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Original Article

Productivity of bean cultivars (*Phaseolus vulgaris* L.). Part II. Yield variability as a function of growth

Productividad de cultivares de frijol (*Phaseolus vulgaris* L.). Parte II. Variabilidad del rendimiento en función del crecimiento

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ABSTRACT: The research was developed in areas of the Base Scientific Technological Unit, Los Palacios, Pinar del Río, belonging to the National Institute of Agricultural Sciences. The objective was to evaluate the variability of the yield in bean cultivars (*Phaseolus vulgaris* L.), associated with growth variables in the final stage of crop development. Six bean cultivars were used (Holguin 518, Tazumal, Tomeguin 93, Bat 304, Bat 832 and Cuba Cueto 25-9), which were planted on four different sowing dates (October 2010, December 2011, January 2012 and October 2012), on a Hydromorphic Gley Nodular Ferruginous Petroferric soil. A randomized block experimental design with three replications was used. At the time of harvest, dry mass of pods, grains, stems and total dry mass of the aerial part were determined by adding the dry mass of organs. Harvest Index and pod harvest index were determined. It was shown that there is a positive relationship between the mass of the grains and the agricultural yield regardless of the cultivar and the sowing date, so that this variable constitutes a fundamental component in the formation of yield in the bean crop. Increases in the dry mass of the stems and pods affect the harvest index, so it is not possible that the greater amount of the total biomass production becomes part of the agricultural productivity.

Key words: yield, drought, beans.

RESUMEN: La investigación se desarrolló en áreas de la Unidad Científico Tecnológica de Base, Los Palacios, Pinar del Río, perteneciente al Instituto Nacional de Ciencias Agrícolas. El objetivo fue evaluar la variabilidad del rendimiento en cultivares de frijol (*Phaseolus vulgaris* L.), asociados a variables del crecimiento en la etapa final de desarrollo del cultivo. Se utilizaron seis cultivares de frijol (Holguín 518, Tazumal, Tomeguín 93, Bat 304, Bat 832 y Cuba Cueto 25-9), los cuales se sembraron en cuatro fechas de siembra (octubre 2010, diciembre 2011, enero 2012 y octubre 2012), sobre un suelo Hidromórfico Gley Nodular Ferruginoso Petroférrico. Se utilizó un diseño experimental de bloques al azar con tres réplicas. En el momento de la cosecha se determinó, masa seca de vainas, granos, tallos y masa seca total de la parte aérea por sumatoria de la masa seca de órganos. Se determinó el Índice de cosecha y el Ìndice de cosecha de vainas. Se demostró que existe una relación positiva entre la masa de los granos y el rendimiento agrícola, independientemente del cultivar y la fecha de siembra, por lo que dicha variable constituye un componente fundamental en la formación de rendimiento en el cultivo del frijol. Incrementos en la masa seca de los tallos y vainas afectan el índice de cosecha y no se logra que la mayor cantidad de la producción total de biomasa llegue a formar parte de la productividad agrícola.

Palabras clave: rendimiento, granos, frijol.

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INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is the most important legume consumed in the world (1, 2). Its nutritional value is due to its high protein, vitamin and mineral content (3). These elements distinguish it as a necessary food, since large segments of the population in developing countries suffer from protein malnutrition. In addition, projections based on current trends indicate a widening gap between human population and protein supply (4). In very diverse environments, beans are grown, and it is in the countries of East and West Africa, Central America and the Caribbean that large producing areas and the populations that consume the most beans are concentrated (5).

In Cuba, about 110 thousand tons are imported per year to satisfy domestic demand and considerable sums of money are spent on its importation, because it represents one of the main dishes in the food culture of the population. The behavior of bean import costs, during the period from 2007 to 2015, was between 812 USD/t to 1308 USD/t and with average annual growth rates of 6.8 % (6). Agricultural yields in the country have remained between 0.8 and 1.0 t ha^{-1} below the potential of the cultivars used and climate variability is one of the aspects that affect these results. Climate change has become a decisive factor that prevents their stability. In recent years, extreme weather events have become more evident, global precipitation patterns have changed, as have the intensity of droughts and the increase in temperatures (7, 8).

In a previous analysis, where the variability of yield was determined in association with meteorological variables. Yield is positively related to air temperature during the growth phase from emergence to flowering and negatively during the flowering to harvest phases. This is evidence of possible changes in the availability of assimilates in the final stages of growth. This result demonstrates that under current conditions, in order to achieve stable yields over time or increase them. It is necessary to understand the physiological processes prevailing in the development of the crop, where the most complex character is the production of grains and dry matter, because of the functioning of the plant in the environment where the seed has been sown to develop. In this way, it is possible to analyze which are the main factors that contribute to determine the final yield of the crop and create the basis to propose management strategies in order to achieve higher agricultural productivity.

