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Original article

Bean (*Phaseolus vulgaris* L.) productivity. Part I. Yield as a function of meteorological variables

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ABSTRACT

The research was carried out in areas of the Scientific Technological Base Unit "Los Palacios", Pinar del Río, belonging to the National Institute of Agricultural Sciences (INCA). The objective was to evaluate the variability of the yield in bean cultivars and its relationship with meteorological variables, according to sowing date. Six bean cultivars were used (Holguin 518, Tazumal, Tomeguin 93, Bat 304, Bat 832 and Cuba Cueto 25-9), which were planted on four sowing dates (October 2010, December 2011, January 2012 and October 2012), on a Hydromorphic Gley Nodular Ferruginous Petroferric soil. An experimental design of random blocks with three replications was used and the agricultural yield and its main components were evaluated; in addition, meteorological variables (temperatures, solar radiation, relative humidity), in different phenological stages of the crop. From the results it is possible to conclude that the yield is positively related to the air temperature in the growth phase from emergence to flowering and negatively, during the flowering to harvest phase, an aspect associated with possible changes in the availability of assimilates. The cultivars under study require a range of accumulated heat to complete their life cycle that ranges from 900 to 1350 °C, approximately.

Key words: cultivar, temperature, phenology

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is the most important legume for consumption in the world. It is grown in very diverse environments and it is the Central American and Caribbean countries where large producing areas and the populations that consume it the most are concentrated, as it is an essential component of their daily diet [1,2] and a rich source of protein, vitamins and minerals [3]. In Cuba, its cultivation is becoming increasingly important and the country has increased its planting from 122 thousand hectares in 2016 to 147 thousand in 2018 [4,5]. Its yields have been kept between 0.8 and 1.0 t ha^{-1} lower than the potential of the cultivars used; however, domestic production still does not meet consumer demand [6,7]. Furthermore, climate change has become a decisive factor for the stability of yields. In recent years, extreme meteorological events have become more evident, global precipitation patterns and drought intensity have changed [8]. Therefore, promoting the use of cultivars better adapted to current environmental conditions can help national productions to satisfy the demand of Cuban population [9].

These aspects show to a certain extent that the behavior and response of bean cultivars to environmental conditions is different according to the sowing date, so the analysis of meteorological variables may be adequate to detect differences in bean adaptation in a certain environment. For this, in accordance with the previous criteria, the present work was developed with the objective of evaluating the variability of yield in bean (*Phaseolus vulgaris* L.) cultivars and its relationship with meteorological variables, according to the sowing date.

MATERIALS AND METHODS

The experiments were developed in the Base Scientific Technological Unit "Los Palacios" (UCTB-LP), belonging to the National Institute of Agricultural Sciences, located in the southern plain of Pinar del Río province, at 22° 44' North latitude and at 83° 45' west latitude, at 60 m a.s.l, with an approximate slope of 1 %. Six bean cultivars were evaluated (Holguin 518, Tazumal, Tomeguin 93, Bat 304, Bat 832 and Cuba Cueto 25-9), which were planted on four sowing dates: October 2010; December 2011; January 2012 and October 2012.

The soil of the experimental area is classified, according to the New Version of Genetic Classification of Cuban Soils [10], as Hydromorphic Gley Nodular Ferruginous Petroferric. As a result of the soil sampling of the experimental area, some properties that characterize its fertility are shown (Table 1).

Table 1. Some properties of the arable layer (0-20 cm) that characterize the fertility of the soil where the experiments were developed

pH H_2O	Ca^{++}	Mg^{+}	Na^{++} (cmol kg^{-1} soil)	K^{+}	P_2O_5 (mg 100 g^{-1} of soil)	OM (%)
6.31	7.20	3.16	0.18	0.21	19.17	2.02

The main characteristics of cultivars under study are presented in Table 2 [6], those that were sown by direct sowing at a distance (manual), 0.70 m between rows and 0.05 m between plants, with a norm of 54 kg ha^{-1} of seeds. The phytotechnical work was carried out as recommended in the Technical Manual for Bean Cultivation [6]. A randomized block experimental design with six treatments (the cultivars) and three replicates was used. The experimental plots had a total area of 30 m^2.

