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Biofertilization of topinambur with *Azospirillum brasilense* and native mycorrhical fungi, cultivated in the Central Valley of Catamarca, Argentina

Abstract

To evaluate the effect of *Azospirillum* and mycorrhizal soil fungi on the nutrition of the Jerusalem artichoke crop (*Helianthus tuberosus* L.), determinations of agronomic parameters and the health status of the plants were carried out under field conditions. The tests were carried out, at the time of the implantation of the culture: the "seeds" were inoculated with *A. brasilense* and with native mycorrhizal fungi, generating four treatments including the control and the co-inoculation of the consortium of the microorganisms under study (T0: control or uninoculated control; T1: inoculation with native *A. brasilense*; T2: inoculation with native mycorrhizal fungi and T3: joint inoculation with *A. brasilense* and native mycorrhizal fungi). The results indicate that co-inoculation with *A. brasilense* and native mycorrhizal fungi, significantly increased plant growth in height, leaf area, biomass, dry matter, and yields. It was determined that the application of the selected microorganisms has a promoting effect of plant growth, increasing the growth and productivity of the topinambur crop.

Keywords: interactions, mycorrhizae, jerusalem artichoke, *Helianthus tuberosus*

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Introduction

Helianthus tuberosus L., commonly known as topinambur, belongs to the botanical family Asteracea, and there are four main uses: horticultural, forage, inulin extraction and ethanol production.[1–3]

The topinambur could be considered a functional food due to its high inulin content.[4] Inulin is considered a biological fiber, the ingestion of which confers several health benefits: it lowers the level of cholesterol in the blood, promotes the activity of bifidobacteria in the intestine, and reduces blood sugar.[3,5,6]

It is poorly digested by humans and therefore has the potential to be used in low calorie food formulations.[7,8] Long inulin chains can be used to replace fat in foods, as they simulate its texture. This is used in the production of low-calorie dairy products.[9] Inulin acts as a prebiotic, favoring the development of beneficial bacteria in the colon. The Jerusalem artichoke flour is gluten-free, which makes it suitable for celiacs and, in addition, has a reduced energy value. Ibarguren et al.,[3] evaluated the potential of the topinambur as a food and observed that foods formulated with different proportions of topinambur are highly accepted by potential consumers and constitute a healthy alternative to the usual diet due to its high inulin content and the benefits that it provides contributes to human health.

The tubers of Jerusalem artichoke, in addition to having beneficial nutrients and fibers, also contain low levels of various chemical pollutants (insecticide residues; organophosphates, organochlorines, carbamates and pyrethroids), heavy metals (cadmium, lead, arsenic and mercury) and naturally toxic substances (nitrate, nitrite, cyanide, etc.). These levels are lower than those stipulated for food intended for human consumption by the Ministry of Public Health of Thailand, so they cannot cause any health problems and are considered healthy foods for consumers.[10]

The topinambur is an excellent double production forage, green forage, and tubers. The tubers are used as an energy reserve for the winter and are commonly used in pig feeding, which is why the topinambur is also called "potato chanchera".[11]

Numerous studies indicate the potential of topinambur to produce bioethanol.[12–16] It has advantages over other crops, mainly due to its high biomass yield.[16] Ethanol production can be carried out both from the aerial part and from the tubers.[12,17]

However, other uses are being investigated. As the topinambur is considered a highly invasive weed in European cultivation systems, the allelopathic potential of *H. tuberosus* was investigated, and the inhibitory capacity of its extracts on the germination and growth of weed and crop seedlings was discovered. that the implementation of integrated weed management programs has gained great interest, considering the suppressive capacity of topinambur and its residues for weed management in the field.[18,19] Also, the use of Jerusalem artichoke leaf extracts was investigated for its potential use in improving the preservation of fruits and vegetables in storage. The results obtained imply that topinambur leaves could be a potential antimicrobial agent and source of natural fungicides.[20] Willscher et al.,[21] determined that *H. tuberosus* is a suitable plant for the phytoremediation of sites contaminated with heavy metals. On the other hand, Klímek et al.,[22] investigated the viability of the residues of topinambur (*H. tuberosus*) and other agricultural crops to be used as alternative raw materials for boards, and due to their physical and mechanical characteristics, they determined that they are suitable to be used in production of furniture, since they comply with the European standard of conditions of use.

For all the, it is considered valuable to increase the production of topinambur through the incorporation of more productive and profitable cultivation technologies such as the use of biofertilizers, which in turn allows to reduce production costs and reduce the use of agrochemicals. Biofertilizers can contain one or more selected microorganisms, which can be applied to the seed or the soil to increase its density and its association with the root system of the plant to promote its nutrition. This improves the vegetative and productive development of the plant. Among the microorganisms most used for their potential contribution to plant development are the rhizobacteria *A. brasilense* and the arbuscular mycorrhizal fungus *Glomus intraradices*.[23]

Therefore, the objective of this work was to evaluate the effect of *A. brasilense* and native soil mycorrhizal fungi on the nutrition of the topinambur (*H. tuberosus* L.) crop, by determining agronomic parameters and the health status of the plants.

Materials and methods

Two bioassays were carried out in the field. The treatments carried out on topinambur were: - T0: Control or control (without inoculation); - T1: Inoculation with *A. brasilense*; - T2: Inoculation with native mycorrhizal fungi; - T3: Joint inoculation with *A. brasilense* and native mycorrhizal fungi.

The inoculated treatments consisted of applying the selected microorganisms to the Jerusalem artichoke tubers, by immersing them in the inoculant just prior to implantation. While the tubers of the control treatments were placed in sterile running water. For the plantations, tubers of Jerusalem artichoke (*H. tuberosus*) of approximately 10 g of weight were used (Figure 1).

