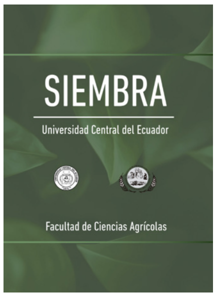
Diversity of arthropods associated with rice cultivation (Oryza sativa L.), Sébaco, Nicaragua

Diversidad de artrópodos asociados al cultivo de arroz (Oryza sativa L.), Sébaco, Nicaragua



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Abstract

Rice (*Oryza sativa* L.) is an important source of energy in the human diet; and, in Nicaragua, it constitutes a substantial component of the population's diet. The present study was exploratory, and aimed to determine the diversity of arthropods associated with rice cultivation in the municipality of Sébaco, an intensive rice production region, in the 2022-2023 agricultural cycle. Production systems with extensions over 100 hectares, where equal agronomic and phytosanitary management was used, were selected. For entomofauna monitoring, ten points were randomly selected in each production system, and at each point, and 20 double zigzag passes with entomological nets were used at each point. The number of individuals per order and family was quantified. For the diversity analysis, they were grouped according to their feeding habits. Abundance and richness information was analyzed using descriptive analysis, analysis of variance, and Shannon Weaver and Simpson's diversity index. Seven orders, 13 families, and 16 genera were found, most of them of the phytophagous habit. The highest abundance corresponded to the species *T. orizicolus* Muir (n = 46,663), reported in the reproductive and maturation phases. Likewise, *Hydrellia* sp (n = 5,229) presented the largest populations in the vegetative phase. Among the beneficial organisms, siders (n = 1,523) and *Atrichopogum* sp (n = 419) stood out. Diversity indices were low both in the production systems and in the different phenological phases of the crop.

Keywords: diversity, *Tagosodes orizicolus*, arthropod, *Oryza sativa*

Resumen

El cultivo de arroz (*Oryza sativa* L.) representa una fuente de energía de importancia en la dieta humana, y en Nicaragua constituye un sustancial componente de la dieta de la población. El presente estudio fue exploratorio y tuvo como objetivo determinar la diversidad de artrópodos asociada al cultivo de arroz en el municipio de Sébaco, en el ciclo agrícola 2022-2023, una región intensiva en la producción de arroz. Se seleccionaron sistemas productivos con extensiones mayores a 100 hectáreas, en donde se empleó igual manejo agronómico y fitosanitario. Para el monitoreo de la entomofauna, en cada sistema productivo se seleccionaron diez puntos al azar y en cada punto se emplearon 20 pases dobles en forma de zig-zag con red entomológica. Se cuantifico el número de individuos por orden y familia; para el análisis de diversidad se agruparon por sus hábitos alimenticios. La información de la abundancia y riqueza se analizó mediante estudio descriptivo, análisis de varianza e índice de diversidad de Shannon Weaver y Simpson. Se encontraron siete órdenes, 13 familias y 16 géneros, la mayoría del hábito fitófago. La mayor abundancia correspondió a la especie *T. orizicolus* Muir (n=46.663), reportada en la fase reproductiva y maduración. Así mismo, *Hydrellia* sp (n=5.229), present**ó** las mayores poblaciones en la fase vegetativa. Dentro de los organismos benéficos sobresalieron las arañas (n=1.523) y *Atrichopogum* sp (n=419). Los índices de diversidad fueron bajos tanto en los sistemas productivos como en las diferentes fases fenológicas del cultivo.

Palabras clave: diversidad, *Tagosodes orizicolus*, artrópodos, *Oryza sativa.*

1. Introduction

Agriculture represents the food base of the world population, and the cultivation of rice (*Oryza sativa* L.) is a cereal widely cultivated in all tropical and subtropical regions (Bridgewater et al., 2019; Ghiglione et al., 2021). According to the Food and Agriculture Organization of the United Nations (Organización de las Naciones Unidas para la Agricultura y la Alimentación [FAO], 2018), rice provides, on average, 20 % of the world's food energy supply. Their consumption is predominant in countries in Asia, Africa, and Latin America, where they provide between 30 and 70 % of dietary energy. Particularly in poorer areas, it is considered an essential source of nutrients and calories in the daily diet (Troncoso-Sepúlveda, 2019).

