Biomass, yield and competitiveness of maize and bean crops in an association system[1]

Gustavo Adolfo Ligarreto-Moreno[2*], *Evelyn Gisela Arenas-Ochoa*[2]

10.1590/0034-737X202370020003

ABSTRACT

Polycultures are of great importance in conventional agriculture in the tropical zone, where they are a sustainable source of food production. In this study, the biomass distribution, crop yield and competition were determined in the maize and bean association. The total dry biomass accumulation of maize plants of the monoculture Simijaca SM(o) was higher than that of beans of monocultures cultivars Iraca IB(o) and Hunza HB(o). In monoculture, cultivar Iraca obtained the highest bean yields reaching 2744.0 kg ha^{-1} in the municipality of Gama, whereas cultivar Simijaca had the highest yields with a value of 7766.7 kg ha^{-1}. In the association, the best environment was the municipality of Simijaca for the SMxIB treatment, which showed a total yield of 9767.5 kg ha^{-1}. The total land equivalent ratio (LERt) was higher than 3.65, showing the advantage of this association. Additionally, the competitive ratio (CR) of the crops showed the high competition effect between maize and the two bean cultivars. The study generated new knowledge about the genetic resources of maize and climbing beans grown at the same time and in the same place, in the search for sustainable and resilient production.

Keywords: *Zea mays*; *Phaseolus vulgaris*; land equivalent ratio; competitive ratio.

INTRODUCTION

Crops grown in association play an important role in the development of sustainable agriculture and world food production (Yang *et al.*, 2017) due to several advantages, such as the increase of total productivity per unit area by optimization of land, water, and labor resources. Additionally, these systems contribute to soil conservation by improving crop fertility and reducing harvest time by up to 25% (Ajala *et al.*, 2019). According to Tsubo & Walker (2002), association systems increase yields compared to monocultures.

Regarding the maize and bean association, research related to crop yields is still scarce. Additionally, studies on this subject do not address topics, such as the estimation of the competitive relationship between species and the land equivalent ratio (LER), that allows demonstrating the advantages of crop associations compared to monocultures (Vélez *et al.*, 2007; Alemayehu, 2014).

Maize and bean crops grown in association belong to the ancient cultures of the Andes and are part of the crop diversification in production systems for the efficient use of land and the integral conservation of natural resources. The most recent research on the subject was reported by

Submitted on July 03rd, 2021 and accepted on August 01rst, 2022.
[1] This paper belongs to the second Author master's dissertation, Project funded by Sistema General de Regalías de Colombia (General System of Royalties of Colombia).
[2] Department of Agronomy, Faculty of Agricultural Sciences, Universidad Nacional de Colombia, Bogotá, Colombia. galigarretom@unal.edu.co; egarenaso@unal.edu.co
*Corresponding autor: galigarretom@unal.edu.co

Pérez *et al.* (2013), who analyzed the biomass accumulation and distribution of maize and bean crops grown in association and monoculture. According to that study, pods accumulated higher dry weight in the commercial varieties of "bola roja" (red seeded) bean of variable growth habit when grown in association. On the other hand, when evaluating the effect of the competition of beans associated with maize, competition for light prevailed over that for water or nutrients (Vélez *et al.*, 2011).

Maize and beans are essential crops for food security. Furthermore, maize is considered an indispensable resource for livestock nutrition due to its high energy content. Maize with beans could be an alternative to increase the forage nutritional value. Growers use two production models to take advantage of these harvested crops, when planted in the association system, harvesting the fresh grain or incorporating it into the silage (Vélez *et al.*, 2011). The objective of this study was to determine the biomass production, yield components, and level of competition of maize and red seeded beans grown in an association system.

MATERIALS AND METHODS

Growth environments and plant material

Crops were established in two environments in Colombia during the first semester of 2017. The first environment was in the municipality of Simijaca (05°29.5'1.5'' N and 073°48'48.2'' W) at an altitude of 2,563 m a.s.l., with an average annual temperature of 14 °C, solar radiation of 17.3 MJ m^{-2} day^{-1}, average relative humidity (RH) of 78.65%, annual average rainfall of 900 mm, and soil pH of 5.3. The second environment was in the municipality of Gama (04°45'42.5'' N and 073°36'42.1'' W) at an altitude of 2,180 m a.s.l., with an average annual temperature of 17 °C, solar radiation of 14.6 MJ m^{-2} day^{-1}, RH of 90.1%, annual average rainfall of 1,150 mm, and soil pH of 4.7.