The native strain Pi8 of *A. brasilense* was used, isolated from the endorhizosphere of paprika (*Capsicum annum* var. Elephant trunk) cultivated in the Province of Catamarca, whose identification was carried out biochemically and molecularly.[24–26] The concentration of A. brasilense used for the inoculations was $5x10^7$ azospirilos. mL^{-1} quantified in a Neubauer chamber.[27]

The inoculum of mycorrhizal fungi native to the province was constituted by roots of *Melilotus officinalis* L., *Avena sativa* L., *Hordeum vulgare* L., *Secale cereale* L., *Panicum maximun* Jacq. and *Cenchrus ciliaris* L. colonized by these. The percentage of mycorrhizal colonization of the roots used as inoculum was 81.38%, estimated by the method of on-line intersections and microscopic observation of roots by Sieverding[28] and Mc Gonigle et al.[29]

The bioassays were carried out in different localities of the Central Valley of the Province of Catamarca in Valle Viejo (28 ° 28'19.52 "S; 65 ° 43'54.40" W) and Miraflores (28 ° 35'22 "S; 65 ° 53 ' 45 "O) (Figure 2). The experimental design used was randomized blocks with three repetitions per treatment. Each repetition corresponded to a 3m x 3m plot with 25 plants (experimental units), in 5 cultivation lines 70 cm apart. Periodic evaluations of plant growth were carried out in different phenological stages of the topinambur crop. In each collection, 3 plants of each treatment and repetition were taken. In one of the topinambur experiments, collections were made at 118, 125, 139, 146, 153 and 180 days after implantation, and in another experiment at 147, 172, 192 and 222 days after sowing.

EMERGENCY	VEGETATIVE PHASE	PIPING	FLOWERING	FRUCTIFICATION	MATURATION
Shoots emerge to the surface of the soil.	Small, slightly elongated bumps appear at the terminal end of the roots.	Green stems and leaves appear.	The first flowers open.	The first fruits begin their maturity.	The tubers reach the size and color of the variety. the leaves change their color to pale yellow and brown. Leaf fall.

Figure 1 Phenology of the topinambur (*H. tuberosus*) crop.

The following data were recorded on each evaluation date: plant height; number of stems; leaf area index (LAI),[30] fresh weight (FW), dry (DW) and% DM of stems, leaves, roots, propagules, tubers, and whole plant; number of tubers per plant; average weight and tuber yield.

With the data of dry weight (DW) and fresh weight (FW) the% of dry matter (% DM = DW x 100 / FW) was calculated, both for stems, tubers, roots, and other parts of the plant. The results were statistically analyzed by analysis of variance (ANAVA) and the means were compared by Fisher's LSD (Least Significant Difference) test at a significance level of 0.05 using the Infostat statistical program.[31]

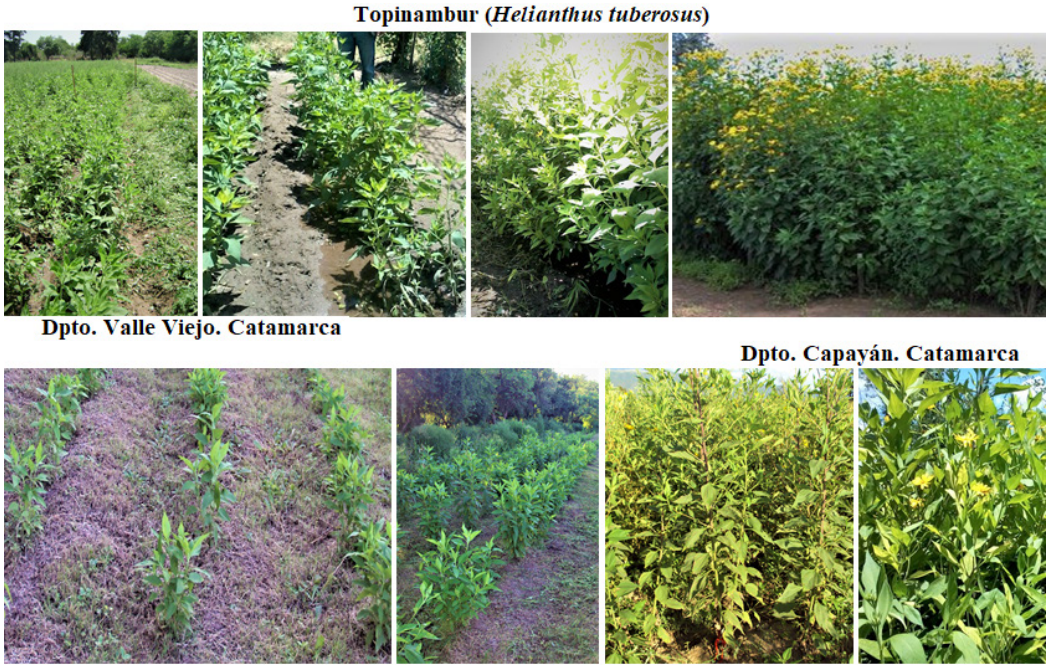

Figure 2 Trials of topinambur (*Helianthus tuberosus*) the localities of Valle Viejo and Miraflores, Catamarca (Argentina).

Results

The cultivation of topinambur was developed in sites with sandy loam textural class soil. This crop does not thrive in waterlogged soils where the water stagnates for several days,[32] they adapt to different types of soils, they grow without major problems in poor soils, but they develop better in fertile soils.[1] The topinambur adapts to a relatively wide range of soil pH, production is favored in slightly alkaline soils,[32] such as those found in the Central Valley of the Province of Catamarca.

Plant height: The inoculated topinambur plants (T1, T2 and T3), presented higher height throughout the crop cycle, registering statistically significant differences with respect to the control treatments (T0) (Tables 1&2). In the Miraflores topinambur crop, this variable was evaluated up to 192 days after implantation, because later the "delivery" of the crop occurred where the stems turned brown, dry, and brittle. However, magnitudes like those obtained in the experiments carried out by Rebora[1] were recorded.

