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RESEARCH ARTICLE

Fruits foraging patterns and seed dispersal effect of frugivorous birds on *Hippophae rhamnoides sinensis*

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Abstract Behaviors of 18 species of birds eating fruits of *Hippophae rhamnoides* spp. *sinensis* were observed from September 2003 to March 2004. Their foraging patterns were found to be very different and can be divided into five classes: (1) direct swallowing the fruits on crown of the shrubs and sometimes regurgitating seeds soon after; (2) carrying the fruits to their perching sites and swallowing; (3) pecking the fruits from the shrubs to the ground, eating pulp and seeds but leaving pericarp; (4) pecking through the pericarp, eating pulp and leaving pericarp and seeds; (5) pecking through the pericarp on the top of fruits, and only eating seeds. These foraging patterns have different effects on seed dispersal of *H. rhamnoides* spp. *sinensis*. The germination experiment of three groups of seeds (seeds from feces, dry fruits and extracted seeds from dry fruits) was carried out. Although ingestion processes of birds had some adverse effects on the seed germination of *H. rhamnoides* spp. *sinensis*, the seeds from feces still have a relatively higher germination ratio. *H. rhamnoides* spp. *sinensis* provides food to a variety of frugivorous birds, and the birds disperse its seeds. Thus, a mutually beneficial relationship between the bird and the seed is formed.

Keywords *Hippophae rhamnoides* spp. *sinensis*, frugivorous birds, foraging patterns, seed dispersal

1 Introduction

Seed dispersal can be seen as anon-initiative process, during which the seed leaves the maternal plant to the habitat which is fit for sprouting and breeding (Howe and Estabrook,1977; Janzen, 1975). There are various ways of seed dispersal, and many plant dispersed their seeds by birds (Ridley, 1930; Van der, 1972). On the basis of the different dispersal mechanisms, the birds can be divided into two kinds: eating fresh fruit and eating dry fruit. Seed dispersal by birds has many potential benefits, e.g., it can help seeds get away from preying (Janzen, 1972; Wenny, 2000), take up a new habitat (Livingston, 1972; Smith, 1975; Westcott and Graham, 2000), and strengthen gene flow (Hamilton, 1999; Levin and Kerster, 1974). Domestic scholars have studied some of the dispersal of the seeds of *Pinus koraiensis, Taxus chinensis, Phellodendron amurense, Taxillus* spp. etc. by birds and the results indicate that the carpophagous birds play a significant role in the' reproduction and renewal of these plants (Liu, 1988; Li et al., 1999; Xiao and Pu, 1994; Chang et al., 2000).

Hippophae rhamnoides spp. *sinensis* is a kind of heliophyllous, widely distributed in most areas of northern China, highly acclimated to the barren mountainous sand of hilly areas. It often becomes the dominant species in the sunny side where the forest hardly extends. It is of great significance for improving the environment of unused hills and slopes, resisting wind, fixing sand as well as checking soil erosion. *H. rhamnoides* spp. *sinensis* blooms in April and May, bears berries in September and the bacca in the trees may linger until the next spring. The shrubs grow thick, dense and dark; consequently they provide good habitats and hiding places for birds. Particularly, in winter, the bird population in the communities of *H. rhamnoides* spp. *sinensis* is higher than in other regions. To a certain extent, the extension of *H. rhamnoides* spp. *sinensis* communities depends on the seed dispersal done by foraging birds. There are some preliminary studies on the birds spermatophyta of the shrubs and the birds feeding (Ma et al., 1985; Feng et al., 1986), but no report has been found on birds eating baccas of *H. rhamnoides* spp. *sinensis* and its influence in seed dispersal. This study attempts to observe the way of birds eating bacca, finds out the manner and approach of birds dispersing the seeds of *H. rhamnoides* spp. *sinensis* and evaluates the impact of

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birds' foraging patterns on *H. rhamnoides* spp. *sinensis* community structure.

