample was also taken to determine the bulk (dry) density by means of the cylinder method.

For the estimation of C, the soil weight was established as a function of the bulk (dry) density at a depth of 20 cm and the average % MOc. The % C of the soils was calculated based on the IPCC guidelines (Eggleston *et al*., 2006), which corresponded to 35% organic matter (MO). A C mineralization rate of 1.39 % was estimated as reported by (Cardona and Sadeghian, 2005), for open-air coffees; in addition, a 44/12 kg C to kg CO_2e conversion factor was used.

Estimation of CO_2e fixation by biomass accumulation

To quantify the CO_2e fixation rate through the accumulation of biomass for the harvest period (T1 to T2), where T1 was August 2014 and T2 was February 2015, the estimation was based on the age and planting density of the different lots of each farm because the coffee farms usually have several lots of different ages, varieties and agronomic management, which directly influences the biomass storage; for this reason, the change of existence of Carbon (ΔCB) as a function of age and weighted density of the farms was quantified. The measurements were developed at 20 sites randomly in the lot most relevant to the age and weighted density of each farm, for a total of 600 measurements per farm.

To quantify the aerial biomass of coffee at each site, the useful volume of the section was estimated according to Farfan and Rendon (2014) with Equation (4) and multiplied by the density of the coffee wood (0.91 g cm^{-3}), and then multiplied by the total number of farm trees, which allowed us to estimate the total aerial biomass of the coffee plantation at a given time.

$$Vs = \frac{1}{3}.\pi.h.\left(R^2 + r^2 + \left(R + r\right)\right) \quad (4)$$

Where:
Vs = Volume of the tree´s section
h = Height of section
R = Largest radius
r = Smallest radius

To estimate the aerial biomass in T2, lower diameters were measured at the base of the stem of each axis (R). The

upper diameter (r) was measured in the transition zone from woody to green stem. The height (h) included the section of the woody stem, from the base to the transition zone between the lignified stem and green stem.

The aerial biomass in T1 was projected from the same site or tree in which the biomass of T2 was evaluated. The height was determined by subtracting the T2 height from the total height of tree growth, taking into account the rate of emission of one internode per month, according to recommendations of Ramirez (2014). Therefore, the height difference between the first (upper) internode and the seventh (lower) internode was measured. The lower diameter (R) measurement was taken at a height above the base corresponding to the growth height. The upper diameter (r) was the same as that measured in T2.

The CO_2e fixation was estimated with the ΔCB equation of the existence difference method (Aalde *et al*., 2006), where the rate of accumulation or growth of the biomass included the sum of the aerial and underground biomass (root) for such period. A coffee biomass/aerial biomass ratio of 27% was estimated (Eggleston *et al*., 2006).

$$\Delta CB = \frac{(C_{T2} \quad C_{T1})}{(T_2 \quad T_1)} \qquad (5)$$

$$C\sum_{i=j} = \sum_{i=j}^{n} \left(A_{i-j} * V_{i-j} * BCF_{SI.J} * \left(1+R\right) * Cf_i \right) \qquad (6)$$

Where:

ΔCB = annual change in carbon existences of biomass (the sum of aerial and underground biomass) on land remaining in the same category (kg C period).

C_{T1} = total carbon in biomass for each subcategory of land remaining in the same category at time T_1 (kg C).

C_{T2} = total carbon in biomass for each subcategory of land remaining in the same category at time T_2 (kg C).

C = total biomass carbon for the period T_1 to T_2.

A = land area that remains in the same land use category (ha).

V = volume of growing venal existence corresponding to the woody volume of the tree and excludes the branches, shoots, foliage and underground components, such as roots), (cm^3 ha^{-1}).

i = ecological zone i (i = 1 a n)

j = climatic domain j (j = 1 a n) $^{-1}$

R = relationship between the aerial biomass and underground biomass, kg d.m. of underground biomass (kg d.m. of aerial biomass). Where R = 0.27

CF = dry matter carbon fraction, kg C (kg d.m.)$^{-1}$. Being CF = 0.5 kg C/kg of dm. (Lasco *et al*., 2006).

BCEFS = biomass conversion and expansion factor, for expansion of growing venal existence volume to aerial biomass, tons of aerial biomass growth (cm^3 of growing existences volume)$^{-1}$.

The quantification of CO_2 accumulated in each fraction of biomass has been calculated through the relationship between the total weight of a CO_2 molecule and the weight of the carbon atom.

In order to estimate the CO_2e fixation per kg of coffee cherry through the annual change equation in carbon existence of biomass, the area of land (A) was modified by the total trees of the farm and the biomass conversion and expansion factor (BCEFS) was replaced by the projection of biomass accumulation from T2 to T1.

Balance of emission and fixation of GHG

The greenhouse gas emission and fixation balance (BefGEIcc), in kg of CO_2e per kg of produced coffee cherry (kg cc), was quantified using Equation 8 according to the guidelines of IPCC (Eggleston *et al*., 2006).

$$BefGEIha = \frac{\left[(Fixation\ kg\ CO_2 ha) - (emission\ CO_2 ha)\right]}{Period\,(months)} \qquad (7)$$

$$BefGEIcc = \frac{\Delta CB - ((N_2O - N) + FSOM + (CO_2 - C))}{kg\ cc} \qquad (8)$$

Experiment setup

Four experiment units were established in the locations of Ciudad Bolivar, Giraldo, Retiro-La Ceja and Urrao. Two different parameters were measured for each experiment unit: fixation and emissions.

- GHG emission estimates (N_2O-N, FSOM and CO_2-C) were carried out in the four locations on 30 different

farms with potential special coffees production. The measurements were taken at two different times: one in the initial period (T1) and another one in the final period (T2).

- The GHG fixation estimation was carried out in the same four locations and 30 farms. On each farm, 20 sub-samples were chosen in the most representative lots in relation to the density and age of the crop in order to determinate the annual change in the carbon existence of biomass (ΔCB). The biomass of the coffee was measured the initial period (T1) and the final period (T2).

The different elements that comprised the response variable for both the emission and fixation were analyzed for differences between the locations through an analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Average estimate per center of GHG emission in kg of CO_2e per kg of coffee cherry:

The Anova of average GHG emission by application of synthetic nitrogen fertilizers (kg of CO_2e per kg of coffee cherry) (FSN) showed significant differences (P<0.0001) in the mean GHG emissions from nitrogen fertilizer applications in kg CO_2e per kg of coffee cherry between the locations. Table 2 shows the comparison between the locations using the LSD test at a 0.05 significance level. Urrao emitted the most with 0.215 kg of CO_2e per kg of coffee cherry, followed by La Ceja-El Retiro and Giraldo.

Table 2. Average GHG emission per location with potential specialty coffee production from synthetic nitrogen fertilizer applications in kg CO_2e per kg of coffee cherry.

Location	kg CO_2e coffee cherry
Urrao	0.215 ± 0.086 a
La Ceja-El Retiro	0.127 ± 0.085 ab
Giraldo	0.083 ± 0.032 b
Ciudad Bolívar	0.055 ± 0.019 b

Means with the same letter do not differ significantly in the emissions from applications of nitrogen fertilizers (LSD test at 5%).

Ciudad Bolívar and Giraldo emitted less GHG with 0.055 kg and 0.083 kg of CO_2e per kg of coffee cherry, respectively. This was especially influenced by the fact that these locations presented the highest average cherry production in kg per tree, with 1.6 and 1.2, respectively.

The average emission by application of nitrogen fertilizers was 0.125 kg of CO_2e per kg of coffee cherry, which accounts for 15.7% of total emissions, as reported by Noponen *et al.* (2012), in their studies on the quantification of the carbon footprint in conventional coffee in Costa Rica, which was 0.26 to 0.67 kg of CO_2e per kg of coffee cherry, representing 50% of all emissions. Segura and Andrade (2012) reported an emission participation of nitrogen fertilizer applications ranging from 0.033 to 0.117 kg of CO_2e per kg of coffee cherry, for a participation of 68 to 82% of the emissions. These percentages of participation in the emissions differ from the 15.7% quantified in this paper. This is probably due to the fact that these authors did not take into account the losses of C from soil MO and the decomposition of leaf litter.

The Anova of the average GHG emissions by loss of C from MOs, decomposition of leaf litter and input of MO in kg of CO_2e per kg of produced coffee cherry showed significant differences (P = 0.003) in the mean emission by loss of C from MOs, decomposition of leaf litter and input of organic matter in kg of CO_2e per kg of coffee cherry between the locations. Table 3 shows the corresponding average values per location.

An emission range from 0.38 to 1.180 was found, with an average emission of 0.674 kg of CO_2e per kg of coffee cherry. Urrao presented statistical differences from all the other locations, duplicating the average emission of CO_2e by loss of C at 1.108 Kg CO_2e per kg of coffee cherry, in comparison with the other locations. This could be mainly because this location had the highest average content of % Moc, with 29.5%, as compared to

Table 3. Average GHG emissions by loss of C from MOs, decomposition of leaf litter and input of MO in kg of CO_2e per kg of produced coffee cherry per location

Location	kg CO_2e per kg of coffee cherry
Urrao	1.108 ± 0.513 a
Ciudad Bolívar	0.491 ± 0.404 b
La Ceja-El Retiro	0.472 ± 0.260 b
Giraldo	0.378 ± 0.132 b

Means with the same letter do not differ significantly in the emissions from the loss of C from MOs, decomposition of leaf litter and input of MO (5% LSD test).