Rice is grown using conventional techniques, which involve the implementation of chemical pesticides, which cause resistance in pest organisms (Zhang et al., 2013) and affect the beneficial biodiversity that exerts natural control (León-Burgos et al., 2019). It is estimated that pests are responsible for causing losses of 35 % of rice production (Vivas-Carmona et al., 2017). According to Instituto Nacional de Información de Desarrollo (INIDE, 2012), rice covers approximately 85 thousand hectares in Nicaragua in the rainy season and represents 64% of the total production area. Likewise, it is mentioned that the main problems facing rice production in the country are low (national average of 1.4 t ha^{-1}) and irregular yields, scarcity of improved varieties adapted to climate variability, and low-tech systems (INIDE, 2012).

In rice cultivation, various organisms represent a crucial component in the functioning of the agroecosystem, providing some benefit to humans directly or indirectly (León-Burgos et al., 2019; Ghiglione et al., 2021). It has been reported that rice production systems are stable in the long term, favoring the stability of insect populations (Silva et al., 2019). In fact, in the rice agroecosystem, there are relationships between organisms with different trophic roles (predators, parasitoids, and phytophages); within these functional groups, spiders (Tetragnathidae and Lycosidae), parasitoid wasps, and predatory bugs stand out, controlling arthropod crop pests in early and late periods. (He et al., 2020; Obregón-Corredor et al., 2021; Zhang et al., 2013).

Considering the constant changes in climatic scenarios (Lamichhane et al., 2015) and the search for knowledge of the diversity of the rice agroecosystem as a tool to implement integrated pest management, this study proposed the objective of determining the arthropod diversity associated with rice cultivation in the municipality of Sébaco, Matagalpa in Nicaragua.

2. Materials and Methods

2.1. Climatic conditions and location of the study area

The municipality of Sébaco belongs to the department of Matagalpa. It is located between 12° 51' north latitude and 86° 06' west longitude coordinates. The climate is characterized by an average annual temperature between 21 and 30 °C, precipitation varying from 800 to 2,000 mm yearly, with an average altitude of 466.8 m above sea level. Based on the distribution of the climate, two types of seasons have been defined: the dry season of November-April and the rainy season of May-October (Benavidez Meza, 2023). During the execution of the study, a meteorological station (Davis Vantage Pro2™ plus, 001D0A00BD6D) owned by Formuladora Nicaragüense Hanon Talavera [FORMUNICA], located on the San Benito Agrícola farm, recording temperatures, relative humidity and precipitation (Figure 1).

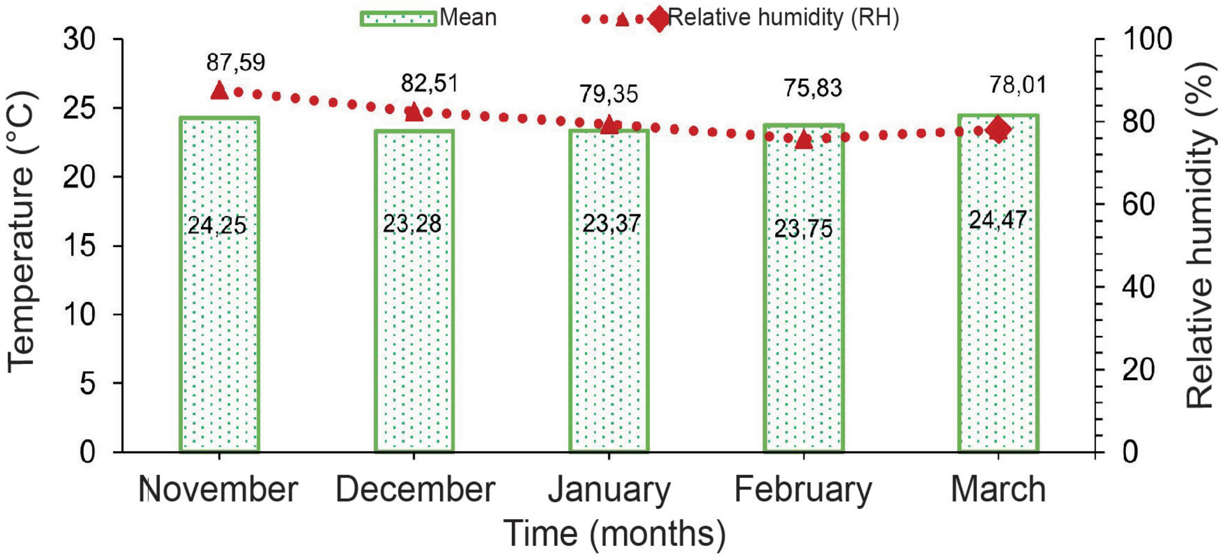

Figure 1. Climate data during the development of the research study, Sébaco Valley, Matagalpa, dry season 2022-2023 (Davis Vantage Pro2™ plus, 001D0A00BD6D).

