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A REVIEW OF ENDOZOOCHOROUS SEED DISPERSAL BY HERBIVORES AND ITS POTENTIAL EFFECT ON SEED GERMINATION

A thesis submitted in partial fulfillment of the requirements for the degree of Master in General Ecology

By

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DECLERATION

I, Muhammad Atif Bilal hereby declare that this thesis titled;

"A REVIEW ON ENDOZOOCHOROUS SEED DISPERSAL BY HERBIVORES AND ITS POTENTIAL EFFECT ON SEED GERMINATION".

is a result of my own research findings and investigations. This work has not been previously printed, published and submitted in any university or research institute.

Signature.............................

Date.....................................

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Muhammad Atif Bilal

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ABSTRACT

Endozoochorous seed dispersal by large herbivores provides a possible aid for ecological restoration of plant communities. This review thesis determines and analyses seed dispersal and seed germination via sheep, cattle, horse, rabbit, deer and herbivore birds dung in different ecosystems. Large amounts of viable seeds of different plant species have been found in herbivore dung in previous studies; however which species produce seeds that can survive and germinate after ingestion by herbivores is still not well understood.

According to my review study out of 31 plant families Poaceae and Cyperaceae are the most common plant families which are dispersed by all six herbivores dung in different ecosystems. Cattle are among the most seed disperser as compared to other herbivores, while herbivores birds disperse the seeds at long distances then other herbivores due to migration over longer distances. Seed germination success rate depends on initial mastication and rumination by the herbivores rather than mean retention time.

Those plants which have smaller seeds are more likely to disperse by herbivores dung than the plants which have large seeds. And the seed passage through the animal gut may affect the fraction of seed germination it may costly if inhibit the process of seed germination by reducing the mechanical protection of seed coat and this cost can be offset if animal deposit the seeds in very favorable microhabitats. This study also indicates that there are potentially high costs to endozoochory that have to be balanced against the benefits of long-distance dispersal by large herbivores.

Key words: Endozoochorous, Seed dispersal, Poaceae, Cyperaceae, Herbivores, Mastication, Rumination, Germination, Ingestion, Ecosystem.

1.0 INTRODUCTION

Large herbivores are potentially important to disperse seeds over the long distances (Janzen 1984). Seeds of many plants especially herbaceous species can be dispersed in dung, especially those which have smaller and hard seeds (Yamashiro & Yamashiro 2006). Endozoochory and epizoochory are evolutionary adaptations which not only promote the process of seed dispersal, but also the reseeding of areas under intense herbivory (Howe & Smallwood 1982).

Seed dispersal is one of the most important ecosystem service provided by herbivores. Seed dispersal by herbivores birds is especially geographically widespread; both the birds and plant participants are taxonomically diverse. Plants and their seed dispersers form a complex mutualistic network to maintain the biodiversity and community structure. Herbivore birds are considered that they can contribute to restore the deforest land in both arid and deforested landscapes. (Bascompte & Jordano 2007).

The process of seed dispersal is critically important and is of great interest because of population structure and species response to climate (Bullock *et al.* 2002). Environmental changes (natural and anthropogenic) are constantly altering the local ecosystem and habitat patterns, which may influence the demographic process in plants (Cain *et al.*2000). Seed dispersal process is an important component for the plant colonization and may also influence many key aspects of plant ecology including the migration of species, plant recruitment and species diversity under climate change (Higgins *et al.* 2003).

Plant species that disperse through endozoochory have seeds which have the ability to survive and germinate after passing through herbivore’s gut (Mouissie *et al.* 2005; D’hondt & Hoffmann 2011). Therefore endozoochory is considered as an important source for long-distance seed dispersal which benefits the plants that are more readily ingested and can survive during digestion (Pakeman *et al.* 2002).

The endozoochorous dispersal of seeds through the digestive tract of herbivores has been known for a long time, although most of the available information comes from isolated observation of seeds in herbivore dung (Janzen 1984). Endozoochorous dispersal of seeds by wild ungulates in an altered environment may facilitate the evaluation of the "foliage-as-fruit" hypothesis (Janzen 1984). According to the hypothesis, herbaceous plants which have small seeds and lack apparent adaptations for seed dispersal may gain an advantage from their dispersal through the herbivore digestive tract, and the evolution of many of their traits is driven by selective pressures which is linked to the mechanism of endozoochory (Janzen 1984).