2 Study area and methods

2.1 Study area

Sample region I is in Mapo town, Yuzhong county of Lanzhou, Gansu Province, China. The elevation is 2 450 m. There are *H. rhamnoides* spp. *sinensis* growing in the hillside of the verge of tilth, and the area is about 400 m^2. No other plants livein such a place, except few *Rosa xanthina, Ribes burejense* and so on. Tilth stands the majority, where jute, wheat and horsebean grow. Sample region II lies in Dangzhigou,the suburb of Hezuo in Gannan Zang Autonomous Region of Gansu Province. It is located in the eastern edge of the Qinghai-Tibet plateau. With an altitude of 2850m, the area belongs to the second-alp community of *H. rhamnoides* spp. *sinensis*. *H. rhamnoides* spp. *sinensis* grows on the verge of the forest, scatters in spots, mixes with *Salis matsudana*, *Berberis diaphana*, *Spiraea mongolica*, *Lonicera rupicola* and *Sibiraea angustata*.

2.2 Methods

2.2.1 Feature observation

Fresh fruits are collected for observing their colors, measuring and recording stem length, the diameter, volume, weight and other parameters. Changes of the ripe fruit in fall and winter in field were also observed and recorded.

2.2.2 Species of birds and their frugivorous way

From September 2003 to March 2004, we went to the sample regions every month, and used telescope (8 × 10) and camera to observe and record the activity and foraging pattern of the birds. Birds were identified based on their character, such as sizes, feather colors and flecks, and together with their voices and chirps.

2.2.3 Seed germination

Three different types of fruits (seeds) were classified: (A) seeds in birds' feces mainly come from *Cyanopica cyana* which eat on the fruits of *H. rhamnoides* spp. *sinensis s*; (B) dry fruits from the *H. rhamnoides* spp. *sinensis* next year (the complete dry fruit should be soaked in water for 24h before the experiment); (C) peel off the pulp and pericarp of complete fruits, and only leave seeds.

We took 100 seeds of three types and laid them in the thermostat (25ºC) to culture, and then counted for accumulative germination percentage.

3 Results

3.1 Characteristics of fruits of *H. rhamnoides* spp. *sinensis*

The fruits of *H. rhamnoides* spp. *sinensis* were bacca. Part of the flesh were up-growth by calyx (hypanthium), remaining with pseudocarp, when it riped. It usually formed a vesica covering the seed. They had membrane pericarp surrounding the seeds. The fruits of *H. rhamnoides* spp. *sinensis* had many shapes and many types of subgenus (Lian et al., 1997). We conducted an investigation of *H. rhamnoides* spp. *sinensis* in September 2003 (Table 1). The results showed that there were three different subgenus in the sample region, based on Lian et al. (1997). They were classified into different types as big saffron yellow apple, small saffron yellow apple and small chrysoidine apple. When riped, it turned juicy and colorful, red or yellow. Many fruits clustered along the wattle. But in February or March of the following year, there were little juice left or no juice at all. The color faded out gradually and became a black dried fruit, and it was difficult for frugivorous birds to spot.

Table 1 Fruits characteristics of *Hippophae rhamnoides sinensis*

Types name	Big saffron yellow apple	Small saffron yellow apple	Small chrysoidine apple
Fruit stem length /mm	1.3~1.8	1.5~2.0	1.0~2.5
Fruit vertical diameter /mm	5.9~6.4	3.4~4.2	3.8~4.0
Fruit transverse diameter/mm	6.8~6.9	4.2~5.3	4.3~4.5
Vertical diameter / transverse diameter	1.1~1.16	1.27	1.18
Fruit volume/ (cm^3·100grain^{-1})	16	5	5.4
Fruit weight/(g·100grain^{-1})	14.0~15.4	4.6	5.5
Fruit color	Saffron yellow	Saffron yellow	Chrysoidine