Therefore, in accordance with the above criteria, the present work was developed with the objective of evaluating yield variability in bean cultivars (*Phaseolus vulgaris* L.), associated with growth variables in the final stage of crop development.

MATERIALS AND METHODS

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

Table 1. Average values of agrometeorological variables for the duration of the experiments

	MaxT (°C)	MinT (°C)	GSR (MJ m^2 day^{-1})	Hr (%)
October 2010	25.23	14.87	15.21	72.90
December 2011	28.23	18.30	16.74	76.53
January 2012	29.79	19.54	21.30	71.23
October 2012	27.82	17.65	14.90	80.21

Maximum temperature (MaxT), Minimum temperature (MinT), Global solar radiation (GSR), Relative humidity (Hr)

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

Ten representative plants were taken at random at the time of harvest, always taking into account the border area, and the following variables were evaluated in each plant:

- Dry mass of pods (P pods).
- Dry mass of grains (P grains)
- Total dry mass of the aerial part (P total)

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

	Holguin 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
P Date	sept-jan	sept- jan	sept- jan	sept- jan	sept- jan	oct-nov
Type of growth habit	Undetermined type II	Undetermined type II	Undetermined type II	Undetermined type III	Undetermined type III	Undetermined type III

Yield: yield, P. date: recommended planting date

- Dry mass of stems (P stems).

From the above variables, it was determined:

- Harvest Index (HI) (10)

Harvest index

$$HI = \frac{PTotal}{Pgrain}*100$$

Pod harvest index

$$HI = \frac{Pgrain}{Ppods}*100$$

Agricultural yield was also determined, 8 m^2 were harvested from the center of each plot, the plants were threshed and the grains were dried to 14 % grain moisture. For the dry mass of plant parts (P pods, P grains, P stems), each part was separated and kept in an oven for 72 hours at a temperature of 70 °C until constant weight. The total mass of the plant (total P) was calculated by summing the dry mass of each individual organ (11).

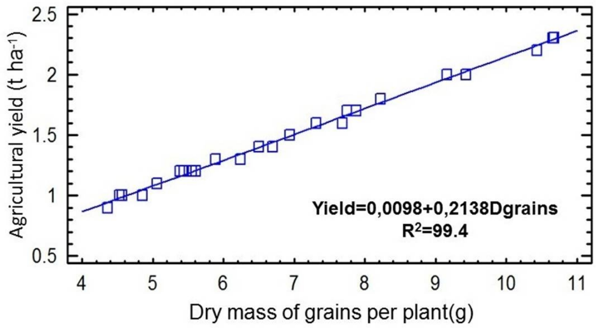
For the same sowing date, an analysis of variance was made for each variable and the significant differences between the means of the different treatments (cultivars) were determined by Tukey's test at 95 % and from the experimental error, the confidence interval was calculated (12). The data were plotted for analysis in order to achieve a comparison between dates.

A regression analysis was performed between agricultural yield and dry mass of grains per plant to establish the relationship between these two variables. A data matrix was also constructed; cultivars by sowing date; dry mass of pods; dry mass of grains; dry mass of stems; total dry mass; harvest index and harvest index of pods. These were processed by the Principal Components multivariate technique, by means of a Biplot representation to establish the degree of association between the variables determined with the weight of the grains for the conditions of the sowing season. The statistical package Statgraphics 5.1 (13) was used for all analysis.

RESULTS AND DISCUSSION

In terms of agricultural yield, it was observed that a specific behavior pattern cannot be defined, which may be related to the fundamental role played by external factors such as climate. However, internal factors, such as grain mass, influence yield formation. This is demonstrated in Figure 1, which shows the relationship between agricultural yield in t ha^{-1} and the dry mass of grains per plant in grams.

Although not all authors are of the criterion that the mass of grains is the component most related to yield. They consider it as a varietal character related to the size of the grain (14), in some investigations it has been concluded that the increase in yield can be attributed to the considerable increase in the number of pods per plant and the weight of grains (15). In spite of the fact that each component is affected with different intensity by the environment in the different stages of crop development and within certain limits, plants have the capacity to compensate the reductions in one component with the increase of another (16). In this sense, in studies developed in a wide range of agronomic conditions, it was demonstrated that the number of grains as the main component of yield could only be compensated by their mass (17). Other studies carried out in Cuba with the cultivation of beans, demonstrated the relation of yield with the variables of legumes per plant and dry mass of 100 grains (18). That is why, with the result reached in this work, the criterion that the mass of grains per plant is one of the variables of greater influence on the agricultural yield of the crop is corroborated (19). Therefore, this can contribute a selection criterion in the genetic improvement program of the crop in Cuba in the current conditions, where lines with tolerance to biotic and abiotic stress but with high yield potential are identified.



