Comparison of native maize and squash in monoculture and intercropping systems †

[Comparación de maíces nativos y calabaza en monocultivo y en sistema intercalado]

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SUMMARY

Background: The large amount of native maize available in Mexico can be used in different associations with other crops, such as squash. However, it is necessary to determine whether its productivity is adequate and whether maize germplasm has an influence on it. **Objective**: To evaluate the yield of different native maize germplasms in monoculture and in intercropping with squash and to determine the most productive system using the Land Equivalent Ratio (LER). **Methodology**: In 2022, three maize landraces from the Yucatan Peninsula, a commercial hybrid as a control, and a local squash species were studied in Keste, Campeche, Mexico. With the data, Pearson's correlation, analysis of variance, Tukey's multiple mean comparison test ($\alpha = 0.05$), and LER were determined. **Results**: Maize in monoculture yielded significantly higher (2.35 t ha-1) than in the intercropping system. Nal Xoy and X'mejenal Nal maize landraces had the highest yields, although the hybrid exceeded them. The yield of squash seeds was statistically the same in monoculture and intercropping. In the association of native maize and squash, the type of maize germplasm has a direct impact on yield. The Land Equivalent Ratio (LER) confirmed the different levels of productivity in the two systems and the effects of maize germplasm. **Implications**: A relationship exists between the production system, maize germplasm, and yield. **Conclusion**: Maize yield is higher in monoculture than in the intercropping system. The LER could be a helpful coefficient to choose the right maize landrace to be planted in intercropped systems. The identified LER coefficients of 1.6–1.9 indicate that intercropping systems utilise land area more efficiently than monoculture systems.
Key words: *Zea mays; Cucurbita argyrosperma;* Land Equivalent Ratio (LER); Productivity.

RESUMEN

Antecedentes: La gran cantidad de maíces nativos disponibles en México puede ser utilizada en diferentes asociaciones con otros cultivos, como la calabaza; sin embargo, es necesario determinar si su productividad es adecuada y si el germoplasma de maíz influye en ello. **Objetivo:** Evaluar el rendimiento de diferentes germoplasmas de maíz nativo en monocultivo y en cultivo intercalado con calabaza y determinar el sistema más productivo mediante la Razón Equivalente de Tierra (RET). **Metodología:** En 2022, se estudiaron tres maíces nativos de la península de Yucatán, México, un híbrido comercial como testigo y una especie de calabaza local, en Kesté, Campeche, México.

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Con los datos se realizó la correlación de Pearson, análisis de varianza, prueba de comparación múltiple de medias de Tukey (α = 0.05) y la RET. **Resultados:** El maíz en monocultivo mostró un rendimiento significativamente mayor (2.35 t ha^{-1}) que el sistema de cultivo intercalado, Nal Xoy y X'mejenal Nal presentaron los mejores rendimientos, aunque fueron superados por el híbrido. Los rendimientos de semilla de calabaza fueron estadísticamente iguales en monocultivo y cultivo intercalado. En la asociación de maíces nativos y calabaza, el tipo de germoplasma de maíz tiene un impacto directo en el rendimiento. La Razón Equivalente de Tierra (RET) confirmó el diferente nivel de productividad en los dos sistemas y los efectos del germoplasma de maíz sobre ésta. **Implicaciones:** Existe un efecto entre el sistema de producción, el germoplasma de maíz y el rendimiento. **Conclusión:** El rendimiento de maíz es mayor en monocultivo que en el sistema intercalado. La RET podría ser un coeficiente que ayude a tomar decisiones sobre qué maíces nativos son recomendables para sembrar en sistemas intercalados. Los coeficientes RET identificados de 1.6 a 1.9 muestran que los sistemas de cultivos intercalados, utilizan la superficie de cultivo de forma más eficiente que los sistemas de monocultivo.
Palabras clave: *Zea mays; Cucurbita argyrosperma;* Razón Equivalente de Tierra (RET); productividad.

