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Original article

Coinoculation of rhizobia and Arbuscular Mycorrhizal Fungi in two common bean cultivars

Coinoculación de rizobios y Hongos Micorrízicos Arbusculares en dos cultivares de frijol común

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ABSTRACT: The work was carried out with the objective of determining the best combination of rhizobia and arbuscular mycorrhizal fungi strains in two bean cultivars: CC25-9 black and Lewa in a Nitisol soil. It was used in a randomized block design. Using a bifactorial arrangement, the factors under study were: four levels of rhizobia: three strains and a control without inoculation and four levels of mycorrhizal inoculation: two strains and a control without inoculation, for a total of twelve treatments. The variables evaluated were: height of the plant, diameter of the stem, dry mass of the leaves and the stem, yield and its components. The results in the yield of the crop, showed that the best combinations for the cultivar CC 25-9 are INCAM 4+CIAT 899 and INCAM 11 with CF 1 and CIAT 899 and although these results did not differ from the rest of the coinoculated treatments, they were superior to the simple inoculation of the microorganisms. In the Lewa cultivar, the best combination was INCAM 4+CIAT 899, although without differences with INCAM 4+CF 1; INCAM 11 combined with the three rhizobia strains and the simple inoculation of CIAT 899. The effectiveness of the simple inoculation of the AMF strains INCAM 4 and INCAM 11 was different, it was depend on the cultivars under study. The degree of effectiveness of the simple inoculation of the rhizobia also depended on the cultivar, with CIAT 899 behaving as the best strain for the Lewa cultivar, while in the CC 25-9 N cultivar the three strains behaved similarly. The most effective coinoculation turns out to be INCAM 11+CIAT 899, INCAM 11+CF 1 and INCAM 4+CIAT 899, this last combination being the most efficient for cultivar Lewa.

Key words: bacteria, biofertilizers, *Phaseolus vulgaris*.

RESUMEN: El trabajo se realizó con el objetivo de determinar la mejor combinación de cepas de rizobios y cepas de hongos micorrizógenos arbusculares en dos cultivares de frijol: CC25-9 negro y Lewa, en un suelo Ferralítico Rojo Lixiviado. Se utilizó en un diseño de bloques al azar con arreglo bifactorial, los factores en estudio fueron: cuatro niveles de rizobios: tres cepas y un control sin inoculación y cuatro niveles de inoculación micorrízica: dos cepas y un control sin inoculación, para un total de doce tratamientos. Las variables evaluadas fueron: altura de la planta, diámetro del tallo, masa seca de las hojas y el tallo, rendimiento y sus componentes. Los resultados en el rendimiento del cultivo mostraron que las mejores combinaciones para el cultivar CC 25-9 son INCAM 4+CIAT 899 e INCAM 11 con CF 1 y CIAT 899 y, aunque estos resultados no difirieron del resto de los tratamientos coinoculados, si fueron superiores a la inoculación simple de los microorganismos. En el cultivar Lewa, la mejor combinación fue INCAM 4+CIAT 899, aunque sin diferencias con INCAM 4+CF 1; INCAM 11 combinado con las tres cepas de rizobios y la inoculación simple de CIAT 899. La efectividad de la inoculación simple de las cepas de HMA INCAM 4 e INCAM 11 fue diferente, en función de cada cultivar en estudio. Del mismo modo, el grado de efectividad de la inoculación simple de los rizobios dependió del cultivar, comportándose CIAT 899 la mejor cepa para el cultivar Lewa, mientras que en el cultivar CC 25-9 N las tres cepas se comportaron semejantes. Las coinoculación más efectiva resulta ser INCAM 11 + CIAT 899, INCAM 11+CF 1 y INCAM 4+CIAT 899, siendo esta última combinación la más eficiente para el cultivar Lewa.

Palabras claves: bacterias, biofertilizantes, *Phaseolus vulgaris*.

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INTRODUCTION

The bean (*Phaseolus vulgaris* L.) is the most widely cultivated species of the genus Phaseolus in the tropics and subtropics of Latin America, the Caribbean and Africa, mainly because it is a source of proteins, vitamins and minerals, which place it among the five crops with the largest surface area dedicated to agriculture in Latin American countries (1).