Table 2. Main characteristics of the bean cultivars studied in the experiments

	Holguín 518	Tazumal	Tomeguín 93	Bat 304	Bat 832	CC-25-9
Yield (t ha^{-1})	2,9	3,0	2,9	2,9	3,2	3,3
Recommended sowing date	september-january	september - january	september - january	september - january	september - january	october-november
Days to flowering	43	41	38	38	43	47
Days to physiological maturity	75	75	69	68	74	86
Cycle (days)	86	86	80	75	87	100

In Figure 1 the daily maximum, minimum and average temperature (Tmax, Tmin, Tmed), rainfall, global solar radiation (GSR) and relative humidity (Rh) are recorded, of the period of experiment duration, which were obtained from the Paso Real de San Diego Meteorological Station, in Los Palacios.

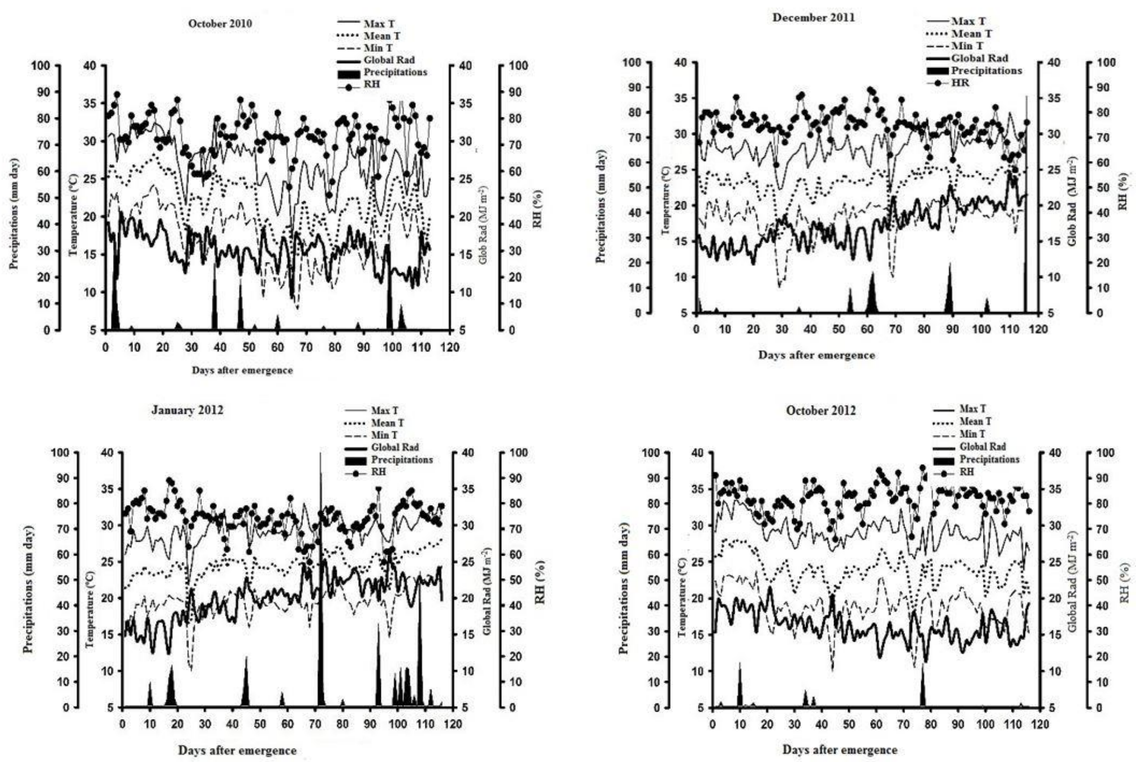


Figure 1. Temperatures (maximum, average, minimum), rainfall, global solar radiation and relative humidity, taken from the Paso Real Agro-meteorological Station in San Diego during the period that the experiments lasted

The duration in days of each growth phases was calculated, taking into account that reported by the technical guide for the production of common beans and corn, which appears in Table 3 [6]. Each phase was decreed when more than 50 % of plants in the experimental plots presented the characteristics according to what was described.

Table 3. Description of each of the different growth phases in bean cultivation

Phase	Stage		Identification of the stage start
	Code	Name	
Vegetative	V_1	Emergency	Cotyledons appear at ground level.
	R_5	Pre-flowering	The first buttons or clusters have appeared
Reproductive	R_6	Flowering	The first flower has opened
	R_9	Maturation	Color change of at least one pod

The thermal sum or accumulated degree days (ADD) was calculated by the following method [11]:

$$ADD = \sum \frac{T_{maximum} + T_{minimum}}{2} - T_{base}$$

Where

$T_{maximum,}$ maximum daily air temperature

$T_{minimum,}$ daily minimum air temperature

$T_{base,}$ base temperature, which is the temperature at which the process of interest does not progress and in this case 10 ºC was taken [5].