There are many potential interactions between plant and herbivore traits. Especially herbivore birds may disperse seeds by various mechanisms. In the most common, endozoochory, birds consume a fleshy fruit and regurgitate or defecate the seeds. Another variation of endozoochory is that many birds like waterfowl and shorebirds dispersing aquatic plants many of which are ingested inadvertently. Some birds also cache seeds (synzoochory) of primarily pines (*Pinus* spp.), and oaks (*Quercus* spp.) especially in the North Temperate Zone (Nogales *et al.* 2002). Similarly large herbivores may ingest seeds, move and excrete at different locations. After the seeds are ingested, herbivores excrete them in the form of dung piles, and may also graze and trample in different areas, which affect the seed germination and seed establishment after the dispersal process (Figure 1).

This figure (1) below illustrate the different morphological (e.g. size and shape), physiological (e.g. nutritional requirements, diet and foliage palatability) and behavioral (e.g. mean retention time, reproductive status, social interactions) characteristics of the seeds and animal which may influence the seed dispersal process. And Animal morphology and physiology further determine whether a seed will be dispersed or predated, and also the speed of passage through the gut, which together with animal movement, determines where seeds are deposited.

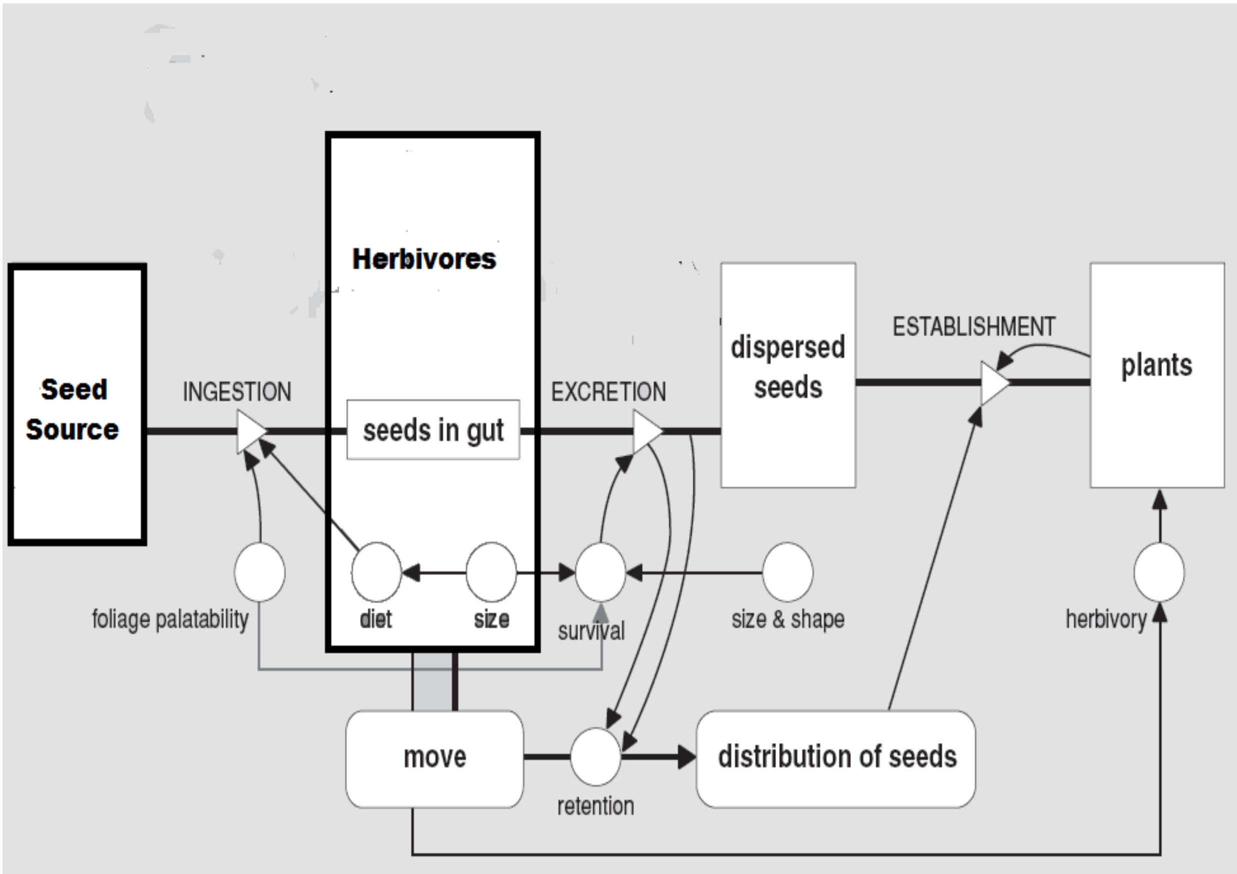

Figure 1: Flow chart is description of the relationships between large herbivores, seed dispersal and establishment. Boxes represent quantitative units, circles represent parameters and ellipses represent the spatial units that are required for seed dispersal (personally modified from Mouissie *et al.* 2005).

