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# Urban Foraging and Plant Toxicological Risks for Rose-Ringed Parakeets (*Psittacula krameri*) in Athens

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## Abstract

The Rose-ringed Parakeet (*Psittacula krameri*) is an invasive parrot increasingly established in European cities, including Athens, Greece, yet its diet and exposure to plant toxins in Mediterranean ecosystems remain poorly documented. We examined seasonal foraging patterns in Athens and assessed the toxicity of key food items using a brine shrimp lethality assay. Field observations recorded 601 feeding events across 10 plant species. Four foods—cypress seeds (*Cupressus sempervirens*), chinaberries (*Melia azedarach*), Canary Island dates (*Phoenix canariensis*), and olives (*Olea europaea*)—accounted for 82.9% of feeding events. Dietary diversity was highest in winter and summer, while foraging density remained relatively stable, peaking in autumn. Toxicity assessment of aqueous plant extracts with Brine Shrimp (*Artemia franciscana*) Lethality Test (BSLT) identified chinaberries as the most toxic, indicating potential dietary risks. These findings indicate that *P. krameri* exhibits flexible, opportunistic foraging and can tolerate plant compounds that are harmful to other vertebrates, suggesting that toxicity does not seem to limit its diet. Seasonal dietary shifts and ecological plasticity likely support its urban invasion success, highlighting the importance of understanding diet composition and potential exposure to plant toxins in urban parakeet populations.

**Keywords:** Rose-ringed Parakeets; *Psittacula krameri*; Athens; Greece; diet; food toxicity; olives; chinaberries; cypress seeds; Canary Island dates

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Academic Editors: Pietro Buzzini, Massimiliano Renna, Luigi De Bellis and Ignasi Torre

Received: 2 October 2025
Revised: 15 November 2025
Accepted: 16 November 2025
Published: 18 November 2025

**Citation:** Christodoulopoulos, M.A.B.; Cotou, E.; Politakis, N.; Tsekouras, N.; Paraskeuas, V.V.; Kotzamanis, Y.; Christodoulopoulos, G.; Pappas, A.C. Urban Foraging and Plant Toxicological Risks for Rose-Ringed Parakeets (*Psittacula krameri*) in Athens. *Diversity* **2025**, *17*, 801. https://doi.org/10.3390/d17110801

## 1. Introduction

Parakeets are non-migratory birds native to South America, South Asia, and sub-Saharan Africa. When introduced outside their native range, individuals establishing free-living populations are described as feral. Populations that reproduce and persist without human assistance are regarded as naturalized; if they expand and cause ecological or economic harm, they are classified as invasive [1,2]. Being native to predominantly warm climates, frost might be expected to limit their expansion. However, although their distribution in Europe correlates negatively with frost days [1], low temperatures are not a strict barrier; populations in Chicago, Illinois, survive winter lows of −33 °C [3].

Among parakeet species, the Rose-ringed Parakeet (*Psittacula krameri*) is the most widespread [1]. A medium-sized parrot (38–42 cm, 110–182 g) with a long tail (up to 25 cm) and a distinct neck ring in adult males, it mainly forages in trees, feeding predominantly on seeds (about 80% of the diet) and smaller amounts of fruits, buds, bark, and insects [4–7]. The species nests in tree cavities, often displacing other cavity-nesting birds, and is highly social, foraging, roosting, and breeding in groups [8,9].

Through the pet trade, *P. krameri* has spread worldwide and is now recorded in at least 92 countries [1,9,10]. Feral populations, including *P. krameri*, have successfully established in many European cities, adapting to urban environments and forming stable colonies [1,11,12]. Invasive parakeets can impact biodiversity through competition, herbivory, habitat alteration, and pathogen transmission [13–15]; in Belgium, their abundance has been linked to declines in native nuthatches due to nest-site competition [8]. Rose-ringed Parakeets are also recognized agricultural pests, damaging crops such as citrus, guava, mango, sorghum, and maize, and may strip bark and destroy seeds, affecting tree regeneration and facilitating the spread of alien plants [6,16–20].

In Athens, Rose-ringed Parakeets are the most numerous exotic parakeet species. The Monk Parakeet (*Myiopsitta monachus*) forms the second-largest feral population, foraging on both ground and trees and feeding on seeds, fruits, buds, grasses, and urban food waste. Both species have been present for over three decades, forming colonies in parks and green spaces [21,22].

This study focuses on Rose-ringed Parakeets as the major feral parakeet population in Athens. In 2021, their population was estimated at around 1000 individuals according to Hulot [21], a gray literature source; no peer-reviewed studies provide local population estimates, though numbers have likely increased since. Despite their long presence, the biology of parakeets in Athens remains largely unstudied, and no research has examined their feeding ecology in Greece, despite growing scientific and public interest [21].

This study aims to quantify the diet of the Rose-ringed Parakeet in Athens and assess potential toxicological risks of its food plants. Many parrot species tolerate seeds and fruits with bioactive compounds, gaining access to a wider resource base and reducing competition [23]. Understanding the ecology of urban species is essential, as cities create novel ecosystems with unique selection pressures and potential impacts on biodiversity, while also serving as hubs for species introduction [24]. By linking diet, toxicity, and urban foraging, this study sheds light on how the Rose-ringed Parakeet adapts to Mediterranean urban green spaces and informs biodiversity management, urban wildlife strategies, and public engagement.

