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USE OF A DIGITAL CITIZEN SCIENCE PLATFORM TO FILL GAPS IN THE DIET OF THE BLUE-AND-YELLOW MACAW, *ARA ARARAUNA* (PSITTACIDAE)

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Abstract: This study innovates by using citizen science, specifically by collecting, applying and identifying 377 photographic records of feeding by the blue-and-yellow macaw (*Ara ararauna)*, made available by 279 citizen scientists in Brazil in 1999 and between the years 2006 to 2019, on the wikiaves digital platform. From this, we identified 80 food species, corroborating, and describing for the first time, 46 new ones in the diet of this bird. Six plant parts were consumed, apparently, indicating some control in the recruitment and establishment of consumed species, via predation and seed dispersal. This bird showed a high association with exotic species, showing some resistance to the deleterious factors of technoecosystems. We observed their diet in 14 Brazilian states, 4 biomes and 3 ecotone zones, whose diet showed high dissimilarity (IJ<0.5) between them. Despite incipient use, projects involving citizen scientists are flourishing, particularly in ecology and environmental science. This research method has great potential to influence policies and guide the management of resources, producing data sets that would be unfeasible to generate.
Keywords: Citizen scientist. Limited information. Food ecology. Conservation. Wikiaves.

INTRODUCTION

The antagonistic and mutualistic role of vertebrate frugivores and granivores in seed dispersal, predation and pre-dispersal (Fleming and Kress 2013), may influence seed composition, abundance (Dirzo and Miranda 1991), distribution and promotion of gene flow in a wide group of plants, being determinant in the structuring and functioning of ecosystems (Wisz et al. 2013).

Parrots (Aves; Psittacidae) are primary consumers, ie, they feed on seeds, pulp and fruit arils and, to a lesser extent (varying with seasonality and resource availability), on flowers, nectar, gastropods, insects, algae and mud rich in sodium, which serve to reduce the toxicity of some tropical fruits (Sick 1997), especially seeds (Renton et al. 2015).

These birds usually inhabit the forest canopy, which makes it difficult to obtain biological data for most species in this group (Terborgh et al. 1990). This limitation is worrying, as one third of parrots are threatened with extinction (Berkunsky et al. 2017) and conservation actions require basic information about the natural history of these birds (*sensu* Beehler 2010). Considering species with a wide geographic distribution, the situation becomes worse, as effective conservation action may depend on knowledge of their ecology throughout the area where they occur. An attractive way to minimize this limitation, and increase the amount of biological information about parrot species, is the use of citizen science digital platforms focused on birds (sensu Devictor et al. 2010). On these platforms, ordinary citizens contribute ecological data on a variety of species. Citizen science projects vary in subject matter, objectives, activities, and scale (Wiggins and Crowston 2015). However, they have a common goal, which is the production of reliable data that can be used for scientific purposes (Kosmala et al. 2016). However, so far, the use of this information is still incipient.

In order to evaluate efficiency, and thereby encourage the use of citizen science, we sought to expand knowledge on the blue-and-yellow macaw (*Ara ararauna)* diet and thereby promote its conservation. Using the Brazilian citizen science platform, Wikiaves, we were able to determine the plants involved in their diet, based on photographic records. Although the diet is known, we assume that such an investigation is essential to fill gaps and expand knowledge about the natural history of this parrot (Devictor et al. 2010), for example, to determine its food plants in various regions, especially to identify new species vegetables involved in their diet. Ultimately, to promote effective landscape management and restoration initiatives and strategies aimed at the conservation of the blue-and-yellow macaw in multiple areas (Silva and Melo 2013).

METHODS

FOCUSED SPECIES

The blue-and-yellow macaw is a large parrot with a high energy demand. They occupy the canopy areas, outside the forest extract or peripheral forest areas. They inhabit floodplains, gallery or riparian forests with buritizais, babassu palms and other species of palm trees, which makes this species the American parrot with the widest range of distribution (Forshaw 1989). Although with Least Concern status (ICMBIO/IUCN 2018), this bird is endangered in the states of São Paulo, Minas Gerais and Rio de Janeiro. The main threats come from capture for illegal trade. A notable fact about the species is its ecological plasticity: it seems to thrive in modified landscapes, especially in urban areas (Silva 2018).