The regional variety of floury maize Simijaca and bean cultivars Hunza and Iraca with a variable or indeterminate growth habit (type IV) were used. 'Iraca' has a life cycle 15 to 20 days shorter than 'Hunza' and shows high defoliation during the grain maturation. Cultivar Hunza has a large grain with an average weight greater than 80 g for 100 grains, while 'Iraca' has a lower weight with 68.0 g for 100 grains. A randomized complete block design (RCBD) was used for each environment. The treatments consisted in the establishment of different cultivation systems, as follows: monocultures of Simijaca maize SM(o), 'Iraca' bean IB(o), and 'Hunza' bean HB(o), and crop associations of Simijaca maize + 'Iraca' beans (SMxIB) and Simijaca maize + 'Hunza' beans (SMxHB). Four replicates were established, and each experimental unit corresponded to three rows of 10 m long with a distance of 1 m between them (30 m^2). In the plots that included the two species, four maize seeds and two bean seeds were sown simultaneously in the same place with a 0.90 m distance between plants. In monoculture plots, seeds were sown at a distance of 0.50 m for beans and 0.40 m for maize.

Thirty days before sowing, pH was corrected to 5.3 with a dose of 5.70 kg/plot (2 t ha^{-1}) of dolomite lime in the Gama environment. Thirty days after emergence (DAE), when weeding and hilling were carried out, the plants were fertilized with a mixture of the following soil fertilizers: i) Diammonium phosphate (DAP) at a dose of 70 kg ha^{-1}, ii) urea at a dose of 80 kg ha^{-1}, and iii) potassium chloride (KCl) at a dose of 50 kg ha^{-1}.

Dry biomass estimation

Dry matter accumulation per plant organ was determined: stem, leaves, grains, and total plant weight including flowers and inflorescences. Three sampling points were determined per treatment and repetition. The evaluation was carried out at 119 days after sowing (DAS) in Simijaca and at 111 DAS in Gama during the phenological stage of reproductive structure formation. During grain maturation, the sampling was carried out at 154 DAS in Simijaca and 141 DAS in Gama. The plant material was dried in an oven (Binder, APT. Line, Germany) at a constant temperature of 80 °C until the constant weight.

Maize and bean yield

The maize was harvested at the milk kernel stage at 167 DAS in Simijaca and 148 DAS in Gama. The number of ears per plant and the morphological characteristics of the ear were quantified and determined in 10 ears per plot, according to the methodology proposed by Delgado *et al.* (2014). In beans, the dry grain harvest was carried out at 201 DAS in Simijaca and 159 DAS in Gama. The yield components were recorded in five plants per plot and the yield per hectare was determined based on the yield of the central row of the maize and bean plot.

Harvest Index

The harvest index (HI) was determined at the grain maturation stage at 154 DAS in Simijaca and 141 DAS in Gama.

$$HI = \frac{\text{Grain yield}\left(g\ m-^2\right)}{\text{Total shoot dry biomass}\left(g\ m-^2\right)} \quad (\textit{Equation 1})$$

Land equivalent ratio (LER)

Total LER is expressed as:

$$LERt = LERmaize + LERbeans \quad (\textit{Equation 2})$$

(Dhima *et al.*, 2007).

LERmaize = Ymb/Ym and LERbeans = Ybm/Yb are the partial LER of maize and beans, where Ymb is the yield of MxB, Ybm is the yield of BxM, Ym is the yield of maize and Yb is the yield of beans. Hereinafter, LERmaize will be represented as LERm and LERbeans as LERb. When LERt > 1, the association favors the growth and yield of both species, and if LERt < 1, the growth and yield of the plants are negatively affected.