3.2 Species of frugivorous birds on *H. rhamnoides* spp. *sinensis* and their foraging patterns

There were y 18 different species of birds eating the bacca of *H. rhamnoides* spp. *sinensis*. They were *Phasianus colchicus strauchii*, *Streptopelia orientalis, S. decaocto, C. cyana, Pica pica, Garrulus glandarius, Corvus macrorhynchus, Phoenicurus erthrogaster, Turdus ruficois, Garrulax davidi, G. ellioti, Rhopophilus pekinensis, Parus palustris, Aegithalos caudatus, Parus major, Carpodacus thura, Emberiza cia* and *Emberiza cioides*. Their frugivorous ways were found to be different: (1) directly swallowing the fruits on crown of the shrubs and sometimes regurgitating seeds soon after (*S. orientalis, Streptopelia decaocto, C. cyana, Co. macrorhynchus*); (2) carrying the fruits to their perching sites and swallowing (*C cyana, Co. macrorhynchus*); (3) pecking the fruits from the shrubs to the ground, eating pulp and seeds but leaving pericarp; (4) pecking through the pericarp on the top of fruits, and only eating seeds; (5)pecking through the pericarp, eating pulp and leaving pericarp and seeds.

3.3 Germination ratio of seeds

Seeds of type A germinated earlier than the other two types, 2 days earlier than type C, 4 days earlier than type B. The germination ratio of type A was 42%, lower than type C (74%), but higher than type B (34%) (Table 2, Fig. 1).

Table 2 Germination of *Hippophae rhamnoides sinensis* seeds under different situations

	Seeds from birds' feces (type A)	Peel off the pulp and pericarp only leave seeds (type C)	The integral dry fruit soaked in water for 24h (type B)
Germination amount	100	100	100
accumulative germination grains	42	74	34
accumulative germination percent /%	42	74	34

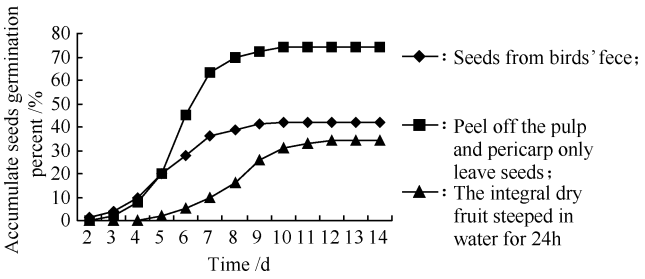

Fig. 1 Germination of *Hippophae rhamnoides sinensis* seeds under different situations

4 Discussion

4.1 Seed dispersal effect of frugivorous birds on *H. rhamnoides* spp. *sinensis*

When the fruit of *H. rhamnoides sinensis* riped, it has a vivid color, so it is eye-catching enough to attract birds. At the same time, *H. rhamnoides* spp. *sinensis* grows dense and low, so the interference between birds is negligible during their foraging. It can hold many species of birds foraging simultaneously. Eighteen species of birds eating the fruits of *H. rhamnoides* spp. *sinensis* were observed and recorded in the sample region. According to Ma et al. (1985) and Feng et al. (1986), there are 49 species of birds in Loess Plateau, among which there are 45 species eating the fruits of *H. rhamnoides* spp. *sinensis*. The period of fruits in the tree is longer than most other plants. From September when it is riped to April or May of the following year, the fruits stem usually do not depart from matrix by generating abscise layer or by wind. Little fruits leaving matrix in virtue of biological and abiological factors, the fruits or seeds dispersal mainly depend on birds foraging.

The birds' frugivorous ways were found to be various, and different behaviors of eating fruits have different effects on the seed dispersal. The investigation indicates that among these different eating patterns, the swallowing of the integral fruits and only leaving fruit stem takes up the greatest part. After these frugivorous birds eat the fruit, they digest or partly digest the pulp. Seeds and seeds with partial pulp and inner pericarp digest with feces, then part of seeds meets suitable environment. All of these are the process of *H. rhamnoides* spp. *sinensis* seed spreading. Besides, seeds can be dispersed in other ways. Birds can throw up the seeds without pulp or pick the fruit. During this process, the seeds fall down and are not been eaten out. Pulp that has been eaten with the seeds is left. So, the birds can bring the fruits and seeds to different environments. All these ways can also play an important role in seed dispersal. The number of birds that only eat pulp and seeds by pecking the fruits from the shrubs to the ground or pecking through the pericarp on the top of fruits, is relatively fewer, but can also spread the seeds. Those birds, only eating pulp or only absorb the juice, can also make the fruit or seeds of *H. rhamnoides* spp. *sinensis* fall off onto the ground. The time of seeds detaining in the frugivorous birds' alimentary canal determines the potential dispersal distance, as well as whether the seeds can reach the suitable environment or not (Murray, 1988).

