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Dispersal of *Cayratia japonica* Seeds by Birds in an Urban Green Space in China

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Authors' Contribution
GH Wang and QH Zhou conceived and designed the study. Y Pan and Y Huang contributed in field data collection. Y Pan wrote the article, and GH Wang, QH Zhou modified the manuscript.

Key words
Functional traits, Seed dispersal, Frugivorous birds, *Cayratia japonica*, Urban green space

ABSTRACT

Frugivorous birds play important roles in seed dispersal. In this study, we assessed the contributions of bird functional traits (behavioral traits: foraging quantity, number of birds per visit, and foraging duration; morphological traits: weight and body, wing, and tail lengths) to both seed removal patterns and dispersal distances of *Cayratia japonica* in an urban garden in southwest China. Eleven bird species were recorded feeding on its seeds, and eight bird species were confirmed to be seed dispersers. Oriental turtle-dove (*Streptopelia orientalis*), red-whiskered bulbul (*Pycnonotus jocosus*), and red-billed blue magpie (*Urocissa erythrorhyncha*) were the main seed dispersers. The number of seeds removed increased with bird foraging frequency, and seed dispersal distance increased with bird body and tail lengths. Our results highlight the importance of bird functional traits in seed dispersal patterns of *C. japonica*, which should be considered for tree management.

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INTRODUCTION

Seed dispersal is an important process for determining the spatial structure, dynamics, and composition of plant populations (Rumeu *et al*., 2020; Silva *et al*., 2021). Frugivorous birds are one of the principal agents of seed dispersal for fleshy-fruited plant species owing to their high abundance, mobility, diversity (Carlo and Morales, 2016; Camargo *et al*., 2020), and differences in body characteristics, which aid in removing the seeds of variety fruit species simultaneously (Wang *et al*., 2019). Through the feeding behavior of birds, seeds can reach a suitable habitat for germination, expand their area of distribution, escape the frequent high mortality frequently associated with offspring and parents, and promote gene flow within and among populations (Kleyheeg *et al*., 2015).

Many field and theoretical studies have shown that frugivorous birds contribute differentially to seed dispersal. This unequal contribution may be related to functional traits, especially their morphological traits (Farwig et al., 2017; Camargo *et al*., 2020). For example, bill size or wing morphology influences fruit handling and maneuverability to access fruits (Dehling *et al*., 2016). Small and medium-sized birds frequently visit plants, remove a few seeds per visit, and generally deposit them near the source tree; however, they are capable of dispersing seeds much further (Godínez-Alvarez *et al*., 2020). In contrast, large birds have longer visit, consume more fleshy fruit, and disperse seeds over longer distances than small birds in mutualistic assemblages, thereby connecting distant populations (Spiegel and Nathan, 2007; Muñoz *et al*., 2017). Additionally, avian body mass determines energy requirements, foraging behavior, and the fruit size that frugivores can ingest (Kitamura *et al*., 2002). Thus, the interactions between fleshy-fruited plants and frugivorous birds are influenced by bird morphological and behavioural traits (Farwig *et al*., 2017; Li *et al*., 2018).

Cayratia japonica is a perennial vine of the Vitaceae

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family with an aggressive growth habit; it climbs and shades the surrounding vegetation (Hansen and Goertzen, 2006). It is native to the temperate, subtropical, and tropical forests of Southeast Asia, Japan, India, Malaysia, Australia, and Taiwan (West *et al.*, 2010). *C. japonica* seeds become black after maturity (length: 8.79±0.66 cm; width: 8.09±0.62 cm; weight: 0.35±0.06 g, n=30) and rely on bird dispersal (Liu *et al.*, 2021). In previous observations in the Guilin Botanical Garden, the fruits of *C. japonica* were consumed by frugivorous birds. However, whether *C. japonica* forms a reciprocal relationship with local birds or the functional characteristics of birds influence the effectiveness of seed dispersal is unknown.