INTRODUCTION

Maize (*Zea mays* L.) is the most important crop worldwide, with an annual production exceeding one billion metric tons (García-Lara *et al*., 2019). Mexico is the 7^{th} producer worldwide with a production of 26,553,239 t per year (SIAP, 2023); Maize occupies the second place in national production (FAOSTAT, 2024). It is also the most important food in the daily Mexican diet. Traditionally intercropped with beans and squash, this association called milpa has a long history in Latin America; and is still used in different regions of Mexico (Fonteyne *et al*., 2023). In Campeche state, the milpa is recognized as a provider of basic foods for the Mayan family, as mentioned also for Yucatán´s milpa (Mijangos-Cortés *et al.* 2019). In general, the traditional milpa is being increasingly replaced by monocultures, because it requires more labor, compared to a mechanized monoculture. Milpa does not allow the use of machinery, so the labor in the milpa is significantly greater than in monoculture.

The germplasm used in the traditional milpa are local varieties, known as natives or also in spanish criollos (creole). For Mexico, 64 native races with many local types of maize are described; 59 are native, and 5 are introduced (CONABIO, 2019). Three races are cultivated in the tropics: Nal-Tel, Dzit Bacal, and Tuxpeño. Each of these also has several local types (Dzib-Aguilar *et al*., 2016; Santillán-Fernández *et al*., 2021). In the milpa, maize provides physical support to the growth of indeterminate beans, the bean supports the system with nitrogen fixation for crop nutrition and the squash controls weeds by covering the soil with its foliage; in addition, these three species represent a simple, but healthy diet.

In the state of Campeche, the squash species *Cucurbita argyrosperma* Huber has an important economic impact; it is the third crop in planted area after maize and soybeans, with an annual area of 28,829 ha (SIAP, 2023). *C. argyrosperma*, locally called Chihua squash is currently grown partially intercropped with maize in the studied area, although it is also grown associated with maize and beans, similar to the Mayan milpa of Yucatan described by Canul-Ku *et al*. (2005). It is grown to obtain seeds that are consumed in different ways. The seeds have a protein crude content from 26.9 to 33.6% (Ruiz García *et al*., 2020). Therefore, the objective of this work was to evaluate the yield of different native maize germplasms, in monoculture and in intercropping with squash, and determine which system is more productive through the Land Equivalent Ratio (LER).

MATERIALS AND METHODS

Area of study

The experiment was carried out in the state of Campeche, Mexico, in a community called Santo Domingo Kesté (coordinates: 19.505167 N, 90.504683 W). The experimental area is humid tropical, the predominant climate corresponds to AW_0, according to the classification described by Köppen and modified to García-Amaro (1973). The environmental characteristics are a warm and subhumid climate with rainfall in summer, distributed mainly from May to October. The annual rainfall is about 1290 mm.

Vegetal material

Three local varieties of tropical maize from the Yucatan Peninsula were studied (Nal Tel, X'mejen Nal, Nal Xoy) and the commercial hybrid P4082W® (Pioneer/Corteva). Nal Tel and X'mejen Nal are planted mainly in the state of Campeche. Nal Xoy from the Tuxpeño group, has its origin in Yucatan and is meanwhile introduced to Campeche. The hybrid P4082W® is widely planted in the study region and was used as control. All four types of maize have white seeds.

For the Chihua squash (*C. argyrosperma* Huber), seed from a collaborating farmer was used because there is no commercial seed of this squash. The main product of the Chihua squash is its seeds, which are either consumed directly or processed. It is used in traditional dishes nationwide.

Planting system

To make a comparison between monoculture and intercropping production systems, sowing was carried out as follows: All experimental units had the same size of 4.5 m × 8.0 m, with a surface area of 36.0 m^2. The distances between rows and plants varied depending on the crop and the planting system (Table 1). The sowing distance of maize varied between hybrid and native maizes, like it is ususal in the experimental area, but the planting density was the same. For the intercropped system, the squash was planted in the middle of two maize rows. The combination of each genotype of maize intercropped with squash and each crop in monoculture was evaluated.

Experimental design

The nine treatments, 5 in monoculture and 4 in intercropping (Table 2), were established under a factorial experimental design, considering the planting system and germplasm as factors, with three repetitions.

Crop management

The soil preparation consisted of a harrow step. The trial was implemented in the rainy season without irrigation, no occurred drought or excess humidity conditions. The sowing was carried out on May 30 for squash and on June 15, 2022 for maize. The fertilization dose for maize was 120-80-00 (kg ha^{-1} of N, P and K), all P and half of the N were applied at sowing; the rest of the N was applied 35 days after sowing (Conceição dos Santos *et al.* 2019). The dose for squash was 27-59-00 applied when the first true leaf appeared; it was complemented with the dose 35-00-46 at the flowering time (INIFAP, 2014). Weed control was carried out mechanically without using herbicides. The insecticide Foley Rey® (chlorpyrifos+permethrin) was applied to maize and squash to control harmful insects. In addition, the fungicide Benlate® (benomyl) was applied to the squash to control powdery mildew; and Cupravit® (copper oxychloride) for leaf spots. All products were applied at the recommended commercial doses.