## 2. Materials and Methods

### 2.1. Study Site

We observed the foraging behavior of Ring-necked Parakeets at two neighboring field sites: Platonos Academia Park (Kolonos, Athens) and the campus of the Agricultural University of Athens (AUA) (Botanicos, Athens) (Figure 1). The combined study area is located between 37°58′ and 37°59′ N latitude and approximately 23°42′ E longitude. Both sites are largely similar in vegetation composition.

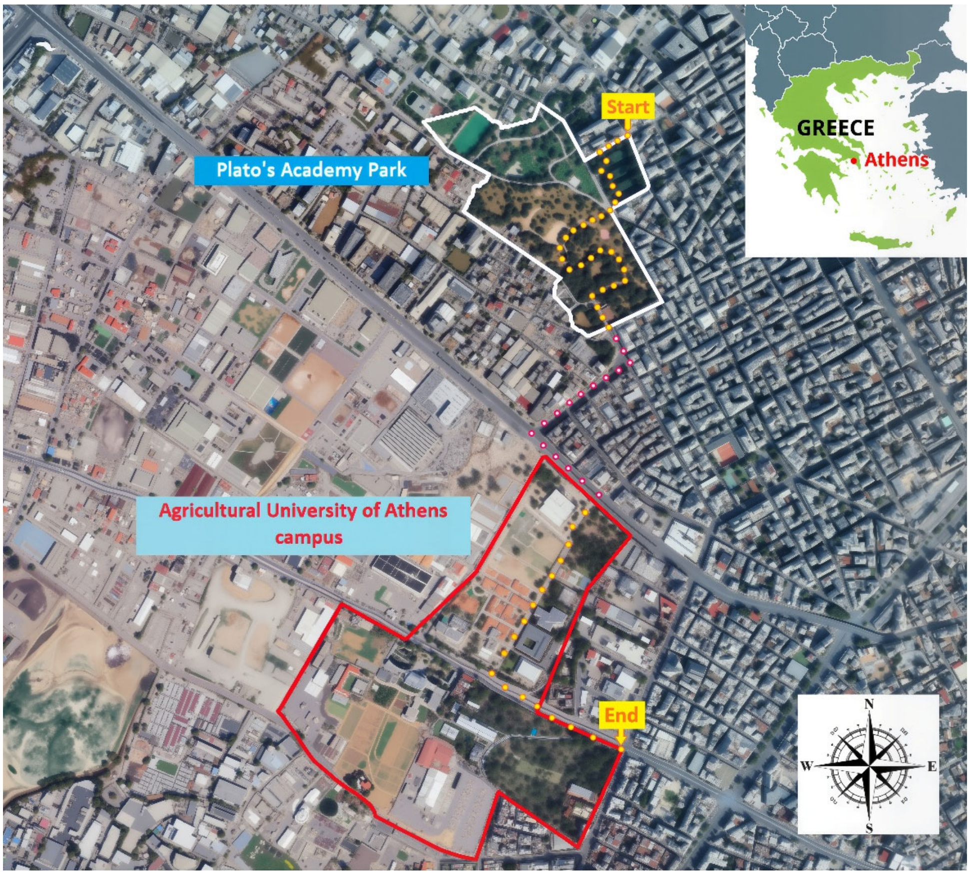

**Figure 1.** Transect marked with yellow spots, designed to pass through trees frequented by foraging parakeets and along roads regularly used by people, minimizing disturbance from the observer. The inset shows the location of Athens within Greece on the Balkan Peninsula.

Platonos Academia Park covers approximately 100 hectares and, in addition to its archaeological monuments, hosts a variety of ornamental and fruit trees. Olive trees (*Olea europaea*) and carob trees (*Ceratonia siliqua*) are the most abundant species.

The AUA campus lies about 1.4 km south-southwest of Platonos Academia Park, covering roughly 250 hectares on both sides of the historic "Iera Odos" (Sacred Way). The vegetation is similarly diverse, dominated by olive trees (*Olea europaea*) and Canary Island date palms (*Phoenix canariensis*). Historically, the Agricultural University campus occupies part of the land where Theophrastus (371–287 BC), Aristotle's student and successor at the Lyceum, established the earliest known botanical garden in Europe. This legacy is reflected in the name "Botanicos," which the area still carries today. Theophrastus is widely regarded as the founder of botanical science.

These two sites were selected as study fields primarily for their proximity to the main investigator (M.A.B.C.) and the regular presence of Rose-ringed Parakeets in both areas. Their relatively low parakeet densities allowed detailed observations while minimizing potential observation bias. Conducting observations at both sites increased the overall area surveyed. Transects were performed along usual pedestrian paths so that the birds, accustomed to human presence, were not disturbed by the observer.

### *2.2. Foraging Observations*

Parakeet foraging was monitored through weekly transects along predefined routes at both sites from September 2022 to August 2025. Transects began at sunrise and lasted approximately one hour. To avoid double-counting, the observer (M.A.B.C.) followed a one-way route, beginning at Platonos Academia Park and continuing to the AUA campus

(Figure 1). Observations were grouped by season: autumn (September–November), winter (December–February), spring (March–May), and summer (June–August).

Feeding events were recorded only when birds were actively consuming plant material. For each event, the plant species, plant part (e.g., pulp, seed), and fruit maturity (ripe/unripe) were noted, with binoculars used when needed. Plant identification was verified by AUA botanists using field samples or photographs. Fruits or seeds of the same species and maturity stage as those consumed were collected on the same day for further analysis.

As a supplementary measure, "foraging density" was defined as the number of birds observed on food plants per transect, with each transect lasting approximately one hour.