In Cuba, it constitutes one of the indispensable dishes in the Cuban menu, being the black bean the most common in Creole food (2). Despite its importance and the fact that it is a traditional crop, it is necessary to increase the productivity of the plants in a sustainable way, with a low amount of resources and with the best quality standards (3). However, national production does not meet the demands of the population, as there is a need to import 14.400 tons of this grain annually (4).

In this context, biofertilizers represent a sustainable, economically attractive and ecologically acceptable means to reduce external inputs and improve the quantity and quality of agricultural products, through the use of properly selected soil microorganisms, capable of making available to plants, through their biological activity, an important part of the nutrients needed for their development, as well as supplying hormonal or growth-promoting substances (5).

Among the most widely used biofertilizers are arbuscular mycorrhizal fungi (AMF) and rhizobia, which associate symbiotically with the plant and generate a positive exchange of nutrients, in which the plant supplies carbohydrates to the symbionts and these, in turn, favor the absorption and translocation of water and nutrients. These include phosphorus, zinc and copper, biological nitrogen fixation, protection against root pathogens and plant tolerance to various biotic and abiotic stresses (6).

In rhizobia - AMF - legume co-inoculation, symbiotic relationships have been reported to provide enhanced exchange between symbionts and superior effects to plants. In this case, the rhizobia-legume symbiosis provides N2 and the mycorrhizae increase the absorption of other elements, among them P, very important to guarantee an adequate biological fixation of N, increase the number, dry mass in the nodules and the growth of the plants (7).

Considering this problem, the present research was aimed at determining the best combination of rhizobia strains and arbuscular mycorrhizal fungi strains in two cultivars of CC25-9 black and Lewa in a Nitisol soil.

MATERIALS AND METHODS

The experiments were carried out at the Department of Agricultural Services (Las Papas farm), of the National Institute of Agricultural Sciences (INCA), located at 23º01' North Latitude and 82º08' West Longitude, at 138 meters above sea level. The experiment was carried out on a Ferrallitic Red Leached soil, according to the Cuban Soil Classification (8). An initial soil sampling was carried out to determine some chemical properties, by the following methods (9): pH (H_2O) by the potentiometric method, with a soil:solution ratio of 1:2.5; organic matter (% M. O) by the Walkley and Black method; assimilable P by extraction with H_2SO_4 0.1 N with a soil:solution ratio of 1:2.5; exchangeable cations (cmol kg^{-1}) by extraction with NH_4Ac 1 Mol L^{-1} at pH 7 and determination by complexometry (Ca and Mg) and flame photometry (K and Na). The agrochemical characteristics of the soil where the experiment was planted are shown in Table 1.

The determination of the spore count of arbuscular mycorrhizal fungi was carried out by wet sieving and decanting, the sample was taken before planting.

Two bean cultivars were planted in the experiment: Cuba Cueto 25-9 (CC25-9 N), the color of the bean testa is black, the recommended planting date for this cultivar is from October 1 to November 30, and Lewa, the color of the bean testa is white, the recommended planting date for this variety is from October 1 to January 30.

Two AMF strains were used, which come from the National Institute of Agricultural Sciences (INCA): *Glomus cubense*, strain INCAM-4 and *Rhizophagus irregularis* strain INCAM-11.

Regarding the rhizobial strains, three bean strains were used: strain CF 1 (*Rhizobium leguminosarum*), strain PRF 81 (*Rhizobium freirei*) and strain CIAT 899 (*Rhizobium tropici*), from the INCA's Department of Physiology and Biochemistry.

Seeds of each cultivar were soaked in the rhizobium-based inoculant corresponding to each treatment at a dose equivalent to 200 mL ha^{-1}. The control without inoculation was soaked in tap water. The application of the Arbuscular Mycorrhizal Fungi was carried out at a dose equivalent to 8 % of the total mass of the seed to be inoculated, sprinkling the product on the wet seed to be sown, the inoculated seeds of each treatment were put to dry in the shade and then proceeded to sowing.

Experiments were composed of a total of 48 plots each, each plot consisted of 6 furrows of 5 m long by 4.2 m wide, with a distance of 70 cm between ridges.