To determine the agricultural yield, 8 m^2 of the center were harvested in each experimental plot, the plants were threshed and the grains were dried until reaching 14 % humidity.

The four sowing dates were climatically characterized, through an analysis of main components with said variables, dividing the crop cycle into two periods: V_1-R_6, vegetative phase; R_6-R_9, reproductive phase [6]. The means of the evaluated variables obtained by cultivar and sowing date were subjected to analysis of variance (ANAVA) and the significant differences between means were determined with the Tukey test ($p < 0.05$). Several data matrices were constructed, which were processed by the Principal Components multivariate technique, through the representation of a Biplot. The statistical package Statgraphics 5.0 was used [12].

RESULTS AND DISCUSSION

Figure 2 shows the behavior of the agricultural yield of cultivars in the different evaluated dates. In general, a variation of this variable is observed, both between planting dates and between cultivars. It is shown that a specific behavior pattern cannot be defined for yield, so it is necessary to take into account the role that internal factors, related to the cultivar and external factors, related to the climate, play in the yield formation process. Despite this, the cultivars BAT 304 and BAT 832 showed a favorable behavior on all sowing dates.

In October 2010, the best performance is observed for all cultivars with yields of approximately 2 t ha^{-1}, a value that differs significantly from those achieved on the other sowing dates (December 2011, October 2012 and January 2012). However, in October 2012, agricultural yields were close to 1.5 t ha^{-1} for most cultivars except for the cultivar CC-25-9, which reached 1 t ha^{-1}.

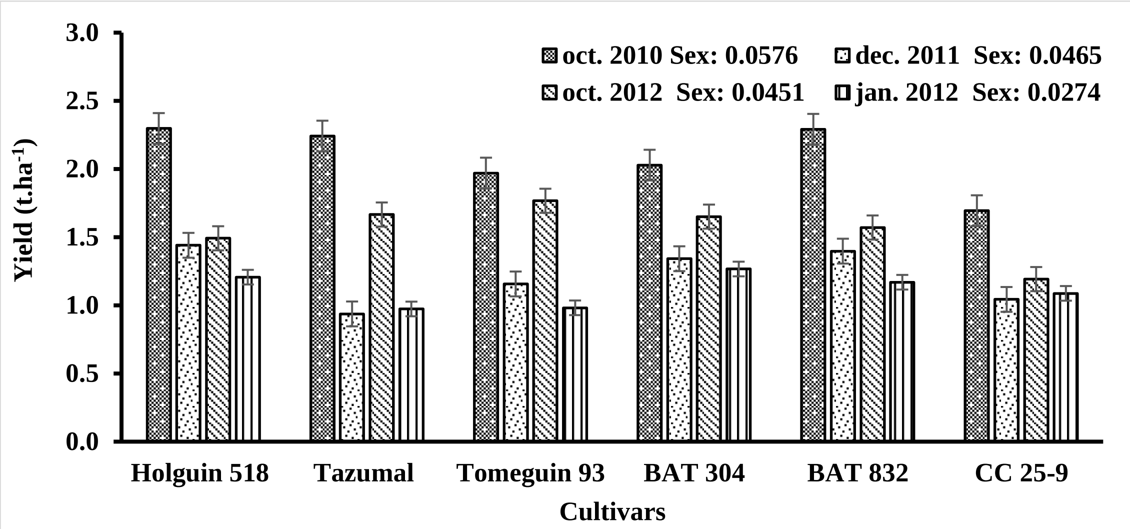


Figure 2. Agricultural yield (t ha^{-1}) at 14 % grain moisture of bean cultivars planted on four sowing dates