Competitive ratio (CR)

CR interprets the ratio of the individual LERs of maize and beans in relation to the number of seeds per planting site (Dhima *et al.*, 2007). was estimated as:

$$CR = \left(LERm / LERb\right) x \left(Xbm / Xmb\right) \quad (\textit{Equation 3})$$

Where Xbm and Xmb are the proportions of beans in association with maize and of maize in association with beans, respectively. When CR < 1, there is a positive effect of growth in the MxB association according to the methodology proposed by Esmaeilian *et al.* (2011).

Statistical analysis

A combined analysis of variance for environments was performed and Duncan's new multiple range test was used for the comparison of means; SAS University edition® software was used for this purpose (SAS Institute, 2015).

RESULTS AND DISCUSSION

Biomass production

At the stage of reproductive structure formation, highly significant differences were observed for the environments (E), treatments (T), and ExT (Table 1). In Gama, plants reached a total weight of 334.88 g, while lower values were observed in Simijaca with 158.85 g (Figure 1A). This difference was due to the higher rainfall in Gama, which allowed a better compensation of the water transpired by these crops in association compared to the Simijaca environment. According to Mao *et al.* (2012), maize, as a C4 crop transpires more water than bean as C3 crop. Also, the lower radiation in Gama favored that the assimilated products were dedicated to the growth of the aerial part of the plant, mainly the stem (Figure 1A).

The treatment of maize in monoculture SM(o) reached a biomass production of 296.39 g in the Simijaca environment at the stage of reproductive structure formation at 119 DAS. This value differs significantly from the other treatments that showed a lower production (Figure 1B). These results coincide with those previously found by Vélez *et al.* (2007) who indicate an increase in the total dry matter of maize in monoculture and a reduction of this variable in the association system. According to Ren *et al.* (2016), maize shows a higher growth rate than soybeans during the entire growth period when sown in an intercrop, since maize is a C4 plant compared to soybean that is a C3 plant. Gama, the environment with higher rainfall, favored a higher biomass production compared to Simijaca. The accumulation of biomass was not affected by the association; thus, SM(o) showed similar values to those obtained in SMxHB and SMxIB compared to bean monocultures at 111 DAS, which exhibited low values of total biomass (Figure 1C).

At the grain maturation stage, significant differences were observed between maize and bean crops treatments only (Table 1, Figure 1D). In the municipality of Simijaca, SM(o) behaved differently from the other treatments, with a value of 503.55 g for the highest total dry weight of the plant. Regarding the dry weight of grains, there were no statistical differences between HB(o), IB(o), and SMxHB and SMxIB associations at 154 DAS (Figure 1E). The translocation of assimilates to grains could have been favored in this environment of higher radiation (Yang *et al.*, 2017).

In the municipality of Gama at 141 DAS, the SM(o) treatment showed a total shoot dry biomass production of 491.76 g, 285.41 g in the stem, and 59.71 g in the leaves. This last value was similar to those obtained in the SMxHB (57.67 g) and SMxIB (50.58 g) associations. Additionally, the dry weight of grains was not significant in the sowing systems SM(o), SMxHB, and SMxIB (Figure 1F). Consequently, the biomass accumulation was not affected by the association in the humid environment. According to Pérez *et al.* (2013), biomass distribution to the leaves increases in maize associated with red seeded beans compared to maize in monoculture and decreases during grain maturation. Other studies indicate that increasing the leaf area of beans in association reduces a biomass production in maize as the main crop (Habibollah *et al.*, 2015; Habte *et al.*, 2016).

Table 1: Yield components of maize and beans in two environments of Colombia in 2017[+/]