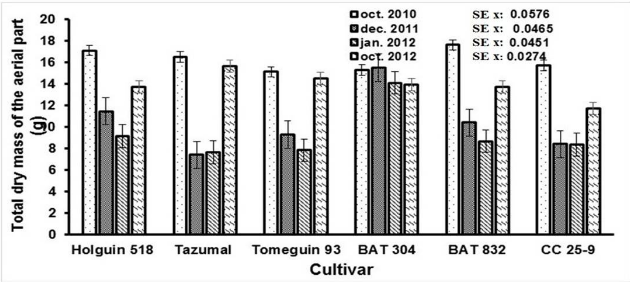
Cultivars: Holguín 518, Tazumal, Tomeguín 93, BAT 304, BAT 832, CC-25-9

Dates of sowing: October 2010, December 2011, January 2012 and October 2012 N=24

Figure 1. Ratiotionship between agricultural yield (t ha^{-1}) and dry mass of beans per plant (g) of bean cultivars (*Phaseolus vulgaris* L.) at different sowing dates

Regarding the behavior of the dry mass of pods, stems and the dry mass of the aerial part, there was a wide variability in the results for the cultivars in the different sowing dates. Although in all cases, the same pattern of behavior was found, so that in Figure 2 the values of the total dry mass of the aerial part of the plants are shown. In general, the influence of sowing dates on the values of this variable can be seen, since in most cultivars the highest values were reached in October 2010 and 2012. Only the cultivar BAT 304 shows a similarity between the values for each sowing date studied.

The accumulation of dry mass in the bean crop, which is a C3 type plant, is a product of the balance of carbon metabolism where, despite the production of photoassimilates due to photosynthetic activity, there are losses through respiration and photorespiration, mainly in stages of the crop where variables such as air temperature can have high values (above 30 ºC). Although it is important to achieve high biological productivity values in cultivars, it is also necessary to ensure that a large part of this total biomass production becomes part of agricultural productivity, i.e. grain yield.



Cultivars: Holguín 518, Tazumal, Tomeguín 93, BAT 304, BAT 832, CC-25-9.

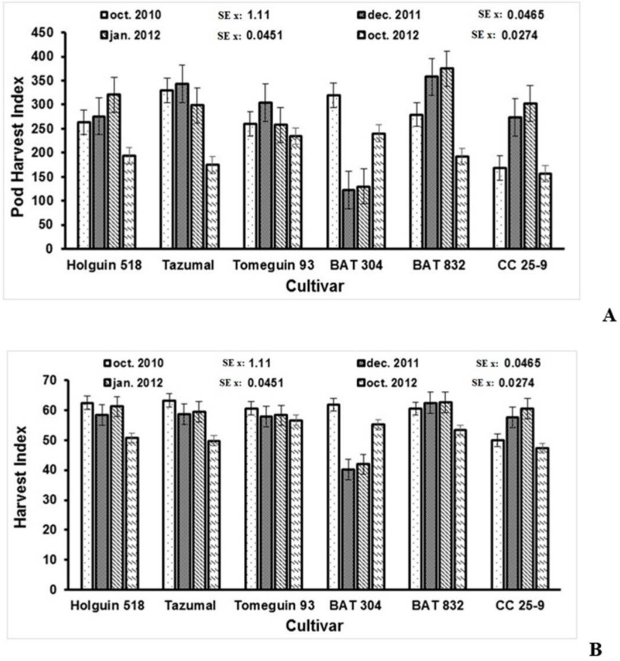
Planting dates: October 2010, December 2011, January 2012 and October 2012.

Bars represent confidence intervals at p≤0.05

Figura 2. Total dry mass values of the aerial part of the plant of six bean cultivars (*Phaseolus vulgaris* L.) at four sowing dates