Number of stems: During the development of the crop, plants with similar amounts of aerial stems were observed (Tables 1&2). However, in the first collection, statistically significant differences were recorded between the treatments, where the highest number of aerial stems were observed in the plants corresponding to the inoculation treatment with the microbial consortium of *A. brasilense* and mycorrhizal fungi (T3) (Table 1). Where the number of stems obtained was much higher than those observed in previous experiments.[33]

Percentage of dry matter of aerial stems: In almost all the collections there were no differences with statistical significance between the treatments (Tables 1&2), except for the first collection of the topinambur plants from Miraflores, in which, if detected significant statistical differences, with higher percentages of stem dry matter in plants inoculated with the microbial consortium (T3) (Table 2). The highest values of fresh weight of stems were observed in the inoculated plants (T1, T2 and T3), registering statistically significant differences, mainly in the phase of full vegetative growth (first collections), when the stems are more turgid and palatable (Tables 1&2). This is important to produce feed for swine, who prefer the stems of Jerusalem artichoke over leaves.

Similar behavior occurred with the dry weight of the stems, being able to reach an average of 700 $kg.ha^{-1}$ of dry stems with the application of the microorganisms under study (T1 and T3) (Table 2), generating another benefit, since the dried stems of these crops are used in the generation of steam and electricity necessary for the ethanol manufacturing process,[16] and low-cost fuel for the producer.

Number of tubers per plant: Statistically significant differences were determined between the treatments, where the inoculated plants generated a greater number of tubers (Tables 3&4). From the Valle Viejo experiment, the average quantity of plant topinambur tubers from the inoculated treatments is higher than those observed by Andrada et al.,[34] but the number of tubers of the control plants are like those obtained by these investigators. While, in the Miraflores trial, the average number of inoculated plant tubers coincides with those observed by Andrada et al.,[34] and the number of tubers from the controls was well below those reported by these researchers, who carried out their experiments in the Central Valley of the Province of Catamarca.

Weight of tubers per plant: The highest weights of tubers per plant of Jerusalem artichoke were recorded in the treatments with the inoculation of the microbial consortium of *A. brasilense* and mycorrhizal fungi (T3) and with the bacterial inoculation (T1), where differences were observed statistically significant between the microbial inoculation treatments and the controls, during the development of the cultures (Tables 3&4).

Table 1 Comparison of agronomic parameters of topinambur (height, quantity, dry matter, fresh and dry weight of stems) produced in the field of Valle Viejo Department

Treat.	Variable	Days after the implantation of topinambur (Valle Viejo)				
		118	125	139	146	153
Control	*Height (cm)*	83,33±8,02 d	153,0±11,5 b	128,3±45,6 b	112,7±12,9 b	113,7±26,1 c
	Number	4,67±0,58 a	9,0±1,0 a	10,0±7,55 a	12,0±1,73 a	7,67±2,52 a
	FW (g)	27,6±15,4 a	55,4±12,6 a	59,6±16,4 a	68,9±37,3 a	53,7±39,5 a
	DW (g)	11,9±6,2 a	24,7±7,9 a	22,9±10,8 a	20,5±5,3 a	19,4±12,3 a
	DM (%)	43,84±4,67 a	43,77±5,06 b	36,85±9,4 ab	36,73±19,7 a	40,99±17,1 a
Azosp.	*Height (cm)*	179,0±7,2 b	192,0±3,0 a	179,7±32 ab	181,3±6,5 a	152,3±12,5 b
	Number	10,0±1,0 b	9,33±0,58 a	8,67±0,58 a	11,0±2,0 a	7,33±2,89 a
	FW (g)	166,9±10,6a	114,4±14 a	128,7±25 ab	129,1±11 bc	98,8±50,5 a
	DW (g)	43,2±4,7 a	36,9±1,9 a	39,4±1,20 a	37,7±4,2 bc	36,4±7,4 a
	DM (%)	25,86±1,36a	32,46±2,61 a	31,26±5,5 ab	29,14±1,63 a	40,9±14,9 a
Myco.	*Height (cm)*	113,7±13,9c	176,7±4,2 ab	140,7±17 ab	158,7±11 b	161,7±10,3 b
	Number	6,0±1,0 a	9,33±1,53 a	9,0±3,61 a	10,0±2,0 a	7,33±0,58 a
	FW (g)	48,7±49,9a	119±9,5 a	177,8±64,9 b	102,5±10 ab	93,5±41,8 a
	DW (g)	16,2±12,4a	35,1±1,3 a	70,1±27 b	29,2±4,3 ab	32,9±7,4 a
	DM (%)	39,43±17,3a	29,58±1,46 a	39,13±1,68 b	28,36±1,75 a	39,22±17,0 a
Azosp. + Myco.	*Height (cm)*	201,3±6 a	181,3±22,7 a	185,7±13,6 a	188,3±5,7 a	196,7±7,6 a
	Number	14,33±2,52c	10,67±2,08 a	9,33±2,08 a	10,0±1,0 a	5,67±3,51 a
	FW (g)	361,8±159 b	144,5±28,3 b	164,4±28,4 b	155,8±32,1 c	92,9±44,6 a
	DW (g)	136,2±70,6b	40±3,9 b	44,8±6 ab	43,6±6 c	33,7±8,9 a
	DM (%)	36,29±6,92a	28,09±3,10 a	27,47±3,82 a	28,36±3,94 a	40,61±13,7 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 2 Comparison of agronomic parameters of topinambur (height, quantity, dry matter, fresh and dry weight of stems) produced in the Miraflores field