The objective of this study was to evaluate the contribution of bird functional traits (behavioral traits: foraging quantity, number of birds per visit, and foraging duration; morphological traits: weight and body length, wing, and tail lengths) to seed removal patterns and dispersal distance of *C. japonica*. We hypothesized that bird functional traits strongly affected seed removal patterns and dispersal distance.

MATERIALS AND METHODS

Study site

The field work of this study was conducted in the Guilin Botanical Garden (107°17′ E, 25°01′ N) in Guangxi Province, southwest China (Fig. 1). The altitude ranges from 180 to 300 m above sea level. The climate is dominated by the mid-subtropical zonal monsoon, and the average annual air temperature was approximately 19.2°C, ranging from -4.2°C in January to 36°C in July. The average annual precipitation was 1800 mm, and the mean annual relative humidity was more than 78% (Tang *et al.*, 2009). The local vegetation comprises a middle subtropical evergreen and deciduous broad-leaved mixed forest, and the fruits of plant species, such as *Cinnamomum camphora*, *Machilus thunbergii*, and *Ficus concinna* provide sufficient food resources for birds in autumn.

Frugivores behavior observation

Five mother trees were selected as the target trees because they were easy to observe during the seed maturation season from October 2020 to January 2021. Observations were recorded between 06:30-18:30 h with binoculars from a concealed location at least 10 m from the trees. Observations ended when no more seeds remained on the mother trees. We counted the number of fruits that were swallowed and pecked by each bird species, the number of birds per visit, and the total foraging time (from arrival to departure) for every observation. Each observation was continued until the birds disappeared. The focal first stopping distance of the bird (the distance between the first resting place of the visiting birds and the sample plant, also regarded as the potential minimum seed dispersal distance) was measured using a laser range finder (Breitbach *et al.*, 2010; Spiegel and Nathan, 2012).

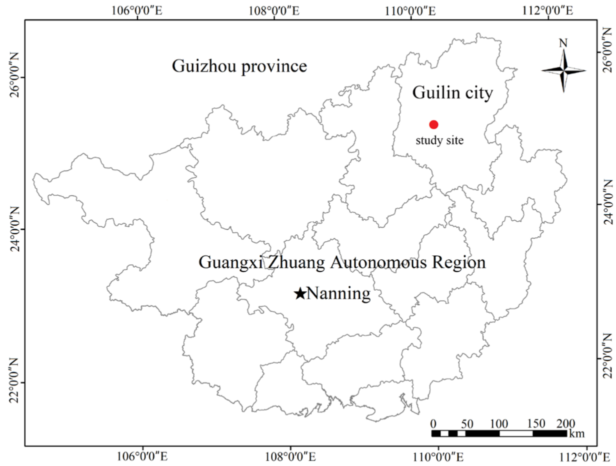

Fig. 1. Location map of Guilin Botanical Garden, China.

Statistical analysis

We used a *t*-test to compare the total feeding frequency, average feeding duration, amount of fruit consumed per visit, and first stopping distance of each bird species. We used the random forest model (R package Random Forest) to analyze the effects of foraging behavior (foraging pattern, number of birds per visit, and foraging duration) on the number of seeds removed and bird flight traits (wing and, tail, weight, and body lengths) on seed dispersal distance to quantify how the functional traits affected seed dispersal patterns and removal, respectively (Li *et al.*, 2018). The morphological traits of birds were obtained from A field guide to the birds of China (Mackinnon and Phillipps, 2000) and A handbook of the birds of China (Zhao, 2001).

Prior to analysis, the morphological traits of birds, number of seeds removed, and dispersal distance were log10 transformed for better linear fitting. All data analyses and figure creation were performed using the R version 4.1.3 (R Core Team, 2022), and $P<0.05$ was considered significant.