17.1% in Ciudad Bolívar, 15% in La Ceja-El Retiro, and 9.5% in Giraldo. Similarly, Urrao presented the lowest averages in the average production of coffee cherry per tree and planting density, with 0.82 kg of coffee cherry and 4.081 trees ha^{-1}, respectively.

Segura and Andrade (2012), reported 6.95 kg CO_2e per kg of coffee cherry, along with Montilla *et al*. (2008), who reported 6.23 kg CO_2e per kg of coffee cherry, mainly because of the organic matter inputs. These results are far from the data obtained here since this measurement was taken more directly through the soil calcination method, which is closer to that published by Hergoualc'h *et al*. (2012).

The Anova of average fixation of GHG by accumulation of biomass in kg of CO_2e per kg of coffee cherry per center (ΔGB) did not show significant differences (P=0.117) in the mean fixation produced during the period between the locations. Table 4 presents the corresponding averages per location. However, Urrao and Giraldo fixed the most. The fixation oscillated between 0.682 and 1.459 for an average of 1.068 kg of CO_2e per kg of coffee cherry, which is the same as fixing an average of 8.941 kg of CO_2e ha^{-1} $year)^{-1}$, which is lower than that reported by Segura and Andrade (2012) of 13.1 kg of CO_2e per kg of green coffee, representing an approximate equivalence of 2.6 kg of CO_2e per kg of coffee cherry, but higher than that reported by Hergoualc'h *et al*. (2012, 2008).

Table 4. Average GHG fixation per location with potential specialty coffee production in kg CO_2e per kg of produced coffee cherry.

Location	kg CO_2e per kg of coffee cherry
Urrao	1.459 ± 1.038 a
Giraldo	1.037 ± 0.379 a
Ciudad Bolivar	0.835 ± 0.280 a
La Ceja-El Retiro Giraldo	0.682 ± 0.265 a

Means with the same letter do not differ significantly in the fixation of GHG (LSD test at 5%).

Average GHG emission and fixation balance per center with potential for specialty coffee production (BefGEIcc).

The Anova did not show significant differences (P=0.584) in the mean emission and fixation balances between the locations. Table 5 shows the balance between average fixation and emission of GHG per locations, in kg of CO_2e per kg of coffee cherry. Generally, the production of coffee cherry in areas with a potential for specialty coffee production has a positive balance, fixing between 0.083 and 0.575 kg CO_2e per kg of coffee cherry, for an average of 0.27 kg CO_2e per kg of coffee cherry. Noponen *et al*. (2012) estimated the balance as a function of the changes in soil C stock, obtaining BefGEIcc values between 0.26 and 0.67 kg CO_2e per kg of coffee cherry, results that are comparable with those found in this research.

Hergoualc'h *et al*. (2012), estimated the emission balance and fixation of GHG in mono-culture of coffee in Costa Rica in 3.83 Mg ha of CO_2e year, also incorporating the traditional emission sources

Table 5. Emission and fixation balance of GHG per kilogram of coffee cherry.

Location	kg CO_2e per kg of coffee cherry
Giraldo	0.575 ± 0.379 a
Ciudad Bolívar	0.289 ± 0.321 a
Urrao	0.136 ± 1.005 a
La Ceja-El Retiro	0.083 ± 0.125 a

Means with the same letter do not differ significantly for the emission and fixation balance of GHG (5% LSD test).

(applications of N fertilizers, limes and organic matter), finding emissions from changes in soil C of 0.27 kg CO_2e per kg of coffee cherry, which are in line with those found in this research when doing conversions (3.2 Mg ha CO_2e per year).

These results indicate that the coffee cherry production process in these locations with the applicable agronomic processes are being carried out in a sustainable and environmentally responsible way in terms of the GHG storage.

CONCLUSIONS

This research revealed that the balance of emission and fixation of GHG per locations with a potential for specialty coffee production was positive, which shows the environmental sustainability of the agronomic activities. This is worth highlighting for future uses of these productive systems in markets seeking green certifications/Green Seal certification.

It was estimated a positive fixation of 0.27 kg of CO_2 equivalent per kg of coffee cherry. The statistical analysis did not show significant differences in the emission balance and GHG fixation in coffee cherry production between the locations with a potential for specialty coffee production in the Antioquia Department.

References

Aalde H, Gonzalez P, Gytarsky M, Krug T, Kurz WA, Ogle S and Ravindranath NH. 2006. Capitulo 4: Tierras forestales. pp. 1-93. En: Directrices del IPCC de 2006 para los inventarios nacionales de gases de efecto invernadero. Editorial IGES, Japón. 425 p.

Andrade HJ, Segura MA, Canal DS, Feria M, Alvarado JJ, Marín LM, Pachón D and Gómez MJ. 2014. Chapter 3. The carbon footprint of coffee production chains in Tolima, Colombia. pp. 53-66. En: Oelbermann M (ed.). Sustainable agroecosystems in climate change mitigation. Editorial Wageningen Academic Publishers, Netherlands. 272 p. doi: 10.3920/978-90-8686-788-2_3.

Cardona C and Sadeghian S. 2005. Ciclo de nutrimentos y actividad microbiana en cafetales a libre exposición solar con sombrio de *Inga* spp. Cenicafé 56(2): 127–141.

De Pinto A, Li M, Haruna A, Hyman G, Martinez MAL, Creamer B and Martinez JD. 2016. Low emission development strategies in agriculture. An Agriculture, Forestry, and Other Land Uses (AFOLU) Perspective. World Development 87(1): 180–203. doi: 10.1016/j.worlddev.2016.06.013

Farfan VF and Rendon SJ. 2014. Producción de madera por la variedad Castillo y Tabi en sistemas agroforestales. En: Avances técnicos Cenicafé, http://biblioteca.cenicafe.org/bitstream/10778/563/1/avt0448.pdf. 4 p; Consulta: marzo 2015.

Federación Nacional de Cafeteros de Colombia FNC. 2014. Comportamiento de la industria cafetera colombiana. En: Federación Nacional de Cafeteros de Colombia, https://www.federaciondecafeteros.org/static/files/Informe_Industrial_2014_Web.pdf. 62 p; consulta: noviembre 2015.

Hergoualc'h K, Blanchart E, Skiba U, Hénault C and Harmand JM. 2012. Changes in carbon stock and greenhouse gas balance in a coffee (*Coffea arabica*) monoculture versus an agroforestry system with *Inga densiflora*, in Costa Rica. Agriculture. Ecosystems and Environment 148(1): 102–110. doi: 10.1016/j.agee.2011.11.018

Hergoualc'h K, Skiba U, Harmand JM and Hénault C. 2008. Fluxes of greenhouse gases from Andosols under coffee in monoculture or shaded by *Inga densiflora* in Costa Rica. Biogeochemistry 89(3): 329–345. doi: 10.1007/s10533-008-9222-7

Eggleston HS, Buendia L, Miwa K, Ngara T and Tanabe K. 2006. IPCC Guidelines for national greenhouse gas inventories, prepared by the National Greenhouse Gas Inventories Programme. IGES, Japón. 425 p.

Klein CD, Novoa RSA, Ogle S, Smith KA, Rochette P, Wirth TC and Rypdal K. 2006. Capitulo 11: Emisiones de N_2O de los suelos gestionados y emisiones de CO_2 derivadas de la aplicación de cal y urea. pp. 1-56. En: Directrices del IPCC de 2006 para los inventarios nacionales de gases de efecto invernadero. Editorial IGES, Japón. 425 p.

Lasco RD, Ogle S, Raison J, Verchot L, Wassmann R, Yagi K and Smith P. 2006. Capitulo 5: Tierras de cultivo. pp. 1–74. En: Directrices del IPCC de 2006 para los inventarios nacionales de gases de efecto invernadero. Editorial IGES, Japón. 425 p.

Noponen MRA, Jones G, Haggar JP, Soto G, Attarzadeh N and Healey JR. 2012. Greenhouse gas emissions in coffee grown with differing input levels under conventional and organic management. Agriculture. Ecosystems and Environment 151(1): 6–15. doi: 10.1016/j.agee.2012.01.019

Organización Internacional del Café. 2014. Comercio mundial del café (1963—2013): Reseña de los mercados, retos y

oportunidades con que se enfrenta el sector. En: ICC 111-5 Rev. 1, http://juntadelcafe.org.pe/documentos/comercio-mundial-del-cafe-1963-2013-resena-de-los-mercados-retos-y-oportunidades-conque. 29 p; consulta: mayo 2015.

Ponte S. 2004. Estándares y sostenibilidad en el sector cafetero: una aproximación global a la cadena de valor. Revista Federación Nacional de Cafeteros 20(1): 1–79.

Ramirez BV. 2014. La fenología del café una herramienta para apoyar la toma de desiciones. Avance Técnico Cenicafé, http://biblioteca.cenicafe.org/handle/10778/489. CENICAFE. 8 p; consulta: noviembre 2015.

Rees RM, Flack S, Maxwell K and Mistry A. 2014. Chapter 23: Air: Greenhouse gases from agriculture. pp. 293-304. En Encyclopedia of Agriculture and Food Systems. Oxford: Academic Press. doi: 10.1016/B978-0-444-52512-3.00088-7

Montilla PJ, Arcila PJ, Aristizabal LM, Montoya REC, Puerta QGI and Cadena GG. 2008. Propiedades físicas y factores de conversión del café en el proceso de beneficio. Cenicafé 59(2): 120–142.