Source / Location		Total biomass (g plant^{-1})		Seeds pod^{-1}	Pods plant^{-1}	Weight of 100 seeds (g)	Seeds pod^{-1}
		Reproductive stage	Maturation stage				
Environment (E)		**	ns	**	**	*	*
Treatments (T)		**	**	**	ns	*	*
E x T		**	ns	ns	**	ns	ns
Simijaca		158.85 b	318.14	5.49 b	**28.80 a**	**75.93 a**	5.49 b
Gama		334.88 a	313.24	**6.41 a**	16.23 b	65,17 b	**6.41 a**
Source / Location / Treatments		**Ears per plant**	**Kernels per row**	**Rows per ear**	**Kernels per ear**	**Ear diameter (mm)**	**Ear length (cm)**
Environment (E)		**	ns	ns	*	*	*
Treatments (T)		ns	ns	ns	ns	ns	ns
E x T		ns	ns	ns	ns	ns	ns
Simijaca	SM(o)	1.95 a	20.90 a	10.65 a	220.37 a	67.65 a	19.68 a
	SMxHB	1.70 a	17.87 a	14.00 a	209.94 a	64.93 a	19.00 a
	SMxIB	2.10 a	18.35 a	10.30 a	218.29 a	67.41 a	18.53 a
Gama	SM(o)	1.20 a	18.95 a	10.90 a	215.35 a	77.26 a	17.26 a
	SMxHB	1.15 a	17.70 a	11.20 a	193.21 a	79.82 a	16.62 a
	SMxIB	1.30 a	17.10 a	10.37 a	186.16 a	77.37 a	17.04 a
Simijaca		**1.91 a**	19.04 a	11.65 a	**216.20 a**	66.66 b	**19.07 a**
Gama		1.21 b	17.91 a	10.82 a	198.24 b	**78.15 a**	16.97 b

SM(o) = Simijaca maize, SMxHB = Simijaca maize x Hunza beans, SMxIB = Simijaca maize x Iraca beans.
[+/]Highly significant = **, significant = *, not significant = ns. Column averages with the same letter in each environment and between environments do not show significant differences according to Duncan's test (P < 0.05).

No differences were observed between the environments in the production of total shoot biomass at the grain maturation stage as shown in Table 1 and Figure 1D. Differences were observed between the biomass of leaves, being higher in Simijaca with a value of 56.68 g, while the biomass of the stem was higher in Gama with a value of 140.48 g. The higher rainfall in Gama (compared to Simijaca) was an unfavorable factor that caused sanitary problems on the leaves of beans and plant defoliation. The dry environment of Simijaca could have allowed higher light interception due to its greater solar radiation. These factors together are fundamental in the translocation of photoassimilates at the grain maturation stage and, at the same time, contribute to the accelerated growth and the total dry weight of the plant.