RESULTS

Fruit feeding and seed dispersal by frugivorous birds

During the fruiting season, 11 bird species visited *C. japonica* trees, of which eight species were observed to swallow the whole fruit as seed dispersers. *Pycnonotus xanthorrhous*, *Zosterops japonicus*, and *Pycnonotus* *sinensis* were the most common foragers, and the results on seed removal rate showed that *Streptopelia orientalis*, *Pycnonotus jocosus*, and *Urocissa erythrorhyncha* were the most common dispersers of *C. japonica* (Table I, Fig. 2). There were significant differences in the frequency (t=3.841, *df*=10, *P*=0.003) and duration of bird feeding (t=11.246, *df*=10, *P*<0.001), number of fruits consumed per visit (t=15.277, *df*=10, *P*<0.001), and dispersal distance (t=10.065, *df*=10, *P*<0.001) between the different birds (Table I).

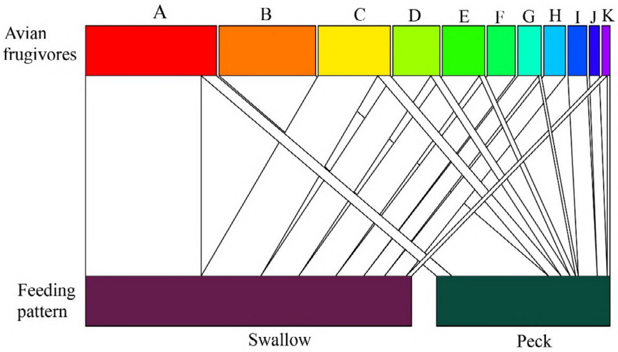

Fig. 2. Correspondence relationship between avian frugivores and *Cayratia japonica* based on feeding behavior. Widths of connecting lines denote the number of observed interactions (wider represents higher intensity of visiting). Avian frugivores: A, *Pycnonotus xanthorrhous*; B, *Zosterops japonicus*; C, *Pycnonotus sinensis*; D, *Hemixos castanonotus*; E, *Hypsipetes mcclellandii*; F, *Urocissa erythrorhyncha*; G, *Turdus merula*; H, *Streptopelia orientalis*; I, *Parus venustulus*; K, *Parus major*; J, *Pycnonotus jocosus*.

Effects of bird functional traits on seed removal and dispersal distance

Considering the contribution of bird foraging traits to seed removal, the random forest analysis revealed that 42.58% of the seed removal data could be explained by seven variables: number of birds per visit, feeding pattern, foraging time, wing length, tail length, weight, and body length. Only foraging time significantly affected the seed removal patterns, and the bird foraging time and number of seeds removed were positively associated (Fig. 3).

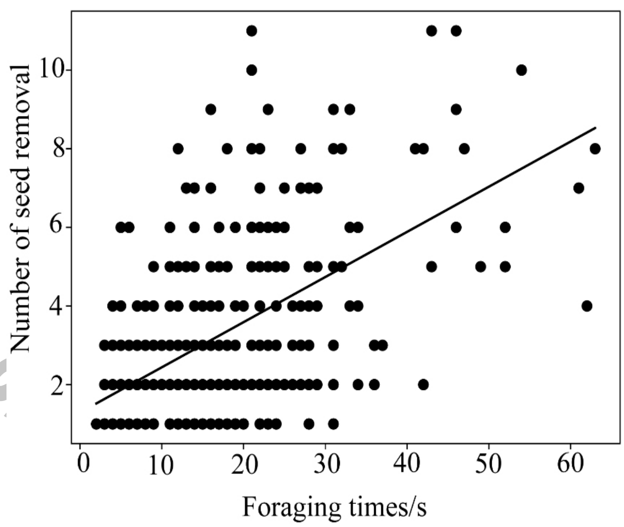

Fig. 3. Relationship between bird foraging time and the number of seeds removed.

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Table I. Bird feeding behaviors on the seeds of *Cayratia japonica*.