Segura MA and Andrade HJ. 2012. Huella de carbono en cadenas productivas de cafe (*Coffea arabica* L.) con diferentes estandares de certificacion en Costa Rica. Luna Azul 35(1): 60-67.

Zhang H and Wang JJ. 2014. Loss on Ignition Method. In: Agricultural Service Laboratory (ed.). Soil test methods from the Southeastern United States. En: Book. Retrieved from Methods Manual SERA, http://saaesd.ncsu.edu/docs/MethodsManualFinalSERA6.pdf. 157 p; consulta: febrero 2015.

ÍNDICE DE AUTORES

Sanín Villarreal Alejandra. Evaluation of bioactive compounds with functional interest from yellow pitahaya (*Selenicereus megalanthus* Haw). 70(3): 8311-8318. 2017.

Sehgal Deepmala. Genetic analysis of morpho-physiological traits and yield components in F2 partial diallel crosses of bread wheat (*Triticum aestivum* L.). 70(3): 8237-8250. 2017.

Seleguini Alexsander. Economic viability of muskmelon cultivation in different planting spacing in Brazil central region. 70(3): 8319-8325. 2017.

Serna-Jiménez Johanna Andrea. Evaluation of bioactive compounds with functional interest from yellow pitahaya (*Selenicereus megalanthus* Haw). 70(3): 8311-8318. 2017.

Tamayo Vélez Álvaro. Agroindustrial performance of sugarcane varieties for panela in Antioquia, Colombia. 70(3): 8303-8310. 2017.

Torres Grisales Yennifer. Evaluation of bioactive compounds with functional interest from yellow pitahaya (*Selenicereus megalanthus* Haw). 70(3): 8311-8318. 2017.

Torres-Valenzuela Laura Sofía. Evaluation of bioactive compounds with functional interest from yellow pitahaya (*Selenicereus megalanthus* Haw). 70(3): 8311-8318. 2017.

Valero Nelson. Effect of a low rank coal inoculated with coal solubilizing bacteria for the rehabilitation of a saline-sodic soil in field conditions. 70(3): 8271-8283. 2017.

Vázquez Bedoya Elizabeth. Characterization and typification of coffee production systems (*Coffea arabica* L.), Andes municipality. 70(3): 8327-8339. 2017.

Vendruscolo Eduardo Pradi. Economic viability of muskmelon cultivation in different planting spacing in Brazil central region. 70(3): 8319-8325. 2017.

Yahyaoui Amor. Genetic analysis of morpho-physiological traits and yield components in F2 partial diallel crosses of bread wheat (*Triticum aestivum* L.). 70(3): 8237-8250. 2017.

POLÍTICA EDITORIAL

REVISTA FACULTAD NACIONAL DE AGRONOMÍA

La Revista Facultad Nacional de Agronomía (RFNA), es una publicación de la Facultad de Ciencias Agrarias de la Universidad Nacional de Colombia - Sede Medellín. Esta orientada a profesores, investigadores, estudiantes, extensionistas y a todos aquellos profesionales que crean conocimiento y articulan la ciencia y la tecnología para hacer más productivo el campo a nivel empresarial y de economía campesina.

La periodicidad de la Revista es cuatrimestral, con circulación nacional e internacional y tiene como objetivo divulgar artículos escritos en inglés, originales e inéditos de carácter científico que respondan a preguntas específicas y que proporcionen soporte y pruebas a una hipótesis, en aspectos relacionados con las Ciencias Agronómicas, Zootecnia, Ciencias Forestales e Ingeniería Agrícola y de Alimentos y otras afines que contribuyan a la solución de los limitantes del agro en el trópico.

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Artículos de revisión: Documentos producto de una investigación terminada donde se analizan, sistematizan e integran los resultados de investigaciones publicadas o no publicadas, sobre un campo en ciencia o tecnología, con el fin de dar cuenta de los avances y las tendencias de desarrollo. Se caracteriza por presentar una cuidadosa revisión bibliográfica de por lo menos 50 referencias.

Artículos de reflexión: Documento que presenta resultados de investigación terminada desde una perspectiva analítica, interpretativa o crítica del autor, sobre los temas específicos ya citados, recurriendo a fuentes originales.

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INSTRUCCIONES A LOS AUTORES

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Se debe utilizar el Sistema Internacional de Unidades (SIU), y aquellas unidades específicas de mayor uso por parte de la comunidad científica. Cuando se requiera se debe usar la forma exponencial. Ejemplo: kg ha^{-1}. El significado de las abreviaturas debe citarse por extenso cuando se mencionan por primera vez en el manuscrito. El estilo de escritura debe ser absolutamente impersonal, en tiempo gramatical pasado para la introducción, los procedimientos y los resultados y presente para la discusión, evitando la conjugación de verbos en primera o tercera persona del singular o el plural.

Los números del uno al nueve se escriben en palabras, excepto cuando incluyen unidades de medida o se mencionan varios números. Ejemplo: "ocho tratamientos", "3, 7 y 9 lecturas", "15 kg". Use cero antes del punto decimal. Para separar números en intervalos de uno o más años, use la letra "a", y guión para temporadas de crecimiento. Ejemplo: Periodo 2002 a 2005; temporadas de crecimiento 1999-2000, 2000-2001.

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El título del artículo no debe incluir abreviaturas y es obligatoria su respectiva traducción al idioma español. En lo posible, el título no debe exceder de 15 palabras y debe reflejar con precisión el contenido del documento. Cuando contenga nombres científicos de especies vegetales o animales, éstos se deben escribir con letra cursiva (itálica) en minúsculas, sólo con mayúsculas la primera letra del género y del clasificador. Debajo del título en inglés se escribe el nombre(s) y apellido(s) de los autores, sin sus respectivos títulos académicos, ni cargos laborales, en una línea horizontal y de acuerdo con su contribución en la investigación y/o preparación del artículo.

Como nota al pie de la primera página, se escribe el título de pregrado, el cargo laboral de los autores, el nombre y la ciudad de ubicación de la entidad a la cual prestan sus servicios o del patrocinador para la realización del trabajo y su respectiva dirección de correo electrónico, indicando el autor de correspondencia. Además, se debe adjuntar un resumen de la hoja de vida de los autores, donde se mencionen los artículos publicados en otras revistas.

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El resumen no debe exceder de 250 palabras escritas en un único párrafo. Se debe escribir en inglés y español. Debe contener en forma breve la justificación, los objetivos, los métodos utilizados, los resultados obtenidos más relevantes y las conclusiones. Es obligatorio acompañar el resumen con un máximo de seis palabras clave distintas a las utilizadas en el título. Se aceptan como palabras clave no sólo las palabras simples, sino también términos compuestos hasta de tres palabras. Deben ir escritas en minúsculas y separadas por comas.

Introducción

Puede tener o no título. Define el problema e informa sobre el estado del arte respecto al tema principal del artículo; además, señala las razones que justifican la investigación y plantea los objetivos de la misma. Es obligatorio acompañar los nombres vulgares con el nombre(s) científico(s) y la abreviatura(s) del clasificador en la primera mención dentro del texto. No se deben mencionar marcas de productos, sino su nombre genérico o químico

Materiales y métodos

En este apartado se deben describir en forma clara, concisa y secuencial, los materiales (vegetales, animales, implementos agrícolas o de laboratorio) utilizados en el desarrollo del trabajo; además, se mencionan los aspectos relacionados con la ubicación, preparación y ejecución de los experimentos. Se debe indicar el diseño seleccionado, las variables registradas, las transformaciones hechas a los datos, los modelos estadísticos usados y el nivel de significancia empleado. Evitar detallar procedimientos previamente publicados.

Resultados y discusión

Son la parte central del artículo, deben estar respaldados por métodos y análisis estadísticos apropiados. Se deben presentar de manera lógica, objetiva y secuencial mediante textos, tablas y figuras; estos dos últimos apoyos deben ser fáciles de leer, autoexplicativos y estar siempre citados en el texto. Las tablas se deben elaborar con pocas columnas y renglones. Se debe tener

la precaución de incluir el nivel de significancia estadística representado por letras minúsculas del comienzo del alfabeto (a, b, c, d,...), un asterisco simple (*) para *P*<0,05, doble asterisco (**) para P<0,01 o triple asterisco (***) para *P*<0,001. Las investigaciones que no siguen un diseño estadístico, deben mostrar la información de manera descriptiva. Use subíndices para modificaciones, reserve superíndices para potencias o notas al pie en tablas y figuras.

La discusión Se refiere al análisis e interpretación objetiva de los resultados, confrontándolos con los obtenidos en otras investigaciones, o con los hechos o teorías conocidos sobre el tema. Explica los resultados en particular cuando difieren de la hipótesis planteada. Destaca la aplicación práctica o teórica de los resultados obtenidos y las limitaciones encontradas. Resalta la contribución que se hace a una determinada área del conocimiento y el aporte a la solución del problema que justifica la investigación. Finalmente, proporciona elementos que permitan proponer recomendaciones o lanzar nuevas hipótesis. No se deben hacer afirmaciones que van más allá de lo que los resultados pueden apoyar.

Conclusiones

Son las afirmaciones originadas a partir de los resultados obtenidos, deben ser coherentes con los objetivos planteados y la metodología empleada; además, expresar el aporte al conocimiento en el área temática estudiada y proponer directrices para nuevas investigaciones.