The experiment used a randomized block experimental design with four replications, in a bifactorial arrangement. The factors under study were three levels of mycorrhizal inoculation (two strains and a control without inoculation) and four levels of inoculation with rhizobia (three strains and a control without inoculation), for a total of twelve treatments. The experiments were conducted under field conditions in the period from December 2018 to March 2019. The NPK complete formula (9-13-17) was applied at the rate of 200 kg ha, at the bottom of the furrow before planting in all treatments evaluated.

Table 1. Agrochemical characteristics of the soil where the experiment was planted (0-20 cm depth)

Bean crops	Na	K	Ca	Mg	P	MO	pH	No. AMF spores in 50g of soil
	(cmol.kg^{-1})				mg 100 g^{-1}	%	H_2O	
CC 25-9N	0.05	0.48	11.25	4.88	619.25	3.63	6.2	108.5
Lewa	0.05	0.45	12.00	3.88	558.50	3.44	6.3	65.75

From 35 to 45 days after sowing the crop, at the pre-flowering stage, the central plants of 1 linear m were taken in each treatment and in each replicate. Growth variables were measured: plant height (cm), stem diameter (mm), stem and leaf dry mass (g). At harvest, yield and its components were evaluated: number of pods per plant, number of grains per plant, mass of 100 grains (g) and yield (t ha^{-1}).

For the statistical analysis, first, the normality of the data and the homogeneity of variance of the variables evaluated were checked. Subsequently, an analysis of variance was performed on the data obtained, according to the experimental design, comparing the treatments and their interactions.

In the case that the interactions were significant, the means of the treatments were compared by Duncan's Multiple Range test (p≤0.1). The STATGRAPHICS Centurion XV program II was used.

RESULTS

When analyzing the morphological behavior of the plants in the cultivars under study (Table 2), an interaction between the factors (rhizobia inoculation and AMF) was found for the two variables evaluated, and a different behavior was observed in each treatment with respect to plant height and stem diameter.

In the single inoculations of rhizobia on plant height and stem diameter for the different cultivars, a differentiated behavior was found among the cultivars. In the CC25-9 N cultivar, all rhizobia strains produced higher heights than the control, with no significant differences among them. In the cultivar Lewa, only a significant response to the application of strain CIAT 899 was found with respect to the control without inoculation. In the CC 25-9 N cultivar, the inoculation of the three rhizobia strains caused increases in stem diameter with respect to the control. In the cultivar Lewa, no differences were found between the rhizobial strains under study and the control without inoculation.

With respect to inoculation with AMF strains, it was found that plant height was greater with the inoculation of both mycorrhizal strains than with the uninoculated control in the two cultivars. It is noteworthy that in the cultivar Lewa, the single inoculation of INCAM 11 was superior to any of the co-inoculations studied. With respect to stem diameter after single applications of AMF, INCAM 11 inoculation caused an increase in the value of the variable in both cultivars.

Regarding co-inoculation, the effectiveness of co-inoculation on plant height varied with cultivars. For the cultivar CC 25-9 N, co-inoculation presented greater increases in the variable with the combinations INCAM 4+PRF 81, INCAM 11+PRF 81 and INCAM 11+CIAT 899.As for the cultivar Lewa, the greatest plant heights were found with the co-inoculation of INCAM 11+CIAT 899, INCAM 11+CF 1 and INCAM 4+CF 1, although all these combinations were similar to the single inoculation of INCAM 11.

The highest values of stem diameter in the cultivar CC 25-9 N were found in the combinations INCAM 4+CF 1 and INCAM 11+PRF 81 and without differences with the other combinations of microorganisms and the simple inoculation of INCAM 11, although differences were found with INCAM 4+CIAT 899. In the cultivar Lewa, the best combination was INCAM 11+PRF 81, not differing from the simple inoculation of INCAM 11.

When analyzing the behavior of stem and leaf dry mass (Table 3), interaction between the factors under study was found. In the cultivars studied, the greatest effect of rhizobia inoculation on stem dry mass was achieved with strain CIAT 899 with respect to the non-inoculated control. While in leaf dry mass, significant effects were only found in the cultivar CC 25-9 N, with strains PRF 81 and CIAT 899.

