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RESEARCH ARTICLE

Assessing agroecosystem sustainability in Cuba: A new agrobiodiversity index

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The main constraint to sustainable agrarian development in Cuba has been a poorly balanced agrobiodiversity in its agroecosystems. This is the result of mainstream agrarian policy that focuses on sugarcane monocropping, following the principles of modern agriculture as promoted over the last 50 years. This paper discusses the development of a new Index of Agrobiodiversity (IDA), a tool used to identify the extent to which agroecosystems are sustainable, based on their agrobiodiversity. It describes the research carried out to identify the index components, how the index was developed and how its efficiency was assessed. The paper also presents a practical experience whereby agroecosystems from Cuba's urban agriculture movement were measured. Our analysis suggests that the Index of Agrobiodiversity is a valid proposal: its main success lies in the fact that few material and human resources are needed, and that the required information is generated through the work of local farmers themselves. Moreover, the results can encourage farmers to increase agrobiodiversity in their agroecosystems. *Please refer to Supplementary Materials*, DOI: https://doi.org/10.1525/elementa.336.s1*, for a full text Spanish version of this article.*

Keywords: Agroecosystem assessment; Index of Agrobiodiversity; Species value; Agrobiodiversity; Sustainability

La principal limitante del desarrollo agrario sostenible en Cuba ha sido la carencia de una equilibrada agrobiodiversidad en los agroecosistemas, consecuencia de la política agraria tradicional sustentada en el monocultivo de la caña de azúcar y conducida bajo los principios de la agricultura moderna durante los últimos 50 años. El resultado que se expone en este trabajo tuvo como objetivo crear un nuevo Índice de Agrobiodiversidad (IDA), herramienta que identifica el grado de cercanía o distanciamiento de la sostenibilidad de los agroecosistemas basados en el indicador de agrobiodiversidad. El texto recoge las investigaciones realizadas para la identificación de los componentes del índice, su elaboración y evaluación de su eficiencia. También se incluye una experiencia práctica de medición en agroecosistemas del movimiento de la agricultura urbana en Cuba. Nuestro análisis sugiere que el Índice de Agrobiodiversidad propuesto es una propuesta valiosa, cuyo principal éxito está en que su conducción requiere de escasos recursos materiales y humanos, y la información necesaria para su determinación surge del trabajo de los propios agricultores locales cuyos resultados pueden servir de estímulo para incrementar la agrobiodiversidad en sus agroecosistemas. *La versión en español de este artículo se puede encontrar en Materiales Suplementarias*, DOI: https://doi.org/10.1525/elementa.336.s1.

Palabras clave: Evaluación de agroecosistemas; Índice de Agrobiodiversidad; Valores utilitarios de las especies; Agrobiodiversidad; Sostenibilidad

1. Introduction

In agroecology, plant agrobiodiversity refers to the functional diversity found in agroecosystems, which meets human needs and ensures the planet's natural balance (Vásquez et al., 2011). According to the FAO (2007), agrobiodiversity is an essential indicator of sustainable agrarian development. It also represents the basis of food for humans, animals and other forms of non-plant life. Its presence in agroecosystems has an impact on how many food varieties can be found in local markets (Leyva et al., 2000).

Assessing the efficiency of agrobiodiversity in agroecosystems based on the three dimensions of sustainability (economic, ecological and social) is cumbersome, given the quantity and diversity of specialised material as well

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as human resources required. Such an assessment would entail the analysis of a wide variety of indicators, given the different processes and interactions that take place within crop subsystems in any given agroecosystem (González, 2016). Because of this complexity, there are several methodologies available to this end.

Altieri and Nicholls (2012), Zuluaga et al. (2013), and Rogé and Astier (2013) have analysed agrobiodiversity from different perspectives. These authors have placed emphasis on its capacity to play a role in climate change adaptation. Funes-Monzote et al. (2013) have analysed agrobiodiversity in terms of energetic efficiency, while Astier et al. (2012) and Dellepiane and Sarandón (2008) view it as an attribute of sustainability. Other functions identified by researchers are linked to the structure of agroecosystems (León, 2010), and to its efficiency for the design and management of complexities in spatial, structural and temporal arrangements (Vázquez et al., 2011, Vázquez, 2013).

Despite previous research, there are no proposals that consider agrobiodiversity for its utilitarian values and functionality in relation to its users' needs. Against this backdrop, a research project was initiated with the goal of designing a tool to identify, in each agroecosystem, deficits in functional and associated diversity with respect to varieties that fulfil functions for human, animal and soil life.

2. Materials and Methods

The research was carried out in three different phases between 1996 and 2016. The objectives of the different phases were as follows: (*i*) to assess a municipality's agrobiodiversity and its contribution to the local diet, (*ii*) to develop an Index of Agrobiodiversity (IDA) and to test its efficiency, (*iii*) to test the possible similarity between the IDA and the methodology that the Urban Agriculture (AU) and Suburban (ASU) movements used for their agroecosystem assessment in Cuba (GNAUSF, 2016).[1] The next section describes the three phases in detail.