2.2. Selection of farms, varieties, and planting conditions

INSIDE (2012) reported 205 producers; 61 cultivate areas greater than 50 hectares, and the rest cultivate smaller areas. A prospecting tour was carried out through the municipality, where productive systems larger than 100 hectares established with rice were selected. It was considered that all systems used the same agronomic and phytosanitary management of the crop. The cultivated varieties were: Lazarroz, INTA-Dorado, IRGA-424, and Irval. Direct sowing (machinery) with minimum tillage was used in the San Benito Agrícola, El Plantel, and Yerba Buena systems. In contrast, conventional tillage (Fangueo) was used in the remaining farms with 140 kg ha^{-1} of certified seed. Agronomic management consists of fertilization, weed management, and applying chemical products (agrochemicals) for pest and disease management (Table 1).

***Table* 1.** Geographical location of rice farms, Valle de Sébaco-Matagalpa, Nicaragua.

N.º	Production Systems	Variety	m a.s.l.*	Latitude (UTM)	Longitude (UTM**)	Sowing type	Area (ha)
1	El Escobillo	Lazarroz	469	0593951	1418187	Fangueo	110
2	Yerba Buena	INTA-Dorado	464	0585897	1416310	Direct	361
3	San Benito Agrícola	INTA-Dorado	473	0592465	1424507	Direct	262
4	La Perla	IRGA-424	474	0596932	1426412	Fangueo	119
5	El Plantel	Irval	464	0588690	1421281	Direct	196

* m a.s.l.**:** Meters above sea level

** UTM: Universal Transverse Mercator.

2.3. Identification and monitoring of arthropods

Sampling was carried out to analyze the diversity of arthropods in terms of richness and abundance, in which ten points were selected in each productive system, and at each point 20 double zig-zag passes were made with an entomological net. So that they were well distributed using snap capture sampling (Montgomery et al., 2021). The collected arthropods were preserved in 70 % alcohol for subsequent identification in the laboratory; a stereoscope (Carl Zeiss, model 475002), dichotomous taxonomic keys (Rodríguez Flores & Jiménez Martínez,

2019) were used, specialized literature on insects of agricultural interest in Nicaragua (Jiménez-Martínez, 2020). Monitoring tasks were carried out eight days after the germination of the rice crop (Obregón-Corredor et al., 2021; Sánchez-Alvarado et al., 2023). The captures were related to the phenological stages of the crop.

2.4. Information Analysis

The study was exploratory since it was limited to describing the behavior of the arthropods present in the systems under study in the different phenological stages of rice cultivation. According to the methodology used by Obregón-Corredor et al. (2021), the collected data were organized by taxonomic order and family. Then, the trophic role (morphotype) in the productive system was assigned to each collected individual. Descriptive analysis (frequency) was used for the study variables. They were transformed using a logarithmic scale (base 10) to adjust the data to normality. The data was subjected to normality (Bartlett test) and homogeneity of variance (Kolmogorov-Smirnov test). Linear models were used, declaring the production systems as a fixed effect and the sampling as random effects, selecting the model with the lowest AIC value. (Akaike). Likewise, the Shannon Weaver Index and Simpson index were applied, and the average values were compared with the Tukey HSD test ($p < 0.05$). The statistical software R v.4.2.3 (R Core Team, 2023) was used.

3. Results and Discussion

The evaluation of the different arthropods, in the productive systems, cultivated varieties and stages of development of the rice plant, determined that the abundance of the species *T.* orizicolus was significant, as well as *Hydrella sp., Atrichopogum sp, Tetragnata sp. and Agriopes sp*. showed different behavior in the crop development phases. An important aspect is that arthropods behave similarly in the different established rice varieties, possibly susceptible to damage by these organisms (Table 2). Regarding population dynamics, arthropods vary with the phenological stages of the crop, with the vegetative stage being where the populations are smaller (Albertini, 2022), and this result is related to what was reported by Benites Ronquillo (2019), which indicates that the abundance of insects is related to the development stage of the crop.