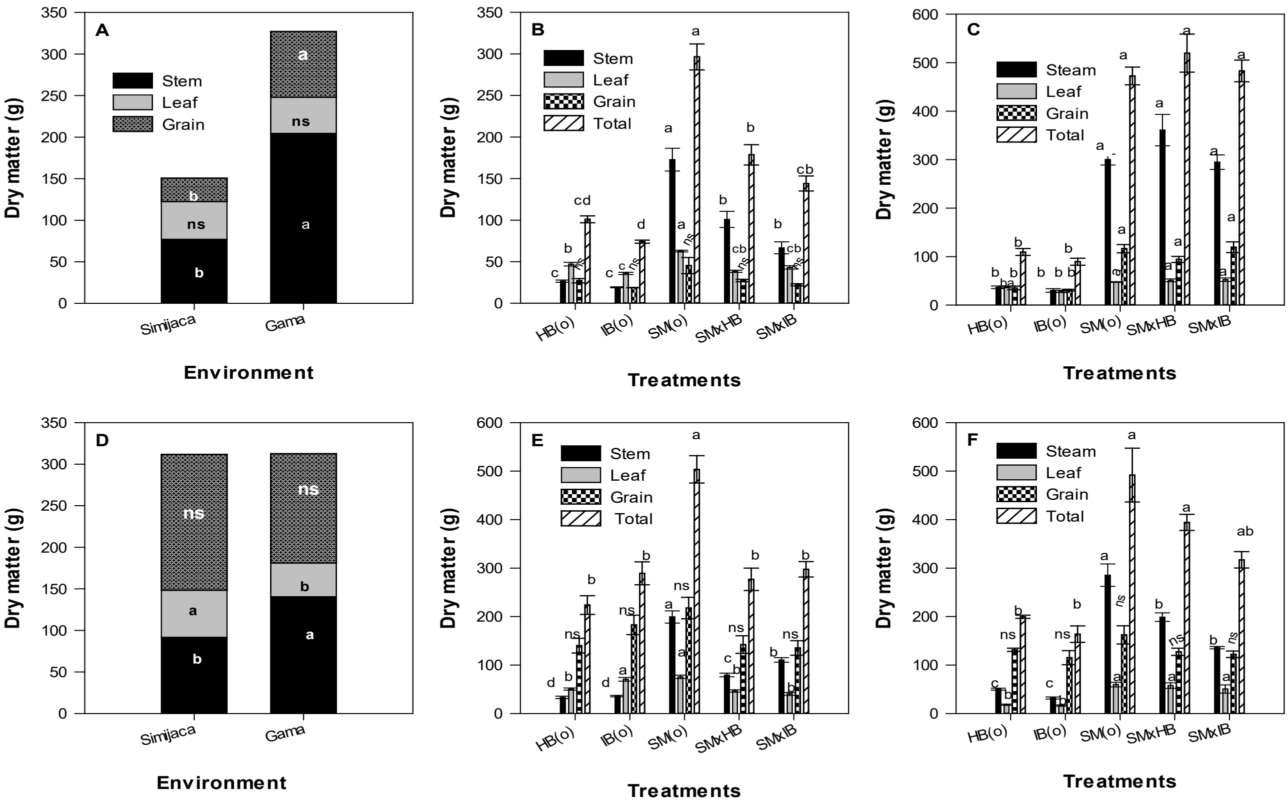

Figure 1: Dry matter distribution at the stage of reproductive structure formation of maize and beans: A) In environments, B) Simijaca, C) Gama. At a stage of grain maturation: D) In environments, E) Simijaca, F) Gama. HB(o) = Hunza, IB(o) = Iraca bean, SM(o) = Simijaca maize, SMxHB = Simijaca maize x Hunza beans, SMxIB = Simijaca maize x Iraca beans. Means with the same letter are not significantly different according to Duncan's test (P < 0.05).

Maize and bean yield

Regarding the maize yield components, statistical differences were only observed between the environments (Table 1). The radiation and relative humidity conditions in Simijaca significantly favored the production of ears per maize plant with an average number of 1.91, 216.20 kernels per ear and an average length of 19.07 cm at 167 DAS (Table 1). These results were higher than those found in the municipality of Gama, except for the equatorial diameter of 78.15 mm. In Gama, the ears had a higher proportion of husk and a lower number of kernels per ear at 148 DAS. The reduction in maize yield is attributed to the effect of the environment due to the low radiation and high relative humidity since maize has a high capacity to intercept photosynthetically active radiation (Yang *et al.*, 2017). Regarding the number of kernels per row and rows per ear, no significant differences were observed between treatments and environments. These results can be attributed to the lower phenotypic plasticity of these characters to the environment, which coincides with that reported by Barary *et al.* (2014) (Table 1).

The SMxHB association in the municipality of Simijaca differs significantly from the other treatments, with an average of 37.82 pods per bean plant at 201 DAS. In Gama, the higher yields were found in HB(o) and IB(o), with 22.55 and 20.90 pods per plant at 159 DAS, respectively (Figure 2A). According to Infante *et al.* (2018), when cultivars adapt to the environment, they increase grain production and decrease biomass production. In this case, beans have adapted better to Simijaca than to Gama.

In the two studied environments, the highest number of grains per pod was for 'Iraca' beans. In Simijaca, the IB(o) system averaged 7.60 grains per pod, whereas, in the SMxIB, the value for this variable was 7.12. The bean variety Hunza obtained a fewer number of grains per pod, both in HB(o) and in SMxHB (Figure 2B). These results coincide with those obtained by Fageria *et al.* (2010), who indicate that yield components differ between bean genotypes.