Variables evaluated and statistical analysis

The yield of each treatment in each experimental unit was determined by harvesting all maize ears and squash fruits. The yield was used to calculate the Land Equivalent Ratio (LER), also called Relative Land Efficiency, which corresponds to the area in monoculture, which is required to generate the same yield, as in one ha of the intercropped system (Mead *et al.*, 1980; Gliessman, 1985). The following formula was considered:

$$LER = \frac{YiC1}{YsC1} + \frac{YiC2}{YsC2}$$

Where:
YiC1 = yield of the intercrop of crop 1,
YsC1 = yield of the single crop of crop 1,
YiC2 = yield of the intercrop of crop 2, and
YsC2 = yield of the single crop of crop 2.

The returns of the experimental units were extrapolated to a hectare. The data were analyzed using the SAS® version 9.0 statistical program. Analysis of variance (ANOVA) and Tukey's multiple comparison test of means were performed ($p = 0.05$). In the case of squash, Pearson correlations were calculated to compare the number of fruits harvested with the seed yield.

RESULTS AND DISCUSSION

Squash yield

The Pearson correlation coefficient between the number of fruits ha^{-1} and their respective seed yield was 0.66, which implies a directly proportional, moderately strong association between these variables. When performing the variance analyses, significant differences were found in the production system and the type of germplasm. In the means (Tukey, $p = 0.05$) it was found that statistically the production system in monoculture or intercropping and the type of maize germplasm showed a significant difference regarding the number of squash fruits ha^{-1}. There were significant differences between the association of native maize X'mejen Nal/squash that presented 9,907 fruits ha^{-1} and the squash monoculture with 5,185 fruits ha^{-1}.

Table 1. Monoculture and intercropping maize-squash planting system.

Planting system	Germplasm	Number of rows	Distance between rows (m)	Distance between plants (m)	Plants by place	Planting density per ha
Monoculture	Hybrid maize	8	1.0	0.3	2	66,666
Monoculture	Native maize	8	1.0	0.6	4	66,666
Monoculture	Squash	4	2.0	1.5	2	6,666
Intercropping	Hybrid maize	4	2.0	0.3	2	33,333
Intercropping	Native maize	4	2.0	0.6	4	33,333
Intercropping	Squash	4	2.0	1.5	2	6,666

Table 2. Treatments, production systems and germplasm of maize and squash used in the study.

Treatment	Production system	Germplasm
1	Monoculture	P4082W® (Hybrid maize)
2	Monoculture	Nal Tel (Native maize)
3	Monoculture	X'mejen Nal (Native maize)
4	Monoculture	Nal Xoy (Native maize)
5	Monoculture	Squash Chihua
6	Intercropping	P4082W® and squash Chihua
7	Intercropping	Nal Tel and squash Chihua
8	Intercropping	X'mejen Nal and squash Chihua
9	Intercropping	Nal Xoy and squash Chihua

In contrast to this, squash seed yields (kg ha^{-1}) turned out to be statistically equal in the two production systems, in monoculture (216.2 kg ha^{-1}) and in intercropping system (304.5 kg ha^{-1}); with the different maize germplasms (Table 3). However, squash in association with maize presented higher yields, reaching differences of more than 100 kg of seed between the associated crops of Nal Tel maize/squash and Nal Xoy maize/squash, concerning the yield of the squash monoculture. These yields are similar if we compare them with the average production of the states of Campeche and Yucatan for 2022, which was 365 kg ha^{-1} (SIAP, 2024).

Maize yield

Under a factorial experimental design, the production system (monoculture or intercropping), the maize germplasm (Nal Tel, X´mejenal Nal, Nal Xoy and P4082W®) and the combination of both factors (production system x germplasm) presented a significant variation in the analysis of variance in yield of maize (t ha^{-1}).