(i) Assessment of a municipality's agrobiodiversity and its contribution to local diets

The first assessment of agrobiodiversity was carried out in Jaruco, a municipality located in the province of Mayabeque. When the research began, the population of Jaruco was 30 thousand inhabitants, 70% of whom lived in urban settlements. The research team had easy access to the municipality, given its proximity to the capital (40 km east of Havana). In Jaruco, productive soils are predominantly red and yellowish ferralitic soils (Hernández et al., 2015). The climate is suitable for agriculture all year round, when irrigation is available, and 80% of annual average rainfall (1400 mm) takes place between May and October (Lecha et al., 1994).

To start with, a participatory rapid rural appraisal (Schonhuth y Kievelitz, 1994) was undertaken in order to evaluate the agrobiodiversity present in agroecosystems, and to identify those farmers who were hindering the presence of varied foods on the market. For this purpose, a questionnaire was sent out to key actors in Jaruco (Leyva et al., 1995). A total of 344 actors participated in the appraisal, including farmers, facilitators, and decision-makers directly linked to vegetable farming. These actors represented over 10% of the total population group directly involved in production, including all forms of organisations[2] from the municipality's farming sector. The survey covered 20% of all agroecosystems. Additionally, written information on the municipality's agriculture was reviewed, and data was also obtained from the municipality's historian. Furthermore, the amount of land available to increase food production in both space (land not under production) and time (land that could be used more intensively), and according to the local population's needs, was measured.

The information was then processed. Some qualitative data were standardised, examined through a participatory process, and categorised on a scale of 1 to 10. The results were then processed using non-parametric statistics, and the research culminated in a proposal for local self-sufficiency[3] (Leyva, 2003).

(ii) Development of an Index of Agrobiodiversity (IDA)

In 2004, a new research phase was initiated in Zaragoza, a village located in the municipality of San Jose de Las Lajas (capital of Mayabeque province). With a population of 6000, Zaragoza flanks the southeast border of Jaruco municipality, with which it shares the same agrarian culture. During this phase, the research goal was to gain an understanding of the local agrobiodiversity, in order to develop an easy method for assessing the sustainability of agroecosystems based on their utilitarian values.

Farmers (a sample of approximately 12% of the total) and personnel from local agricultural services were interviewed about agricultural practices in Zaragoza. The research was geared toward two specific objectives: (*a*) the development of what became the IDA index, and (*b*) an analysis of the similarity between IDA and the General Index of Sustainability (IGS).[4] To develop the IDA index, a spatial and temporal analysis of agrobiodiversity was conducted for each agroecosystem, based on its utilitarian values, yields, and relationship to people's needs. Due to limited space, the analysis regarding the similarity between IDA and IGS (Zinck et al., 2006) – which is measured through the use of sustainability indicators (Masera et al., 1999; Sepúlveda et al., 2002; Sarandón et al., 2006) – were not included in this paper. They were included, however, in the doctoral thesis of Lores (2009), and presented at the International Symposium on Sustainable Agriculture (SOMAS) in Mexico (Lores et al., 2010).

(iii) Similarity between IDA and the Methodology used by Urban (AU) and Suburban Agriculture (ASU) Management

Once the index was developed and the efficiency of the index assessed, in 2013 the third phase of the research was initiated. It began with the gathering of information on those agroecosystems that were classified as "excellent" by AU and ASU management, according to the methodology used by the organisation at the national level (GNAUSF, 2015). Twenty-six agroecosystems of excellence were randomly selected from five provinces across the country. The goal was to understand the role played by agrobiodiversity in agroecosystem sustainability, and to assess it by applying the IDA. The value attributed to excellent agroecosystems was assumed to lie between 0.8 and 1.0 on the IDA (see below for calculation details).

3. Results and Discussion

(i) Results of the agrobiodiversity evaluation in the municipality of Jaruco and its contribution to local diet

The results of the diagnostic demonstrated that sugarcane monocropping was predominant in the municipality of Jaruco. This represented a significant contribution to the country's economy, but did not have any direct positive consequence for local people (**Table 1**).

The abundance of land dedicated to cattle and small livestock farming (**Table 1**) was the result of a national development strategy. This land distribution had limited benefit with respect to the overall quality of life in the region, although workers employed directly in the livestock sector did benefit. Only 3% of municipal land was used for tuber and grain production, thus demonstrating that the strategy was not sufficiently balanced to guarantee basic foods for local subsistence.

Fruit trees, which made up 10% of the total surface, did not constitute a significant source of income for small-scale farmers due to the absence of a structured trading system. As a result, fruit was grown mainly for consumption within the family. The inclusion of fruit trees in agroecosystems is linked to peasant farming traditions, that valued having an ecological niche close to the family home that served to guarantee a variety of fresh fruits.[5]

The percentage of forest cover was only 53.8% of the national average, which at that time reached 21% nationally (Alonso, 2001). Potatoes, the second most widely cultivated agricultural crop in the municipality, were not produced for consumption, but rather for the production of seed, an activity that addressed national interests but did not contribute to local needs.

There was no record of freshwater fish or honey production within the agroecosystems, thus leading to a deficit of those foods at the family level. Eggs and pork, which are the main sources of Cubans' protein from animal origin, were also scarcely produced. Milk production within the municipality was only sufficient to guarantee children's needs were met.