Agradecimientos

Si se considera necesario, se incluyen los agradecimientos o reconocimientos a personas, instituciones, fondos y becas de investigación, que hicieron contribuciones importantes en la concepción, financiación o realización de la investigación.

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Ponencias en memorias de congresos, seminarios, simposios: García M. 1998. La ingeniería geotécnica y la protección del medio ambiente. pp. 65-94. En: Memorias IX Congreso Colombiano de la Ciencia del Suelo. Sociedad Colombiana de la Ciencia del Suelo. Santa Fé de Bogotá.

Tesis, trabajos de grado. Gómez C. 2004. Autoecología del Mortiño (*Vaccinium meriodinale* Swartz Ericaceae). Tesis Magister en Bosques y Conservación Ambiental. Facultad de Ciencias Agropecuarias. Universidad Nacional de Colombia. Medellín. 78 p.

Abril G. 2002. Biogeografía y descripción de las especies del género *Collaria* sp. en seis zonas lecheras del Departamento de Antioquia. Trabajo de grado Ingeniería Agronómica. Facultad de Ciencias Agropecuarias. Universidad Nacional de Colombia. Medellín. 49 p.

Cita de cita. Magalhaes LM e da Cruz AJ. 1979. Fenologia do pau-rosa (*Aniba duckei* Kostermans), Lauraceae, em floresta primária na Amazônia Central. Acta Amazónica 9(2): 227- 232. Citado por: Gómez CP. 2004. Autoecología del mortiño (*Vaccinium meriodinale* Swartz Ericaceae). Tesis Magister en Bosques y Conservación Ambiental. Facultad de Ciencias Agrarias, Universidad Nacional de Colombia. Medellín. 46 p.

Suplemento de revista. Silva AM y Carrillo NN. 2004. El manglar de piruja, Golfito, Costa Rica: un modelo para su manejo. Revista de Biología Tropical 52 Supl. 2: 195-201.

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The National Faculty of Agronomy Journal (RFNA) is published by the Faculty of Agricultural Sciences of Universidad Nacional de Colombia – Medellín. It is aimed at teachers, researchers and students in agronomy, animal, and forestry sciences, food and agricultural engineering, agricultural advisers and at all those professionals who create knowledge and articulate science and technology to make the field more productive at business and rural economy levels.

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Units, abbreviations and style

International System of Units (SI), and those specific units of greater use by the scientific community must be used. When required must be used the exponential form. Example: kg ha^{-1}. The meaning of abbreviations should be cited in full when first mentioned in the manuscript. The writing style should be totally impersonal. Introduction, procedures and results should be written in grammatical past tense. Discussion should be written in grammatical present tense, avoiding the conjugation of verbs in first or third person singular or plural.

The numbers from 1 to 9 are written in words, except when they include units of measure or several numbers are listed. Example: "eight treatments", "3,7 and 9 readings", "15 kg". Use zero before the decimal point. To separate numbers in intervals of one to two years, use the letter "a" and hyphen for growing seasons. Example period 2002a2005, growing seasons 1999-2000, 2000-2001.

Title and authors

The article should not include abbreviations and its translation into English is required. As far as possible, the title should not exceed 15 words and must accurately reflect the paper content. When the article contains scientific names of plants or animals, they should be written in italics in lower case, only the first letter of gender and classifier should be capital. Under the title in English the author or authors' name (s) and surname (s) is /are written, without academic degrees or job positions, in a horizontal line according to the contribution to research and / or preparation of the article.

As a footnote on the first page, write the title of undergraduate, authors' job positions, the name and city location of the entity to which they serve, or the sponsors for the research work and their respective email address. In addition, a summarized authors' résumé including reference to the articles published in other magazines should be attached.

Abstract and key words

The abstract should not exceed 250 words written in a single paragraph. It must be written in English, Spanish or Portuguese. It should contain in brief the justification, aims, methods used, the most relevant results, and conclusions. It is required to accompany the abstract with a maximum of six key words, translated into English, different from those used in the title. Single words as well as compound terms of up to three words are accepted as key words. They must be written in lowercase, separated by commas.

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It may or not have a title. It defines the problem and reports on the state of the art on the main subject of the article, it also points out the reasons for the research and sets out its aims. It is required to accompany common names with the corresponding scientific name (s) name and abbreviation (s) of the classifier at the first mention in the text. Brands must not be mentioned but the generic or chemical name.

Materials and methods

In this section, materials (crops, livestock, agricultural or laboratory implements) used in the development of work should be clearly, concisely and sequentially described. Aspects related to the location, preparation and execution of experiments should also be mentioned. The selected design, the recorded variables, the changes made to data, the statistical models used and the significance level used should be indicated. Authors must avoid detailing procedures previously published.

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They are the central part of the article and must be supported by appropriate statistical methods and analysis. They should be presented in a logical, objective and sequential way through texts, tables and figures; the latter two supports should be easy to read, self- explanatory and always quoted in the text. The tables should be composed by few columns and rows. Care should be taken to include the statistical significance level represented by lowercase letters of the beginning of the alphabet (a, b, c, d,…), a single asterisk (*) for $P<0.05$, double asterisk (**) for $P<0.01$ or triple asterisk (***) for $P<0.001$. Researches that do not follow a statistical design should display the information in a descriptive way. Use subscripts to modifications, reserve superscripts for potencials or footnotes in tables and figures.

Discussion

It refers to the analysis and objective interpretation of results, comparing them with those obtained in other researches, or with known facts or theories on the subject. It explains the results, especially when they differ from the stated hypothesis. It emphasizes the practical or theoretical application of the obtained results and constraints encountered. Discussion also highlights the contribution that is made to a particular area of knowledge and to the solution of the problem that justifies the research. Finally, it provides elements that allow making recommendations or launching new hypotheses. Statements that go beyond what the results may support should be avoided.

Conclusions

Conclusions are assertions arising from the obtained results. They should be consistent with the objectives stated and the methodology used. They should also express the contribution to knowledge in the studied subject area and propose guidelines for further researches.

Acknowledgements

If necessary, acknowledgements or recognitions to individuals, institutions, funds and research grants that made important contributions in the design, financing or carrying out of the research are included.

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Only bibliographical references cited in the text are listed. Lecture notes, articles in preparation or in press, or any other publication with limited circulation are not accepted. Excessive self-citation should be avoided.

The bibliography should be included at the end of the text, containing only the references cited in it, including the doi number. Citations in the text should include author's surname and year, with comma between author and year. Example: Pérez, 1995. They should also keep the following citation order:

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Presentations in Memoirs of Congresses, seminars and symposia: García M. 1998. Geotechnical engineering and environmental protection. p. 65-94. In: Memorias IX Colombian Congress of Soil Science. Colombian Society of Soil Science. Santa Fé de Bogotá.

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Abril G. 2002. Biogeografía y descripción de las especies del género *Collaria* sp. en seis zonas lecheras del departamento de Antioquia, Dissertation. Faculty of Agricultural Sciences. Universidad Nacional de Colombia. Medellín. 49 p.

Citation of a citation: Magalhaes LM e da Cruz AJ. 1979. Phenology do pau-rosa (*Aniba duckei* Kostermans), Lauraceae, em floresta primária na Amazônia Central. Acta Amazónica 9(2): 227-232. Cited by: Gomez CP. 2004. Autoecología de mortiño (*Vaccinium meriodinale* Swartz Ericaceae). Master's Thesis in Forestry and Environmental Conservation. Faculty of Agricultural Sciences, Universidad Nacional de Colombia. Medellín. 46 p.

Journal Supplement: Silva AM y Carrillo NN. 2004. El manglar de piruja, Golfito, Costa Rica: un modelo para su manejo. Journal of Tropical Biology 52 Suppl. 2: 195-201.

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POLÍTICA EDITORIAL

REVISTA FACULTAD NACIONAL DE AGRONOMÍA

A Revista Facultad Nacional de Agronomía é uma publicação da Facultad de Ciencias Agrarias da Universidad Nacional de Colombia – Sede Medellín. Orienta-se a professores, pesquisadores, estudantes e a todos os profissionais que criam conhecimento e articulam a ciência e a tecnologia para fazer o campo mais produtivo no âmbito empresarial e da economia camponesa.

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Deve utilizar-se o Sistema Internacional de Unidades (SIU), e aquelas unidades específicas de maior uso por parte da comunidade científica. Quando seja necesario debe-se usar a forma exponencial Exemplo: kg ha^{-1}. O significado das abreviaturas deve ser citado por extenso quando mencionadas por primeira vez no manuscrito. O estilo da escrita deve ser absolutamente impessoal, em tempo gramatical pretérito na introdução, procedimentos e resultados, e presente na discussão, evitando a conjugação de verbos em primeira ou terceira pessoa do singular ou do plural.

Os números de um a nove devem-se escrever em palavras, exceto quando refletem ou indicam unidades de medida ou se colocam vários números consecutivamente Exemplo: "oito tratamentos", "3, 7 y 9 leituras", "15 kg". Deve-se utilizar o zero antes do ponto decimal. Para separar intervalos de um o mais anos, deve-se usar a letra "a", e hífen para períodos de crescimento (safras). Exemplo. Período 2002 a 2005, safras 1999-2000, 2000-2001.