The germination success rate of seeds from dung is determined by three main factors. First, seed must have to be eaten by a disperser, which may happen deliberately or accidentally by herbivores during the consumption of seeds (Pakeman *et al.* 2002). Second, the seeds which are consumed by an animal have to survive in the gut (Cosyns *et al.* 2005). And third, dormancy may need to be broken depending on plant species (Malo, 2000).

1.1. The **aim of this study is** to find out:

- The contribution of herbivores to endozoochorous seed dispersal.

- Identify the plant species/families dispersed by large herbivores.
- The role of endozoochory in seed germination and seed establishment.

2.0 Importance and process of seed dispersal

2.1 Seed dispersal as key process in vegetation dynamics

Herbivores influence the vegetation of landscapes in diverse ways; processes related to disturbances like compositional shift, herbivores may affect the vegetation process by dispersal patterns of the plant species (Fenner & Thompson, 2005). Seed dispersal is an important component of plant population dynamics with consequences for colonization of new habitats and maintenance of diversity. Seed dispersal of the 25 to 80% of temperate plant species and 40–90% of tropical rainforest woody species depends on herbivory (Bascompte & Jordano, 2007).

Seed dispersal is an important process for the conservation and restoration of plant communities. In contrast with other methods like seed dispersal by wind, in which seed can be dispersed just about 10 kilometers away from parent plant, herbivores dung contain many germinable seeds of many plant species retain into digestive tract and spread these seeds across 10 kilometers (Cosyns *et al*. 2005).

Seed dispersal is considered a major factor driving the plant spatial dynamics at both local and regional level (Cain *et al*. 2000). It also determines the distribution of the plant communities, gene flow between plant communities and also plant meta-population dynamics (Eriksson 1996, Cain *et al*. 2000). In addition, seed dispersal over long distances also determines the range shift of plants at global scale. Ecologists observe the dispersal distance on average few tens of meters per year of many plant species (Bossuyt *et al.* 1999).

2.2 Endozoochory and mechanism of endozochorous seed dispersal

Endozoochory refers to the dispersal of plants where the viable seeds are defecated or regurgitated by animals. Herbivores disperse seeds by ingesting the seeds into the gut together with plant foliage (Janzen 1984). Seed dispersal by herbivores involves fruits with small seeds that are produced in large quantities and are consumed in wide range especially by herbivore birds (Howe, 1986). Such dispersal systems may rely on chance relationships with common herbivore where fruit is a component of a varied diet.

Endozoochrous seed dispersal by large herbivores also depends on various behavioral components of the dispersing vectors like foraging, handling of seeds (ingestion and gut treatment etc), movement of vector away from parent plant and defecation (Wang & Smith 2002).

Janzen (1988) hypothesize that there are some important characteristics that would enhance the seed dispersal of a plant which are the following:

- The plant is edible to the herbivores.
- If the leaf palate has sufficient amount of nutritional value and tasty then it will be more attractive to herbivore.
- If the palate is not edible and attractive then it should change into the mature crop.
- Maturation of seed is limited to the coincide to peak herbivory.
- If the seeds are intermingled with the foliage or in its closest vicinity.
- If the mature seed retain on the plant.
- Seeds are tough, small and hard.
- If the seed coating/cover is resistant to ruminant digestion.
- If the seed are chemically protective from the seed predators.

Endozoochorous seed dispersal by large herbivores depends on many biotic and abiotic factors which may act separately or collectively. In addition, seed dispersal is a multistage process which includes the movement phase (transience phase), pre-dispersal phase and post-dispersal phases (Figure .2), which may affect by the plant and animal interactions (Wang & Smith 2002).

In the pre-dispersal phase or feeding phase in which herbivores intake the seeds in their body , which is not only depends on the temporal and spatial arrangement of the fruits/seeds but also depends on the attractiveness of seed as well to disperser which is mediated by the crop size, seed size (Lehouck *et al*.2009).