Species used to improve soil properties (such as green manures) were completely absent, and grains such as corn and soybean, which are used to feed poultry and pigs, were scarce. Nevertheless, natural pasture for livestock was prioritised. This was a new idea within agroecology, but was consistent with its principles provided that leguminous plants were integrated into the pasture to ensure a better Carbon-Nitrogen (C:N) ratio (Leyva y Pohlan, 2005).

The total identified agrobiodiversity was 136 plant species (**Table 2**), from which only 41 were used for food. Farmers from Jaruco were specifically interested in 39 species: 24 fruit varieties, 5 varieties that provide carbohydrates, 6 vegetable varieties (from which 4 are used for seasoning), 3 that provide protein and one oilseed for fat. The agrobiodiversity of species for human consumption fluctuated between 15 and 26 varieties in the different agroecosystems of the study, with a minimum of 8 and a maximum of 31. In addition, 15 animal species were identified, of which 11 could be used for human consumption.

The presence of vegetables rapidly increased due to promotion by the urban agriculture movement (Rodríguez, 2010), and related dissemination programmes. Nevertheless, community members in rural areas were not accustomed to eating vegetables and consumed only a limited amount. There was a rise in vegetable consumption in urban areas, but this was not witnessed in rural areas. The rural population did not substantially change their dietary habits, and openly rejected vegetables, as per their own food traditions.

The results show that the agroecosystems we analyzed did not fully correspond to the notion of a diversified production system. It was clear that important species were missing, meaning the systems did not have the necessary agrobiodiversity for food self-sufficiency based on internationally recognised daily nutritional needs (Sasson, 1993).

Table 1: Organisational composition of municipal agriculture in Jaruco in 1996. DOI: https://doi.org/10.1525/elementa.336.t1

Components	Surface (ha)	Percentage
Total surface	27.570	100.0
Agricultural surface	**21.235**	**77.0**
Non-agricultural surface	6.335	23.0
Sugarcane	9.512	34.5
Livestock	5.097	18.5
Forests Fruit trees	3.120 2.705	11.3 9.8
Tubers and grains (for subsistence)	842	3.0
Pasture	139	0.5

Source: Information obtained at the Municipal Office for Statistics in Jaruco.

Table 2: Groups of plant varieties registered in agroecosystems in Jaruco (1996–2000). DOI: https://doi.org/10.1525/elementa.336.t2

Groups of plant varieties	Total of species registered
Fruit trees	28
Ornamental	31
Cut flowers	24
Vegetables	11
Pasture and non-crop plants	10
Timber	08
Roots, tubers*	05
Basic Grains	02
Leguminous plants	01
Oilseeds	01
Sedative, melliferous, medicinal, hedges and other	15
Total	136

* This is the name given to varieties that reproduce with asexual seeds, in the ground, such as potatoes (*S. tuberosus* L), and yams (*Ipomea batata* L.). These varieties provide carbohydrates.

A field assessment of the existing diversity for each agroecosystem showed that there were differences depending on the month. The month with the most diversity was November, while the months with the least diversity were August and February, during which 87% of local demand was unmet by local production (Leyva et al., 2000). The causes of this temporary imbalance for the least diverse months could be linked to the lack of irrigation during the three months that precede February (a period of scarce rainfall) and the excessive rainfall in the three months that precede August (rainy season). It could also be caused by maladjustments in sowing and harvesting programmes, a lack of resources, or the fact that producers were not taking advantage of opportunities for sequential production systems. An absence of efficient rotational systems was noted, as pointed out by Puentes et al. (1982).

We found similar levels of diversity in all agroecosystems assessed, although there was a difference in the level of priority local farmers assigned to different crops. The diversity that local farmers prioritised can be viewed in **Table 3**.

The diversity in individual agroecosystems reached on average a total of 26 varieties. Cassava (*Manihot esculenta* L.), corn (*Zea mays L.*), beans (*Phaseolus vulgaris* L.) and avocado (*Persea americana L.*), were the most used varieties by all interviewed producers. These species represented calories/carbohydrates (cassava and corn), protein (beans), and minerals, vitamins and fats (avocado).

Although farmers had no knowledge of these dietary criteria, the order in which predominant varieties were prioritised in their agroecosystems corresponds to human dietary needs as per energy and protein indicators. They were not aware of the fact that they possessed a rich peasant food heritage. Moreover, this knowledge was not taken into account in the local production strategy, even though as early as the 1950s precise information on dietary components of different crops was already available (Merrill and Watt, 1955).

Of the different types of farmers' organisations, Credit and Services Cooperatives (CCS) were the most diverse in their agroecosystems (**Table 4**). The CCS member farmers had generally maintained traditional farming methods and were therefore less affected by reductions in available external inputs,[6] thus demonstrating their higher levels of resilience (Funes-Aguilar, 2016).

Across the three types of cooperatives represented in **Table 4**, approximately 50% of the functional species were for human consumption. The CCS had almost twice as many (41) as the UBPC (24). As explained above, these figures are still low. Given this situation, a proposal to introduce new varieties was developed. The MEDEBIVE[7] proposal emerged from these results, which are collated in the Ministry of Environment (CITMA) project final report, published by Leyva (2003). The outcome formed the basis for the development of the Index of Agrobiodiversity (IDA).