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O título do artigo não deve incluir abreviaturas e é obrigatória sua tradução ao inglês. Sempre que possível, o título não deve superar as 15 palavras e deve refletir com precisão o conteúdo do documento. Em caso de conter nomes científicos de espécies vegetais ou animais, estes devem ir em itálica minúscula, com maiúscula somente a primeira letra do gênero e do classificador. Embaixo do título em inglês escreve-se o nome(s) e sobrenome(s) dos autores, sem seus títulos acadêmicos, nem cargos laborais, numa linha horizontal e conforme a sua contribuição à pesquisa e/ou preparação do artigo.

Na parte inferior da primeira página, como nota ao rodapé, escreve-se o cargo laboral dos autores, o nome e a cidade onde se localiza a entidade para a qual trabalham ou do patrocinador para a realização do trabalho e o correspondente endereço eletrônico. Adicionalmente, deve anexar-se um resumo do currículo dos autores, onde se mencionem os artigos publicados em outras revistas.

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O resumo não deve superar as 250 palavras escritas num único parágrafo. Deve ser redigido em espanhol, inglês ou português. Deve conter em forma breve justificação, objetivos, métodos utilizados, resultados obtidos mais relevantes e conclusões. É obrigatório acompanhar o resumo com um máximo de seis palavras-chave, traduzidas ao inglês (key words), diferentes às utilizadas no título. Aceitam-se como palavras-chave não somente palavras simples, mas também termos compostos por até três palavras. Estas devem ir escritas em minúscula e separadas por vírgulas.

Introdução

O título não é obrigatório. Define o problema e informa sobre o estado da arte a respeito do tema principal do artigo, além disso, indica as razões que justificam a pesquisa e propõe os objetivos da mesma. É obrigatório acompanhar os nomes vulgares com o nome(s) científico(s) e a abreviatura(s) do classificador na primeira menção dentro do texto. Não mencionar marcas de produtos, mas nomes genéricos ou químicos.

Materiais e métodos

Aqui devem ser descritos em forma clara, concisa e seqüencial, os materiais (vegetais, animais, implementos agrícolas ou de laboratório) utilizados no desenvolvimento do trabalho, assim mesmo mencionam-se os aspectos relacionados com a localização, preparação e execução dos experimentos. Devem indicar-se o desenho escolhido, as variáveis registradas, as transformações feitas aos dados, os modelos estatísticos usados e o nível de significância empregado. Evitar detalhar procedimentos previamente publicados.

Resultados

São a parte central do artigo, devem ir respaldados por métodos e análises estatísticas apropriadas. Devem apresentar-se de maneira lógica, objetiva e seqüencial mediante textos, tabelas e figuras; estes dois últimos apoios devem ser de fácil leitura, interpretáveis de forma autônoma e ir citados sempre no texto. As tabelas devem conter poucas colunas e linhas. É preciso incluir o nível de significância estatística representado por letras minúsculas do começo do alfabeto (a, b, c, d,...), asterisco simples (*) para $P< 0,05$, duplo asterisco (**) para $P< 0,01$ ou três asteriscos (***) para $P<0,001$. As pesquisas que não obedecem um

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Discussão

Refere-se à análise e interpretação objetiva dos resultados, confrontando-os com os resultados obtidos em outras pesquisas, ou com os fatos ou teorias conhecidas sobre o tema. Explica os resultados, particularmente quando diferem da hipótese proposta. Destaca a aplicação prática ou teórica dos resultados obtidos e as limitações encontradas. Ressalta a contribuição a uma determinada área do conhecimento e o aporte à solução do problema que justifica a pesquisa. Finalmente, proporciona elementos que permitem propor recomendações ou lançar novas hipóteses. Não devem ser feitas afirmações que vão além do que os resultados podem apoiar.

Conclusões

São as afirmações originadas a partir dos resultados obtidos, devem ser coerentes com os objetivos propostos e a metodologia empregada; adicionalmente, expressar a contribuição ao conhecimento na área temática estudada e propor diretrizes para novas pesquisas.

Agradecimentos

Caso for necessário, incluir-se-ão os agradecimentos ou reconhecimentos a pessoas, instituições, fundos ou bolsas de pesquisa que fizeram contribuições importantes na concepção, financiamento ou realização da pesquisa.

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Devem aparecer somente as referências bibliográficas mencionadas no texto. Não se aceitam notas de aula, artigos em construção ou no prelo, ou qualquer outra publicação de circulação limitada. Evitar o excesso de auto-citas.

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As referências deverão conter todos os dados que permitam sua fácil localização.

Exemplos:

Para livros: Autor(es), ano. Título do livro, edição, cidade de sua sede, casa editora e, páginas consultadas (pp. # - #) ou páginas totais (# p.). Exemplo: Robinson A, Morrison J, Muehrcke P, Kimerling AJ and Guptill S. 1995. Elements of Cartography. Sixth edition. John Wiley and Sons, Inc., New York. 674 p.

Para capítulos de livros: Autor(es), ano. Título do capítulo, páginas consultadas (pp. # - #). Em: Sobrenomes e nomes dos compiladores ou editores (eds.), título do livro, edição, casa editora e cidade de sua sede, páginas totais (# p.). Exemplo: Bernal H. 1996. Capítulo 6: Evapotranspiración. pp. 112-125. Em: Agrios G. (ed.). Fitopatología. Segunda edição. Editorial Limusa, México D.F. 400 p.

Para revistas: Autor(es), ano. Título do artigo, nome completo da revista (volume)número: página-página. Exemplo: García S, Clinton W, Arreaza L and Thibaud R. 2004. Inhibitory effect of flowering and early fruit growth on leaf photosynthesis in mango. Tree Physiology 24(3): 387-399. http://dx.doi.org/10.1093/treephys/24.4.38

Participações em memórias de congressos, seminários, simpósios: García M. 1998. La ingeniería geotécnica y la protección del medio ambiente. p. 65-94. Em: Memorias. IX Congreso Colombiano de la Ciencia del Suelo. Sociedad Colombiana de la Ciencia del Suelo. Santa Fé de Bogotá.

Teses, trabalhos de formatura. Gómez C. 2004. Autoecología del mortiño (*Vaccinium meriodinale* Swartz Ericaceae). Tese Mestrado em Bosques e Conservação Ambiental. Facultad de Ciencias Agropecuarias. Universidad Nacional de Colombia. Medellín. 78 p.

Abril G. 2002. Biogeografía y descripción de las especies del género *Collaria* sp. en seis zonas lecheras del Departamento de Antioquia, Trabalho de formatura. Facultad de Ciencias Agropecuarias. Universidad Nacional de Colombia. Medellín. 49 p.

Citação de citação. Magalhaes LM e da Cruz AJ. 1979. Fenologia do pau-rosa (*Aniba duckei* Kostermans), Lauraceae, em floresta primária na Amazônia Central. Acta Amazónica. 9(2): 227-232. Citado por: Gómez CP. 2004. Autoecología del mortiño (*Vaccinium meriodinale* Swartz Ericaceae). Tese Mestrado em Bosques e Conservação Ambiental. Facultad de Ciencias Agropecuarias, Universidad Nacional de Colombia. Medellín. 46 p.

Suplemento de revista. Silva AM y Carrillo NN. 2004. El manglar de piruja, Golfito, Costa Rica: un modelo para su manejo. Revista de Biología Tropical 52, Supl. 2: 195-201.

Para citas de internet: Autor(es), ano. Título do artigo. Em: Nome(s) da publicação eletrônica, da página web, portal ou página e sua URL, páginas consultadas (pp.#) ou páginas totais (# p.); data de consulta. Exemplo: Arafat Y. 1996. Siembra de olivos en el desierto palestino. Em: Agricultura Tropical, http://agrotropical. edunet.es. 25 p.; consulta: novembro 2003.

ÉTICA EN LA PUBLICACIÓN CIENTÍFICA Y ACUERDO SOBRE POSIBLES MALAS PRÁCTICAS

La revista Facultad Nacional de Agronomía espera y verificará que los autores, revisores, editores y en general la comunidad académica y científica involucrada en nuestro proceso editorial, sigan estrictamente las normas éticas internacionales requeridas en el proceso de edición.

La revista Facultad Nacional de Agronomía sigue las normas éticas presentes en el COPE Best Practice Guidelines for Journal Editors y por el International Standars for Editors and Authors publicado por Committee on Publication Ethics.

Los autores deben evitar incurrir al plagio de la información. La revista define los siguientes lineamientos, criterios y recomendaciones sobre la ética en la publicación científica:

1. Criterios generales[1]

1.1. Los artículos deben contener suficiente detalle y referencias que permitan replicar o rebatir el estudio.

1.2.Declaraciones fraudulentas o deliberadamente inexactas constituyen un comportamiento poco ético.

1.3. Si el estudio incluye productos químicos, procedimientos o equipos que tienen cualquier riesgo inusual inherente a su uso, el autor debe identificar claramente estos en el artículo.

1.4. Si el estudio implica el uso de animales o de seres humanos, el autor debe asegurarse que el artículo contenga una declaración que haga explícito que se realizaron todos los procedimientos de conformidad con las leyes y directrices institucionales.

1.5. Se deben respetar los derechos de privacidad de los seres humanos.

2. Autoría[2]

Criterios:

2.1. Un "autor" es la persona que ha hecho una contribución intelectual significativa al artículo, por lo tanto, todas las personas nombradas como autores deben reunir los requisitos de autoría, y todos aquellos que los reúnan deben ser mencionados de forma explícita.