In the transience phase, herbivores determine the direction and distance of seed dispersal through the gut transit time and post-foraging time, which may vary from animal to animal. Gut passage rate generally depends on morphology, behavior and physiology of the herbivores and also depends on seed properties like seed size, seed shape, hardness and pulp to seed ratio (Lehouck *et al*.2009).

In the settlement phase (post-dispersal), herbivores may affect the success rate and germination speed of seeds by increasing the permeability of the seed coat for nutrient and water, removing fruit pulp, and embed the seed in mineral rich facial material (Traveset 1998). In addition, seed survival, establishment and germination depend on where the seed is deposited (Russo and Augspurger 2004**).**

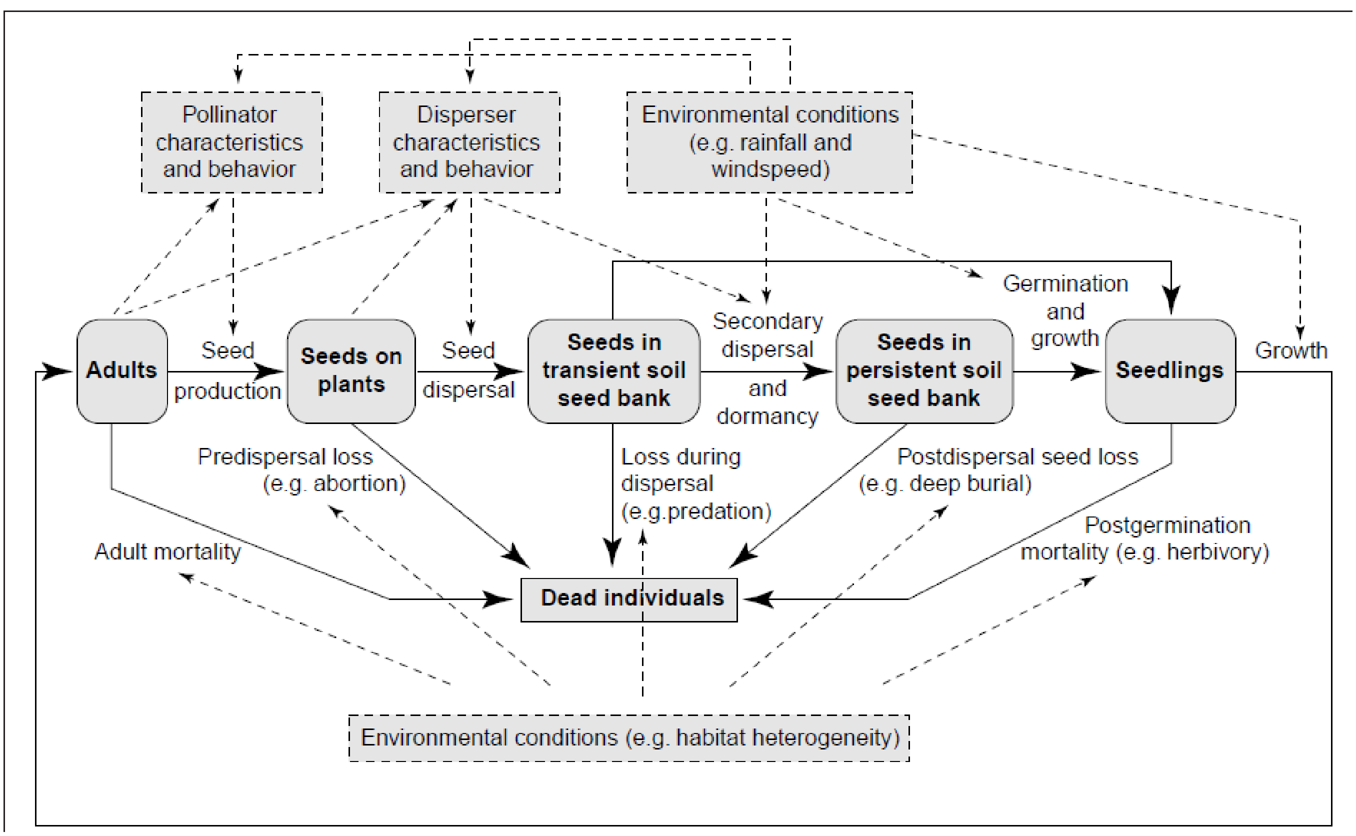

Figure 2: This figure describes the various stages of endozoochorous seed dispersal. Unbroken arrows represent processes, broken arrows show influences upon these processes, broken boxes

denote influencing factors, and rounded boxes indicate the dispersion patterns (Nathan *et al*.2000).