### 2.3. Toxicity Testing

The brine shrimp lethality assay (BSLA) was used as a preliminary screening method to evaluate the overall toxicity of fruits and seeds consumed by Rose-ringed Parakeets. This bioassay employs the invertebrate *Artemia* as a test organism and is favored for its simplicity, rapidity, and cost-effectiveness. It has been widely used as an alternative to traditional vertebrate testing for assessing the general toxicity or biological activity of plant extracts [25–28]. The BSLA determines the median lethal concentration ($LC_{50}$), defined as the concentration of a plant extract causing 50% mortality in *Artemia* nauplii under controlled experimental conditions. Lower $LC_{50}$ values indicate higher toxicity. A strong correlation between $LC_{50}$ values from BSLA and $LD_{50}$ values from acute oral toxicity tests in mice has been demonstrated [29]. Toxicity levels are typically classified according to the criteria of Meyer et al. [25] and Gosselin et al. [30], as summarized by Hamidi et al. [27]. Extracts with $LC_{50} < 1$ mg/mL are considered bioactive, indicating the presence of potentially toxic compounds that warrant further investigation [31,32].

#### 2.3.1. Sample Collection and Processing

Samples of fruits and seeds consumed by parakeets but not typically eaten by humans were collected during fieldwork. Six samples per plant species were dried at <40 °C to constant weight at the Laboratory of Nutritional Physiology and Feeding (AUA), ground through a 1 mm sieve, pooled into composite samples, and coded prior to submission to the Laboratory of Toxicology & Biomarkers (IMBBC-HCMR) for blinded toxicity testing.

#### 2.3.2. Preparation of Plant Aqueous Extracts

Three grams of each composite sample were placed into separate 50 mL Falcon tubes containing 15 mL of sterile, filtered artificial seawater (salinity: 35 g/L; Classic Sea Salt, Tropic Marin; Wartenberg, Germany). The mixtures were homogenized for 10 min using a Teflon-coated magnetic stirrer, then centrifuged at 3000 rpm for 20 min at 25 °C. The resulting supernatants were filtered through Whatman No. 1 paper and stored at 4 °C until use in bioassays. This procedure was developed and standardized in the Laboratory of Toxicology & Biomarkers (IMBBC-HCMR), based on modifications of methods previously described by Mbwambo et al. [33], Karchesy et al. [34], and other studies using comparable extraction approaches.

#### 2.3.3. Hatching of Artemia Cysts

Commercial *Artemia franciscana* cysts were incubated in artificial seawater (salinity: 35 g/L) prepared with commercial sea salt (Classic Sea Salt, Tropic Marin, Germany) at 25 °C under continuous illumination and aeration, following Vanhaecke et al. [35]. A homogeneous population of early-stage *Artemia* nauplii (Instar II–III) was used for all bioassays.

### 2.3.4. Brine Shrimp Lethality Test (BSLT)

Bioassays were conducted in 24-well microplates. Preliminary tests established appropriate concentration ranges for each extract. A series of geometric dilutions (100%, 10%, 1%, 0.1%, 0.01%) was prepared using artificial seawater. Definitive tests used up to 12 concentrations, selected on a logarithmic scale following Doudoroff et al. [36]. Ten *Artemia* nauplii were transferred into each well. Preliminary tests used one well per concentration, while definitive tests were performed in triplicate. Wells containing only artificial seawater served as negative controls. Microplates were covered and incubated at 25 °C in the dark. Mortality was recorded after 24 h and 48 h under a stereomicroscope and calculated as:

$$\text{Mortality } (\%) = 100 \times \frac{\text{Y}}{\text{X}}$$

where Y = number of dead nauplii after treatment, X = number of nauplii in the control.

Median lethal concentrations ($LC_{50}$) and 95% confidence intervals were estimated using the Trimmed Spearman–Karber method [37].

## *2.4. Statistical Analyses*

Chi-square test of independence examined the association between food item consumption and season using a 13 food items × 4 seasons contingency table, with cell frequencies representing feeding observations. Shannon's diversity index ($H'$) was calculated for each season to quantify dietary evenness and richness (alpha-diversity), using proportional abundance of the 13 food items. Bray–Curtis dissimilarity assessed pairwise compositional differences among seasons (beta-diversity) based on food item abundances.

Kruskal–Wallis test was initially applied to test seasonal differences in parakeet foraging presence (response: number of parakeets per visit; explanatory: Season). This non-parametric test revealed no significant seasonal effect ($H = 2.59$, $df = 3$, $p = 0.46$), providing preliminary evidence of stable parakeet density.

These descriptive and exploratory analyses were performed in R version 4.4.1 (R Core Team [38]) using the vegan package version 2.6-4 [39] for diversity indices.

### Mixed Model Analyses

We implemented two Negative Binomial mixed models to provide robust inference accounting for overdispersion, temporal structure, and repeated measures.

### Model 1: Parakeet Foraging Density

Seasonal variation in parakeet abundance was analyzed using a Negative Binomial Generalized Linear Model (NB-GLM). The response variable was the number of parakeets observed feeding per visit (count; range 2–11; N = 114, 2022–2025). Explanatory variables included Season (4-level categorical: Autumn [reference], Winter, Spring, and Summer) and Day-of-year (continuous, standardized). A Negative Binomial family with a log link accounted for overdispersion, and the overall effect of Season was assessed using a Wald chi-square test ($df = 3$, $\alpha = 0.05$). This model confirmed that dietary patterns (Model 2) reflected food preferences rather than seasonal changes in bird availability.