In Tukey's multiple comparison of means (Table 4), the maize monoculture showed a significantly higher yield than the intercropping system. Regarding germplasm, the highest yield was identified for the monoculture system of the hybrid maize P4082W® with 5.59 t ha^{-1}, similar to the reported yield for the region (5.446 t ha^{-1}) (Medina-Méndez *et al.*, 2019). It is not surprising, considering the strong focus on yield heterosis in commercial programs of maize improvement. For native maize Nal Xoy presented the best performance (2.16 t ha^{-1}), although it did not present significant statistical differences with X'mejenal Nal (1.83 t ha^{-1}); while Nal Tel presented the lowest yield (1.23 t ha^{-1}). The native maize was planted at the same planting density as the hybrid, only with another topological design by the recommendations of the area (Table 1), so it would be convenient to carry out studies to use the same topological design in the native maize than the hybrid and determine if it increases yield. However, the differences in yield are determined by the genetics of each maize.

The variation within the three local native maize varieties is interesting, which is also analyzed in the section on Land Equivalent Ratio (LER) (Table 5). The average yield of white maize for Campeche in 2022, which was the year in which the study was carried out, was 2.42 t ha^{-1} (SIAP, 2024).

In the interaction, germplasm * production system, hybrid maize in monoculture and intercropping with squash presented the highest yields. Regarding the three native maize germplasm, Nal Xoy showed the highest yield with 3.22 t ha^{-1} in monoculture; and it presented 1.11 t ha^{-1} in intercropped system with squash. Nal Xoy maize surpassing X'mejenal Nal with 0.6 t ha^{-1} and Nal Tel with 1.3 t ha^{-1} in a monoculture system. Furthermore, in an intercropped system, Nal Xoy with squash surpassed Nal Tel with 0.57 t ha^{-1} (Table 4).

Table 3. Multiple comparison means of squash fruit and seed yield by production system and maize germplasm.

Production System			Germplasm		
Type	Fruits ha^{-1}	Seed kg ha^{-1}	Type	Fruits ha^{-1}	Seed kg ha^{-1}
Monoculture	5185±873 b	216.20±30.72 a	P4082W®/squash	9167±736 ab	255.56±89.11 a
Intercropping	9352±965 a	304.51±67.18 a	Nal Tel/squash	9352±1988 ab	326.85±101.59 a
			X´mejenal Nal/squash	9907±2403 a	294.44±76.34 a
			Nal Xoy/squash	8981±1732 ab	341.20±96.41 a
			Squash	5185±631 b	216.20±63.53 a

Means with the same letter per column are not statistically different (Tukey, α = 0.05).

Table 4. Multiple comparison means of maize yield (t ha^{-1}), considering the production system, maize germplasm and their interaction (germplasm x system).

Production System	t ha^{-1}	Germplasm	t ha^{-1}	Interaction: production x system germplasm System	Germplasm	t ha^{-1}
Monoculture	3.88±1.34 a	P4082W®	5.59±1.31 a	Intercropping	Nal Tel/squash	0.54±0.17 e
Intercropping	1.53±0.59 b	Nal Tel	1.23±0.28 c	Monoculture	Nal Tel	1.92±0.51 dc
		X'mejenal Nal	1.83±0.47 b	Intercropping	X'mejenal Nal/squash	1.04±0.19 e
		Nal Xoy	2.16±0.78 b	Monoculture	X'mejenal Nal	2.62±0.76 bc
				Intercropping	Nal Xoy/squash	1.11±0.26 de
				Monoculture	Nal Xoy	3.22±0.92 b
				Intercropping	P4082W®/squash	3.42±0.89 b
				Monoculture	P4082W®	7.75±1.64 a

Means with the same letter per column are statistically similar (Tukey, $\alpha = 0.05$).

Table 5. Maize and squash seed yield in two cropping systems, equivalent area and corresponding Land Equivalent Ratio (LER).