During the research process, local farmers received capacity-building, which significantly increased their knowledge of the utilitarian values of biodiversity in relation to human nutritional needs. However, even though there were positive results in terms of learning, the expected changes in attitude and aptitude among farmers were not observed. The absence of decision-makers in the capacity-building sessions may have influenced the slow change in agroecosystems. These results coincide with those obtained by Vallejo (2017), following research on the impact of capacity-building on the translation of scientific results into production practices.

(ii) Development of an Index of Agrobiodiversity (IDA)

The IDA is a tool that provides information, by means of a numeric value, on the necessary agrobiodiversity value for any given community. The calculation is made based on a comparison between the existing level of agrobiodiversity and the level needed to meet the community's

Table 3: Varieties prioritised by Jaruco farmers (1996–2000). DOI: https://doi.org/10.1525/elementa.336.t3

Scientific Name	Common name	% of farmers growing the variety during the research period	% of farmers regularly growing the variety
Manihot esculenta	Cassava	87.5	100
Zea mays	Corn	83.3	100
Phaseolus vulgaris	Beans	61.5	100
Persea americana	Avocado	66.6	100
Citrus aurantium	Bitter orange	10.8	90
Mangifera indica	Mango	61.5	90
Cocus nucifera	Coco	33.3	90
Psidium guajaba	Guava	33.3	90
Ipomoea batata	Sweet potato	54.1	90
Citrus sinensis y C. aurantium	Lemon and Bitter Orange	33.3	80
Solanum Lycopersicum	Tomato	45.8	80
Musa spp	Banana	61.6	80
Coffea sp	Coffee	10.8	80
Colocasia esculenta	Taro	15.0	70
Acras sapote	Sapote	20.0	20
Carica papaya	Papaya	12.6	20
Capsicum spp	Cachucha Pepper	19.0	60
Annona Cherimola	Custard Apple	33.3	40
Oryza sativa	Rice	11.1	35
Chrysophyllum caimito	Star Apple	20.0	20
Theobroma cacao	Cacao	20.0	20
Cucurbita pepo	Pumpkin	10.8	20
Citrus grandis	Grapefruit	10.0	10
Tamarindus indica	Tamarind	10.0	10
Manilkara zapota	Mamey	10.0	10

Source: Leyva et al. (2000).
Note: The table only includes the varieties prioritised by at least 10% of farmers.

needs and interests (i.e. for its inhabitants, animals, natural resources and remaining life forms). The IDA builds on known mathematical principles pointed out by Dietrich (1983), in calculating the Equivalent Index of Land Use (IET)[8] and on the General Index of Sustainability (IGS), as proposed by Zinck et al. (2006).

The IDA incorporates elements that are not included in any other index, namely: nutritional values for humans, for animals and for remaining life forms ("consumers") as well as for the protection of soil. Additionally, the IDA considers environmental protection, resilience, carbon capture, climate change and the sociocultural role of agrobiodiversity, underpinned by the educational role played by the dissemination of knowledge of the dietary value of plants, as well as their spiritual functions.

The IDA represents basic food groups and the degree to which these are satisfied through local production, in diversity and quantity. Assessing whether food needs for local demand are met is based on criteria established collectively through a series of participatory activities. These activities define desired values for particular species and compare them against existing values.

Should the IDA value be found to be below 0.6, the system is considered unsustainable. Should the index reach a value of 0.61 to 0.7, it is considered somewhat sustainable. It is considered sustainable if the value fluctuates between 0.71 and 0.8; and strongly sustainable if the value rises above 0.81. An agroecosystem with a value of 1.0 (which is very difficult to achieve) is the optimal value of diversity for a local or territorial system that aims to achieve sustainable agricultural development based on agroecology.

Comparative studies by Lores (2009) on agrobiodiversity values obtained using the IDA versus IGS methodologies found that results were not significantly different. This made the implementation of the new proposal more viable. The main aim of the proposal is to make it easier to assess the sustainability of agroecosystems by means of a functional, efficient and robust indicator.

Table 4: Average diversity of species per agroecosystem as per type of cooperative in Jaruco municipality (1996 and 1998). DOI: https://doi.org/10.1525/elementa.336.t4

Agroecosystem organisational form	CCS*	CPA**	UBPC***
Total number of species (functional diversity)	81	74	52
Species that contribute to food for humans	41	34	24

Source: Leyva et al. (2000).
* Credit and Services Cooperatives.
** Agricultural Production Cooperatives.
*** Basic Units of Cooperative Production.