### Model 2: Food Consumption Patterns

Food consumption was analyzed using a Negative Binomial Generalized Estimating Equation (NB-GEE) to account for clustered data. The response variable was the number of parakeets feeding on each food item per visit (count; N = 1482 = 114 visits × 13 items). Explanatory variables were Food Category (3-level categorical: Fruit [reference], Seed, Foliage), Season (4-level categorical: Autumn [reference], Winter, Spring, and Summer), and Day-of-year (continuous, standardized). Year (2022–2025) was included as a clustering variable with an exchangeable working correlation to account for inter-annual variation. The model used a Negative Binomial family with a log link. Zero observations (78.2% of cases) were adequately captured by the negative binomial variance structure without a separate zero-inflation component.

Model Selection: We initially tested the Food Category × Season interaction, but the interaction covariance matrix was rank-deficient due to sparse data in many food-season combinations (e.g., vegetative material < 10% of observations). The interaction was not supported (Wald test inconclusive due to singularity; AIC unchanged), and raw data showed consistent food rankings across seasons. We therefore adopted the additive model with main effects only for parameter stability.

Statistical Software: Mixed models were implemented in Python 3.11 using statsmodels 0.14.0 [40]. We report coefficients (β) on the log scale and Rate Ratios (exp[β]) representing multiplicative effects on expected counts. All tests: $\alpha = 0.05$ (two-tailed); 95% confidence intervals.

## 3. Results

### 3.1. Foraging Records

A total of 601 foraging events were recorded, involving 10 plant species, in 114 transects in total (Tables 1–3). Four plant foods accounted for the majority of feeding activity, representing 82.9% of all observations (498/601):

1. Chinaberries (154 observations): Ripe fruits were consumed year-round. Birds held the fruit in their beaks and removed the peel with chewing movements before ingestion.
2. Cypress seeds (148 observations): Seeds were taken from green cones throughout the year. Birds broke unripe, non-woody cones with their beaks to access the seeds.
3. Olives (107 observations): Consumed mainly from October to February. Parakeets preferred mature olives, both green and dark-colored. After grasping an olive with their beak, they manipulated it with their feet, consumed portions of the flesh, and eventually discarded the pit (endocarp) (Figure 2).
4. Canary Island dates (89 observations): Consumed from August to January at the mature stage, either eaten whole or partially, the latter in a manner similar to olives.

**Table 1.** Fruits and seeds of tree species consumed by Rose-ringed Parakeets in Athens and their native status in Greece.

| Species Name | Common Name of the Tree | Item | Common Name of the Item | Native Status in Greece |
|---|---|---|---|---|
| *Brachychiton populneus* | Kurrajong Tree | Pod seeds | Kurrajong seeds | Non-native—locally naturalized (rare) |
| *Cupressus sempervirens* | Mediterranean Cypress | Cone seeds | Cypress seeds | Native |
| *Ficus carica* | Fig Tree | Fleshy fruits | Figs | Native |
| *Ligustrum japonicum* | Japanese Privet | Fleshy fruits | Privet berries | Non-native—locally naturalized |
| *Laurus nobilis* | Bay Laurel | Fleshy fruits | Bay laurel berries | Native |
| *Melia azedarach* | Chinaberry tree | Fleshy fruits | Chinaberries | Non-native—occasional naturalization (uncertain extent) |
| *Morus* spp. | Mulberry Tree | Fleshy fruits | Mulberries | Long naturalized (non-native) |
| *Olea europaea* | Olive Tree | Fleshy fruits | Olives | Native |
| *Phoenix canariensis* | Canary Island Date Palm | Fleshy fruits | Canary Island dates | Non-native—not naturalized * |
| *Pistacia lentiscus* | Mastic Tree | Fleshy fruits | Mastic berries | Native |

* Very limited naturalization, recorded in the Kalamiaris palm forest on Lesbos Island.

**Figure 2.** Rose-ringed Parakeets foraging on an olive tree (**a**), grasping an olive with the beak (**b**), and consuming the fruit while manipulating it with the feet (**c**).

Additional seasonal feeding was observed in spring, when parakeets consumed foliage such as fronds, leaves, and young stems from chinaberry, mulberry, and Japanese privet trees. In summer, they fed on figs and mulberries (Figure 3). Occasional foraging was also recorded on bay laurel berries, mastic berries, privet berries, and kurrajong seeds, though these were rare (Table 2).