Treat.	Variable	Days after the implantation of topinambur (Miraflores)			
		147	172	192	222
Control	*Height (cm)*	53,67±18,93 ab	51,33±19,86 a	67,67±49,05 a	-
	Number	6,67±4,04 a	14,33±11,85 a	11,33±8,39 a	4,33±2,08 a
	FW (g)	17,63±1,48 a	26,73±17,78 a	18,46±17,15 a	4,90±3,80 a
	DW (g)	6,35±1,72 a	16,83±17,05 a	12,07±11,45 a	3,50±2,82 a
	DM (%)	35,93±8,45 a	53,28±22,45 a	96,67±61,40 a	65,36±13,45 a
Azosp.	*Height (cm)*	52,00±13,23 a	71,00±35,59ab	60,33±30,66 a	-
	Number	8,00±4,36 a	13,33±9,45 a	22,33±2,52 b	7,00±1,00 a
	FW (g)	31,07±5,46 b	40,34±10,43 a	34,75±26,41 a	14,83±10,13ab
	DW (g)	11,55±1,33 a	26,39±15,08 a	23,06±18,38ab	10,87±7,35 ab
	DM (%)	37,52±4,25 a	74,29±52,91 a	63,99±5,07 a	73,46±0,80 a
Myco.	*Height (cm)*	82,33±18,72 bc	108,67±22,03 b	108,0±12,17 a	-
	Number	7,67±1,53 a	8,33±4,04 a	8,67±4,73 a	8,00±6,24 a
	FW (g)	46,44±0,53 c	76,00±22,11 a	41,96±16,41 a	21,93±10,77 b
	DW (g)	18,22±1,92 b	39,16±12,38 a	36,41±13,57ab	16,40±8,94 b
	DM (%)	39,22±3,69 ab	56,05±25,78 a	87,09±2,62 a	73,40±5,11 a

Citation: Barbaro GD, Andrada H, Silvana BM, et al. Biofertilization of topinambur with Azospirillum brasilense and native mycorrhical fungi, cultivated in the Central Valley of Catamarca, Argentina. *J Appl Biotechnol Bioeng.* 2021;8(6):174–184. DOI: 10.15406/jabb.2021.08.00271

Table Continued

Treat.	Variable	Days after the implantation of topinambur (Miraflores)			
		147	172	192	222
Azosp. +Myco.	*Height (cm)*	86,33±12.34 c	97,33±23,01ab	109,0±7,00 a	-
	Number	2,67±2,08 a	16,33±10,97 a	11,67±5,51 ab	5,00±6,08 a
	FW (g)	23,48±9,60 ab	67,06±45,85 a	54,89±22,11 a	11,80±9,10 ab
	DW (g)	11,44±5,30 a	48,60±26,65 a	42,15±14,88 b	8,50±6,58 ab
	DM (%)	47,96±3,55 b	76,94±17,79 a	77,66±6,87 a	71,19±2,36 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 3 Comparison of agronomic parameters of topinambur (fresh and dry weight, dry matter, quantity, average weight, and tuber yield) produced in Valle Viejo

Treat	Variable	Days after the implantation of topinambur (Valle Viejo)				
		118	125	139	146	153
Control	FW (g)	78,9±34,6 a	150,5±12,9 a	132,3±74,5 a	310,2±100,4a	357,7±252,2a
	DW(g)	16,5±8,1 a	30,5±3,3 a	27,8±15 a	55±14,6 a	71,8±50,5 a
	DM (%)	20,5±1,5 ab	20,2±0,8 a	21,3±1,2 a	18,5±4,8 a	20,1±0,1 a
	Number	10,7±4,2 a	28,3±9,9 a	17,3±11,2 a	19,7±5,1 a	20,7±11,1 a
	AW (g)	7,3±0,5 a	5,8±1,9 a	8,3±1,9 a	15,6±2,3 a	15,9±3,9 a
	Yield(kg.ha^{-1})	149,2±10,5 a	117,6±39,7 a	168,6±38,5 a	318,8±45,9 a	324,5±80,7 a
Azosp.	FW (g)	472,9±2,8 b	373,4±16 d	330,5±89,5 b	442,9±382,8a	487,7±51,1 a
	DW(g)	107,5±2,6 b	78,3±1,1 c	69±20,4 b	104,1±69,6 a	101,7±10,4 a
	DM (%)	22,7±0,4 ab	21±0,6 a	20,8±0,8 a	26,1±4,8 b	20,9±0,05 b
	Number	43,7±6,5 b	24,0±3,6 a	22,3±1,5 a	40,3±7,6 c	22,3±2,1 a
	AW (g)	11±1,6 ab	15,7±1,8 c	14,7±3,5 bc	10,9±8,9 a	21,8±0,3 ab
	Yield(kg.ha^{-1})	224,3±33,3ab	321,3±37,7 c	300,2±71,1bc	222,3±181 a	445,4±5,7 ab
Myco.	FW (g)	120,1±27,1 a	201,2±15,1 b	291,4±62,7 b	318,2±43,1 a	427,3±7,2 a
	DW(g)	22,9±10,4 a	53,6±10,4 b	66,6±18,9 b	65,3±10,6 a	89±1,5 a
	DM (%)	18,35±4,9 a	26,5±3,7 b	22,6±2,6 a	20,5±0,6 ab	20,8±0,01 b
	Number	12,7±2,5 a	23,3±3,5 a	15,7±1,5 a	25±3 ab	22,7±3,8 a
	AW (g)	9,9±4,1 ab	8,7±0,7 b	18,5±3,02 c	12,9±2,9 a	19,2±3,2 a
	Yield(kg.ha^{-1})	203,1±84,1ab	177,3±13,9 b	377,9±61,7 c	263,3±58,1 a	392±65,5 a
Azosp. + Myco.	FW (g)	872,2±344,1c	236,9±21,4 c	260,1±16,6 b	308,5±75,4 a	505,5±157 a
	DW(g)	208,8±86,8 c	52±4,7 b	57,7±8,6 ab	68,4±12 a	109±36 a
	DM (%)	23,7±1,5 b	20,95±0,4 a	22,13±2,2 a	22,4±1,4 ab	20,1±0,1 b
	Number	54,7±10,6 b	39,7±2,1 b	26,3±9,9 a	31,3±4,2 bc	17,7±3,2 a
	AW (g)	15,6±4,4 b	5,98±0,5 a	11,0±4,6 ab	9,8±1,2 a	28,1±4,4 b
	Yield(kg.ha^{-1})	318,3±89,2 b	122±10,8 a	224,8±93,2ab	199,4±24,9 a	573,9±90,3 b

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Percentage of dry matter of the tubers: A higher percentage of dry matter of tubers was determined from the inoculated treatments, mainly with the microbial consortium (T3), observing in most of the collections significant statistical differences with respect to the controls (T0) (Tables 3&4).