DATA COLLECT

From the Wikiaves online page, we opted for an advanced search. We filtered from the insertion of the name of the taxon (*Ara ararauna)*, filling only the field referring to the main action caught in Feeding-se/Hunting. Thus, we obtained 746 images. When clicking on it, it opens in high resolution, while information about the image is also available, such as: the date the image was taken, the author's citation and the municipality and state in which the registration was made. In this study, we adopted image selection criteria such as: mandatory recognition of the attack, possession of food by the blue-and-yellow macaw (zygodactyl feet/beak) and records that did not correspond to organisms in captivity.

DATA ORGANIZATION

The images were archived and numbered. We prepared two worksheets: the first dealt with: model organism; image number; registration date; plant species used; botanical family; item consumed; County; state; biome and quotes from the authors of the images. The second worksheet characterized the consumed species, such as: species names; frequency; origin; degree of risk of extinction; states and the biome where the records occur.

BOTANICAL IDENTIFICATION AND ANALYSIS OF FOOD PLANTS

We compared the collected images with the botanical literature: (Lorenzi 2008, Souza and Lorenzi 2008; Lorenzi 2009ab, Lorenzi *et al*. 2010; Ramos et al. 2015, Souza *et al*. 2018). Aspects such as: morphological similarities of structures, sizes of plant parts, distribution and color patterns were analyzed. With the help of the plantnet application project. org2, we were able to identify some species, families and items, through the application's artificial intelligence and citizen science process. We used the botanical identification key, (adapted from Capellari Júnior *et al.* (1999), with revision by APG II, except for Mimosaceae, Fabaceae and Caesalpiniace sensu Cronquist). We apply a greater criterion for the distribution of food species, using the database of the Reflora digital platform.

To help identify items (Benavidez *et al.* 2018) and new species, a literature review of the blue-and-yellow macaw diet was carried out (see Annex 2).

The characterization of consumption by liquid endosperm was made from the posterior elongation movement of the skull/neck backwards, in order to access the resource.

To identify the biomes, IBGE data and maps were used and they take into consideration, the original plant composition. From Google Earth Engine, we compare the locations in the log with the maps.

SIMILARITY

The Jaccard index was used to measure the degree of similarity between the food plants found in Wiki Aves and those already published. We also applied it to determine the similarities between plants consumed in states and biomes. For this, the FITOPAC program was used. The generated values range from 0 (no similarity) to 1 (completely similar), that is, the closer to one, the more similar the results. The cophenetic value measures the degree of matrix distortion. Values above 0.7 indicate robust and reliable matrices in the dendrogram groups.

RESULTS

We used in a descriptive and documentary way, of a qualitative-quantitative nature, 377 photographs taken by 279 citizen scientists in the years 1999 and between 2006 and 2019, as illustrated in (Figure 1).

USE OF CITIZEN SCIENCE

Records varied due to volunteers and possibly the demography of blue-and-yellow macaw populations.

Based on the criteria adopted for this study, 50.53% (n=377) of the analyzed images were used. The level of similarity (Jaccard Index) between the consumed species illustrated in this study and those already described in the bibliography was 0.437 (ie, 47.7%).

FOOD ECOLOGY OF THE BLUE-AND-YELLOW MACAW

We identified 80 plant species in the blue-and-yellow macaw's diet. Where a (Table 1), represents the food species, which were used at least 5 times by the blue-and-yellow macaw, denoting greater significance.

We observed 46 new plant species, of these: 27 new genera and 9 families never described. Representing 30.76% (n=116) of the total number of episodes. In addition to the episodes with species never described (n=116), 9.54% (n=36) of the episodes, the consumed item, for plant species already described in the diet, had not been portrayed before. (Figure 2) displays the 6 most consumed plant parts: Fruits, seeds, leaves, inflorescence, liquid endosperm and stem.

ORIGIN OF FOOD SPECIES

In 77.50% of the episodes, the food plants were native (n=62), particularly *Caryocar brasiliensis* (Caryocaraceae), and 22.50% exotic (n=18), especially *Terminalia catappa* (Combretaceae). Of the native species, 20.96% are endemic to Brazil (n=13), mainly *Attalea speciosa* (Arecaceae). While, 27.41% (n=17) behaved as regional exotics, having at least 1 record outside their areas (state) of occurrence. Of the exotic species, 44.44% (n=8) are naturalized, and 38.88% (n=7) were cultivated species, with emphasis on *Mangifera indica* (Anacardiaceae).