Table 2. Statistical significance for arthropods recorded in rice production systems in the Sébaco valley, Matagalpa, Nicaragua.†

Arthropods	Production systems	Days after germination	Varieties	R^2	AIC
Tagosodes orizicolus (Muir)	0,0318*	0,0001**	0,0487*	0,84	40,65
Hydrellia sp.	0,6290^{NS}	0,0001**	0,7160^{NS}	0,55	78,37
Spodoptera sp.	0,0526^{NS}	0,0605^{NS}	0,0546^{NS}	0,65	75,01
Atrichopogum sp.	0,9780^{NS}	0,0001**	0,0830^{NS}	0,78	78,95
Tetragnata sp.	0,5300^{NS}	0,0001**	0,1210^{NS}	0,73	94,88
Argiopes sp.	0,4589^{NS}	0,0095**	0,0098**	0,66	86,69

† R^2 = Coefficient of determination, AIC = Akaike value. ^{NS} = Not significant (∞ > 0,05), * = Significant (∞ ≤ 0,05), ** = Highly significant (∞ ≤ 0,01).

3.1. Distribution and arthropods' feeding habits

A total of 56,610 arthropods were quantified during the research period, distributed in seven orders, 13 families, and 16 genera. The Homoptera, Diptera, and Lepidoptera orders were the most representative, as were the Delphacidae, Ephydridae, and Noctuidae families. The most abundant species were *T. orizicolus, followed by Hydrellia sp.* and *Spodoptera sp*. These results show the diversity of arthropods present in rice cultivation and agree with previous studies carried out by Pérez Iglesias and Rodríguez Delgado (2019), Ghiglione et al. (2021), Obregón-Corredor et al. (2021). Regarding the distribution by feeding habits, they mostly correspond to phytophages, where the species *T. orizicolus* is of interest given that it was the primary pest reported for the crop. However, ten predatory species and one parasitoid species were identified (Table 3). These records correspond to those reported in the study by Vivas-Carmona et al. (2017), where it is reported that *T. orizicolus* is the most important pest for rice cultivation, being abundant in the dry season. All these records of arthropods confirm that in rice production systems, there is functional diversity, where arthropods can perform various ecological functions (León-Burgos et al., 2019; Obregón-Corredor et al., 2021).

Table 3. Abundance of arthropods and feeding habit found in rice cultivation in the Sébaco Valley, Matagalpa dry season 2022-2023.

Order	Family	Species/Morphospecies	Trophic role	Amount
Homoptera	Delphacidae	*Togosodes orizicolus* (Muir, 1926)	Phytophage	46.663
Diptera	Ephydridae	*Hydrellia* sp. (Korytkowski, 1982)	Phytophage	5.229
	Ceratopogonidae	*Atrichopogum* sp. (Kieffer, 1906)	Parasitoid	419
	Sciomyzidae	*Sepedomerus macropus (*Walker, 1849*)*	Depredador	204
Lepidoptera	Noctuidae	*Spodoptera* sp. (Smith, 1797)	Phytophage	1.544
Araneae	Tetracnathidae	*Tetragnata* sp. (Walckenaer, 1841)	Predatory	1.104
	Araneidae	*Argiopes* sp. (Pallas, 1772)	Predatory	388
		Alpaida veniliae (O. Pickard-Cambridge,1889)	Predatory	31
	Oxyopidae	*Oxiopes* sp. (Latreille, 1804)	Predatory	53
Hemiptera	Cicadellidae	*Hortensia similis* (Walker, 1851)	Phytophage	247
		Empoasca sp.	Phytophage	60
	Reduviidae	*Zelus pedestris (Fabricius, 1803)*	Predatory	170
	Pentatomidae	*Oebalus insularis* (Stal, 1872)	Phytophage	65
Odonata	Libellulidae	*Sympetrum danae (Sulzer, 1776)*	Predatory	191
Coleoptera	Coccinellidae	*Cicloneda sanguinea (*Linneo, 1763)	Predatory	191
		Coleomegilla maculata (De Geer, 1775)	Predatory	51

T. orizicolus was present throughout the crop cycle, with greater abundance in the primordium phase (60-65 days after germination - DAG). However, the *Hydrellia sp.* and *Spodoptera sp.* behavior corresponded to the first stages of crop development (before 60 DAG). Sánchez-Alvarado et al. (2023) determined that the population dynamics and abundance of each species vary depending on the phenological stages of the rice crop. These results demonstrate the preference of certain pest species according to the stages of crop development. Only *T. orizicolu*s showed different behavior in the production systems, crop development phases, and established varieties, with the largest populations reported at the end of the reproductive phase and throughout the maturation phase. The opposite occurred with *Hydrellia sp*., where its largest population was recorded in the vegetative phase and the beginning of the reproductive phase. In contrast, the populations of *Spodoptera* sp. behaved constantly in all phases of crop development (Table 4). This coincides with what was found by Vivas-Carmona et al. (2017), who mention *T. orizicolus* as the main rice pest in the tropical regions of the American continent, with its populations being most abundant in the months (March-April) of the dry season.