Table 5: Proposal of species, organized by function, for developing the Index of Agrobiodiversity (IDA). DOI: https://doi.org/10.1525/elementa.336.t5

Sub-Indices	No.	Species and functions
Sub-index FER Biodiversity for human diet	I	Plant-based (leguminous plants)
	II	Animal-based (milk, meat, eggs, fish)
	III	Energy-giving (roots, tubers, and cereals)
	IV	Energy-giving (oil seeds)
	V	Regulating (vegetables)
	VI	Regulating (annual and perennial fruits)
Sub-index FE Biodiversity for animal feed	VII	Plant-based (leguminous plants, trees and creeping plants)
	VIII	Energy-giving (pasture, forage and cereals)
Sub-index AVA Biodiversity to improve soils	IX	Green manures, crop residues, organic fertilisers, inert weeds (or non-crop species), live cover for soil protection
	X	Species that contribute to the production of bio-fertilisers
Sub-index COM Complementary and Associated Biodiversity for non-dietary use	XI	Medicinal, stimulating and seasoning species
	XII	Flowers, ornamental plants, food plants for wild birds
	XIII	Timber, domestic use, energy-building
	XIV	Other uses: species with spiritual values, religious uses, industrial or artisanal use
	XV	Climate Change (living fences to protect against the wind) repellents and attractants, hedges, melliferous, amongst others.

Source: Leyva and Lores (2012).

In order to align with the principles upon which it was developed, the IDA uses four sub-indices: IFER (food for humans), IFE (food for animals), IAVA (to improve physical, chemical and biological properties of soil), and ICOM (complementary species) (**Table 5**). Each sub-index includes species that are considered food for each group. The robustness of each sub-index lies in the diversity and dominance of species, according to their food provisioning role and other functions.

Given that the IDA is equal to the sum of the IFER, IFE, IAVA and ICOM sub-indices, divided by the number of sub-indices (four), it is assumed that the value of each sub-index is of equal importance. This method attempts to break away from the generalised approach of decision-makers and farmers, who primarily focus on food for humans, thus paying less attention to adequate nutrition for other life forms, including non-crop species that play a balancing role in agroecosystems (Blanco-Valdés, 2016).

An agroecosystem that is structured on agroecological principles would have to include all dietary components, and would be more sustainable if it would also include medicinal plants, ornamental plants and flowers. This proposal corresponds to the principles put forward in La Via Campesina's conceptualisation of food sovereignty (La Via Campesina, 2003).

(ii.a) Description of the Index of Agrobiodiversity (IDA) for its application

The inclusion of different groups and components of agricultural biodiversity in our analysis led to the development of an index of diversity for agroecosystems in mathematical terms:

$$IDA = \frac{\sum_{1}^{S_t} Vi}{S_t(Vi\ .\ \max)} \qquad (1)$$

where *Vi*: Value of each component; *Vi* máx.: Maximum possible value of each component; and S: total amount of components.

As explained above, biodiversity (in its practical use) is divided into four groups, and these in turn are made up of a specific number of biodiversity components. Based on this division, a Specific Index for each Group (IEG) was established in order to individually assess each group, taking into account its main functions in the agroecosystem.

Therefore, in each group:

$$IEG = \frac{\sum_{1}^{S_e}(Vi)}{S_e(Vi.\max)} \quad (2)$$

in such a way, that IDA reflects the inclusion of all IEG:

$$IDA = \frac{\sum_{1}^{n} S_e(IEG)}{S_t} \quad (3)$$

In other words: $IDA = \frac{S_1 IFER + S_2 IFE + S_3 IAVA + S_4 ICOM}{S_t}$; where: *IFER* is the biodiversity sub-index for human diets; IFE is the sub-index for animal feed; *IAVA* is the biodiversity sub-index to improve the physical, chemical and biological properties of soil; *ICOM* is the complementary biodiversity sub-index; and *St* is the total number of components in each group.

Given that formulas (1) and (2) assume that all components of agricultural biodiversity are equally important, and that calculating IDA with (2) allows for an independent analysis of each group to understand which has/have deficit(s), formula (3) was adopted in order to calculate IDA, i.e.: $IDA = \frac{\sum_{1}^{n} S_e(IEG)}{S_t}$.

This formula takes into account the behaviour of indices specific to each group (Lores, 2009). The final formula therefore would be: $IDA = \frac{S_1 IFER + S_2 IFE + S_3 IAVA + S_4 ICOM}{S_t}$.

The advantage of using this index is that the desired values for each species in each group are established through a consensual, participatory analysis conducted with farmers and facilitators. The disadvantage is that the evaluators are not always able to register the total existing diversity in the agroecosystem with a defined functionality. Therefore, farmers and facilitators should receive capacity-building and trainings so as to be able to register information in the most exact way possible. After determining the IDA, the final value obtained, which reflects the values of the sub-indices, is submitted for consideration by all involved farmers.

(ii.b) Applying the IDA in Zaragoza

Even though the number of species found during the research in this municipality reached a total of 161 (11 more than in Jaruco), the optimal value for this area should still be defined using participatory activities. Despite the wide availability of fruit (24 species), it should be noted that there are 165 available species nationwide (Rodríguez and Sanchez, 2002). A further assessment would be needed in order to determine whether the available (24) species are sufficient to meet local dietary needs and customs.

In Zaragoza, of the total list of plant species registered on participating agroecosystems, 65 were considered human food. Of these, 28 fruit species covered 14% of cultivated land (**Table 6**) and were thus predominant.

The little land used for leguminous and oilseed plants contrasts with the wide variety of food species that could potentially be introduced into the country's agroecosystems. This represents a cultural issue, as historically black beans have been the only product with demand for daily consumption in Cuba. Additionally, although corn mainly provides protein, it falls under "grains" in the statistics. A lack of available technology for management and harvesting has inhibited the potential for oilseed production. Oilseed production for possible artisanal processing at the local scale has not been encouraged, leading to the need to import to meet local need.