DISTRIBUTION OF EPISODES

With regard to geographic areas, (Figure 3) describes consumption in 14 Brazilian states, as well as (figure 4) exposes the diet in the 4 biomes and 3 ecotone zones.

The similarity (Jaccard index), represented in (Figure 5; Figure 6), showed high dissimilarity (IJ<0.5) between food species, in relation to states, as well as for biomes. The maximum similarity between states was 0.37 with a minimum of 0.00. With a cophenetic correlation of 0.8858. For biome, the maximum was 0.30 and the minimum was 0.00. Whose cophenetic correlation of 0.7832.

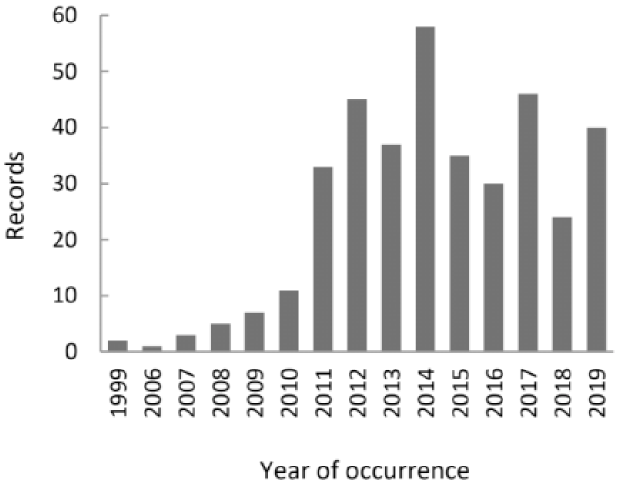

FIGURE 1. Contribution episodes. Changes over time in the eating habits of blue-and-yellow macaw.

Family	Species	Frequency of consumption	Food item
Caryocaraceae	*Caryocar brasilense*	32	LI;SE
Arecaceae	*Mauritia flexuosa*	27	CL;FO;FR
Combretaceae	*Terminalia catappa*	22	FO;SE
Arecaceae	*Attalea phalerata*	19	LI;SE
Anacardiaceae	*Anacardium occidentale*	18	FO;IF;SE
Anacardiaceae	*Mangifera indica*	18	FO;FR
Arecaceae	*Roystonea oleracea*	14	LI;SE
Arecaceae	*Attalea maripa* *	13	SE
Arecaceae	*Cocos nucifera*	12	SE;IF
Euphorbiaceae	*Hevea brasiliensis*	12	SE
Arecaceae	*Attalea speciosa* *	8	SE;CL
Poaceae	*Saccharum officinarum* *	8	LI
Myrtaceae	*Psidium guajava*	7	FR
Arecaceae	*Acrocomea totai* *	6	FR
Fabaceae	*Delonix regia*	6	FR;IF
Anacardiaceae	*Spondias mombin*	6	SE;CL;LI
Arecaceae	*Syagrus oleracea*	6	FR
Apocynaceae	*Araujia sericifera* *	5	FR
Vochysiaceae	*Qualea multiflora* *	5	FO;SE

Acronym: * = species never described in the diet of *A. ararauna*; FR = fruit; SE = seed; FO = leaf; IF = inflorescence; LI = liquid endosperm; CL = stem.

TABLE 1. Vegetable species most consumed. Distributed in 25 families, with emphasis on Arecaceae 27.16% (n=22) and Fabaceae 20.98% (n=17).

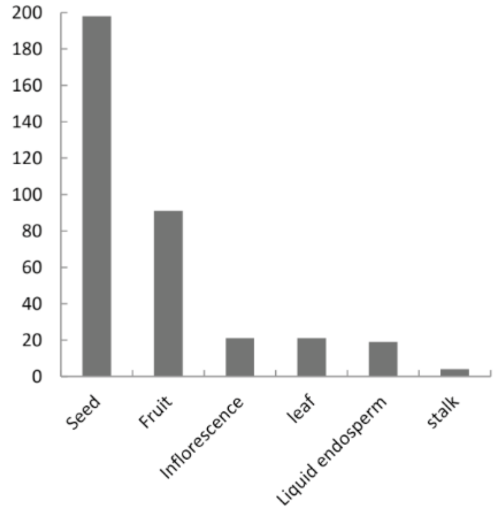

FIGURE 2. Consumption per item.