Average weight of the tubers: The topinambur tubers with the highest average weight were observed in the inoculated treatments and fundamentally in the last collections, registering significant statistical differences in most of the collections, with respect to the control treatment (Tables 3&4). In the Valle Viejo experiment, tubers of average 28 g in T3 were obtained after 5 months of cultivation, with a range of variation of average weight of tubers from 23.5 to 32.5 g. Meanwhile, in the Miraflores experiment, in the last collection (7.4 months), tubers of 34.5 g average were obtained in T3, with a range of variation of average weight of tubers from 31.8 to 37.2 g, weights similar to those obtained by Andrada et al.,[34] who harvested 8 months after implantation and achieved tubers of 33 to 39 g, for which it is estimated that the anticipated harvest is the fundamental reason for the lower average mass of tubers, due to the fact that no the Valle Viejo experiment to the phenological phase of ripening of Jerusalem artichoke tubers characterized by the translocation of nutrients from the aerial part to the tubers.

Yield (kg or t of tubers per ha^{-1}): In the harvest of mature tubers, the highest yields were achieved with the inoculation of the microbial consortium of *A. brasilense* and mycorrhizal fungi (T3), at which time significant statistical differences were recorded. in comparison to the control treatments (T0) (Tables 3&4).

Table 4 Comparison of agronomic parameters of topinambur (fresh and dry weight, dry matter, quantity, average weight, and tuber yield) produced in the Miraflores field

Treat	Variable	Days after the implantation of topinambur (Miraflores)			
		147	172	192	222
Control	FW (g)	40,14±34,43 a	61,41±47,29a	251,84±175,01a	182,50±136,71 a
	DW(g)	8,03±6,88 a	12,23±9,43 a	50,36±34,99 a	36,52±27,35 a
	DM (%)	20,00±0,01 a	19,89±0,12 a	20,00±0,004 a	20,02±0,02 a
	Number	5,33±3,79 a	16,33±12,1 a	15,33±2,08 a	6,67±2,89 a
	AW (g)	5,60±4,39 a	4,17±2,51ab	15,58±10,27 a	27,92±24,13 a
	Yield(kg.ha^{-1})	819,2±702,7a	1253,3±965,1a	5139,5±3571,5a	3724,5±2790,0a
Azosp.	FW (g)	38,70±48,08a	55,68±33,3 a	374,18±212,51a	320,57±237,27ab
	DW(g)	7,89±9,81 a	11,53±7,02 a	51,01±55,66 a	64,77±45,66 ab
	DM (%)	20,34±0,10 b	20,62±0,22 b	14,48±10,83 a	20,29±0,25 b
	Number	6,33±6,81 a	20,33±9,07 a	26,67±2,89 a	9,67±5,86 ab
	AW (g)	4,79±2,01 a	2,63±0,41ab	14,05±8,40 a	29,04±10,23 a
	Yield(kg.ha^{-1})	789,8±981,1a	1136,4±679,5 a	7636,2±4336,8a	6542,1±4842,2ab
Myco.	FW (g)	71,82±57,94 a	58,01±21,13a	416,98±66,20 a	347,93±174,93ab
	DW(g)	14,96±12,07 a	12,10±4,37 a	88,74±14,09 a	72,49±36,44 ab
	DM (%)	20,79±0,07 c	20,88±0,10 b	21,28±0,003 a	20,83±0,0022 c
	Number	10,00±8,19 a	33,67±18,58a	28,67±15,95 a	15,00±6,00 ab
	AW (g)	6,73±2,13 a	1,97±0,70 a	16,55±5,55 a	22,34±4,73 a
	Yield(kg.ha^{-1})	1465,8±1182,5a	1183,9±431,1 a	8509,8±1350,9a	7100,6±3569,9ab
Azosp.+Myco.	FW (g)	106,33±42,68 a	76,55±42,61a	338,35±75,58 a	584,0±26,09 b
	DW(g)	22,62±9,08 a	16,43±8,92 a	74,35±17,92 a	124,27±5,57 b
	DM (%)	21,27±0,003d	21,58±0,53 c	21,91±0,55 a	21,28±0,003 d
	Number	13,33±6,03 a	16,33±7,57 a	26,00±6,56 a	17,00±2,0b
	AW (g)	8,40±2,16 a	4,56±0,40 b	13,14±1,27 a	34,56±2,72 a
	Yield(kg.ha^{-1})	2069,9±871a	1562,2±869,6 a	6905,1±1542,3a	11918,3±532,41 b

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05

In the Valle Viejo experiment, the highest average yield was estimated with the inoculation of the microbial consortium (T3) 5 months after the implantation of topinambur, achieving average increases of 76.8% with respect to the control treatment, while with the inoculation with *A. brasilense* (T1) increases of 37% and with the application of mycorrhizal fungi (T2) of an average 20.8%.

With co-inoculation (T3), average yields of 573.94 kg.ha^{-1} were achieved, varying from 483.6 kg.ha^{-1} to 664.2 kg.ha^{-1} (Table 3), magnitudes lower than those informed by the bibliography, which is due to the realization of a very early collection, 3 months before the traditional harvest. Meanwhile, in the Miraflores experiment, with the co-inoculation (T3), yields of greater than 11,000 kg.ha^{-1} were achieved, estimating a maximum of 12,500 kg.ha^{-1} (Table 4), magnitudes lower than those reported in the literature.[1,16,35]

However, *H. tuberosus* is a species with potential to produce energy and has advantages over other crops, mainly its high biomass yield, which can produce 100 to 130 t of tubers per ha.[36] There is information that indicates that 4500 l of ethanol can be obtained from 50 tonnes of Jerusalem artichoke tubers.[16] The yields achieved indicate that more than 1000 liters of ethanol could be obtained per hectare of topinambur cultivation. Research carried out in Spain indicates that 1 l of ethanol can be obtained from 12 kg of Jerusalem artichoke tubers.[37]

Fresh weight of leaves per plant: The highest production of foliar mass was recorded in the inoculated topinambur plants, establishing differences with the control with statistical significance in the phenological stage of vegetative growth (Tables 5&6), characterized by the production of leaves and stems, an important quality for the development and yield of the crops.