Bird species	Feeding frequency	Feeding time/s	Number of consumed fruits per visit	First stopping distance/m	Feeding pattern
Pycnonotus xanthorrhous	145	13.12±0.61	3.01±0.17	13.83±0.40	P/S
Zosterops japonicus	107	19.75±1.46	3.14±0.20	8.56±0.42	P
Pycnonotus sinensis	80	16.9±1.24	2.98±0.27	10.21±0.52	P/S
Hemixos castanonotus	52	10.71±0.98	2.21±0.21	14.38±0.71	P/S
Hypsipetes mcclellandii	47	10.78±1.04	2.89±0.30	12.60±0.93	P/S
Urocissa erythrorhyncha	31	6.99±1.26	3.42±0.32	16.68±0.98	P/S
Turdus merula	26	10.19±1.17	2.62±0.27	11.15±0.84	P/S
Streptopelia orientalis	24	13.04±1.32	3.63±0.40	9.58±0.69	P/S
Parus venustulus	21	12.19±1.57	2.00±0.25	4.52±0.39	P
Parus major	11	9.91±2.33	1.82±0.26	7.00±0.65	P
Pycnonotus jocosus	9	9.67±1.62	3.56±0.80	15.11±1.26	P/S

Feeding pattern: S, swallow; P, peck. Data are based on five mother trees. Mean and SE are displayed in the table, except for feeding frequency which represents the total number of visits.

Considering the contribution of bird flight traits to seed dispersal distance, the random forest analysis revealed that 22.09% of the seed dispersal distance could be explained by four variables (wing length, tail length, weight, and body length). Bird body and tail lengths significantly affected seed removal patterns, and showed a positive association between bird body (Fig. 4a) and tail lengths (Fig. 4b), and seed dispersal distance.

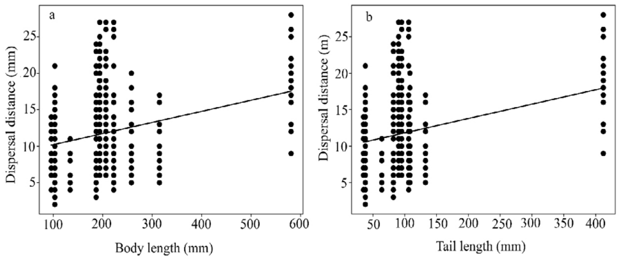

Fig. 4. Relationship between seed dispersal distance and bird flight traits (a, b).

DISCUSSION

Our study showed that *C. japonica* tree could attract local birds to disperse its seeds (Table I, Fig. 1) and transport the seeds away from the mother tree, and ultimately influencing the spatial distribution of seedlings. The black aril of mature *C. japonica* seeds can create a strong visual contrast with the green background of the surrounding plants attracting a large number of birds with different body characteristics to feed on their seeds (Schaefer *et al.*, 2007). Other studies have shown that black fruits are the most attractive to birds (Duan *et al.*, 2014; Gagetti *et al.*, 2016). Furthermore, *C. japonica* seeds contain many lipids and sugars, which can provide sufficient food resources for winter birds and are essential for maintaining the diversity of urban green spaces.

Foraging behavior traits strongly affected the seed removal patterns of birds, and foraging duration played an important role in determining the seed removal patterns (Fig. 2). Longer foraging duration means that birds can forage more seeds, and the Guilin Botanical Garden is located in the suburbs, with dense vegetation and little human interference, providing a safe environment for birds to forage on seeds of *C. japonica* for a long time.

Furthermore, our results showed that seed dispersal distance increased with body and tail lengths (Fig. 3). Body length played an important role in determining the dispersal distance of birds in the present study (Fig. 3a). A larger body size means that birds can forage more seeds, have a longer retention time of seeds, and possess strong flight abilities that can aid the spread of many seeds to further places. Another study confirmed that seed dispersal distance increases with increasing body length (Muñoz et al., 2017). In addition, our results highlighted the interaction between bird tail length and seed dispersal distance (Fig. 3b). Birds with long tail lengths exhibit high tolerance to forest adaptation (Li *et al.*, 2018), enabling them to disperse seeds to different habitats.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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