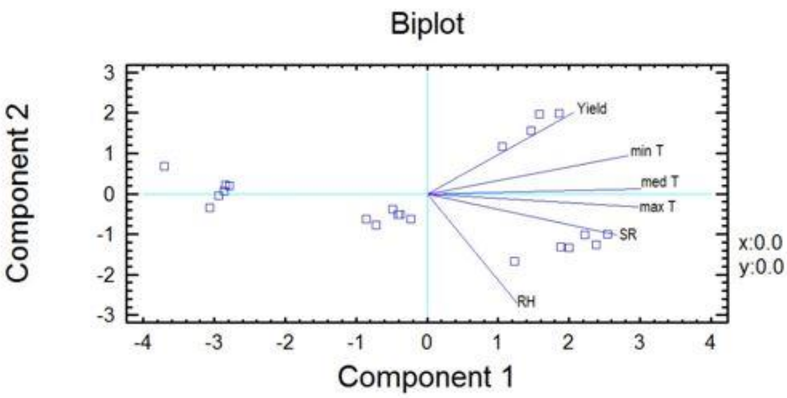
The fact that cultivars reached the highest yield values in October 2010 could be related to the influence of meteorological variables on yield formation. Analyzing the behavior of temperatures, on this date it is observed that between 40 and 70 days after emergence (flowering stage of the cultivars) the temperatures were relatively lower by approximately 1.5 °C, compared to the remaining dates in the same period (Figure 1). In the literature, the variability of yields is closely related to meteorological conditions for a specific cultivar, an aspect that allows explianing how some cultivars respond better than others do to the edaphoclimatic conditions of a certain locality.

Results from other investigations also indicate the influence of temperatures (between 20-25 °C) on yield stability of some grain species, specifically, rice, soy and beans [(13–15)].

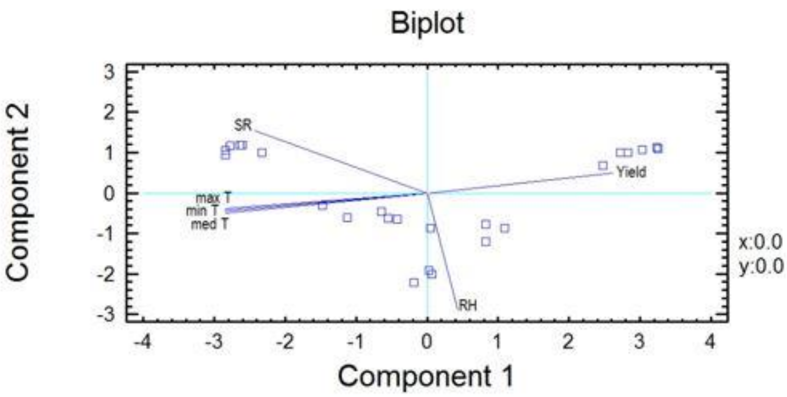
The results in this work show how despite the variability in climate, the response of certain cultivars (BAT 304 and BAT 832) can be positive in the face of prevailing local conditions, which is why the selection of these by locality is important. In this regard, some authors suggest that the environment in which agricultural crops are developed has an effect on them, this can be positive or negative, depending on the behavior of climatic variables. In addition, they also highlight that it is interesting to know that plants reflect a different behavior in the face of climatic variables, which means that cultivars of the same species show different behaviors in the face of a climatic variable similar effect [(16)]. These studies are of great importance for genetic improvement programs, since the parameters most influenced by the environment can be determined and thus achieve a more accepted selection criterion.

The graphic representation of main component analysis is in Figure 3, which shows the association of the agricultural yield behavior of cultivars in the different sowing dates, compared to the meteorological variables, both for stage V_1-R_6, as for that of R_6-R_9.

A



B



A: stage V_1-R_6, B: stage R_6-R_9 Yield: Efficiency (t ha^{-1}), GSR: Global solar radiation (Mjm^2), Hr: Relative humidity (%),max T: Maximum temperature, min T: Minimum temperature . Cultivars: Holguin 518, Tazumal, Tomeguin 93, BAT 304, BAT 832, CC-25-9. Sowing dates: October 2010, December 2011, October 2012, January 2012

Figure 3. Association of the main meteorological variables with the yield of the six bean cultivars for the four sowing dates

When taking into account the degree of association between variables for the V_1-R_6 stage (Figure 3A), the best positive association with performance was presented by the temperature values, especially the minimum temperatures. In this regard, in the literature it is stated that beans are a plant of tropical origin and that it develops better at temperatures between 18 and 24 °C and it is highlighted that highest yields are obtained at indicated average temperatures. In addition, it is reported that in hot areas beans can be produced satisfactorily, if night temperatures are not very high, since hot nights commonly induce the fall of flowers to the detriment of production [(6)]. Low temperatures (below 15 °C) can cause a decrease in yield, since they affect vegetative development as growth is very slow and cause delays in flowering, which considerably prolongs the growth cycle (17).