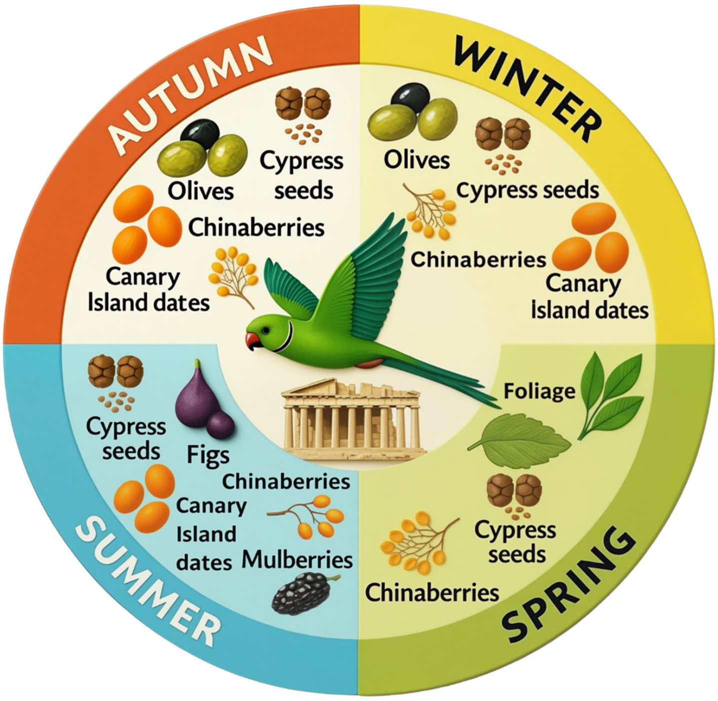

**Figure 3.** Seasonal feeding patterns of Rose-ringed Parakeets in Athens.

**Table 2.** Seasonal feeding records of Rose-ringed Parakeets on different food items in Athens. Numbers represent the total feeding observations per season, with percentages (%) indicating the proportion of each food item within the respective season.

| **Tree Name** | **Item** | **Feeding Observations (%)** | | | |
|---|---|---|---|---|---|
| | | **Autumn n = 185 (100%)** | **Winter n = 139 (100%)** | **Spring n = 158 (100%)** | **Summer n = 119 (100%)** |
| Kurrajong Tree | Pod seeds | 0 (0%) | 0 (0%) | 0 (0%) | 8 (6.7%) |
| Mediterranean Cypress | Cone seeds | 31 (16.8%) | 27 (19.4%) | 55 (34.8%) | 35 (29.4%) |
| Fig Tree | Fleshy fruits | 0 (0%) | 0 (0%) | 0 (0%) | 18 (15.1%) |
| Japanese Privet | Fleshy fruits | 0 (0%) | 4 (2.9%) | 0 (0%) | 0 (0%) |
| | Foliage | 0 (0%) | 0 (0%) | 15 (9.5%) | 0 (0%) |
| Bay Laurel | Fleshy fruits | 0 (0%) | 10 (7.2%) | 0 (0%) | 0 (0%) |
| Chinaberry tree | Fleshy fruits | 48 (25.9%) | 33 (23.7%) | 64 (40.5%) | 9 (7.6%) |
| | Foliage | 0 (0%) | 0 (0%) | 10 (6.3%) | 0 (0%) |
| Mulberry Tree | Fleshy fruits | 0 (0%) | 0 (0%) | 0 (0%) | 16 (13.4%) |
| | Foliage | 0 (0%) | 0 (0%) | 10 (6.3%) | 0 (0%) |
| Olive Tree | Fleshy fruits | 55 (29.7%) | 48 (34.5%) | 4 (2.5%) | 0 (0%) |
| Canary Island Date Palm | Fleshy fruits | 45 (24.3%) | 16 (11.5%) | 0 (0%) | 28 (23.5%) |
| Mastic Tree | Fleshy fruits | 1 (0.5%) | 1 (0.7%) | 0 (0%) | 2 (1.7%) |
| **Shannon Index (H′)** | | 1.480 | 1.603 | 1.399 | 1.720 |

### 3.2. Foraging Density

Parakeet foraging density showed no significant seasonal variation (Negative Binomial GLM: Wald $\chi^2 = 0.27$, df = 3, $p = 0.97$; Table 3). Predicted marginal means ranged from 5.97 birds per census in winter to 6.97 in autumn, representing only a 14% difference with broadly overlapping 95% confidence intervals (winter: 4.99–7.07; autumn: 5.99–8.23). Individual seasonal comparisons revealed no significant pairwise differences (all $p > 0.6$): winter vs. autumn (Rate Ratio = 0.85, $p = 0.62$), spring vs. autumn (RR = 0.92, $p = 0.81$), summer vs. autumn (RR = 0.91, $p = 0.78$). Day-of-year showed no linear trend ($\beta = -0.008$, $p = 0.96$), indicating stable abundance throughout the year. This consistency validates that observed dietary shifts reflect genuine food preferences rather than seasonal changes in parakeet availability.

**Table 3.** Seasonal "foraging density" of Rose-ringed Parakeets in Athens. "Foraging density" represents the number of birds observed on trees per transect.

| **Season** | **Birds Observed** | **Transects** | **Foraging Density** | **Standard Error** |
|---|---|---|---|---|
| Autumn | 230 | 33 | 6.97 | 0.36 |
| Winter | 179 | 30 | 5.97 | 0.34 |
| Spring | 188 | 29 | 6.48 | 0.38 |
| Summer | 141 | 22 | 6.41 | 0.43 |

No significant seasonal variation (Kruskal–Wallis: $p = 0.44$; Negative Binomial GLM: Wald $\chi^2 = 0.27$, $p = 0.97$).

### 3.3. Food Consumption Patterns

Mixed model analysis revealed significant effects of both food category (Wald $\chi^2 = 47.9$, df = 2, $p < 0.001$) and season ($\chi^2 = 28.9$, df = 3, $p < 0.001$) on consumption intensity (Table 4).