When analyzing the PHI (Figure 3A), it was found that there are differences between cultivars and sowing dates. Therefore, it is not possible to establish a general pattern of behavior for this variable. The lowest values for the sowing dates studied were observed in October 2012. In the case of the cultivars, BAT-304 reaches the lowest values. All this may be related to the fact that, in bean cultivation, the development of the pods is affected and, consequently, malformations are caused that can damage the development of the bean, resulting in what is known in the literature as vain pods. This can be caused by the prevailing climatic conditions, which are favorable for the appearance of fungal and bacterial diseases that persist in periods where high temperatures, high relative humidity and high rainfall are combined (20). However, when analyzing the HI (Figure 3B), it was observed that for most cultivars and sowing dates, the values of this index were between 55 and 60. Only the cultivar BAT-304 obtained values of approximately 40 on two sowing dates. There are authors who state that normally the values of this index in the cultivation of beans are in a range of 50 and 60, since lower indexes indicate a poor formation of pods or seeds in relation to the development of the crop (15). These results show the high efficiency in the conversion of economically useful dry mass in the bean cultivars studied. This may be related to the genetic characteristics and the response of the cultivar to the prevailing conditions during crop development. In studies carried out in bean cultivation, there is evidence of the differences found between cultivars in terms of HI, and in general, where the highest value of this variable was reached, the highest yields were found (21).

From the principal component analysis it was possible to obtain a number of linear combinations of the six variables studied, which best explain the variability of the data. The results of the analysis showed that most of the variability



Cultivars: Holguín 518, Tazumal, Tomeguín 93, BAT 304, BAT 832, CC-25-9.

Planting dates: October 2010, December 2011, January 2012 and October 2012.

Bars represent confidence intervals at p≤0.05

Figure 3. Pod harvest index (PHI) (A) and harvest index (HI) (B) of bean (*Phaseolus vulgaris* L.) cultivars at different sowing dates

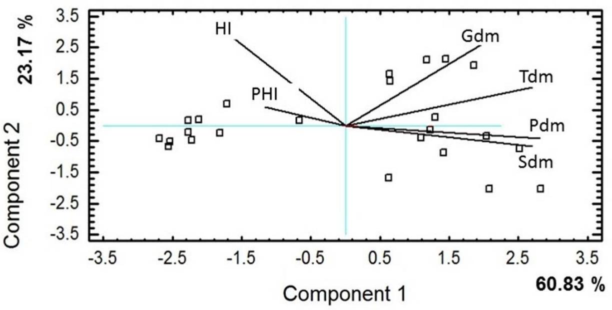
was associated with the first two components, so that six variables were reduced to two components and these together contributed 83.9 % of the total variance of the experiment (Table 3).

Variables that contributed the greatest positive variation to principal component 1 were pod weight, stem weight and total weight; this component was related to pod weight. In component 2 the most effective variable was pod harvest index.

A two-dimensional representation (biplot) of the growth variables and the spatial distribution of the cultivars for each sowing date in the first two components are shown in Figure 4, for a better explanation of the previous results and to be able to make a comparison of all the elements. Figure 4 shows that the harvest index and pod harvest index showed a positive association as did pod weight and total weight, which is evidenced by the angular separation between them. However, there was a negative relationship between harvest indexes (HI, PHI) and pod and stem mass. This shows that a greater dry mass of stems and pods can decrease the harvest index and therefore the probability that the dry mass-produced and stored in the different organs of the plant does not become part of the agricultural productivity (grain mass).

Table 3. Principal components of the growth variables used

Growth variable	**Components**	
	1	**2**
Harvest index	-0,2991	-0,1442
Pod harvest index	-0,2116	0,9634
Grain weight	0,3547	-0,0231
Stems weight	0,4903	0,2005
Total weight	0,4897	0,0580
Weight of pods	0,5096	0,0828
Eigenvalues	3,65	1,39
Contribution to total variance	60,83	23,17
% of cumulative	60,83	83,99



Cultivars: Holguín 518, Tazumal, Tomeguín 93, BAT 304, BAT 832, CC-25-9.

Planting dates: October 2010, December 2011, January 2012 and October 2012)

PHI: pod harvest index, HI: harvest index, Gdm: grain dry mass, Tdm: total dry mass of the aerial part, Pdm: pod dry mass, Sdm: Stem dry mass

Figure 4. Association of bean dry mass with pod dry mass, stem, total, harvest index and pod harvest index of bean cultivars (*Phaseolus vulgaris* L.) at different sowing dates

These results explain that there can be a low efficiency in the conversion of the economically useful dry mass, which can be related to the genetic characteristics of the cultivars and their response to the prevailing climatic conditions during the development of the crop. The literature highlights the importance of the HI to have a measure of plant efficiency under certain climatic conditions such as the use of light, water and nutrients in terms of grain production (16).

CONCLUSIONS

- It was shown that there is a positive relationship between grain mass and agricultural yield, regardless of cultivar and planting date, so that this variable is a key component in the formation of yield in the bean crop.
- Increases in the dry mass of stems and pods affect the harvest index and the greater part of the total biomass production does not become part of the agricultural productivity.

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