2.2. Se deben cumplir colectivamente tres criterios básicos para ser reconocido como autor:

a) Contribución sustancial a la concepción y diseño, adquisición de datos, análisis e interpretación del estudio.

b) Redacción o revisión del contenido intelectual.

c) Aprobación de la versión final.

2.3. El orden de la autoría debe ser una decisión conjunta de los coautores.

2.4. Las personas que participen en un estudio pero que no se ajusten a los criterios de autoría deben aparecer como "Colaboradores" o "Personas reconocidas".

2.5. Hay tres tipos de autorías que se consideran inaceptables: autores "fantasma", que contribuyen sustancialmente pero no son reconocidos (a menudo pagados por promotores comerciales); autores "invitados", que no hacen ninguna contribución discernible pero se nombran para aumentar las posibilidades de publicación; y autorías "honorarias", que se basan únicamente en una afiliación tenue con un estudio.

Recomendaciones:

2.6. Antes de iniciar la investigación se recomienda documentar la función y la forma como se reconocerá la autoría de cada investigador.

2.7. No se debe mentir sobre la participación de una persona en la investigación o publicación, si su contribución se considerada "sustancial" se justifica la autoría, bien sea como coautor o colaborador.

2.8. No se debe asignar una autoría sin contar con el consentimiento de la persona.

2.9. Todas las personas nombradas como autores deben reunir los requisitos de autoría, y todos aquellos que reúnan los requisitos deben aparecer como autores o contribuidores.

2.10. Algunos grupos colocan los autores por orden alfabético, a veces con una nota para explicar que todos los autores hicieron contribuciones iguales al estudio y la publicación.

3. Cambios en la autoría[3]

Criterios:

3.1. Hace referencia a la adición, supresión o reorganización de los nombres de autor en la autoría de un artículo aceptado.

3.2. Las peticiones de añadir o eliminar un autor, o para reorganizar los nombres de los autores, deben ser enviados por el autor correspondiente del artículo aceptado, y deben incluir:

a) La razón por la cual debe ser añadido o eliminado, o los nombres de los autores reorganizado.

b) La confirmación por escrito (e-mail) de todos los autores que están de acuerdo con la adición, supresión o reorganización. En el caso de adición o eliminación de los autores,esto incluye la confirmación de que el autor sea añadido o eliminado.

4. Conflicto de intereses[4]

Criterios:

4.1. Cuando un investigador o autor, editor tenga alguna opinión o interés financiero/personal que pueda afectar su objetividad o influir de manera inapropiada en sus actos, existe un posible conflicto de intereses. Este tipo de conflictos pueden ser reales o potenciales.

4.2. Los conflictos de intereses más evidentes son las relaciones financieras, como:

a) Directas: empleo, propiedad de acciones, becas, patentes.

b) Indirectas: honorarios, asesorías a organizaciones promotoras, la propiedad de fondos de inversión, testimonio experto pagado.

4.3. Los conflictos también pueden existir como resultado de relaciones personales, la competencia académica y la pasión intelectual. Por ejemplo, un investigador que tenga:

a) Algún tipo de interés personal en los resultados de la investigación.

b) Opiniones personales que están en conflicto directo con el tema que esté investigando.

Recomendaciones:

4.4. Revelar si se está en algún conflicto real o potencial de intereses que influya de forma inapropiada en los hallazgoso resultados del trabajo presentado, dentro de los tres (3) años de haber empezado el trabajo presentado que podría influir indebidamente (sesgo) el trabajo.

4.5. Revelar el papel de un promotor (o promotores) del estudio, si los hubiere, en el diseño del estudio, en la recopilación, análisis e interpretación de los datos, en la redacción del informe y en la decisión de presentar el documento para su publicación.

4.6. Los investigadores no deben entrar en acuerdos que interfieran con su acceso a todos los datos y su capacidad de analizarlos de forma independiente, y de preparar y publicar los manuscritos.

4.7. Al presentar un documento, se debe hacer una declaración (con el encabezamiento "Papel que ha tenido la fuente de financiación") en una sección separada del texto y colocarse antes de la sección "Referencias".

4.8. Algunos ejemplos de posibles conflictos de intereses que deben ser revelados, incluyen: empleo, consultoría, propiedad de acciones, honorarios, testimonio experto remunerado, las solicitudes de patentes / registros y subvenciones u otras financiaciones.

4.9. Todas las fuentes de apoyo financiero para el proyecto deben ser revelados.

4.10. Se debe describir el papel del patrocinador del estudio.

5. Publicación duplicada[5]

Criterios:

5.1. Los autores tienen la obligación de comprobar que su artículo sea basado en una investigación original (nunca publicada anteriormente). El envío o reenvío intencional de su trabajo para una publicación duplicada se considera un incumplimiento de la ética editorial.

5.2. Se produce una publicación duplicada o múltiple cuando dos o más artículos, sin hacerse referencias entre sí, comparten esencialmente las

mismas hipótesis, datos, puntos de discusión y/o conclusiones. Esto puede ocurrir en diferentes grados: Duplicación literal, duplicación parcial pero sustancial o incluso duplicación mediante parafraseo.
5.3. Uno de los principales motivos por los que la publicación duplicada de investigaciones originales se considera no ético es porque puede dar lugar a una "ponderación inadecuada o a un doble recuento involuntario" de los resultados de un estudio único, lo que distorsiona las pruebas disponibles.

Recomendaciones:

5.4. Los artículos enviados para su publicación deberán ser originales y no deberán haberse enviado a otra editorial. En el momento del envío, los autores deberán revelar los detalles de los artículos relacionados (también cuando estén en otro idioma), artículos similares en prensa y traducciones.
5.5. Aunque un artículo enviado esté siendo revisado y no conozca el estado, espere a que la editorial le diga algo antes de ponerse en contacto con otra revista, y sólo si la otra editorial no publicará el artículo.
5.6. Evite enviar un artículo previamente publicado a otra revista.
5.7. Evite enviar artículos que describan esencialmente la misma investigación a más de una revista.
5.8. Indique siempre los envíos anteriores (incluidas las presentaciones de reuniones y la inclusión de resultados en registros) que pudieran considerarse una publicación duplicada.
5.9. Evite escribir sobre su propia investigación en dos o más artículos desde diferentes ángulos o sobre diferentes aspectos de la investigación sin mencionar el artículo original.
5.10. Se considera manipulador crear varias publicaciones a raíz de la misma investigación.
5.11. Si desea enviar su artículo a una revista que se publica en un país diferente o en un idioma diferente, pregúntaselo a la editorial si se puede hacer esto.
5.12. En el momento del envío, indique todos los detalles de artículos relacionados en un idioma diferente y las traducciones existentes.

6. Reconocimiento de las fuentes

Criterios:

6.1. Los autores deben citar las publicaciones que han sido influyentes en la determinación de la naturaleza del trabajo presentado.
6.2. Información obtenida de forma privada, no debe ser usada sin explícito permiso escrito de la fuente.
6.3. La reutilización de las tablas y / o figuras requiere del permiso del autor y editor, y debe mencionarse de manera adecuada en la leyenda de la tabla o figura.
6.4. La información obtenida en el transcurso de servicios confidenciales, tales como manuscritos arbitrales o las solicitudes de subvención, no debe ser utilizada sin el permiso explícito y por escrito del autor de la obra involucrada en dichos servicios.

7. Fraude científico[6]

Criterios:

7.1. El fraude en la publicación científica hace referencia a la presentación de datos o conclusiones falsas que no fueron generados a través de un proceso riguroso de investigación.
7.2. Existen los siguientes tipos de fraude en la publicación de resultados de investigación:
a) Fabricación de datos. Inventar datos y resultados de investigación para después comunicarlos.
b) Falsificación de datos. La manipulación de materiales de investigación, imágenes, datos, equipo o procesos.
La falsificación incluye la modificación u omisión de datos o resultados de tal forma que la investigación no se representa de manera precisa. Una persona podría falsificar datos para adecuarla al resultado final deseado de un estudio.

Recomendaciones:

7.3. Antes de enviar un artículo, lea cuidadosamente las políticas editoriales y de datos de la revista.
7.4. Nunca modifique, cambie u omita datos de forma intencional. Esto incluye materiales de investigación, procesos, equipos, tablas, citas y referencias bibliográficas.
7.5. Tanto la fabricación como la falsificación de datos son formas de conducta incorrecta graves porque ambas resultan en publicaciones científicas que no reflejan con precisión la verdad observada.
7.6. El autor debe hacer una gestión adecuada de los datos que soportan la investigación, teniendo especial cuidado en la recopilación, producción, conservación, análisis y comunicación de los datos.
7.7. Mantenga registros minuciosos de los datos en bruto, los cuales deberán ser accesibles en caso de que un editor los solicite incluso después de publicado el artículo.

8. Plagio[7]

Criterios:

8.1. El plagio es una de las formas más comunes de conducta incorrecta en las publicaciones, sucede cuando uno de los autores hace pasar como propio el trabajo de otros sin permiso, mención o reconocimiento. El plagio se presenta bajo formas diferentes, desde la copia literal hasta el parafraseado del trabajo de otra persona, incluyendo: datos, ideas, conceptos, palabras y frases.
8.2. El plagio tiene diferentes niveles de gravedad, como por ejemplo:
a) Qué cantidad del trabajo de otra persona se tomó (varias líneas, párrafos, páginas, todo el artículo)
b) Qué es lo que se copió (resultados, métodos o sección de introducción).
8.3. El plagio en todas sus formas constituye una conducta no ética editorial y es inaceptable.
8.4. La copia literal solo es aceptable si indica la fuente e incluye el texto copiado entre comillas.