Intercropping	Germplasm	Intercropping Yield (kg ha^{-1})	Monoculture Yield (kg ha^{-1})	Equivalent area	LER
P4082W® and squash	P4082W®	3420.00	7750.00	0.4	**1.6**
	Squash	255.56	216.20	1.2	
Nal Tel and squash	Nal Tel	540.00	1920.00	0.3	**1.8**
	Squash	326.85	216.20	1.5	
X'mejen Nal and squash	X'mejenal Nal	1040.00	2620.00	0.4	**1.8**
	Squash	294.44	216.20	1.4	
Nal Xoy and squash	Nal Xoy	1110.00	3220.00	0.3	**1.9**
	Squash	341.20	216.20	1.6	

The native maize Nal Xoy (a cross between Xnu'uk Naal and Dzit Bacal or Nal Tel) has a long-life cycle compare to Nal Tel and X´mejenal Nal (González *et al*., 2017), which could explain the higher yield observed. The three studied native maize are differentiated by their vegetative cycle, being late and early, respectively (González *et al*., 2017). On the other hand, early varieties can be a production alternative for regions that have a reduced agricultural cycle or for those without humidity restrictions because more than one planting cycle per year could be obtained (Velasco-García *et al*., 2019). Nal Tel and X´mejenal Nal varieties are interesting for their short phenological cycle, which also represents an advantage in rainfed crops in years with delayed rains.

Land Equivalent Ratio (LER)

The LER corresponds to the monoculture area required to generate the same total yield as in the intercropping system. A LER value less than one shows that the intercropping systems are producing less than the monoculture, a value greater than one indicates greater productivity of the intercropping system than the monoculture. In several studies it was determined that the associated cultivation of maize and squash can lead to LER values greater than one (Mahmud *et al*., 2018, Hernandez *et al*., 1997).

In the present study, the LER value was 1.8 in the squash intercropping systems with Nal Tel and X'mejenal Nal maize; whereas in the intercropping system squash with Nal Xoy maize was 1.9; and in the intercropping system squash with the hybrid maize P4082W® the LER was 1.6 (Table 5). This means that all the intercropping systems studied, both those associated with hybrid maize and the associated with local maize varieties, require between 1.6 and 1.9 ha of monoculture to obtain the yields of one intercropped ha, this means the intercropping is a more productive system. It would be needed 0.4 ha of P4082W® hybrid maize and 1.2 ha of squash to obtain the same yield as 1.0 ha of the corresponding intercropping system. In the case of native maize Nal Xoy intercropped with squash, would be needed 0.3 ha of maize and 1.6 ha of squash in monoculture to produce the same yield as in 1.0 ha of the intercropping system. In the Nal Tel maize intercropped with squash, they are required 0.3 ha of maize and 1.5 ha of squash in monoculture to obtain the same yields as in one ha of the intercropping system. For the X'mejenal Nal maize intercropped with squash, are needed 0.4 ha of maize and 1.4 ha of squash to obtain the same yields as in one ha of the intercropping system (Table 5).

The Tukey means of maize yields showed a significant difference between the yield of the hybrid and the yield of the three local varieties studied (Table 4), but the equivalent area is the same, 0.4 for P4082W® and the local maize X'mejenal Nal (Table 5); while for the local varieties Nal Tel and Nal Xoy this value was 0.3. According to Tukey's means (Table 3), there is no significant difference in squash yield, regardless of the intercropped maize germplasm. However, the calculated equivalent area varies from 1.2 in combination with P4082W® hybrid maize; and 1.4 in combination with X'mejen Nal maize; and 1.5 in combination with Nal Tel maize; up to 1.6 in the combination with Nal Xoy maize and therefore the LER is also varying.

With the increase in squash yield in the intercropping system, the equivalent area and therefore the LER is increasing. Increasing squash yields in intercropping systems are increasing the LER from 1.6 in the association with the hybrid to 1.9 in the system with the native maize Nal Xoy (Table 5); the LER of 1.6 coincides with Mahmud et al. (2018) who found LER values of 1.39 to 1.62. No studies were found that evaluated LER in maize - squash intercrops in the Yucatan Peninsula, so its comparison with other studies was not possible. The different germplasm of maize has an important impact on its yield and the squash yield, that is reflected in the variation of the LER.

CONCLUSIONS

Maize yield is higher under monoculture conditions compared to intercropping systems. However, the type of maize germplasm significantly influences productivity within the intercropped system, affecting not only maize performance but also the yield of the associated species. This interaction is reflected in the Land Equivalent Ratio (LER), which serves as a useful indicator for selecting appropriate maize landraces for intercropping. Higher LER values demonstrate that intercropping systems can utilize land more efficiently than monocultures. In particular, intercropping maize with squash (*Cucurbita argyrosperma*) is a productive system. The expansive growth habit of *C. argyrosperma* contributes to effective weed suppression, enhancing the ecological benefits of the system. Overall, intercropping represents a valuable strategy for improving land-use efficiency.

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