In relation to the single applications of AMF on stem dry mass, inoculation with INCAM 4 caused the highest value of the variable in the cultivar CC 25-9 N. In the cultivar Lewa, significant increases of the variable were obtained with the inoculation of any of the two AMF strains evaluated and without differences between them. In leaf dry mass,

Table 2. Effect of rhizobia and arbuscular mycorrhizal fungi strains on plant height (cm) and stem diameter (mm) in the two common bean cultivars

Treatments		Height plant (cm)				Stem diameter (mm)			
		CC 25-9 N		Lewa		CC 25-9 N		Lewa	
Without AMF	**Without R**	39.79	f	46.58	e	0.41	d	0.43	c
	CF 1	49.34	cde	48.42	de	0.47	abc	0.44	c
	PRF 81	52.88	bc	50.3	cde	0.46	abc	0.44	c
	CIAT 899	50.13	cd	52.63	bcd	0.47	ab	0.45	bc
INCAM 4	**Without R**	45.51	e	53.14	bcd	0.44	bcd	0.45	bc
	CF 1	47.54	de	55.82	abc	0.48	a	0.43	c
	PRF 81	58.11	a	51.31	bcde	0.46	abc	0.46	bc
	CIAT 899	49.95	cde	50.97	bcde	0.44	cd	0.44	c
INCAM 11	**Without R**	47.78	de	60.19	a	0.49	a	0.49	ab
	CF 1	49.15	cde	55.81	abc	0.45	abcd	0.45	bc
	PRF 81	55.51	ab	53	bcd	0.48	a	0.51	a
	CIAT 899	57.73	a	56.38	ab	0.47	abc	0.44	c
SE$\bar{x}$		1.61	*	2.13	*	0.012	*	0.013	*

*Same letters in the same column do not differ significantly according to Duncan's test for p≤ 0.1

inoculation with AMF in cultivar CC 25-9 N resulted in a superior response to the control without inoculation with the two AMF strains. In the cultivar Lewa, this response was only observed with strain INCAM 11.

When analyzing the results of coinoculation on stem dry mass, the best result was found with the combination INCAM 4+PRF 81 in cultivar CC 25-9 N. In cultivar Lewa, the best performance was obtained with INCAM 4+PRF 81, with no differences with the coinoculations of INCAM 4 and INCAM 11 with rhizobia strain CF 1.

When observing the results of the coinoculation in the dry mass of leaves, the best combination that behaved in the cultivar CC 25-9 N was INCAM 4+PRF 81, presenting no differences with the rest of the combinations of microorganisms and the simple inoculation of PRF 81, CIAT 899, INCAM 4 and INCAM 11, except with INCAM 11+PRF 81, with which it did present differences. The cultivar Lewa presented the highest value of leaf dry mass with the combination of INCAM 4+CIAT 899, which was similar to the single inoculation of INCAM 11 and without differences with the co-inoculations of INCAM 4+CF 1 and CIAT 899 and the single inoculation of INCAM 11 and the three rhizobial strains.

The effect of treatments on the number of pods per plant (Table 4) was found, in the case of inoculation with rhizobia, that in the cultivar CC 25-9 N there was no response to the simple inoculation with any of the evaluated strains of this microorganism. In the cultivar Lewa, the best rhizobia strain was CIAT 899. In the number of grains per plant, in the bean cultivar CC 25-9 N, the three rhizobia strains were superior to the control. En el Lewa, la mejor cepa de rizobios fue CIAT 899 comportándose semejante a la evaluación anterior.

In the case of AMF inoculation on the number of pods per plant, the CC 25-9 N cultivar did not respond to the inoculation. In the Lewa cultivar, only this strain was significant INCAM 11. For the number of grains per plant, it was observed that in the CC 25-9N cultivar, the two inoculated strains performed better than the control and were similar to each other. In the cultivar Lewa, the best performance was observed with the INCAM 11 inoculation and the INCAM 4 strain was similar to the control.