For stage R_6-R_9 (Figure 3B) a strong but inverse relationship between temperatures (maximum, average and minimum) and performance is observed. These results indicate that an increase in temperatures in this period can cause a decrease in performance or vice versa. Studies carried out with high temperatures showed that these had a negative effect on the yield (values that were low) and the biomass produced, due to the slower growth rate obtained by the crop, while grain size decreased and their wrinkling increased (18). It is emphasized that temperatures above 30 °C reduce the productive capacity, because a decrease in flower and pod production, if the irrigation is not adequate, the fall of the flowers is induced. A different effect was observed in trials carried out with beans; where good results were found in the dry grain yield when temperatures were low (monthly average temperature of 18 °C and a relative humidity of approximately 80).

In studies carried out on soybeans after the beginning of flowering, it is evidenced that the variations in yield are associated with variations in the behavior of meteorological variables, since the associated variables are related to possible changes in the availability of assimilates. Therefore, when temperatures are not very high (they do not exceed 25 °C), all or part of the duration of reproductive growth is extended, while there is a greater interception of solar radiation and an increase in daily photosynthesis of crop, in this way, a greater availability of photoassimilates is guaranteed and, therefore, greater yield (19).

In the present work results, it is evident that temperature is the variable that most influences the development rate of the bean crop, from emergence to harvest, which means that all development stages are sensitive to it. The values of accumulated degrees of heat days (ADHD, ° C) to complete phases and the crop cycle for the different cultivars under study appear in Table 4.

Table 4. Accumulated degrees of heat days (ADHD, ° C) to complete phases and the cycle in six cultivars of bean (*Phaseolus vulgaris* L.)

Cultivars	Phase V1-R6	Phase R6-R9	V1-R9
Holguín 518	591.05±19.9	551.63±34.2	1142.70±30.8
Tazumal	564.23±20.1	578.48±33.9	1142.70±30.8
Tomeguín 93	523.75±18.9	531.30±30.1	1062.48±29.5
BAT 304	591.23±18.9	468.90±22.9	998.70±25.3
BAT 832	641.55±19.8	558.15±33.8	1149.20±28.2
CC-25-9	641.55±20.7	680.93±44.1	1322.45±36.2

± represents the confidence interval of the means, n = 4

V1: emergence, R6: flowering; R9: maturation

Cultivars require a range of accumulated heat to complete their biological cycle that ranges between 900 and 1350 °C approximately although taking into account that Holguín 518, Tazumal, Tomeguín 93, BAT 304 and BAT 832 only reach up to 1200 °C, they could be group as cultivars that need a similar temperature range. CC-25-9 requires values close to 1300 ºC, could be grouped with other cultivars of a longer cycle, which require higher ADHD, so that studies could continue to group cultivars based on this variable.

Thermal time is generally used to include temperature effects and describe the timing of biological processes in the plant; that is, it can be defined as the number of degree-days necessary to complete a certain development process or phenological phase (20). Therefore, in this study, the thermal time must have had a certain impact on the stage duration, in such a way that it could respond to variations in performance. From these results, it is possible to exploit, in a convenient way, the climate conditions, in relation to the genetic characteristics of cultivars and thus take advantage of the most suitable period for the development of the phenological crop phases, the efficiency and the opportunity in the application of inputs and labor to be used. It can manage the sowing dates and select the appropriate cultivars in a given location; taking into account the behavior of temperatures as a fundamental element.

CONCLUSIONS

- Yield is positively related to air temperature in the growth phase from emergence to flowering and negatively during the flowering to harvest phase, an aspect associated with possible changes in the availability of assimilates.
- The cultivars under study require a range of accumulated heat to complete their life cycle that ranges from 900 to 1350 °C, approximately.