**Table 4.** Effects of food category and season on parakeet food consumption patterns [a].

| Effect | % Change [b] | Rate Ratio (95% CI) | *p*-Value | Interpretation |
|---|---|---|---|---|
| **Food Category (vs. Fruit [c])** | | | | |
| Seed | −6.7% | 0.93 [0.72, 1.20] | 0.592 | No significant difference |
| Foliage | −77.5% | 0.23 [0.15, 0.34] | <0.001 *** | Rarely consumed |
| **Season (vs. Autumn [c])** | | | | |
| Winter | −24.1% | 0.76 [0.69, 0.84] | <0.001 *** | Significant reduction |
| Spring | −7.8% | 0.92 [0.77, 1.10] | 0.362 | Similar to autumn |
| Summer | −17.3% | 0.83 [0.68, 1.01] | 0.058 † | Marginal reduction |

[a] Results from Negative Binomial Generalized Estimating Equation with Year as clustering variable (N = 1482 observations = 114 visits × 13 food items; 2022–2025). Overall model effects: Food Category (Wald $\chi^2$ = 47.9, df = 2, $p < 0.001$); Season ($\chi^2$ = 28.9, df = 3, $p < 0.001$). Day-of-year included as covariate ($p$ = 0.84). Model diagnostics: observed zeros = 78.2%; predicted zeros = 67.7%; exchangeable working correlation. [b] Percentage change calculated as (Rate Ratio-1) × 100. Negative values indicate reduced consumption relative to the reference category. [c] Reference categories: Fruit for food category comparisons; autumn for seasonal comparisons. Significance codes: *** $p < 0.001$; † $p < 0.10$.

### 3.4. Toxicity Assessment

Eight dietary items were analyzed for toxicity: olives, cypress seeds, chinaberries, Canary Island dates, bay laurel berries, mastic berries, privet berries, and kurrajong seeds. The responses of *Artemia franciscana* nauplii (Instar II–III) to the aqueous extracts varied among plant species, revealing distinct toxicity profiles (Figure 4). Chinaberry extract showed the highest toxicity, with the lowest $LC_{50}$ value, whereas cypress seed extract was the least toxic, exhibiting the highest $LC_{50}$. Only the chinaberry extract fell within the "bio-active" range ($LC_{50}$ < 1 mg/mL), suggesting the presence of compounds of potential toxicological relevance in the parakeets' diet (Table 5).

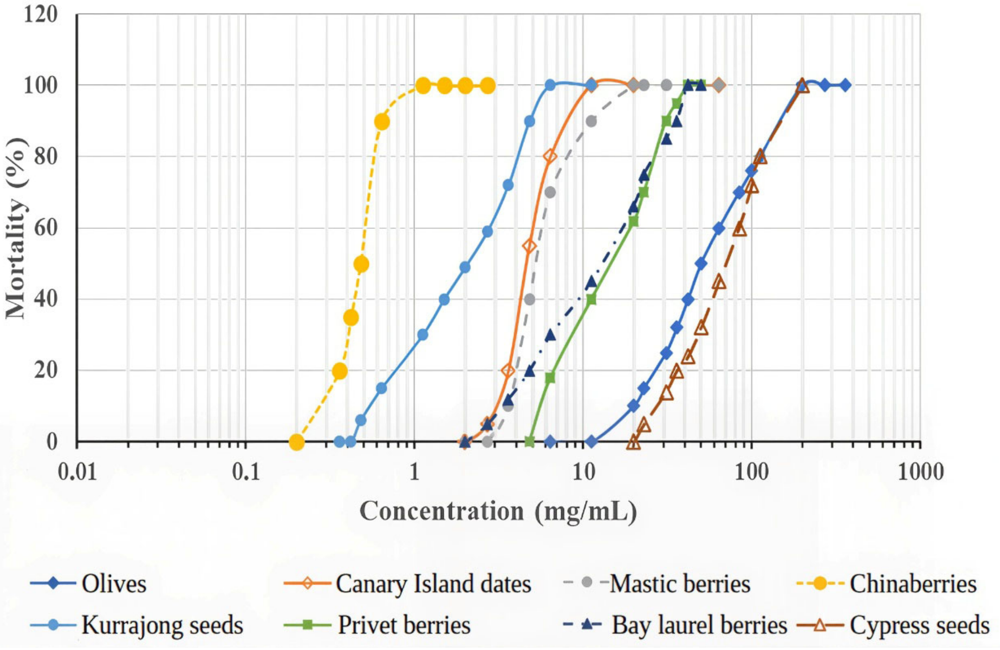

**Figure 4.** Dose–response curves illustrating the toxic effects of eight aqueous extracts on brine shrimp (*Artemia franciscana*) nauplii (Instar II–III) following 48 h exposure.

**Table 5.** Toxicity results of brine shrimp (*Artemia franciscana*) nauplii (Instar II–III) after 48 h exposure to eight aqueous extracts. Toxicity classes are based on Meyer et al. [25] and Gosselin et al. [30].

| Extract Sample | 48 h-LC50 (mg/mL) ± SD | Range (98% Conf. Int.) | Toxicity Class |
|---|---|---|---|
| Kurrajong seeds | 2.14 ± 0.01 | 1.36–3.34 | Moderately toxic |
| Cypress seeds | 84.58 ± 3.80 | 66.48–104.46 | Non-toxic |
| Bay laurel berries | 11.64 ± 0.11 | 7.92–17.14 | Slightly toxic |
| Privet berries | 14.44 ± 0.10 | 10.96–19.04 | Slightly toxic |
| Chinaberries | 0.46 ± 0.01 | 0.38–0.56 | Moderately to Very toxic |
| Olives | 51.70 ± 2.24 | 38.46–69.50 | Non-toxic |
| Canary Island dates | 4.84 ± 0.22 | 3.98–5.90 | Moderately toxic |
| Mastic berries | 5.68 ± 0.02 | 4.54–7.12 | Slightly to Moderately toxic |

Toxicity Class Definitions: Non-toxic: $LC_{50} > 1$ mg/mL, Slightly toxic: $LC_{50} = 0.5$–1 mg/mL, Moderately toxic: $LC_{50} = 0.1$–0.5 mg/mL, Highly toxic: $LC_{50} < 0.1$ mg/mL, Very toxic: $LC_{50} < 0.01$ mg/mL.