Over the course of three years, during which diverse species were introduced through participatory workshops, the research area saw an increase of 18 varieties. Nevertheless, 75% of that increase corresponds to human food (**Table 7**), which shows where the farmers' priorities lie. The registered diversity is similar to that of other Cuban agroecosystems (Wezel and Bender, 2002; Castiñeiras, 2006). In all cases, there is a lack of balance in available species needed in order to meet the community's real needs.

Table 6: Species and percentage of land covered (in % of total) in agroecosystems of Zaragoza (2004–2006). DOI: https://doi.org/10.1525/elementa.336.t6

Groups of varieties	Number of species per year			Land covered in 2006 (%)
	2004	2005	2006	
Energy-giving (roots and tubers)	6	6	6	32.0
Body-building (bean) and energy-giving (corn)	5	10	10	29.0
Complementary (seasoning and stimulants)	11	11	11	17.0
Regulating fruits	28	29	30	14.0
Regulating vegetables	13	15	16	6.0
Energy-giving (oilseeds)	2	4	4	2.0
Total	65	75	77	100.0

Source: Lores (2009).

Table 7: Evolving species diversity in agroecosystems in Zaragoza, from 2004 to 2006. DOI: https://doi.org/10.1525/elementa.336.t7

Groups	Varieties identified per year			Total increase in varieties
	2004	2005	2006	
Human food	65	75	77	12
Animal feed	3	4	5	2
Soil-feeding	0	2	2	2
Complementary species	25	25	27	2
Trees, bushes and weeds	58	58	58	0
Total	**93**	**106**	**111**	**18**

Source: Lores (2009).

Table 8: Values of the Index of Agrobiodiversity (IDA) sub-indices in 15 agroecosystems in Zaragoza, 2004. DOI: https://doi.org/10.1525/elementa.336.t8

IDA Sub-indices	Agroecosystems*														
	MPi	LP	LD	JM	RH	ESC	AU	RG	MPe	FM	JA	EH	RC	AF	JR
IFER**	0.30	0.30	0.39	0.70	0.69	0.69	0.68	0.69	0.58	0.50	0.58	0.68	0.59	0.50	0.60
IFE***	0.20	0.33	0.33	0.50	0.33	0.50	0.17	0.50	0.17	0.17	0.33	0	0	0.33	0.50
IAVA****	0.17	0	0.33	0.33	0.33	0.17	0.17	0.17	0.17	0.17	0.33	0.33	0.17	0.33	0.33
ICOM*****	0.08	0	0.08	0.50	0.42	0.08	0.42	0.42	0.33	0.25	0.25	0.25	0.33	0.33	0.33

Source: Lores (2009).
* Agroecosystems are identified by the interviewed farmers' initials.
** IFER: human food sub-index, IFE (animal feed), IAVA (to improve physical, chemical and biological properties of soil), and ICOM (complementary biodiversity).
*** IFE: animal feed sub-index.
**** IAVA: sub-index to improve physical, chemical and biological properties of soil.
***** ICOM: complementary biodiversity sub-index.

Specific achievements over the course of the research project included the introduction of two new soil-protecting species, and two more for animal feed, signalling a move towards increased balance and agroecological sustainability in the area. This was the first time that new species had been introduced in the community, thus enabling farmers to consider the importance of new species for local and family welfare.

Following the research period 2004–2006, there was an increase in species diversity in Zaragoza resulting from internationally-funded projects aimed at supporting Cuban agriculture. One such project is the Local Agricultural Innovation Programme (PIAL), which is coordinated by the National Institute of Agricultural Sciences (Instituto Nacional de Ciencias Agrícolas) and aims to increase agrobiodiversity, not just in particular communities but across Cuba (Guevara et al., 2011). Unfortunately, this programme does not incorporate the rigorous elements proposed by the IDA methodology.

(ii.c) Results from applying IDA in Zaragoza

After applying the IDA in 15 randomly selected agroecosystems, results showed that the existing local biodiversity reached an acceptable level, which favoured the FER (human food) sub-index. Previous governmental projects aiming to improve local diets also had an impact. In comparison, other types of diversity (animal and soil foods and complementary diversity) were poor (**Tables 8** and **9**).

The data in **Tables 8** and **9** show that most agroecosystems experienced a rise in diversity between 2004 and 2006. Even so, only those farms identified by the initials JM, RH and ESC reached index values that can be considered sustainable, while JR came close to reaching them. Conversely, some agroecosystems did not experience any changes, such as that of the producer MPe. Others, such as JA, experienced a slight drop in diversity, due to low usage of available land over the entire year, even after incorporating new species into the agroecosystem.

The results of the project contributed to strengthening the farmers' productive philosophy, based on market availability, income generation and improved local food quality. Farmers were offered new types of genetic diversity (new species), after which some of them experienced a rise in diversity in the IFER and IFE groups especially, although these were insufficient to be considered optimal, given the short research timeframe (2004–2006).