Table 3. Effect of rhizobia and arbuscular mycorrhizal fungi strains on stem and leaf dry mass (g) in the two common bean cultivars

Treatments		Stem dry mass (g)				Leaf dry mass (g)			
		CC 25-9 N		Lewa		CC 25-9 N		Lewa	
Without AMF	**Without R**	466.1	f	315	c	95.03	c	123.35	d
	CF 1	504.5	def	401.67	c	484.58	bc	185.14	bcd
	PRF 81	484.9	ef	326.66	c	881.68	ab	241.85	bcd
	CIAT 899	527.2	cde	543.89	b	653.93	ab	164.65	cd
INCAM 4	**Without R**	557.2	bc	567.23	b	1926.45	ab	219.59	bcd
	CF 1	549.5	cd	598.89	ab	723.05	ab	408.58	abc
	PRF 81	675.6	a	672.78	a	1065.25	a	354.73	abcd
	CIAT 899	571.1	bc	384.44	c	807.88	ab	547.59	a
INCAM 11	**Without R**	472.7	f	573.33	b	699.95	ab	543.38	a
	CF 1	543.4	cd	591.67	ab	929.63	ab	447.13	abc
	PRF 81	550.7	cd	536.67	b	487.2	bc	467.57	ab
	CIAT 899	598.4	b	376.67	c	931.25	ab	362.59	abcd
SE$\bar{x}$		17.9*		36.36*		162.93*		102.54	*

*Same letters in the same column do not differ significantly according to Duncan's test for p≤ 0.1

Table 4. Effect of rhizobia and arbuscular mycorrhizal fungi strains on the number of pods/plant and the number of beans/plant of two common bean cultivars

Treatments		No of pods /plant				No of grains/plant			
		CC 25-9 N		Lewa		CC 25-9 N		Lewa	
Without AMF	**Without R**	9.85	c	9.28	d	9.85	C	9.28	D
	CF 1	9.98	c	10.43	cd	9.98	C	10.43	Cd
	PRF 81	9.9	c	9.85	cd	9.9	C	9.85	Cd
	CIAT 899	10.78	bc	11.95	bc	10.78	Bc	11.95	Bc
INCAM 4	**Without R**	11.44	bc	10.85	cd	11.44	Bc	10.85	Cd
	CF 1	14.65	a	13.28	ab	14.65	a	13.28	Ab
	PRF 81	11.85	bc	11.61	bc	11.85	bc	11.61	Bc
	CIAT 899	11.45	bc	11.05	cd	11.45	bc	11.05	Cd
INCAM 11	**Without R**	10	c	14.08	a	10	c	14.08	A
	CF 1	10.83	bc	10.93	cd	10.83	bc	10.93	Cd
	PRF 81	12.75	b	10.73	cd	12.75	b	10.73	Cd
	CIAT 899	11	bc	10.6	cd	11	bc	10.6	Cd
SE$\bar{x}$		0.73	*	0.79	*	0.73	*	0.79	*

*Same letters in the same column do not differ significantly according to Duncan's test for p≤ 0.1

When analyzing the effectiveness of co-inoculation on the number of pods, interaction between the factors was found. In the CC 25-9 N cultivar, the best results were obtained with the INCAM 4+CF 1 co-inoculation, which was significantly superior to the single applications and the control. In the cultivar Lewa, the best co-inoculated treatment was INCAM 4+CF 1, although it was not superior to the single inoculation of INCAM 11.

In relation to co-inoculation in the number of grains per plant, the best results in the cultivar CC 25-9 N were found with the application of INCAM 4+PRF 81, which was superior to the other combinations of microorganisms, to the simple applications and to the control. On the other hand, in the cultivar Lewa, the best combination was INCAM 4+CF 1, although without differences with the simple inoculation of INCAM 11.

Table 5 shows the effect of the treatments on both 100-grain dry mass and crop yield. In both evaluations, both cultivars, the treatments inoculated with different rhizobia strains were superior to the control. The same behavior was observed in the single inoculation of AMF strains.

In relation to the co-inoculation in the mass of 100 grains per plant, although different combinations presented high values, in none of the cultivars were these results statistically superior to the simple inoculation of the microorganisms.