3.2. Abundance of the main beneficial arthropods

The abundance of beneficial arthropods was similar in all productive systems. However, two orders stand out: Araneae and Diptera. From the records of beneficial arthropods, two significant species stand out: *Tetragnata sp.* and *Argiopes sp.,* which are considered abundant and have a predatory feeding habit. Likewise, within the diptera order, *Atrichopogum sp*. stands out, being the reproductive and maturation phase where the most beneficial arthropods are reported. This could be directly related to pest organisms in the crop. Castillo-Carrillo et al. (2021) reports that spiders constitute a natural control of *T. orizicolus* in rice cultivation, regulating population density. Another study carried out by Obregón-Corredor et al. (2021) mentions that the predator/prey relationship varies depending on the phenology of the crop and the management carried out by the producer, coinciding with the results found in this study (Table 5).

Table 4. Abundance of insect pests in rice crop in the Sébaco Valley, Matagalpa, dry season of 2022-2023.*

Production systems		*Tagosodes orizicolus*		*Hydrellia* sp		*Spodoptera* sp	
		μ ± δ		μ ± δ		μ ± δ	
El Escobillo		54,53±31,64	b	5,98±14,93	a	0,98±1,32	a
Yerba Buena		107,48±113,54	a	11,79±18,40	a	3,59±5,80	a
San Benito Agrícola		59,49±35,05	b	9,98±12,92	a	0,96±1,21	a
La Perla		55,32±32,34	b	7,38±12,45	a	4,60±9,92	a
El Plantel		56,49±31,80	b	2,19±2,34	a	0,91±1,50	a
Days after germination							
8	Vegetative phase	10,82±2,33	g	29,04±27,86	a	0,10±0,17	a
16		17,00±4,92	fg	13,94±13,49	a	6,08±9,53	a
24		25,22±3,68	efg	18,00±19,74	a	3,60±2,16	a
32		30,94±22,07	def	18,12±18,85	a	1,78±1,86	a
40	Reproductive phase	38,86±2,77	def	5,62±4,04	a	5,40±10,01	a
48		47,58±5,92	def	9,48±5,95	a	7,90±13,25	a
56		53,32±5,12	bcde	4,08±1,76	a	2,04±2,17	a
64		61,64±5,64	bcd	1,34±0,80	a	1,34±1,03	a
72		68,48±6,14	abcd	2,32±1,07	a	0,84±1,45	a
80		76,48±8,22	abc	0,80±0,62	a	0,50±0,71	a
88	Maturation phase	89,40±13,13	abc	0,28±0,41	a	0,50±0,62	a
96		133,64±86,46	ab	0,94±0,62	a	0,60±1,02	a
104		164,22±143,85	a	0,46±0,65	a	0,20±0,45	a
112		115,66±20,58	a	0,12±0,18	a	0,00±0,00	a
Varieties							
Lazarroz		54,53±31,67	b	5,98±14,93	a	0,98±1,32	a
INTA-Dorado		83,48±85,99	a	10,89±15,63	a	2,27±4,32	a
IRGA-424		55,32±32,34	b	7,38±12,45	a	4,59±9,92	a
Irval		56,49±31,80	ab	2,19±2,34	a	0,91±1,50	a

* Means with different letters denote significant difference (p < 0,05), μ = Mean; δ = Standard deviation

3.3. Arthropod diversity index associated with rice cultivation

The diversity of arthropods analysis associated with rice cultivation indicates a large number of individuals, however, they are contained in few species and families. In the productive systems, a low diversity of arthropods was determined using the Shannon-Weaver index and Simpson index, indicating the presence of a dominant species *(T. orizicolus)*. When analyzing the crop's phenological phases (DAG), it was found that the most remarkable diversity manifested from 16 to 48 days (beginning of tillering to maximum tillering of the crop). In rice cultivation, being a monoculture, pests are managed through chemical products in a scheduled manner, possibly generating resistance in these arthropods in production systems (Table 6). Vivas-Carmona et al. (2017) mention that the largest populations of *T. orizicolus* are related to the time-of-year crop development phase. Likewise, Obregon-Corredor et al. (2021) reported that, as a result of the trophic relationships of the species, low or high densities of organisms can be found and that the crop development phase and environmental conditions influence the dynamics of the populations (Mirhosseini et al., 2017).