Recomendaciones:

8.5. Recuerde siempre que es esencial reconocer el trabajo de otros (incluidos el trabajo de su asesor o su propio trabajo previo) como parte del proceso.
8.6. No reproduzca un trabajo palabra por palabra, en su totalidad o en parte, sin permiso y mención de la fuente original.
8.7. Mantenga un registro de las fuentes que utiliza al investigar y dónde las utilizó en su artículo.
8.8. Asegúrese de reconocer completamente y citar de forma adecuada la fuente original en su artículo.
8.9. Incluso cuando haga referencia a la fuente, evite utilizar el trabajo de otras personas palabra por palabra salvo que lo haga entre comillas.
8.10. El parafraseado solo es aceptable si indica correctamente la fuente y se asegura de no cambiar el significado de la intención de la fuente.
8.11. Incluya entre comillas y cite todo el contenido que haya tomado de una fuente publicada anteriormente, incluso si lo está diciendo con sus propias palabras.

9. Fragmentación[8]

Criterios:

9.1. La fragmentación consiste en dividir o segmentar un estudio grande en dos o más publicaciones.
9.2. Como norma general, con tal de que los "fragmentos" de un estudio dividido compartan las mismas hipótesis, población y métodos, no se considera una práctica aceptable.
9.3. El mismo "fragmento" no se debe publicar nunca másde una vez. El motivo es que la fragmentación puede dar lugar a una distorsión de la literatura haciendo creer equivocadamente a los lectores que los datos presentados en cada fragmento (es decir, artículo de revista) se derivan de una muestra de sujetos diferente. Esto no solamente sesga la "base de datos científica", sino que crea repetición que hace perder el tiempo de los editores y revisores, que deben ocuparse de cada trabajo por separado. Además, se infla injustamente el número de referencias donde aparece citado el autor.

Recomendaciones:

9.4. Evite dividir inapropiadamente los datos de un solo estudio en dos o más trabajos.
9.5. Cuando presente un trabajo, sea transparente. Envíe copias de los manuscritos estrechamente relacionados al manuscrito en

cuestión. Esto incluye manuscritos publicados, enviados recientemente o ya aceptados.

10. Consentimiento informado

Criterios:

10.1. Los estudios sobre pacientes o voluntarios requieren la aprobación de un comité de ética.

10.2. El consentimiento informado debe estar debidamente documentado.

10.3. Los permisos y las liberaciones deben ser obtenidos, cuando un autor desea incluir detalles de caso u otra información personal o imágenes de los pacientes y cualquier otra persona.

10.4. Especial cuidado debe tenerse con la obtención del consentimiento respecto a los niños (en particular cuando un niño tiene necesidades especiales o problemas de aprendizaje), donde aparece la cabeza o la cara de una persona, o cuando se hace referencia al nombre de un individuo u otros datos personales.

11. Corrección de artículos publicados[9]

Criterio:

Cuando un autor descubre un error o inexactitud significativa en el trabajo publicado, es obligación del autor notificar de inmediato a la revista y cooperar en el proceso de corrección.

Referencias

Black, William, Rodolfo Russo, y David Turton. «The Supergravity Fields for a D-Brane with a Travelling Wave from String Amplitudes». Physics Letters B 694, n.º 3 (noviembre de 2010): 246-51.

Elsevier. «Autoría. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0010/183394/ETHICS_ES_AUTH01a_updatedURL.pdf.

———. «Conflicto de intereses. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0006/183399/ETHICS_ES_COI01a_updatedURL.pdf.

———. «Envío simultáneo/múltiple, publicación duplicada. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0019/183403/ETHICS_ES_SSUB01a_updatedURL.pdf.

———. «Ethics. Conducting research». Accedido 8 de agosto de 2014. http://www.elsevier.com/journal-authors/ethics#conducting-research.

———. «Ethics. Writing an article». Accedido 8 de agosto de 2014. http://www.elsevier.com/journal-authors/ethics#writing-an-article.

———. «Fragmentación. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0018/183402/ETHICS_ES_SS01a_updatedURL.pdf.

———. «Fraude en investigación. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0017/183401/ETHICS_ES_RF01a_updatedURL.pdf.

———. «Plagio. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0016/183400/ETHICS_ES_PLA01a_updatedURL.pdf.

[1] Elsevier, «Ethics. Conducting research», accedido 8 de agosto de 2014, http://www.elsevier.com/journal-authors/ethics#conducting-research.

[2] Elsevier, «Autoría. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0010/183394/ETHICS_ES_AUTH01a_updatedURL.pdf.

[3] William Black, Rodolfo Russo, y David Turton, «The Supergravity Fields for a D-Brane with a Travelling Wave from String Amplitudes», Physics Letters B 694, n.º 3 (noviembre de 2010): 246-51.

[4] Elsevier, «Conflicto de intereses. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0006/183399/ETHICS_ES_COI01a_updatedURL.pdf.

[5] Elsevier, «Envío simultáneo/múltiple, publicación duplicada. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0019/183403/ETHICS_ES_SSUB01a_updatedURL.pdf.

[6] Elsevier, «Fraude en investigación. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0017/183401/ETHICS_ES_RF01a_updatedURL.pdf.

[7] Elsevier, «Plagio. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0016/183400/ETHICS_ES_PLA01a_updatedURL.pdf.

[8] Elsevier, «Fragmentación. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0018/183402/ETHICS_ES_SS01a_updated updatedURL.pdf.

[9] Elsevier, «Ethics. Writing an article», accedido 8 de agosto de 2014, http://www.elsevier.com/journal-authors/ethics#writing-an-article.

PUBLICATION ETHICS AND PUBLICATION MALPRACTICE STATEMENT

The journal Revista Facultad Nacional de Agronomia follows the COPE Code of Conduct and Best Practice Guidelines for Journal Editors and the International Standards For Editors and Authors, published by Committe on Publication Ethics.
The journal puts forth the following criteria and recommendations for ethical scientific publications:

1. General criteria[1]

1.1. Articles must contain sufficient details and references that allow the study to be replicable or refutable.
1.2. Fraudulent or deliberately inexact statements constitute unethical behavior.
1.3. If a study includes the use of chemical products, procedures, or equipment that presents an inherent risk, the author must state so in the article.
1.4. If the study involves the use of animals or human beings, the article must contain a clear statement that all of the procedures were carried out in strict compliance with laws and institutional directives.
1.5. The privacy of the human beings must be respected.

2. Authorship[2]

Criteria:
2.1. An "author" is a person that has made a significant intellectual contribution to an article; all of the individuals that are named as authors must fulfill the requirements for authorship and all of those individuals that do so must be explicitly named.
2.2. Three basic criteria must be met in order to be considered an author:
a) Substantial contribution to the study concept, design, and data collection, analysis and interpretation.
b) Revision of the intellectual content.
c) Approval of the final version.
2.3. The order of the author list must be a joint decision of the coauthors.
2.4. The individuals that participate in a study but that do not meet the criteria for authorship must be listed as an "Assistant" or "recognized person."
2.5. There are three types of unacceptable authorship: "ghost" authors, who make a substantial contribution but are not recognized (often paid by commercial promoters); "guest" authors, who do not make a discernable contribution but are named in order to increase the probability of publication; and "honorary" authors, who only have a tenuous connection to the study.
Recommendations:
2.6. Before starting the research, establish the function of each researcher and the manner in which they will be recognized.
2.7. It is not necessary to mention an individual's participation in a study or publication, but if their contribution is substantial, than authorship would be justified, either as an author or assistant.
2.8. Authorship cannot be bestowed on an individual without their consent.
2.9. All of the individuals that are named as authors must meet the requirements for authorship and all of those that meet the requirements must appear as authors or assistants.
2.10. Some groups list the authors alphabetically, sometimes with a notation that indicates that all of the authors contributed equally to the study and the publication.

3. Changes in the authorship[3]

Criteria:
3.1. Additions to, removals from, and reorganization of the author names in accepted articles must be noted.
3.2. Petitions to add to, remove from, or reorganize the authors must be sent by the corresponding author of the accepted articles and must include:
a) The reason for the addition, elimination, or reorganization.
b) A written statement (e-mail) from all of the authors that confirms their agreement with the addition, elimination, or reorganization. In the case of an addition or elimination, a confirmation is also required from the author to be added or removed.

4. Conflict of interest[4]

Criteria:
4.1. When a researcher or author has a financial/personal opinion or interest that could affect their objectivity or improperly influence their actions, there exists a possible conflict of interest. Conflicts can be actual or potential.
4.2. The most evident conflicts of interest are financial, such as:
a) Direct: employment, stocks, scholarships, patents.
b) Indirect: assistantship to promoting organizations, investment funds, paid expert testimony.
4.3. Conflicts can also arise from personal relationships, academic competition, and intellectual passion. For example, an author could have:
a) Some personal interest in the results of the research.
b) Personal opinions that are in direct conflict with the research topic.
Recommendations:
4.4. Disclose all conflicts of interest, actual or potential, that inappropriately influence the findings or results of a study, including any that arise within the three (3) years after the start of said study if they could unduly (bias) influence the study.
4.5. Disclose the role of any promoter (or promoters) in the study, if any, in the design, in the collection, analysis or interpretation of the data, in the document review, or in the decision to present the document for publication.
4.6. The researchers must not enter into agreements that interfere with their access to all of the data or with their ability to independently analyze the data or to prepare and publish the manuscript.
4.7. The document must contain a statement (with the heading "Role of the financial source") in a section that is separate from the text and before the References section.
4.8. Some examples of conflicts of interest that must be revealed include: employment, consulting, stocks, honorariums, paid expert testimony, patent requests or registration, and subsidies or other financing.
4.9. All of the sources of financial support for the project must be revealed.
4.10. The role of any study sponsors must be described.