2.3 Effect of endozoochory in seed germination and establishment

Herbivores that swallow the fruit act differently on seed during ingestion, gut passage and defecation. It is expected that plants which are evolved may have physical and chemical changes in fruit and seed, which maximize the proportion of seeds dispersed and subsequently establish successfully. There are different processes (removal of pulp, scarification etc) took place after the ingestion of seeds by herbivores, which may affect the seed germination process (Meyer & Witmer, 1998), which are following:

2.3.1 Removal of pulp from seed

Fruit pulp contains the inhibitors which prevent the process of seed germination and may also inhibit the biochemical pathways required for germination process (Meyer & Witmer, 1998). In addition, fruit pulp also reduces the germination process by altering the microenvironment of the seed (e.g: osmotic pressure and light regime etc.), which in turn promote the germination events (Robertson *et al.*, 2006). For example, in berries and drupes, seeds are protected by fleshy pulp. This pulp is rewarded to herbivores, but also protects the seed and inhibits the germination. This inhibition may be induced due to high osmotic pressure which is caused by high sugar content and due to light blocking pigments preventing sunlight from reaching the seeds to induce germination (Samuels & Levey, 2005).

2.3.2 Chemical and mechanical scarification of seed coat

The seed coat is to a variable extent chemically or mechanically ground/scarified when passed through the digestive system of herbivores. The process of scarification depends upon 1): The species of herbivore ingesting the seed and 2): The intrinsic traits of the seed (Santamaría *et al.*, 2002). The effect of scarification depends on the retention time of the seed in the gut of herbivores and the type of food ingested with the seed by the herbivore. In addition, the process of scarification may also be influence by plant traits, such as seed coat, pulp composition, seed size and seed age. The process of scarification can be observed by comparing the seed germination patterns between the ingested and non-ingested seeds of the same plant species (Samuels & Levey, 2005).

However, long retention time is a disadvantage for the seed because the digestive fluid to which the seed is exposed may damage the embryo, which in turn reduces the seed viability (Pollux *et al.*, 2005). Stanley & Lill (2002) found that large seeds have short retention time in the gut compared to small seeds. Therefore, it is assumed that their germination may be less affected by the digestive fluid than small seeds.

2.3.3 Effect of fecal material

The residues of the food items eaten by the herbivores can affect the microenvironment following defecation which may have fertilizing effect on the process of seed germination (Cosyns *et al.*, 2005). Sometimes the presence of feces may reduce the germination process by promoting fungus and bacterial growth (Meyer & Witmer, 1998). In other cases, fecal material may protect the seed from the bacterial, fungus and species specific parasite attack (Fragoso *et al*., 2003).

Most herbivores vary in their food habits, due to which there is high difference in manure composition of herbivores that in turn may affect the process of seed germination. For example, growth of several species of *Acacia* (Mimosaceace) in dung differ significantly between the species of consuming herbivores; which is may be due to the variability in nutrient contents and water holding capacity of herbivore dung (Miller, 1995).

Some toxic compounds also present in herbivore manure can inhibit the process of seed germination. Animal wastes contain some phenolic compounds and also fatty acids, which inhibit the activity of enzymes in some herbaceous plant species that regulate the germination process (Marambe *et al.*, 1993). In addition, fruit pulp also provides the substrate to grow bacteria or fungi, which can affect seedling survival (Meyer & Witmer, 1998).

2.3.4 Effect of aggregation and seed mixing on germination

Depending on herbivore size and behavior, seeds that are ingested and defecated may be deposited into wide range of densities and also vary in degree of mixing. Most herbivores deposit seeds in fecal clumps after passing through animal gut. And this aggregation of seeds depends on the size of clump. Seed mixing and deposition also depends on the size of the animal and retention time in the gut (Takahashi & Kamitani, 2003). For example, Asian rhino (*Rhinoceros unicornis*; Rhinocerotidae) disperse the seeds in large defecations, which may weigh up to 23 kg and could potentially it contains thousands of seeds (Dinerstein & Wemmer, 1988).

Depending on animal size, seed density and deposition patterns, there may be a nonspecific or hetero-specific seed competition for light, space and nutrients. In addition, these density dependent factors may negatively affect germination and seedling success. So, this competition selection will tend to life history strategies which give the advantage for germination. These tactics may be the early seedling to beat the rush or induce the dormancy (Murray, 1998). In addition, seeds may also produce the allele-pathic chemicals, which are active against the nonspecific or heterospecific neighboring seeds (Suman *et al.*, 2002).