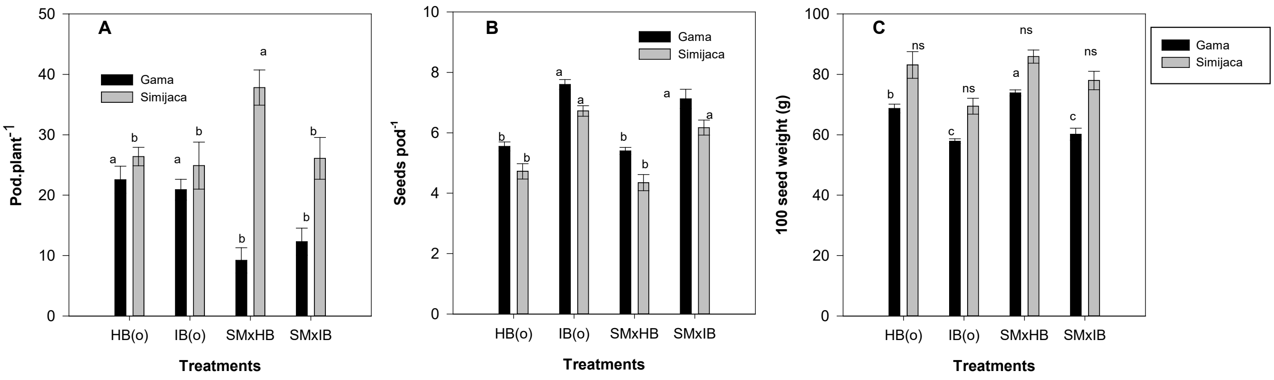

Figure 2: Yield components in bean cultivars Hunza and Iraca. A). Number of pods per plant. B). Number of grains per pod; C). Weight of 100 seeds. HB(o) = Hunza, IB(o) = Iraca bean, SM(o) = Simijaca maize, SMxHB = Simijaca maize x Hunza beans, SMxIB = Simijaca maize x Iraca beans. Means from the same environment with the same letter are not significantly different according to Duncan's test ($P < 0.05$).

Regarding the dry weight of 100 grains, significant differences were observed between the treatments in the municipality of Gama. In this environment, the highest value was obtained for SMxHB with 73.86 g and the lowest weight was registered in IB(o) and SMxIB. It is noteworthy that cultivar Hunza shows a larger grain size than 'Iraca' as a genetic characteristic. On the other hand, no significant differences were observed for this variable between the bean varieties and cultivation systems in the municipality of Simijaca (Figure 2C). The greatest variation between the different cultivation systems occurred for SMxIB, which reached an average of 75.12 g in Simijaca and 60.22 g in Gama for the weight of 100 grains. Consequently, it is possible that the higher radiation in the Simijaca environment could have favored the translocation of assimilates during grain formation in the cultivar Iraca.

The previous results in beans may be due to the fact that large grains compensate when a lower number of pods per plant and a lower number of grains per pod are registered in the Gama environment, which has a higher temperature and precipitation. This approach is supported by Schwerz *et al.* (2017) who state that the increase in grain weight depends on the availability of water in soil and increases the production of assimilates during grain formation.

Regarding bean yield (Table 2), in Simijaca, the best behavior was observed in the cultivar Hunza both in monoculture and associated with 1980.8 kg ha^{-1}. This result contrasts with what was observed in Gama, where 'Iraca' showed better behavior with IB(o) reaching 2744.0 kg ha^{-1}. This result shows that bean cultivars have yield plasticity for the environments given the availability of edaphoclimatic resources and the reduction of interspecific competition. Therefore, a significant increase in yield was observed compared to the SMxHB and SMxIB crops. In this regard, Ajala *et al.* (2019) observed a reduction in grain yield between 262.20 and 908.9 kg ha^{-1} in beans in association with maize. When analyzing the total production of both species, the SMxIB association reached 9767.5 kg ha^{-1}, which was higher than that of SMxHB with a yield of 8897.5 kg ha^{-1} (Table 2). Lower results were reported by Getahun & Abady (2016), who registered an increase in yield of 5398 kg ha^{-1} in association, with a decrease of 5299.5 kg ha^{-1} in maize monoculture. However, higher results were reported by Pour *et al.* (2016), who observed a biological yield of 9157 kg ha^{-1} in maize.

Productive efficiency of crops

The average harvest index (HI) per environment was higher in Simijaca with values of 0.65 for HB(o) and 0.66 for IB(o) during the grain maturation stage at 154 DAS (Table 2). According to Vélez *et al.* (2011), the increase in the harvest index is attributed to the dry weight of the pods. On the other hand, the results obtained in Gama showed a significant increase in IB(o) that reached a value of 0.71 at 141 DAS. This behavior differs considerably from that of SM(o) and the SMxHB and SMxIB associations. The reported values were similar to those observed by Araújo & Teixeira (2012), who found that the HI for beans varied between 0.54 and 0.71.