Table 5. Abundance of beneficial arthropods in rice crop in the Sébaco Valley, Matagalpa, dry season of 2022-2023.

Production systems		*Atrichopogum sp*		*Tetragnata* sp		*Argiopes* sp	
		μ ± δ		μ ± δ		μ ± δ	
El Escobillo		0,22±0,29	a	3,00±3,87	a	1,08±1,31	a
Yerba Buena		1,37±2,02	a	1,79±2,89	a	0,21±0,26	a
San Benito Agrícola		0,75±0,79	a	1,04±0,99	a	0,55±0,59	a
La Perla		0,09±0,13	a	1,15±1,43	a	0,41±0,37	a
El Plantel		0,56±1,21	a	0,88±0,98	a	0,51±1,29	a
Days after germination							
8	Vegetative phase	0,00±0,00	c	0,00±0,00	b	0,10±0,10	a
16		0,02±0,04	c	0,16±0,21	ab	0,18±0,17	a
24		0,00±0,00	c	0,20±0,39	ab	0,08±0,08	a
32		0,00±0,00	c	0,34±0,35	ab	0,10±0,14	a
40	Reproductive phase	0,20±0,25	c	0,50±0,54	ab	0,16±0,15	a
48		0,12±0,13	c	1,24±0,90	ab	0,58±0,67	a
56		0,10±0,14	c	1,26±1,73	ab	1,00±1,11	a
64		0,92±0,89	abc	1,56±2,73	ab	0,78±0,90	a
72		0,66±0,79	bc	3,84±2,72	ab	1,20±1,49	a
80		1,04±1,44	abc	4,76±4,82	a	1,08±1,21	a
88	Maturation phase	0,42±0,58	c	1,86±1,23	ab	1,60±1,93	a
96		0,90±0,77	abc	1,94±1,13	ab	0,28±0,27	a
104		2,14±2,57	a	3,32±4,25	ab	0,52±0,19	a
112		1,86±2,21	ab	1,04±0,92	ab	0,10±0,17	a
Varieties							
Lazarroz		0,22±0,29	a	3,00±3,83	a	1,07±1,31	a
INTA-Dorado		1,06±1,54	a	1,42±2,16	a	0,38±0,48	a
IRGA-424		0,09±0,13	a	1,15±1,43	a	0,41±0,37	a
Irval		0,55±1,21	a	0,88±0,98	a	0,51±1,29	a

* *Means with different letters denote significant difference (p < 0,05), μ = Mean; δ = Standard deviation*

The results obtained in this study demonstrate the importance of arthropods in productive systems and their behavior in the different phenological stages of rice cultivation, demonstrating that the production paradigm in the rice sector must be changed, maintaining beneficial diversity, environmental conservation, and promoting food security and human health.

4. Conclusions

The diversity of arthropods varies in relation to the phenology of the crop, with the species of interest being *T. orizicolus*, the one with the greatest abundance in the productive systems and varieties, constituting the primary pest, followed by *Hidrellia sp.* and *Spodoptera sp*., which affect the first phases of crop development. The beneficial arthropods that stood out were *Atrichopogum sp., Tetragnata, Argiopes sp*., which showed predatory eating habits, playing an essential role as biological controllers, so their populations must be conserved and increased in rice production systems. The diversity, in general terms, was low in all production systems and development phases of rice cultivation.

Table 6. Comparison of biodiversity indices in five rice production systems, Sébaco Valley, Matagalpa, dry season 2022-2023.

Production systems	Shannon-Weaver	Simpson
El Escobillo	0,69	0,27
Yerba Buena	0,57	0,26
San Benito Agrícola	0,57	0,25
La Perla	0,72	0,34
El Plantel	0,42	0,16
Days after germination)		
8	0,75	0,44
16	1,26	0,68
24	1,21	0,64
32	1,14	0,61
40	1,09	0,53
48	1,19	0,56
56	0,96	0,45
64	0,83	0,39
72	0,96	0,44
80	0,87	0,41
88	0,71	0,34
96	0,57	0,27
104	0,56	0,26
112	0,59	0,31

Author contributions

- José Manuel Laguna Dávila: conceptualization, investigation, methodology, resources, data curation, writing – original draft.
- Juan Carlos Morán Centeno: data curation, formal analysis, writing – review and editing.
- Edgardo Jiménez Martínez: supervision, writing – review and editing.

Ethical implications

Ethics approval Not applicable.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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