BIBLIOGRAPHY

1. Estrada Prado W, Chávez Suárez L, Jerez Mompie E, Nápoles García MC, Sosa Rodríguez A, Cordoví Dominguez C, et al. Efecto del Azofert® en el rendimiento de variedades de frijol común (*Phaseolus vulgaris* L.) en condiciones de déficit hídrico. Centro Agrícola. 2017;44(3):36–42.
2. González-Cueto O, Abreu-Ceballo B, Herrera-Suárez M, López-Bravo E. Uso del agua durante el riego del frijol en suelos Eutric cambisol. Revista Ciencias Técnicas Agropecuarias. 2017;26(1):71–7.
3. Calero Hurtado A, Castillo Y, Quintero E, Pérez Y, Olivera D. Efecto de cuatro densidades de siembra en el rendimiento agrícola del frijol común (*Phaseolus vulgaris* L.). Revista de la Facultad de Ciencias. 2018;7(1):88–100.
4. ONEI, Oficina Nacional de Estadísticas e Información. Anuario Estadístico de Cuba 2017. Capítulo 9. Cuba: Agricultura, Ganadería, Silvicultura y Pesca; 2017. 30 p.
5. ONEI, Oficina Nacional de Estadísticas e Información. Anuario Estadístico de Cuba 2018. Capítulo 9. Cuba: Agricultura, Ganadería, Silvicultura y Pesca; 2018. 31 p.

6. Faure Alvarez B, Benítez González R, Rodríguez Acosta E, Grande Morales O, Torres Martínez M, Pérez Rodríguez P. Guía técnica para la producción de frijol común y maíz. La Habana, Cuba: Instituto de Investigaciones en Fruticultura Tropical; 2014 p. 39.
7. FAO-FAOSTAT. Estadísticas. Organización de las Naciones Unidas para la Alimentación y la Agricultura. 2016.
8. Urbina I, Sardans J, Beierkuhnlein C, Jentsch A, Backhaus S, Grant K, et al. Shifts in the elemental composition of plants during a very severe drought. Environmental and experimental botany. 2015;111:63–73.
9. de la Fé Montenegro CF, Lamz Piedra A, Cárdenas Travieso RM, Hernández Pérez J. Respuesta agronómica de cultivares de frijol común (*Phaseolus vulgaris* L.) de reciente introducción en Cuba. Cultivos Tropicales. 2016;37(2):102–7.
10. Hernández Jiménez A, Pérez Jiménez JM, Bosch-Infante D, Castro Speck N. Clasificación de los suelos de Cuba 2015. Mayabeque, Cuba: Ediciones INCA. 2015;93:91.
11. Parra-Coronado A, Fischer G, Chaves-Cordoba B. Tiempo térmico para estados fenológicos reproductivos de la feijoa (*Acca sellowiana* (O. Berg) Burret). Acta Biológica Colombiana. 2015;20(1):163–73.
12. Statistical Graphics Crop. STATGRAPHICS® Plus [Internet]. 2000.(Profesional). 2000.
13. Huang M, Shan S, Zhou X, Chen J, Cao F, Jiang L, et al. Leaf photosynthetic performance related to higher radiation use efficiency and grain yield in hybrid rice. Field Crops Research. 2016;193:87–93.
14. Maqueira-López LA, Rojan-Herrera O, Mesa SAP, Noval WT la. Crecimiento y rendimiento de cultivares de frijol negro (*Phaseolus vulgaris* L.) en la localidad de los Palacios. Cultivos Tropicales. 2017;38(3):58–63.
15. Eid AR, Bakry BA, Taha MH. Effect of pulse drip irrigation and mulching systems on yield, quality traits and irrigation water use efficiency of soybean under sandy soil conditions. 2013;
16. Gonzalo RH, García MJ. Relaciones entre el rendimiento y sus componentes de dos líneas de frijol común (*P. vulgaris* L.) con algunas variables climáticas. Centro Agrícola. 2003;30(4).
17. Rosas JC. El cultivo del frijol común en América Tropical. Honduras: Escuela Agrícola Panamericana; 2003 p. 62.
18. Liu B, Liu X-B, Wang C, Jin J, Herbert SJ, Hashemi M. Responses of soybean yield and yield components to light enrichment and planting density. International Journal of Plant Production. 2012;4(1):1–10.
19. Martignone R, Enrico J, Bodrero M, Adriani J, Sonmarti N. Rendimiento de soja en siembras muy tardías: características diferenciales entre cultivares. EEA Oliveros INTA. 2016;54:137–43.
20. Garcés-Fiallos FR, Ampuño-Muñoz SA, Vásconez-Montúfar GH. Agronomía, producción y calidad de grano de variedades de soya durante dos épocas de cultivo. Bioscience Journal. 2014;30(5).