Table 2: Comparison of yield and harvest index (HI) of maize Simijaca and bean cultivars Hunza and Iraca in two environments of Colombia in 2017+/

Source / Location	Treatments	Yield (kg ha^{-1})+/			HI
		Bean	Maize	Total	
Environment (E)		ns	**	**	*
Treatments (T)		**	ns	**	**
E x T		**	*	**	*
Simijaca	HB(o)	1933.3 a	-	1933.3 c	**0.65 a**
	IB(o)	1628.3 b	-	1628.3 c	**0.66 a**
	SM(o)	-	7766.7 ab	7766.7 b	0.47 b
	SMxHB	1980.8 a	6916.7 b	**8897.5 a**	0.45 b
	SMxIB	1417.5 b	**8350.0 a**	**9767.5 a**	0.47 b
Gama	HB(o)	**2097.5 a**	-	2097.5 b	0.64 b
	IB(o)	**2744.0 a**	-	2744.0 b	**0.71 a**
	SM(o)	-	5575.3 a	5575.3 a	0.37 c
	SMxHB	607.3 b	6085.3 a	6692.7 a	0.29 d
	SMxHB	975.0 b	5386.3 a	6361.3 a	0.38 c
Simijaca		1740.0 a	**7677.8 a**	**5998.7 a**	**0.54 a**
Gama		1606.0 a	5682.3 b	4694.2 b	0.48 b

HB(o) = Hunza, IB(o) = Iraca bean, SM(o) = Simijaca maize, SMxHB = Simijaca maize x Hunza beans, SMxIB = Simijaca maize x Iraca beans. +/ Highly significant = **, significant = *, not significat = ns. Column averages with the same letter in each environment and between environments do not show significant differences according to Duncan's test (P < 0.05).

In Simijaca, the average HI value of the treatments SM(o) and in association showed a significant increase compared to Gama. In this last environment, the HI was reduced due to the high rainfall that caused a higher biomass production. Therefore, the HI varied according to the environment and cultivation system, which coincides with what was reported by Delgado *et al.* (2014). Similarly, the results showed the effect of the environment on the maize HI in Simijaca. In this environment, the SM(o) reached 0.47, while in Gama the HI fell to 0.37. The results reported by Infante *et al.* (2018) show that the HI in maize is equivalent to 0.36 and when the plants adapt to the environment, the HI oscillates between 0.30 and 0.41.

The land equivalent ratio (LER) was greater than 1 in all combinations of the maize x beans association. Therefore, it was more effective in terms of production than the maize and bean crops in monoculture in the two environments. These results are also reported by Ajala *et al.* (2019), who state that maize in intercropping systems with lima beans is more productive since it shows a LERt of 1.95 compared to monocultures of these species.

In the municipality of Simijaca, the highest LERm was found in the SMxIB association, with a value of 1.28. This value indicates that this planting arrangement of maize with 'Iraca' beans had a more efficient yield than the association with 'Hunza' beans (LERm = 1.16). Regarding LERb, the highest value (6.20) was obtained for the SMxIB association. Consequently, the combination of the land equivalent ratio (LERt) indicated a considerable increase, reaching a value of 7.48 for SMxIB (Table 3). This means that there is greater efficiency in the land use when 'Iraca' beans are associated with SM compared to the land use by the bean cultivar Hunza. This difference may be because the cultivar Hunza is more vigorous in the foliage proportion (represented by stems and leaves) than the bean cultivar Iraca, which can affect competition mainly for light and nutrients (Vélez *et al.*, 2007). In Gama, there were no significant differences in the partial LER of maize, beans, and total in the SMxHB and SMxIB associations and, therefore, any bean genotype combines well with SM. When comparing the environments, LERm did not show statistical differences, while LERb and LERt were statistically superior for the Simijaca environment. This result is explained by the higher HI in this environment (Table 2), which means that the grain yield of crops was lower and biomass was higher in Gama compared to Simijaca.