Percentage of dry matter of leaves: In most of the collections there were no statistically significant differences between the treatments for this variable (Tables 5&6). However, in the Valle Viejo experiment, in two collections, the highest percentages of dry matter were recorded in the control plants (T0), which may indicate the lower speed of translocation of nutrients and photosynthates from the leaves to the tubers, fundamentally.

Leaf area index (LAI): The highest LAI was obtained in the inoculated treatments, mainly with T3, during the vegetative growth period of the crop, registering statistically significant differences between the inoculated treatments compared to the control treatments (Tables 5&6). As the crop evolves, the temperature drops and winter approaches, the leaves of the topinambur plants turn yellowish and droopy, which is why the number of leaves and consequently the LAI decreases. The higher production of leaves of the inoculated treatments, evidenced by the variables evaluated, explain the higher production of photosynthates and its direct effect on the growth of the crops.

Root dry matter percentage: The highest root dry matter production was obtained in the inoculated plants, with significant statistical differences between the inoculated treatments in comparison with the controls (Tables 7&8). Because the highest fresh and dry root biomass was observed in the inoculated treatments, in magnitudes much higher

than the controls, results that show the growth-promoting activity of the roots of the microorganisms under study.

The evaluations of whole plants during the development of the culture showed a greater growth of the inoculated plants throughout their cycle, registering significant statistical differences with respect to the control (Tables 9&10).

The total biomass of topinambur plants from the co-inoculation treatments with the microbial consortium (T3), were significantly appreciable, achieving an average of the two experiments, 14,320 kg.ha^{-1}.

Table 5 Comparison of agronomic parameters of topinambur (fresh weight, dry weight, dry matter of leaves and leaf area index) produced in the Valle Viejo field

Treat	Var.	Days after the implantation of topinambur (Valle Viejo)				
		118	125	139	146	153
Control	FW (g)	31,5+19,8 a	63,49+8,56 a	53,74+19,92 a	44,84+21,4 a	31,78+19,2 a
	DW(g)	15,7+8,7 a	26,58+14,6 a	21,25+12,4 a	22,33+10 a	16,65+9,6 a
	DM(%)	51,58+9,8 c	40,33+19,7 a	37,32+9,8 b	50,47+2,2 b	52,42+4,9 a
	LAI(cm 2)	1761+1105a	3549,3+478 a	3004,1+1114 a	2506,4+1197 a	1776,3+1074 a
Azosp.	FW (g)	197,9+2,7 b	120,95+17,8 b	113,23+2,7 b	103,7+21,7 bc	76,62+33,2 a
	DW(g)	60,77+6,8 bc	28,65+1,55 a	28,99+1,4 a	37,31+2,4 b	28,73+6,9 a
	DM(%)	30,8+3,9 ab	23,9+2,2 a	25,61+1,3 a	36,83+6,3 a	41,04+13,3 a
	LAI(cm 2)	11060+150 b	6761,2+994 b	6329,4+151 b	5798+1212 a	4283+1853 a
Myco.	FW (g)	58,47+47,4 a	101,39+8,6 b	91,89+14,9 ab	87,09+12,2 b	57,93+25,5 a
	DW(g)	32,02+33 ab	31,47+2,6 a	25,99+3 a	30,19+3,4 ab	28,58+8,1 a
	DM(%)	46,24+16 bc	31,05+0,3 a	28,45+1,5 ab	35,41+8,6 a	50,43+3,2 a
	LAI(cm 2)	3269+2650a	5668+483 b	5137+830 ab	4868,2+683 b	3238+1428 a
Azosp. +Myco.	FW (g)	339+109 c	123+14,8 b	121,6+33 b	128,7+17,7 c	81,5+48,2 a
	DW(g)	92,28+27,9 c	33,34+5,1 a	35,26+8,3 a	35,63+5,3 b	24,15+9,7 a
	DM(%)	27,39+0,92 a	27,04+1,2 a	29,2+1,3 ab	27,67+0,6 a	34,84+13,2 a
	LAI(cm 2)	18949+6103c	6874+827 b	6798,4+1844 b	7192+993 c	4554,8+2695 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 6 Comparison of the agronomic parameters of topinambur (fresh weight, dry weight, dry matter of leaves and leaf area index) produced in the Miraflores field

Treat.	Variable	Days after implantation (Miraflores)			
		147	172	192	222
Control	FW (g)	22,57+4,5 a	35,96+23,4 a	17,31+14,8 a	0,37+0,15 a
	DW(g)	9,67+2,2 a	11,22+8,6 a	14,37+12,2 a	0,37+0,06 a
	DM(%)	43,37+10,7 a	28,87+5,7 a	106,55+42,1 a	110,00+36,1b
	LAI(cm 2)	1261,5+248,6 a	2010,4+1307,4a	967,83+824,7a	20,50+8,5a
Azosp.	FW (g)	38,61+11,7 ab	50,21+44,9 a	33,28+28,2 a	1,83+0,25 b
	DW(g)	14,75+4,1 a	19,43+13,2 a	29,13+25,8 a	1,4+0,26 a
	DM(%)	38,58+5,99 a	71,16+65,5 a	83,77+6,7 a	76,29+8,3 ab
	LAI(cm 2)	2158,1+652,6ab	2806,6+2507,4a	1860,19+1576,7a	102,48+14 b