## 4. Discussion

Our study highlights the dietary flexibility of Rose-ringed Parakeets. In Athens, the principal food resources are cypress seeds and chinaberries, which are available throughout the year, with their seasonal variation presented in Tables 2 and 4. First-year cypress cones persist on trees year-round, while ripe chinaberries remain until late September, overlapping with the new crop. Seasonal fruits, such as olives (autumn–winter) and dates (late summer–winter), concentrate foraging activity on these resources when they are available, thereby altering the parakeets' overall foraging patterns. Once these resources are depleted in spring, parakeets seldom visit olive or palm trees, resuming their use in autumn with the maturation of new crops. Overall, the diet in Athens relies primarily on cypress seeds, chinaberries, Canary Island dates, and olives (Table 2). Notably, gray literature sources, including Hulot [22], also identify these food items as the most frequently consumed by parakeets in Athens. This independent agreement reinforces the assumption that our study sites were representative of the species' overall feeding activity within the city.

We recorded 13 consumed food items (Table 2), considerably fewer than reported in other studies; for example, Shivambu et al. [7] documented 31 fruiting or flowering species in Durban, South Africa. This difference likely reflects not only the smaller study area and the limited plant diversity of Athens' artificial parks compared with natural ecosystems, but also the lower sampling effort and restricted spatial coverage of our observations. Even with multi-year fieldwork, the relatively small number of sites inevitably constrained the range of plant species detected. Despite this limitation, parakeets did not consume other available resources, such as carob pods (*Ceratonia siliqua*), a recognized food source for various animals [41], highlighting their selective foraging behavior even within a relatively narrow dietary spectrum.

The stability in the numbers of foraging individuals is likely supported by the continuous availability of urban food resources and may also reflect the fact that seasonal temperature extremes in Athens—typically mild winters and hot but tolerable summers—fall within the physiological tolerance of *P. krameri*, which is known to persist in both colder and hotter regions [1,42]. Numerically, foraging presence peaked in autumn (September–November) (Table 3), although it remains unclear whether this represents a consistent pattern, given the birds' ongoing adaptation to the urban environment and broader climatic changes in the Mediterranean [43].

Within this limited dietary spectrum, pronounced seasonal shifts emerged. During winter, olives and chinaberries dominated the diet, whereas in summer the birds expanded their feeding range to include various Mediterranean fruits, demonstrating opportunistic use of seasonally available resources. The mixed model analysis (Table 4) supports this pattern, revealing significant effects of both food category and season on consumption intensity. Fruits were the core dietary component, while vegetative material was rarely exploited (−77.5%, $p < 0.001$), and seeds appeared to supplement fruit intake, reflecting dietary flexibility rather than specialization.

Foraging activity was the lowest in winter (−24.1%, $p < 0.001$), likely reflecting reduced food availability, and marginally lower in summer (−17.3%, $p = 0.058$), whereas spring activity remained stable. These patterns indicate that the Rose-ringed Parakeet dynamically adjusts its foraging behavior to the temporal availability of urban plant resources. Such behavioral plasticity enables the species to persist in the heterogeneous and unpredictable environments of Mediterranean cities.

This flexible foraging strategy represents a hallmark of successful urban colonizers. By exploiting a wide array of native and ornamental plants and alternating between fruits and seeds across seasons, the Rose-ringed Parakeet maintains a continuous food supply, even when preferred resources are scarce. This capacity to buffer seasonal fluctuations in resource availability likely enhances its resilience and may provide a competitive edge over native frugivores, particularly during periods of food limitation. Similar plasticity has been reported elsewhere [7,44–46].

Unlike in South Africa, where dietary diversity peaked in spring (September–November) [7], in Athens, the greatest variety was recorded in winter (December–January) and summer (June–August). This pattern likely reflects the reduced availability of core foods—cypress seeds, chinaberries, olives, and dates—during winter, which compels parakeets to broaden their diet, whereas the seasonal abundance of figs and mulberries increases the range of food items consumed in summer.

Parakeets in our study were frequently observed chewing bark and pecking at tree trunks, suggesting possible insect consumption, although this could not be directly confirmed. In Durban, South Africa, carpenter ants (*Camponotus cinctellus*) made up about 3% of the diet [7]. Several *Camponotus* species are present in Athens and commonly occur on trees, making them plausible prey. However, because observations were made from a distance, we could only infer, rather than verify, insect feeding.

The interpretation of toxicity levels in the present study follows the commonly accepted BSLA threshold, in which $LC_{50} < 1$ mg/mL indicates bioactivity and potential toxicity. This classification serves primarily as a screening criterion rather than an absolute toxicological boundary. In our results, only chinaberry extracts fell within this range, suggesting that it contains compounds of toxicological interest, whereas other species showed higher $LC_{50}$ values, reflecting low or no detectable cytotoxicity under these conditions. The term “bioactive” in this context refers to the presence of compounds capable of eliciting biological responses in the brine shrimp model, not necessarily implying adverse or clinically relevant effects in birds. Therefore, this distinction clarifies that only chinaberry exhibited measurable cytotoxicity in BSLA, while the inclusion of other plant species reflects their ecological importance in the parakeets’ diet rather than confirmed toxicity.