The alimentary canal of the frugivorous birds has many effects on the dispersal of seeds. Studies by Barnea et al.(1991), Cipollini and Levey(1997) and Yagihashi et al. (1998) indicate that the digestion process of birds can raise the germination ratio remarkably. This process can even make the unsprouted seeds germinate. This because the birds digested the pulp that may contain some materials inhibiting the germination of the seeds. Agami and Waisel (1986) indicate that the structure of the seed capsule changed during digestion process, but, Yagihashi et al. (1999) suggest that the digestion process has no obvious effect on germination. The germination experiment of three groups of seeds is carried out, and it shows that the germination ratio of seeds in feces is 42%. Although the rate is lower than that of extracting seeds from dry fruits, it is higher than that of integral dry fruits. All these indicate that the birds have an obvious effect on the spread of *H. rhamnoides* spp. *sinensis*. With the help of birds, long distance spread of *H. rhamnoides* spp. *sinensis* comes true.

4.2 The mutually beneficial relationship between *H. rhamnoides* spp. *sinensis* and frugivorous birds

Frugivorous birds and the plants with fruits form a coevolutionary system (Salomonson, 1978; Herrera, 1981). From an ecological aspect, birds eating fruits can get nutrition and spread seeds in their perching sites, help the seeds reach various environments and raise the germination ratio and sprout ratio. The birds can get pulp as a reward during the seed spread, and seeds are spread as the plant offers the pulp. They form a mutually beneficial relationship. In fact, such a mutually beneficial relationship between a kind of

plant and a kind of frugivorous bird is rare. On the contrary, it is indeed common to see this kind of relationship between many kinds of plant and many species of frugivorous birds (Herrera, 1984; Herrera, 1995). As the fruits in *H. rhamnoides* spp. *sinensis* tree occur longer than other plants, especially in cold winter when snow covers everything, the fruits of *H. rhamnoides* spp. *sinensis* are main food source for many birds. The significance of the frugivorous birds to the seed of *H. rhamnoides* spp. *sinensis* is that the seeds are carried to a new environment by the digestion process. In the new environment, if the condition is suitable, the *H. rhamnoides* spp. *sinensis* seeds can germinate and settle down. But *H. rhamnoides* spp. *sinensis* have better nutritional breeding ability in root. Once they settle down, they have competitive advantage and squeeze out some kinds of lower shrubs and grass, form their own community and expand the distribution region. Thus, a stable community with animals and plants is easy to form with the *H. rhamnoides* spp. *sinensis* as pioneer vegetation. The birds drop the fruits onto ground while eating, and seeds in feces are excreted inside the forest of the *H. rhamnoides* spp. *sinensis*. These seeds are around the matrix and under the suitable conditions for sprouting and growth, which plays a vital role in renewal and maintenance of the community of *H. rhamnoides* spp. *sinensis*. From this viewpoint, birds' successive activity and its dispersal function of more plants seed help the pioneer plants to take up a new habitat (Livingston, 1972), promote the vegetation succession and expansion and make the ecological environment improved.

Generally speaking, both frugivorous birds and plants want to get more benefit and pay less during the mutually beneficial relation. So compromise arises to maintain the balance. Whether the balance point is near plants or birds depends on the environment (Herrera, 1981). Study by Grant and Grant (1989) in ChloralPax archipelago shows that due to the difference of beaks, fruit size and the speed, the variation in climate changes the composition of plant fruit and so determines the evolution direction of birds. The research work of the mutual effects between frugivorous birds and plants has not been carried out in our country (China), and the study on seed dispersal by animals has just begun (Wang and Ma, 1999). In fact, these studies are of great importance to biological protection study.

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