Table Continued

Treat.	Variable	Days after implantation (Miraflores)			
		147	172	192	222
Myco.	FW (g)	44,48+17,4 b	45,22+26,9 a	14,59+9,01 a	1,67+1,4 ab
	DW(g)	18,61+8,76 a	22,47+11,36 a	14,26+8,4 a	1,50+1,39 ab
	DM(%)	40,62+5,36 a	55,57+18,3 a	99,05+3,2 a	88,89+14,3 ab
	LAI(cm 2)	2486,5+974,1b	2528+1506 a	815,59+503,8 a	93,17+80,3 ab
Azosp.	FW (g)	19,15+6,34 a	67,32+37,9 a	35,88+17,02 a	0,63+0,5 ab
+Myco.	DW(g)	10,38+2,23 b	36,34+26,7 a	34,32+16,7 a	0,32+0,2 a
	DM(%)	57,01+17,7 a	51,92+12,04 a	94,84+4,6 a	56,67+12,8 a
	LAI(cm 2))	1070,5+354,1 a	3763,4+2116,1 a	2005,71+951,5 a	35,40+25,8 ab

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 7 Comparison of the agronomic parameters of topinambur (fresh weight, dry weight and dry matter of roots) produced in the Valle Viejo field

Treat.	Variable	Days after the implantation of topinambur (Valle Viejo)				
		118	125	139	146	153
Control	FW (g)	18,11±9,1 a	40,3±3,8 a	34,42±15,7 a	40,26±5,92 a	35,92±19,8a
	DW(g)	8,19±4,1 a	8,86±1,8 a	12,36±8,7 a	12,01±3,7 a	11,24±5,15a
	DM (%)	33,09±19,9 a	21,84±2,5 a	32,85±16,8 a	29,40±4,8 a	33,52±6,2 a
Azosp.	FW (g)	68,53±2,43ab	79,5±2,7 b	69,87±27,4ab	79,36±22 bc	30,67±9,6 a
	DW(g)	17,14±2,35 a	22,11±2,2 b	19,11±7,9 a	18,16±2,95 b	13,24±7,6 a
	DM (%)	24,95±2,6 a	27,77±1,8 b	27,15±1,7 a	23,48±3,3 a	41,04±10,4a
Myco.	FW (g)	21,93±15,1 a	73,87±10 b	44,18±11,4 a	47,34±10,4ab	34,84±14,2a
	DW(g)	9,22±7,53 a	16,39±3,8 b	12,99±4,5 a	11,46±1,81 a	11,78±5,7 a
	DM (%)	37,54±20,9 a	22,06±2,6 a	28,87±3,2 a	24,53±2,9 a	33,32±3,4 a
Azosp. +Myco.	FW (g)	117,2±66,4 b	104,8±14,1c	102,6±44,9 b	112,6±26,3 c	46,12±17,9a
	DW(g)	41,22±21,24b	23,51±3 c	25,16±8,6 a	27,15±2,96 c	16,37±6,7 a
	DM (%)	36,63±3,9 a	22,44±0,4 a	25,49±3,4 a	24,62±3,2 a	35,23±1,5 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 8 Comparison of agronomic parameters of topinambur (fresh weight, dry weight, and dry matter of roots) produced in the field of Miraflores

Treat.	Variable	Days after implantation (Miraflores)			
		147	172	192	222
Control	FW (g)	21,06±3,9 ab	145,55±94,9 a	26,83±21,6 a	15,67±15,7 a
	DW(g)	7,51±0,9 a	12,66±5,1 a	7,75±5,1 a	6,17±5,9 a
	DM (%)	36,74±9,1 a	10,82±5,4 a	49,79±39 a	42,99±6,2 a
Azosp.	FW (g)	23,24±8,9 ab	236,33±155,3 ab	57,60±37,8 a	37,90±28,03 ab
	DW(g)	9,67±3,5 a	21,85±17,5 a	25,70±19,01 a	19,63±14,6 ab
	DM (%)	41,80±3,6 ab	18,14±24,4 a	45,05±11,45 a	50,18±4,9 a
Myco.	FW (g)	31,81±11,8 b	428,57±190,2 b	41,96±16,4 a	64,20±26,5 ab
	DW(g)	11,11±2,3 a	23,51±13,8 a	36,41±13,6 a	34,03±16,7 ab
	DM (%)	36,51±7,9 a	6,95±6,6 a	87,09±2,6 a	51,41±7 a
Azosp. +Myco.	FW (g)	13,28±6,9 a	181,92±81,15 ab	74,04±69 a	80,87±30,6 b
	DW(g)	6,48±3,2 a	29,04±13,6 a	34,00±29,45 a	43,30±20,8 ab
	DM (%)	49,10±3,6 b	17,23±6,9 a	46,92±10,65 a	52,62±6,8 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 9 Comparison of agronomic parameters of topinambur (fresh weight, dry weight, and dry matter of the whole plant) produced in the Valle Viejo field

Treat.	Variable	Days after the implantation of topinambur (Valle Viejo)				
		118	125	139	146	153
Control	FW (g)	156,2+75,4 a	309,8+37,9a	280+121,1a	464,2+163,9a	479,1+305,1a
	DW(g)	50,3+26,2 a	90,6+26,4a	84,3+44 a	109,9+26,4 a	119,1+74,6 a
	DM (%)	31,7+2,6 a	28,8+5,5 a	28,9+4,3 a	24,6+3,8 a	25,3+1,2 a
Azosp.	FW (g)	906,1+10,6 b	688,2+50,4 c	642,3+95,7 b	755,1+332,3a	693,8+124,4a
	DW(g)	228,6+5,6 a	166+6,6 b	156,5+28,6 b	197,2+61,1 b	180,1+20,9 a
	DM (%)	25,24+0,8 a	24,2+0,9 b	24,3+1,34 a	27+3 a	26,1+1,5 a
Myco.	FW (g)	249,1+70,4a	495,4+42,5b	605,2+50,1 b	555,1+25,6 a	613,6+77,7 a
	DW(g)	80,3+38 a	136,5+17,5b	162,3+45,3 b	136,1+7,6 ab	162,3+15,6 a
	DM (%)	31,1+6,9 a	27,5+1,2 a	26,7+6,18 a	24,52+0,8 a	26,5+1,1 a
Azosp. +Myco.	FW (g)	1690+676 c	609,2+77,7 c	648,8+119,5b	705,5+50,6 a	726+266,5a
	DW(g)	478,5+206 b	148,9+16,5b	162,9+31,4 b	174,8+3,6 b	138,6+65,8 a
	DM (%)	27,9+1,8 a	24,47+0,58a	25,1+1,55 a	24,84+1,5 a	20,5+9,2 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Table 10 Comparison of the agronomic parameters of topinambur (fresh weight, dry weight, and dry matter of the whole plant) produced in the field of Miraflores