When analyzing the effect of co-inoculations on crop yield, for cultivar CC 25-9 N, the best combinations were found with INCAM 4+CIAT 899 and INCAM 11 with CF 1 and CIAT 899, and although these results did not differ from the rest of the co-inoculated treatments, they were superior to the simple inoculation of the microorganisms. In the Lewa cultivar, the best combination was INCAM 4+CIAT 899, although without differences with CIAT 899+CF 1; INCAM 11 combined with the three rhizobia strains and the simple inoculation of CIAT 899.

DISCUSSION

In recent years, with the boom in the use of arbuscular mycorrhizal inoculants (10,11) and rhizobia in legumes (12), there has been an increase in publications on the use of soil microorganisms to enhance the biological activity of soil microorganisms and to take advantage of their benefits.

In general, a significant and similar response of cultivars to the application of INCAM 4 or INCAM 11 was found. In recent years it has been established that the effectiveness of the inoculation of these strains is related to the pH (H_2O) of the soil or substrate where the crops grow (13,14), so that in the pH range between 5.6 and 7.2 the INCAM 4 strain presents the highest effectiveness and in the pH range 7 - 8 the highest effectiveness is presented by INCAM 11, with an overlapping zone of effectiveness between 7 and 7.2.

Regarding the behavior of morphological variables, other studies have found a greater height and diameter of the stem of plants in beans inoculated with rhizobia and AMF, being always the inoculated treatments those of better behavior with respect to the control without inoculation (15).

Other authors obtained increases in height values in bean plants, in ranges of up to 10 cm, emphasizing the role played by the availability of nutrients, mainly phosphorus, in plant growth (16), and consistent results have been found worldwide confirming that nutrient absorption is facilitated by the presence in the soil of an effective network of mycorrhizal symbiosis, which also increases plant growth (17).

In relation to dry mass, increases have been observed in bean plants of mycorrhiza + rhizobia and rhizobia treatments than those found in control treatments and mycorrhizae, possibly associated with the levels of nutrients in the soil and making clear the relevance of co-inoculation in the growth and development of the crop (18).

Table 5. Effect of rhizobia and arbuscular mycorrhizal fungi strains on 100-bean mass (g) and agricultural yield (t ha^{-1}) of two common bean cultivars

Treatments		Mass of 100 grains (g)				Yield (t ha^{-1})			
		CC 25-9 N		Lewa		CC 25-9 N		Lewa	
Without AMF	**Without R**	13.5	c	12.9	b	0.89	e	0.79	f
	CF 1	15.4	b	14.83	a	1.15	cd	1.24	bcd
	PRF 81	15.67	ab	15.75	a	1.11	d	1.19	cde
	CIAT 899	15.32	b	15.83	a	1.17	cd	1.32	ab
INCAM 4	**Without R**	16.25	ab	14.88	a	1.18	bcd	1.13	de
	CF 1	16.2	ab	15	a	1.3	abc	1.28	abc
	PRF 81	16.85	a	15.33	a	1.29	abc	1.24	bcd
	CIAT 899	16.27	ab	15.8	a	1.42	a	1.35	a
INCAM 11	**Without R**	15.4	b	14.85	a	1.17	cd	1.1	e
	CF 1	16.35	ab	15.15	a	1.36	a	1.31	ab
	PRF 81	16	ab	14.48	a	1.34	ab	1.28	abc
	CIAT 899	15.92	ab	15	a	1.37	a	1.29	abc
SE$\bar{x}$		0.432	*	0.49	*	0.07	*	0.05	*

*Same letters in the same column do not differ significantly according to Duncan's test for p≤ 0.1

In relation to co-inoculation, the results showed a differentiated behavior depending on the cultivars. Although in all cases some rhizobia-AMF combinations always achieved the highest yields, differences in relation to the yields obtained by single inoculations were significant.

Thus, the results of this work corroborate the compatibility between beans, rhizobia and AMF, which favored growth and yield. These results coincide with other research conducted where they also found differences in the yield components of the bean crop with the combined application of microorganisms (19).

Likewise, the results in this research agree with those obtained by other investigations where a greater number of pods was obtained in plants subjected to rhizobia and mycorrhizae treatments (18).