A significant increase in IFER was noted, reaching sustainability values of up to 60% in agroecosystems (JM, RH, ESC, AU, RG, FM, EH, RC, AF and JR). However, the weak diversity in other sub-indices (IFE, IAVA and ICOM) hampered an overall increase in sustainability with total IDA values remaining relatively low.

Table 9: Values of the Index of Agrobiodiversity (IDA) sub-indices in 15 agroecosystems in Zaragoza, 2006. DOI: https://doi.org/10.1525/elementa.336.t9

IDA Sub-indices	Agroecosystems*														
	MPi	LP	LD	JM	RH	ESC	AU	RG	MPe	FM	JA	EH	RC	AF	JR
IFER**	0.33	0.33	0.39	1.00	1.00	0.78	0.72	0.72	0.56	0.61	0.50	0.61	0.61	0.56	0.67
IFE***	0.20	0.33	0.50	0.67	0.50	0.50	0.33	0.50	0.17	0.17	0.33	0	0	0.67	0.67
IAVA****	0.17	0	0.33	0.67	0.50	0.17	0.17	0.33	0.17	0.17	0.33	0.33	0.17	0.33	0.50
ICOM*****	0.08	0	0.17	0.58	0.50	0.08	0.42	0.42	0.33	0.25	0.25	0.33	0.52	0.33	0.50

Source: Lores (2009).
* Agroecosystems are identified by the interviewed farmers' initials.
** IFER: human food sub-index, IFE (animal feed), IAVA (to improve physical, chemical and biological properties of soil), and ICOM (complementary biodiversity).
*** IFE: animal feed sub-index.
**** IAVA: sub-index to improve physical, chemical and biological properties of soil.
***** ICOM: complementary biodiversity sub-index.

The final IDA values (**Table 10**) did not generate spectacular changes, which shows that IDA is a scientifically rigorous indicator to assess the development of sustainability through agrobiodiversity. Results reveal the need to encourage actors to make a better spatial and temporal use of soil through rotational and polyculture systems, which would lead to a favourable increase in IDA and to further achievements.

An analysis of the extent to which the project had successfully reached its goals to increase agrobiodiversity found that only 26.6% of farmers had wholeheartedly, and with a sense of responsibility, accepted the proposal to introduce new plant species to their fields (JM, ESC, RH, and JR). Meanwhile, 53.2% participated in the work without feeling fully convinced of its merits. The other 20.2% did not accept the new proposals and did not modify their traditional customs, thus making it evident that they were resistant to change, even after seeing the clear progress made by those actors willing to take risks. The final results reflected the different levels of farmers' commitment from the beginning of the research.

(iii) Index of Agrobiodiversity (IDA) and its relation to Agroecosystems Managed by Urban (AU) and Suburban Agriculture (ASU)

After analysing a range of agroecosystems classified as excellent by the Cuban Urban Agriculture movement, results showed that said systems were not sustainable from the perspective of agrobiodiversity (**Table 11**).

Applying the IDA and assessing its sub-indices showed that the best results are directly related to human food diversity. In spite of a lack of species representing oilseed and regulating food groups, the human food sub-index (IFER) exceeds 0.7 (and is thus considered sustainable) in Mayabeque province. However, no total IDA values reached 0.7, due to a lack of other (non human food) species and a lack of advocacy for an increase in diversity.

Mayabeque province, represented by the municipality of San José de Las Lajas, presented the best IDA and sub-index values. One of the influencing factors is the work carried out by scientists from research centres located in that province, as they have encouraged farmers for many years to consider agrobiodiversity in their rotational and polyculture systems (Leyva et al., 2016). Even though existing diversity across the research areas generally meets human needs, there is greater potential for its enrichment. There is no full implementation of a strategy for agrobiodiversity in national agrarian policies and this implies a lack of greater agrobiodiversity in productive areas. The policies do not allow for a spatial and temporal management of productive systems in favour of local self-sufficiency. They also do not allow space for other non-food related aspects, such as the need to attract pollinators, such as the "Chipilín" *(Crotalaria pectavili* L.) species, as pointed out by Marroquín et al. (2015), or the need to grow Stevia (*Stevia rebaudiana* B.), highly coveted by locals as a medicinal plant.

Over the last five years, the IDA efficiency has been tested in assessments of sustainability in mountainous conditions (González, 2016). The results enriched the index with two new functions that fall under the COM sub-index, namely carbon capture and conservation of wildlife diversity. This clearly reflects how flexible the index can be when it comes to incorporating or dismissing any functional element that can adapt, or not, to the agroecosystem or area being researched at any given moment.

4. Conclusions

The goal of the research presented in this paper was to design an evaluation tool based upon the indicator agrobiodiversity. Named the IDA (*Indice de Agrobiodiversidad*, or Agrobiodiversity Index), this tool enabled researchers to identify local agrobiodiversity according to its utilitarian values, and to quantify the extent to which this diversity contributes to human, animal and soil food supplies. Additionally, the index includes an assessment of the necessary levels of agrobiodiversity to maintain other (non-food) forms of life, that serve as the basis for agroecosystem equilibrium and enhance local peoples' quality of life.