Table 3: Comparison of land equivalent ratio (LER) and competitive ratio (CR) means of maize Simijaca and bean cultivars Hunza and Iraca in two environments of Colombia in 2017 [+/]

Source / Location	Treatments	LERm	LERb	LERt	CRm	CRb
Environment (E)		ns	**	*	**	**
Treatments (T)		*	*	*	*	*
E x T		ns	*	*	*	*
Simijaca	SMxHB	1.16 b	4.61 b	5.77 b	**1.02 a**	1.00 b
	SMxIB	**1.28 a**	**6.20 a**	**7.48 a**	0.83 b	1.23 a
Gama	SMxHB	1.21 a	2.95 a	4.16 a	**1.65 a**	0.60 a
	SMxIB	1.14 a	2.50 a	3.65 a	**1.96 a**	0.53 a
Simijaca		1.22 a	**5.40 a**	**6.63 a**	0.92 b	**1.12** a
Gama		1.18 a	2.72 b	3.91 b	**1.81 a**	0.57 b

SMxHB = Simijaca maize x Hunza beans, SMxIB = Simijaca maize x Iraca beans. LERm: maize, LERb: bean, LERt: total, CRm: maize, CRb: bean. [+/]Highly significant = **, significant = *, not significat = ns. Column averages with the same letter in each environment and between environments do not show significant differences according to Duncan's test ($P < 0.05$).

Consequently, the compatibility between the plants in association was evident in Simijaca, with an increase in the productivity per unit area compared to the monoculture, when using a planting pattern (4:2) of maize x beans. On the other hand, Charani *et al.* (2015) found values lower than 1 in the partial yields of maize and beans. The biological yield efficiency depends on the planting density of the species, the consumption of water, nutrients, and productivity per unit area (Pour *et al.*, 2016).

The competitive ratio (CR) in maize (CRm) in the municipality of Simijaca showed a value of 1.02 in SMxHB, indicating the effect of the competition of Simijaca maize on 'Hunza' beans. Similarly, the highly competitive ability of maize was reported in the municipality of Gama with values of 1.96 for SMxIB and 1.65 for SMxHB. These results coincide with those reported by Charani *et al.* (2015), who point out that maize is the most competitive species (Table 3). Other studies report that the upper stratum of the canopy in maize provides shade to beans. This shade inhibits the production of the number of pods and grains, decreasing grain yield as a consequence (Delgado *et al.*, 2014; Getahun & Abady, 2016).

On the other hand, the positive effect of maize was observed in the SMxIB association in Simijaca, with a CRm value of 0.83. The yield per hectare, mainly of maize, was favored, reaching a value of 8350 kg ha^{-1}. This result could be attributed to the morphological characteristics of both bean cultivars; the leaves of cultivar Iraca are smaller compared to those of the bean cultivar Hunza with very large leaflets. Additionally, since 'Iraca' is more precocious in its life cycle, it has lower biomass and high defoliation rate compared to 'Hunza'. Consequently, the ability of maize to compete was lower. Likewise, the CRb, with values lower than 1 in the Gama environment, indicates a lower competition capacity of beans in the association, since their yield was 607.3 kg ha^{-1} for cultivar 'Iraca' and 975.0 kg ha^{-1} for 'Hunza' beans. These values are much lower than those found in Simijaca (Table 2), an environment where maize also achieved the highest yields. These results are in agreement with what was stated by Tilman *et al.* (2001) about the complementarity of maize associated with beans that allows plants to take advantage of resources, such as land area and sunlight capture, according to their architecture.

The study generated new knowledge on the use of corn and bean crops planted at the same time and in the same place on the farms of local growers in two environments of the high tropics, in search of maximizing the efficiency of scarce resources like land, labor, and capital.

CONCLUSIONS

The maize x bean association allowed the generation of a viable productive and sustainable option from two new improved cultivars of climbing bean and maize in two environments of the high tropics. Consequently, it was possible to maximize the use of the land's aerial unit and determine the best association with corn for biomass production and yield through the differential behavior of bean cultivars.

ACKNOWLEDGMENTS

The authors would like to thank the Corredor Tecnológico Agroindustrial - CTA2 for financing this research through the Sistema General de Regalías de Colombia (General System of Royalties of Colombia).

DECLARATION OF INTERESTS

The authors declare no conflict of interest for the publication of this article.

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