Acronym: GO= Goiás; MS= Mato Grosso do Sul; MT= Mato Grosso; SP= São Paulo; MG= Minas Gerais; RO= Rondônia; TO= Tocantins; AM= Amazon; DF= Federal District; RR= Roraima; BA= Bahia; PA= Pará; AC= Acre; ES=Espírito Santo

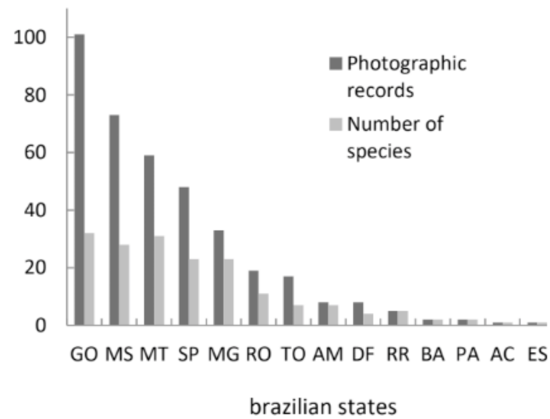

FIGURE 3. Records by state.

Acronym: GO= Goiás; MS= Mato Grosso do Sul; MT= Mato Grosso; SP= São Paulo; MG= Minas Gerais; RO= Rondônia; TO= Tocantins; AM= Amazon; DF= Federal District; RR= Roraima; BA= Bahia; PA= Pará; AC= Acre; ES=Espírito Santo

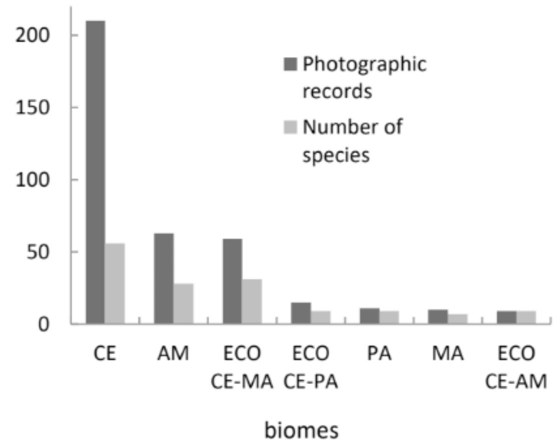

FIGURE 4. Records by biome.

Acronyms: CE = Vegetation of the Brazilian countryside; AM = Amazon; ECO = ecotone; PA = Wetlands; MA = Atlantic Forest.

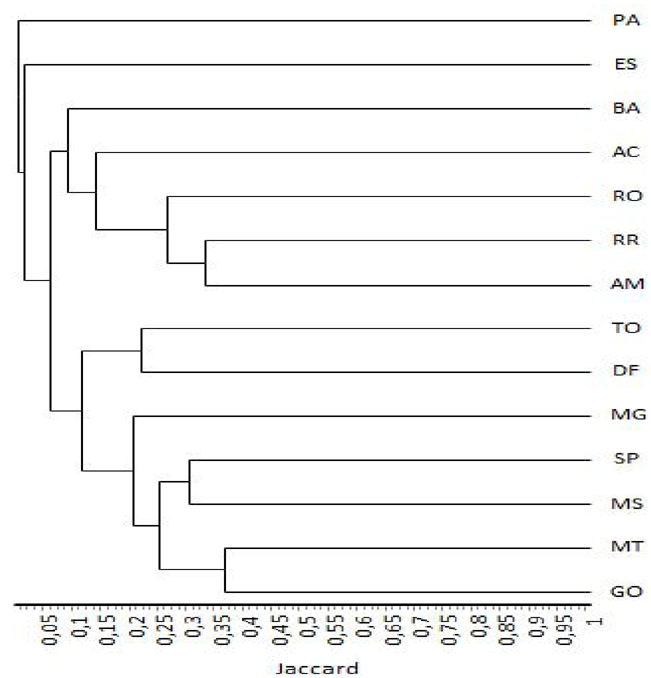

FIGURE 5. Similarity between states.