5. Duplicate publication[5]

Criteria:
5.1. Authors have the obligation of proving that their article is based on original research (never before published). The intentional submission or resubmission of a manuscript for duplicate publication is considered a breach of editorial ethics.
5.2. A duplication publication, or multiple publication, results when two or more articles, without any reference to each other, essentially share the same hypothesis, data, discussion points, and/or conclusions. This can occur to different degrees: literal duplication, partial but substantial duplication or paraphrasal duplication.
5.3. One of the main reasons that duplicate publications are considered unethical is that they can result in the "inappropriate weighting or unwitting double counting" of results from just one study, which distorts the available evidence.
Recommendations:
5.4. Articles sent for publication must be original and not sent to other editors. When sent, the authors must reveal the details of related articles (even when in another language) and similar articles being printed or translated.

5.5. Even though a submitted article is being reviewed and the final decision is not known, wait to receive notification from the editors before contacting other journals and then only do so if the editors decline to publish the article.
5.6. Avoid submitting a previously published article to another journal.
5.7. Avoid submitting articles that essentially describe the same research to more than one journal.
5.8. Always indicate previous submissions (including presentations and recorded results) that could be considered duplicate results.
5.9. Avoid writing about your research in two or more articles from different angles or on different aspects of the research without mentioning the original article.
5.10. Creating various publications based on the same research is considered a type of manipulation.
5.11. If an author wishes to send an article to a journal that is published in a different country or a different language, ask for permission from the editors first.
5.12. When submitting an article, indicate all of the details of the article that were presented in a different language along with the relevant translations.

6. Acknowledging sources

Criteria:

6.1. Authors must cite the publications that had an influence on the determination of the nature of the offered study.
6.2. Privately obtained information cannot be used without the express written consent of the source.
6.3. Republishing tables or figures requires the permission of the author or editor, who must be appropriately cited in the table or figure legend.
6.4. Information obtained through confidential services, such as arbitration articles or subsidy applications, cannot be used without the express written consent of the author of the work involved in said services.

7. Scientific fraud[6]

Criteria:

7.1. Fraud in scientific publications refers to the presentation of false data or conclusions that were not obtained through a rigorous research process.
7.2. The following types of fraud exist for the publication of research results:
a) Fabricating data. Inventing research data and results for later dissemination.
b) Falsification of data. The manipulation of research material, images, data, equipment or processes. Falsification includes the modification or omission of data or results in such a way that the research is not represented in a precise manner. A person may falsify data in order to obtain the desired final results of a study.

Recommendations:

7.3. Before submitting an article, carefully read the editorial and data policies of the journal.
7.4. Never modify, change or omit data intentionally. This includes research material, processes, equipment, tables, citations, and bibliographical references.
7.5. Fabricating and falsifying data constitute grave misconduct because both result in scientific publications that do not precisely reflect the actual observations.
7.6. Authors must appropriately manage the data that supports the research, taking special care in the compilation, production, preservation, analysis and presentation of the data.
7.7. Maintain precise records of the raw data, which must be assessable in case the editors request them after publication of the article.

8. Plagiarism[7]

Criteria:

8.1. Plagiarism is one of the more common types of misconduct in publications; it occurs when an author passes the work of others off as their own without permission, citations, or acknowledgment. Plagiarism can occur in different forms, from literally copying to paraphrasing the work of another person, including data, ideas, concepts, paragraphs, and phrases.
8.2. Plagiarism has different degrees of severity; for example:
a) The quantity of work taken from another person (various lines, paragraphs, pages, or the entire article).
b) What is copied (results, methods, or introduction section).
8.3. Plagiarism, in all of its forms, constitutes unethical behavior and is unacceptable.
8.4. Literal copying is acceptable if the source is indicated and the text is placed in quotation marks.

Recommendations:

8.5. Always remember that it is vital to recognize the work of others (including the work of your assistants or your previous studies).
8.6. Do not reproduce the work of others word for word, in totality or partially, without the permission and recognition of the original source.
8.7. Maintain a record of the sources that are used in the research and where they are used in the article.
8.8. Be sure to accurately acknowledge and cite the original source in your article.
8.9. Even when referencing the source, avoid using the work of others word for word unless it is placed in quotations.
8.10. Paraphrasing is only acceptable if the source is correctly indicated and the source's intended meaning is not changed.
8.11. Use quotations, and cite all of the content that is taken from a previously published source even when using your own words.

9. Fragmentation[8]

Criteria:

9.1.Fragmentation occurs when a large study is divided or segmented into two or more publications.
9.2. As a general rule, as long as the "fragments" of a divided study share the same hypothesis, populations, and methods, this not considered an acceptable practice.
9.3. The same "fragment" can never be published more than one time. Fragmentation can result in distortion of the literature, creating the mistaken belief in readers that the data presented in each fragment (i.e. journal article) are derived from different subject samplings. This not only distorts the "scientific database", but creates repetition that results in a loss of time for editors and evaluators that must work on each article separately. Furthermore, the cited author receives an unfair increase in their number of references.

Recommendations:

9.4. Avoid inappropriately dividing the data of one study into two or more articles.
9.5. When presenting your work, be transparent. Send copies of the manuscripts that are closely related to the manuscript in question, including published, recently submitted and accepted manuscripts.

10. Informed consent

Criteria:

10.1. Studies on patients and volunteers require the approval of the ethics committee.
10.2. The informed consent must be duly documented.
10.3. Permission and waivers must be obtained when an author wishes to include details of a case or other personal information or images of the patients or any other person.
10.4. Special care should be taken when obtaining the consent

of children (especially when a child has special needs or learning disabilities) when their head or face is displayed or when reference is made to the name of an individual or other personal data.

11. Correction of published articles[9]

Criterion:

When an author discovers a significant inexactitude or error in a published article, they must immediately notify the journal and cooperate in the correction process.

References

Black, William, Rodolfo Russo, y David Turton. «The Supergravity Fields for a D-Brane with a Travelling Wave from String Amplitudes». *Physics Letters B* 694, n.º 3 (noviembre de 2010): 246-51.

Elsevier. «Autoría. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0010/183394/ETHICS_ES_AUTH01a_updatedURL.pdf.

———. «Conflicto de intereses. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0006/183399/ETHICS_ES_COI01a_updatedURL.pdf.

———. «Envío simultáneo/múltiple, publicación duplicada. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0019/183403/ETHICS_ES_SSUB01a_updatedURL.pdf.

———. «Ethics. Conducting research». Accedido 8 de agosto de 2014. http://www.elsevier.com/journal-authors/ethics#conducting-research.

———. «Ethics. Writing an article». Accedido 8 de agosto de 2014. http://www.elsevier.com/journal-authors/ethics#writing-an-article.

———. «Fragmentación. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0018/183402/ETHICS_ES_SS01a_updatedURL.pdf.

———. «Fraude en investigación. Ethics in research & publication». Accedido 8 de agosto de 2014.
http://www.elsevier.com/__data/assets/pdf_file/0017/183401/ETHICS_ES_RF01a_updatedURL.pdf.

———. «Plagio. Ethics in research & publication». Accedido 8 de agosto de 2014. http://www.elsevier.com/__data/assets/pdf_file/0016/183400/ETHICS_ES_PLA01a_updatedURL.pdf.

[1] Elsevier, «Ethics. Conducting research», accedido 8 de agosto de 2014, http://www.elsevier.com/journal-authors/ethics#conducting-research.

[2] Elsevier, «Autoría. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0010/183394/ETHICS_ES_AUTH01a_updatedURL.pdf.

[3] William Black, Rodolfo Russo, y David Turton, «The Supergravity Fields for a D-Brane with a Travelling Wave from String Amplitudes», *Physics Letters B* 694, n.º 3 (noviembre de 2010): 246-51.

[4] Elsevier, «Conflicto de intereses. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0006/183399/ETHICS_ES_COI01a_updatedURL.pdf.

[5] Elsevier, «Envío simultáneo/múltiple, publicación duplicada. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0019/183403/ETHICS_ES_SSUB01a_updatedURL.pdf.

[6] Elsevier, «Fraude en investigación. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0017/183401/ETHICS_ES_RF01a_updatedURL.pdf.

[7] Elsevier, «Plagio. Ethics in research & publication», accedido de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0016/183400/ETHICS_ES_PLA01a_updatedURL.pdf.

[8] Elsevier, «Fragmentación. Ethics in research & publication», accedido 8 de agosto de 2014, http://www.elsevier.com/__data/assets/pdf_file/0018/183402/ETHICS_ES_SS01a_updated updatedURL.pdf.

[9] Elsevier, «Ethics. Writing an article», accedido 8 de agosto de 2014, http://www.elsevier.com/journal-authors/ethics#writing-an-article.