It is important to emphasize that the co-inoculation of rhizobia strains and arbuscular mycorrhizal fungi significantly increased the number of grains per pod of the plants evaluated in the two cultivars. In this sense, in previous studies, increases in bean yield were reported with combined inoculations of rhizobia and mycorrhizal fungi, concluding that the combined actions of the microorganisms have a synergistic effect on plant growth (20,21).

The results of these experiments expand the information and bases for the management of co-inoculation with rhizobia and arbuscular mycorrhizal fungi in bean production, proving that there are practical options for the management of the inoculation of efficient strains of both microorganisms that ensure adequate growth, plant development and appropriate indicators of microbial performance, all of which results in sustainable yields with a minimum of agricultural inputs.

CONCLUSIONS

- The effectiveness of the single inoculation of AMF INCAM 4 and INCAM 11 strains depended on the cultivars under study.
- The effectiveness degree of the single inoculation of the rhizobial strains depended on the cultivar under study, with CIAT 899 behaving as the best strain for the cultivar Lewa, while in the cultivar CC 25-9 N the three strains behaved similarly.
- The most effective co-inoculations were INCAM 11+CIAT 899, INCAM 11+CF 1 and INCAM 4+CIAT 899, the latter combination being the most efficient for cultivar Lewa.

BIBLIOGRAPHY

1. Colás, A., Díaz, B., Rodríguez, A., Gatorno, S. y Rodríguez, O. (2018). Efecto de la biofertilización en la morfofisiología y rendimiento del frijol común (*Phaseolus vulgaris* L.). *Ctro. Agríc.*, 45, 34-42.
2. Chazan, M. (2008). *World Prehistory and Archaeology: Pathways through Time*. Pearson Education, Inc. ISBN 0-205-40621-1.
3. Rivera, R.; Calderón, A.; Nápoles, M.C.; Ruiz, L.; Simo, J.; Plana, R. (2012). La validación a escala productiva del biofertilizante EcoMic® y su aplicación conjunta con rizobios en el cultivo del frijol, en centro y occidente del país. Disponible en: https://scholar.google.com.cu/scholar?q=Rivera+2012+validacion+productiva+del+biofertilizante&hl=es&as_sdt=0&as_vis=1&oi=scholar#d=gs_qabs&t=1656518913656&u=%23p%3Dbf9PtcqgG20J
4. ONEI (Oficina Nacional de Estadística e Información). (2019). Anuario Estadístico de Cuba 2018. En: Agricultura. La Habana, Cuba. Disponible en: http://www.one.cu/aec2017/09%20Agriculhtura.
5. Martínez, R.; Dibut, B. (2012). Biofertilizantes bacterianos. Editorial Científico-Técnica, La Habana, Cuba. ISBN 978-959-05-0659-8.
6. Wilches, W.; Ramírez, M.; Pérez, U.; Serralde, D.; Peñaranda, A. y Ramírez, L. (2019). Association of arbuscular mycorrhizal fungi (AMF) with sugarcane plants (*Saccharum officinarum*) for panela production in Colombia. *Terra Latinoamericana*, 37, 175-184. doi: https://doi.org/10.28940/terra.v37i2.481
7. Martín, G.M.; Tamayo, Y.; Hernández, M.; Varela y da Silva, E. (2017). Cuantificación de la fijación biológica de nitrógeno en *Canavalia ensiformis* crecida en un suelo pardo mullido carbonatado mediante los métodos de abundancia natural de ^{15}N y diferencia de N total. *Cult. Tropic.*, 38, 122–130.
8. Hernández, A.; Pérez, J.; Bosch, M.; Castro, D. (2015). Nueva versión de clasificación genética de los suelos de Cuba. Ediciones INCA. Mayabeque, Cuba. ISBN 978-959-7023-77-7.
9. Paneque, V. M.; Calaña, J. M.; Calderón, M.; Borges, Y.; Hernández, T. C. y Caruncho, M. (2010). Manual de técnicas analíticas para análisis de suelo, foliar, abonos orgánicos y fertilizantes químicos. Ediciones INCA. 160 p, ISBN: 978-959-7023-51-7.
10. Zhang, S.; Lehmann, A.; Zheng, W.; You, Z.; Rillig, M.C. (2018). Arbuscular mycorrhizal fungi increase grain yields: a meta-analysis. *New Phytologist*. doi: http://doi.org/10.1111/nph.15570
11. Rillig, M.C.; Aguilar-Trigueros, C.A.; Camenzind, T.; Cavagnaro, R.T.; Degrune, F.; Hohmann, P. et al. (2019). Why farmers should manage the arbuscular mycorrhizal simbiosis? New Phytologist, 222(3), 1171-1175. DOI: http://doi.org/10.1111/nph.15602
12. Santos, M.S.; Nogueira, M. A.; Hungria M. Microbial inoculants: reviewing the past, discussing the present and previewing an outstanding future for the use of beneficial bacteria in agriculture. AMB. 2019. Expr. https://doi.org/10.1186/s13568-019-0932-0
13. Rivera, R.; Fernández, F.; Ruiz, L.; González, P.J.; Rodríguez, Y.; Pérez, E. Manejo, integración y beneficios del biofertilizante micorrízico EcoMic® en la producción agrícola. R Rivera Ed Ediciones INCA, San José de las Lajas, Cuba. 2020. 151p.
14. Buil, P.A.; Jansa, J.; Blažková, A.; Holubík, O.; Dufková, R.; Rozmoš, M.; Püschel, D.; Kotianová, M. & Janoušková, M. Infectivity and symbiotic efficiency of native arbuscular mycorrhizal fungi from high-input arable soils. Plant Soil, 2022. https://doi.org/10.1007/s11104-022-05715-8