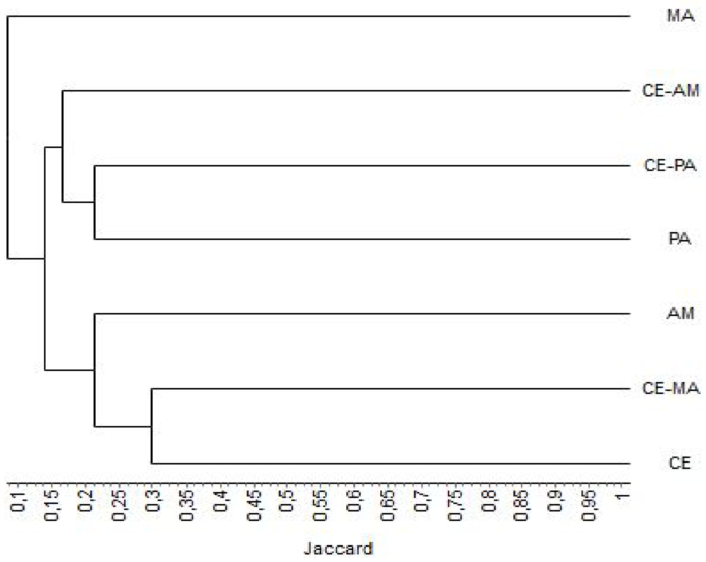

FIGURE 5. Similarity between biomes.

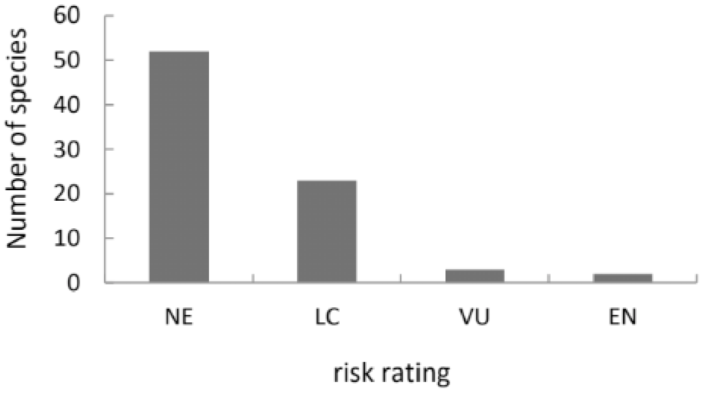

FIGURE 7. Degree of threat.

Acronyms: NE = no information, regarding risk; LC = low risk; VU = vulnerable; EN = in danger.

DISCUSSION

In this study, we were able to identify, for the first time, 46 new species in the blue-and-yellow macaw diet. We were able to determine their food composition over a wide distribution range and in different biomes. Therefore, expanding the knowledge about its natural history. We point out the impact of the consumption of native and exotic species, above all, the conservation of their resources and crucial habitats for conservation. Demonstrating with this, the effectiveness of citizen science. Despite its incipient use, this research method has great potential to influence policies and guide resource management, producing data sets that would be unfeasible to generate (Kosmala et al. 2016).

The possibility of innovation in the blue macaw's diet is high, this species explores several habitats (Sick 1997), where it is likely to expand its diet over time (Ducatez et al. 2014). Among the new species, we identified 21 distinct families, with emphasis on Arecaceae (n=14) (Forshaw 1989).

The priority consumption of seeds 52.51% (n=198), and less frequently the others, corroborate the bibliography (Sick 1997, Renton et al. 2015). For seeds, 16 families were used, mainly Fabaceae (n=12) and Arecaceae (n=9). The consumption of seeds showed some control in the recruitment and establishment of consumed species, thus promoting the diversity of tree species in neotropical forests (Higgins 1979, Francisco et al. 2012). However, fruit consumption can positively affect the functioning of ecosystems by seed dispersal, via epizoocory (Villalobos and Bagno 2012; Baños -Villalba et al. 2017). The fruits were used in 9 botanical families, with emphasis on Arecaceae (n=13).

For leaves there were 8 families, mostly Anacardiaceae, Arecaceae and Fabaceae (all n=3). However, the use of leaves can show other biological phenomena, which are not necessarily feeding, since the blue-and-yellow macaw uses leaves to sharpen its beak.