According to Meyer et al. [25], extracts with $LC_{50} < 1$ mg/mL are considered potentially toxic as they contain bioactive compounds, examples of which include alkaloids, furan derivatives, and terpenoids [47,48]. The BSLA measures general cytotoxicity but does not reveal mechanisms, target organs, or species-specific effects. *Artemia* nauplii are invertebrates, whereas parakeets are vertebrates with distinct metabolism and detoxification pathways. Thus, compounds toxic to shrimp may be harmless to birds, and vice versa. The main limitation is the physiological differences between invertebrates and birds, meaning $LC_{50}$ values cannot be directly extrapolated to avian safety, and this represents a limitation of our study. Nevertheless, the BSLA remains a widely used first-line screening tool for overall cytotoxicity [25,49]. Extracts causing significant mortality ($LC_{50} < 1$ mg/mL) warrant further bioassay-guided fractionation, complementary testing, and review of avian toxicology literature to better assess potential risks.

Another limitation of our study is that we did not test the foliage of the three plant species consumed by Rose-ringed Parakeets. Foliage and especially leaves are generally more toxic than fruits due to higher concentrations of secondary metabolites [50]. However, our field observations indicated that fruits formed the main component of the parakeets' diet, while leaf consumption was occasional. Moreover, we could not precisely determine which parts of the foliage—such as young leaves, mature leaves, or buds—were consumed, as the birds mostly chewed on buds. Therefore, testing fruits allowed us to focus on dietary items clearly ingested in significant amounts. Nonetheless, future studies should include leaf and bud extracts to provide a more comprehensive assessment of potential toxicological risks.

Table 5 and Figure 4 show that chinaberries exhibited the highest toxicity, followed by kurrajong seeds, whereas olives and cypress seeds were clearly non-toxic. The toxicity of ripe chinaberries is well documented [51], with reports of muscle tremors, kicking movements, and respiratory distress in ostriches [52]. Green berries are even more toxic [53], though our samples consisted of ripe fruits.

Kurrajong seeds are generally considered non-toxic, with irritation caused only by seed hairs, which Aboriginal Australians traditionally removed before consuming the seeds raw, roasted, or as flour [54]. This assumption is largely based on traditional use rather than formal toxicological studies. In our analysis, the seeds showed moderate toxicity (Table 5). Cyclopropene fatty acids, particularly sterculic acid, previously identified in kurrajong seed oil, are known to have toxic and co-carcinogenic effects in animals [55–58], consistent with the responses observed in our analysis.

Our results support previous findings that parrot diets often include foods containing measurable toxins [23]. Rose-ringed Parakeets, like many parrots, are generalist herbivores capable of consuming seeds and fruits containing compounds highly toxic to humans and other vertebrates [23,59–61]. Unlike most avian frugivores, they appear able to tolerate or process these compounds [62]. The mechanisms underlying this tolerance are not well understood. Although clay ingestion can reduce the effects of plant toxins in some psittacines [63], in urban Athens, there are no natural clay sources accessible to parakeets, and our observations never recorded ground-foraging activity. Therefore, physiological tolerance is likely a primary factor, but other mechanisms may also contribute, and further research is needed to clarify their role in urban populations.

This ability to exploit chemically defended foods highlights a key ecological advantage: tolerance to plant toxins broadens resource availability, reduces competition with other species, and may facilitate invasion success. Our study demonstrates measurable toxicity in common dietary items, emphasizing the need to investigate detoxification mechanisms, behavioral strategies, and energetic costs. Linking diet composition with physiological adaptations could shed light on the evolution of dietary generalism and niche expansion in parrots, advancing our understanding of plant–herbivore interactions in complex ecosystems.

## 5. Conclusions

The Rose-ringed Parakeet has established a self-sustaining urban population in Athens, showing dietary flexibility that allows year-round use of native and non-native plants. Changes in food preferences, selective consumption, and tolerance of chemically defended resources demonstrate adaptation to urban environments and resilience to variable resources. Although currently confined to the city and not yet impacting surrounding agricultural areas, potential ecological effects, including competition for nesting sites, disruption of native bird communities, and facilitation of alien plant dispersal, remain largely unquantified [64–66]. The species' foraging activity is concentrated on a few key plant foods, some containing bioactive compounds, indicating that parakeets exploit available resources while tolerating potential chemical defenses. Continued monitoring is crucial to assess long-term ecological consequences and to inform management of urban wildlife.

**Author Contributions:** Conceptualization, M.A.B.C. and G.C.; methodology, M.A.B.C., E.C. and A.C.P.; software, M.A.B.C., N.P. and N.T.; validation, E.C., A.C.P. and V.V.P.; formal analysis, M.A.B.C., E.C., N.P., N.T. and V.V.P.; investigation, M.A.B.C., E.C. and N.P.; resources, A.C.P., E.C. and Y.K.; data curation, M.A.B.C., E.C., N.P., V.V.P. and N.T.; writing—original draft preparation, M.A.B.C. and E.C.; writing—review and editing, G.C., E.C. and A.C.P.; visualization, M.A.B.C.; supervision, G.C., A.C.P., E.C. and Y.K.; project administration, A.C.P.; funding acquisition, A.C.P., E.C. and Y.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Data are contained within the article.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| AUA | Agricultural University of Athens |
| IMBBC-HCMR | Institute of Marine Biology, Biotechnology and Aquaculture, Hellenic Centre for Marine Research |

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