Treat.	Variable	Days after implantation (Miraflores)			
		147	172	192	222
Control	FW (g)	101,40+33,1 a	218,37+207 a	314,44+227,3 a	203,43+152,7 a
	DW(g)	31,56+11,3 a	52,94+39,9 a	84,55+62,5 a	46,55+34,9 a
	DM (%)	30,87+1,9 a	27,68+11,6 ab	26,53+1,3 ab	23,10+0,8 a
Azosp.	FW (g)	131,12+43,6 a	382,57+146,7 ab	499,80+301,4 a	375,13+272 ab
	DW(g)	43,86+12,3 ab	79,19+23,1 a	128,91+111,8 a	96,67+68,5 a
	DM (%)	33,72+2,7 a	21,21+2,7 ab	25,11+9,3 a	26,39+1,5 a
Myco.	FW (g)	194,55+64,3 a	607,80+197,6 b	523,90+71,2 a	435,13+272 ab
	DW(g)	62,90+20,2 b	97,24+39,03 a	160,50+33 a	124,42+15 ab
	DM (%)	32,43+0,7 a	16,85+8,1 a	30,57+4,3 ab	30,42+8,5 a
Azosp. +Myco.	FW (g)	162,23+64,3 a	392,85+166,6 ab	503,16+97,6 a	677,30+61,4 b
	DW(g)	50,92+18 ab	130,41+76 a	184,81+50,3 a	176,40+29,5 b
	DM (%)	31,69+3 a	32,77+8 b	36,76+6,6 b	25,93+2,2 a

Uncommon letters in the same variable denote significant differences according to the LSD test (Minimum significant difference) for P <0.05.

Discussion

Although the results obtained are in many cases inferior to those achieved in other parts of the world, there are also many reasons that can explain the differences. The topinambur crop has a good water demand (greater than 800mm), but it can survive long periods of drought, its productivity being significantly affected under these conditions.[38] These circumstances are frequent in the central valley of the Province of Catamarca, immersed in the semi-arid region with problems of access to irrigation water. Furthermore, there is a direct relationship between tuber size and plant productivity.

However, the results obtained showed an increase in the different variables of vegetable production evaluated (plant height, number of tubers and propagules, fresh weight and dry weight of stems, roots, and tubers) in topinambur plants because of inoculation with native microorganisms of *A. brasilense* and mycorrhizal fungi, registering significant statistical differences with respect to the control plants without inoculation. Therefore, the highest productivity of these crops

is obtained through the microbial inoculation of the "seeds" (tubers) at the time of the implantation of the crop.

The microbial consortium used, made up of native, bacterial, and fungal strains, generated the best results due to the greater intake of water and nutrients, and mainly nitrogen that can be incorporated into the soil by biological nitrogen fixation, since the bacterium *A. brasilense* has this capacity, in addition to synthesizing auxins and other phytohormones.[39] The greater uptake of water and nutrients, especially those that are not very mobile such as phosphorus, facilitate their availability and assimilation by plants.[40–43] Furthermore, these microorganisms locate and colonize sites in the rootlets, which could potentially be occupied by phytopathogens.[44]

The selection of effective microorganisms in promoting the growth of cultures is a great challenge. The adaptation to the environment to which they are introduced and the compatibility between the microorganisms that make up the microbial consortia and these with the plants, may be the factors that prevent their use in agricultural production.

This work contributes to making evident the potential of the selected microorganisms as an alternative to improve the nutrition and productivity of the topinambur crop. These results could support the possible use of microbial inoculants in the production of this crop, which would avoid or reduce the use of chemical fertilizers. They also indicate that there was a direct effect of microbial inoculation on the growth and yields of the topinambur culture. In addition, it is important to point out that these microbial interactions with topinambur roots were achieved with native microorganisms and that the crops were carried out in lots with no previous production history of these crops, added to the fact that it is a non-traditional crop in the province and that it is produced almost exclusively by a single farmer in the Central Valley area of Catamarca.

Conclusions

a. The inoculations of the tubers at the time of implantation of the culture of Jerusalem artichoke (*H. tuberosus*) with the selected microorganisms generated a positive effect in all the cultivation conditions and variables evaluated, improving their development and productivity due to better and greater nutrition.

b. Significant differences were detected in the variables evaluated because of the treatments applied to the topinambur crop. The crop harvest in the phenological stage of "delivery" and tuber maturity, together with the variables associated with tuber production (quantity, fresh weight, dry weight, yield, etc.) are the most consistent.

c. The application of the microbial consortium increased the potential of the culture obtaining the best results, due to the co-inoculation with the consortium of *A. brasilense* and mycorrhizal fungi (T3), achieving yield increases of 77% average, widely exceeding the controls.

d. The application of microorganisms in studies, in the implantation of the topinambur culture in field trials, allowed the establishment of beneficial relationships, ensuring survival, promoting the growth of plants in their first stages of growth fundamentally and increasing the yield of crops.

e. The microbial inocula used in these experiments are native species, and due to their origin, they have generated more adequate adaptation mechanisms to the environmental conditions, for which it is estimated that this is one of the reasons for which promising results have been presented for the growth of the topinambur crop.

f. This study is a pioneer in the studied area, so it is considered very promising to obtain a greater production of topinambur for its application with multiple purposes.

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Conflicts of interest

There are no financial conflicts of interest.

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