In 11 families, flowers were used, mainly Fabaceae (n=4). Despite occurring on rare occasions, parrots can influence the reproduction of plant communities, particularly via predation (Galetti 1993, Gilardi and Toft 2012) from pollination (Maués and Venturieri 1996, Araújo 2011).

The liquid endosperm was consumed in 5 families, highlighting Arecaceae, in variety of species and Poaceae, by the frequency of records.

The stem was accessed in three families in greater quantity in Arecaceae (n=2).

We evidenced a significant association of the blue-and-yellow macaw in the consumption of exotic species (Silva 2018). Anthropogenic environments are rich in exotic species (Muñoz et al. 2007, cf. Silva et al. 2015). Such consumption demonstrates that this bird can resist the deleterious factors of technoecosystems very well. Among the most sought-after exotic species, *T. catappa, M. indica* and *R. oleracea,* the items consumed were seeds. There may be some control over these, to the detriment of the conservation of native communities (Silva 2005).

The demographics of the species that make up the blue-and-yellow macaw's diet, shown in (Figure 7), demonstrates a great lack of knowledge regarding most of the plants regarding their conservation status.

This suggested a field for research and highlights a concern regarding the conservation of the species consumed by the blue-and-yellow macaw.

In Goiás, despite having a higher frequency of records, the range of plants used was very close to states with lower frequencies, such as Mato Grosso. Possibly, their breadth of food niche is similar for some localities. Although considered at risk in the states of Minas Gerais, Rio de Janeiro and São Paulo, (Machado et al. 1998, Bergallo et al. 1999, São Paulo 2018). We demonstrated that, in São Paulo and Minas Gerais, the conservation status of the blue-and-yellow macaw seems to improve.

The high dissimilarity (IJ<0.5) between states and biomes demonstrates the generalist habit of the blue-and-yellow macaw (Croat 1967), and as they are not territorial, they moved through the vegetative mosaics seasonally (Ragusanetto and Fecchio 2006). In cases of overlap, they expanded their niche instead of reducing it (Roth 1984), possibly responding to highly concentrated sources in each region, maximizing their foraging efficiency (Silva 2018). The states of Pará and Espirito Santo were different from the others, due to the low occurrences and for dealing with exotic or regional exotic species. Bahia was grouped in the northern region, this was due to the low number of episodes and species that occur in the north such as M. flexuosa (Arecaceae). The central-west and southeast groupings were in accordance with the common phytophysiognomy.

For the Atlantic Forest biome, its very high dissimilarity was due to the frequency of consumption of endemic species such as S. oleracea (Arecaceae) and exotic species such as T. catappa (Combretaceae). While the Savannah Savannah-Atlantic Forest ecotone, presented itself in greater conformity on the Savannah phytophysiognomy domain. As well as the Savannah-Amazon ecotone in relation to the Pantanal areas. In the Amazon, the episodes occurred with species that occur in other biomes and in states with more than one phytophysiognomic domain. There were also many episodes with exotic species. The savannah, with a total area of 2,036,448 km², has only 3.1% areas of integral protection CNUC/MMA (https://www.mma.gov.br/images/arq uivos/A0_Brasil_600_DPI_02_2019.pdf). This reality is worrisome for the conservation of the blue-and-yellow macaw's trophic niches. In 38.98% of the savannah area are anthropic areas. Of which, 26.45% are cultivated pastures (MMA 2002). The savannah represented 55.70% (n=210) of feeding episodes and 70% (n=56) of the total species consumed. The ecotone areas added 22.01% (n=83) of the episodes. Evidencing great relevance for the food ecology of the blue-and-yellow macaw.

This innovative study in the form of data collection, application and identification, through the use of citizen science, leads us to conclude that: I) Citizen science platforms can contribute to the knowledge of the natural history of wild life, to fill gaps and/or expand such information. Our model is the blue-and-yellow macaw, but we believe that similar investigations can be carried out with other parrots; II) We corroborate eating habits, above all, we expand them with the identification of new food species; III) We determined the consumed plants for several states and biomes, and with that we established the variety of their food; IV) We believe that such data contribute to conservation actions for this parrot in anthropogenic landscapes which, by the way, is the keynote of the current world.

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