Because of the ease with which it can be applied, the IDA index can be used to evaluate any local agroecosystem in Cuba, provided that there is active participation of the actors within the system. This participation is necessary to conduct the evaluation, and to ensure that peoples' habits

Table 10: Variation in behaviour of the Index of Agrobiodiversity (IDA) of each small-scale agroecosystem selected in Zaragoza (2004–2006). DOI: https://doi.org/10.1525/elementa.336.t10

Agroecosystems*	IDA values 2004	IDA values 2006	Variation in IDA (2004–2006)
MPI	0.19	0.20	0.01
LP	0.15	0.16	0.01
LD	0.28	0.35	0.07
JM	**0.44**	**0.63**	**0.19**
RH	0.44	0.62	0.18
ESC	0.36	0.60	0.24
AU	0.36	0.41	0.05
RG	0.42	0.49	0.07
MPe	0.31	0.31	0.00
FM	0.27	0.30	0.03
JA	0.37	0.35	–0.02
JR	**0.44**	**0.58**	**0.14**
EH	0.32	0.32	0. 00
RC	0.27	0.33	0.06
Total	**0.31**	**0.37**	**0.06**

Source: Lores (2009).
* Agroecosystems are identified by the interviewed farmers' initials.

Table 11: IDA and sub-index values in agroecosystems classified as excellent by the Urban Agriculture movement in five provinces in Cuba, 2014. DOI: https://doi.org/10.1525/elementa.336.t11

	Province				
	Santiago de Cuba	Guantánamo	Las Tunas	Cienfuegos	Mayabeque
IFER*	0.63	0.59	0.65	0.68	0.71
IFE**	0.57	0.49	0.66	0.56	0.56
IAVA***	0.58	0.39	0.50	0.40	0.48
ICOM****	0.58	0.60	0,53	0.53	0.69
IDA	**0.59**	**0.52**	**0,58**	**0.54**	**0.61**

* IFER: human food sub-index, IFE (animal feed), IAVA (to improve physical, chemical and biological properties of soil), and ICOM (complementary biodiversity).
** IFE: animal feed sub-index.
*** IAVA: sub-index to improve physical, chemical and biological properties of soil.
**** ICOM: complementary biodiversity sub-index.

and customs are respected. The research results demonstrate that the IDA index is as efficient as other evaluation methods that rely on more numerous sets of indicators and are used across the country, for example by the Urban and Sub-Urban Agriculture movement.

The research also demonstrated the importance of capacity-building designed to facilitate a shift toward healthier diets and highlighted that these efforts should include the participation of all actors involved in agrobiodiversity evaluation. Furthermore, the research found that 25% of the participating producers demonstrated high levels of creativity, commitment and independence with respect to the work, while another 25% exhibited the opposite. The remaining participants had the potential to favourably transform their agroecosystems and increase agrobiodiversity according to its utilitarian values, if they applied the IDA index and had the support of facilitators.

Data Accessibility Statement

In the event that anyone would like to access the data included in this article, please contact the corresponding author.

Notes

[1] Urban agriculture in Cuba is defined as the production of food within an urban and suburban perimeter (up to 5 km away from the city's periphery). It is a movement of self-organised producers. They

have over 30 programmes that focus on agroecological food production. The movement promotes the implementation of intensive practices, taking into account the interrelationship between people, crops, animals, the environment and urban infrastructure services that enable workforce stability and diversified production of crops and animals throughout the year, based on sustainable management that allows for waste recycling. The National Group of Urban and Family Farming have their own regulations (GNAUF, 2015).

[2] There are 5 main organisations working in Cuban agriculture that undertake productive work: Credit and Services Cooperatives (CCS), Agricultural Production Cooperatives (CPA), Basic Units of Cooperative Production (UBPC), state farms, small-scale independent farms that are not in cooperatives (Nova and Figueroa, 2018).

[3] According to state policy, local self-sufficiency refers to the production of necessary protein and carbohydrates for the local community.

[4] The General Index of Sustainability (IGS), proposed by Zinck et al. (2006), is a tool that assesses a set of indicators developed through a localized research process that must include the three dimensions of sustainability (economy, ecology and society) of any given agroecosystem or local area, in order to establish how sustainable it is.

[5] According to Jaruco's municipal historian, and pointed out by Vega (1998).

[6] The CCS are comprised of producers who did not integrate into state farms or other types of cooperatives promoted by the state, and who maintained private management of their land and production. In the years before the Special Period, when Cuba could count on inputs from the Socialist Bloc, the State gave preferential treatment to state enterprises and CPAs in the distribution of those inputs. As a result, CCS members and private farmers produced with limited resources (Deere et al., 1992).

[7] MEDEBIVE stands for Methodology for Development of Vegetable Biodiversity, which is based on the introduction of varieties that meet the needs of humans, animals, other species from the agroecosystem, and soil. Additionally, efficient agroecological alternatives were promoted, and local farmers, decision-makers and local facilitators received capacity-building and participated in local decision-making.

[8] The Land Equivalent Ratio (LER) is calculated by dividing the total yield for all crops in a polyculture system by total yield of those same crops grown individually in a monoculture system. When the value is greater than 1, the polyculture is considered to be more efficient, resulting in greater yields with less land (Dietrisch, 1983).

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Competing interests

The authors have no competing interests to declare.

Author contributions

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