15. Liriano, R.; Núñez, D.B.; Barceló, R. Efecto de la aplicación de Rhizobium y micorriza en el crecimiento del frijol (Phaseolus vulgaris L) variedad CC-25-9 negro, Centro Agrícola, 39(4), 17-20. 2012. octubre-diciembre, ISSN papel: 0253-5785 ISSN on line: 2072-2001.
16. Martín, N.J.; Llerena, Á.B.; Acosta, J.L. Influencia de los hongos micorrízicos arbusculares, abonos orgánicos y sacarosa en el cultivo del fríjol (Phaseolus vulgaris L.). Alternativas, 2018. ISSN: 13T90-1915, 19(2), 89-96pp.
17. Bukovská, P.; Rozmoš, M.; Kotianová, M.; Gancarcíková, K.; Dudáš, M.; Hršelová, H.; Jansa, J. Arbuscular Mycorrhiza Mediates Efficient Recycling From Soil to Plants of Nitrogen Bound in Chitin. Front. Microbiol, 12, 574060. 2021. DOI: http://doi.org/10.3389/fmicb.2021.574060
18. Hidalgo, J.E.; Ramos, C.C. Coinoculación de Rhizophagus irregularis y Rhizobium sp. en Phaseolus vulgaris L. var. canario (Fabaceae) "frijol canario". Arnaldoa, 26(3), 991-1006. 2019. DOI: http://doi.org/10.22497/arnaldoa.263.26309
19. Calero, A.; Pérez, Y.; Quintero, E.; Olivera, D.; Peña, K. Efecto de la aplicación asociada entre Rhizobium leguminosarum y microorganismos eficientes sobre la producción del fríjol común. Cienc. Tecnol. Agropec, 20, 295-308. 2019. DOI: https://doi.org/10.21930/rcta.vol20_num2_art:1460
20. Tamayo-Vélez, A.; Bernal Estrada, J.A. Common bean (Phaseolus vulgaris L.) yield response to chemical and biological fertilization in different localities of Colombia. Rev. Fac. Nac. Agron. Medellín, 71, 8573-8579. 2018. DOI: http://dx.doi.org/10.15446/rfnam.v71n3.72392
21. Colás-Sánchez, A.; Díaz-Pérez, B.; Rodríguez-Urrutia, A.; Gatorno-Muños, S.; Rodríguez-López, O. Efecto de la biofertilización en la morfofisiología y rendimiento del frijol común (Phaseolus vulgaris L.). Revista Centro Agrícola, 45(4), 34-42. 2018.