However, consequences of the aggregation or mixing of seed into clumps due to ingestion or deposition patterns by herbivores remains the least studied and understood aspect of seed dispersal. Nevertheless, seed germination and seed establishment success per seed is much higher in clumps than for seeds deposited singly.

2.4 Factors influencing seed fate and establishment

2.4.1 Effect of site and micro- site

Environmental conditions of the micro-habitat in which the seeds are deposited or defecated may influence the process of seed germination and establishment. Many studies have shown that successful seed establishment depends on the type of habitat where seeds are defecated, distance from parent plant, and survival from the pathogens. According to Bustamante *et al.* (1992), herbivores may promote seed germination by passing the seeds through digestive system. However, this may also be insufficient or inefficient for seed germination, if they defecated the seeds in high densities under parent plants or at places like caves and rocky outcrops where the necessary conditions for seedling establishment (light, humidity, temperature etc.) are not found.

Chemical traits of the soil where the seeds are defecated are also important for seed germination, because these can modify the osmotic pressure and also affect the metabolic rate which is important for seed germination (Traveset & Willson 1998).

2.4.2 Time when seed ingested and defecated

Time of season in which the seeds are consumed and then defecated is crucial for seed germination and establishment, especially for those plant species that have a long fruiting period encompassing the whole season. Seeds that are dispersed early in the season have higher or lower probability for seed germination than seeds dispersed later in the season depending on condition both biologically (predation, pathogens) and physically (water, temperature) (Traveset 1990). In addition, the seeds that emerge earlier in season may also outcompete those emerging subsequently (Loiselle, 1990)

2.4.3 Effect of other components in diet

Food selection is also an important factor which may affect the process of seed germination. Herbivore food selection depends on many traits like size, color and nutrient composition. For example, a herbivore may ingest large seeds which may be competitively superior to smaller seeds because larger seeds are more viable and have high germination rates (Banovetz & Scheiner 1994).

Similarly, those seeds that have the high nutritional and water contents in pulp can also affect the seed passage rates and retention time (Traveset *et al*. 1995).

2.4.4 Deposition matrix

Depending on food selection, the composition of feces can potentially affect seedling establishment. Most of herbivores consumed the mixed diet which results in variable composition of their excreta which may affect the seed germination (Herrera 1989).

According to (Quinn *et al*.1994) herbivore dung can increase both percentage and rate of seed germination. Fresh dung may have negative effect on seed establishment of suppress the vegetation, but when the dung partially decomposes then it has become the most favorable micro-habitat due to greater humidity and nutrients.

3.0 METHODOLOGY

Several reviews have synthesized empirical work or explained the theoretical aspects of herbivores and frugivore -mediated seed dispersal. These reviews include the detailed description of morphological and physiological characteristics of herbivores and frugivores, quality and distribution of food resources that ultimately affect the plant and animal interactions (Jordano, 2000; Corlett, 2011), the importance of seed dispersal to the ecology, evolution (Howe & Smallwood, 1982; Wang & Smith, 2002), and a survey of the scale at which seed dispersal processes are studied (Kollmann, 2000). In parallel, there have been a number of recent reviews in the field of animal movement (Borger *et al*., 2008). But none of these especially focus on the endozoochorous seed dispersal by herbivores and its potential effect on the seed germination. This is a critical need because this enables the development of a more mechanistic understanding of herbivore-mediated seed dispersal and open new avenues for researching that which biotic and abiotic factors influence the process of seed dispersal and seed germination.

To aid in this effort, I compiled studies that explicitly link endozoochorous seed dispersal, herbivores, and how animal digestive system affect on seed germination. I carried out a literature review to find out the herbivore-mediated seed dispersal and its effect on seed germination. The studies cover a broad range of herbivores (cattle, horse, sheep, deer, rabbit and birds), plant life-forms (trees, shrubs and herbs), and biomes (tropical rainforests, deserts, temperate forests etc.). For each of the selected studies, I determined: (*i*) which plants and animals are included for seed dispersal, (*ii*) the number of intrinsic and extrinsic factors which may affect the endozoochorous seed dispersal, (*iii*) factors affect the seed germination. I selected the past 20 -30 year literature for my research which is shown in Table (1). For this I searched the articles related to my topic from books, internet and from journals.

Table: 1. This table describes the various types of ecosystem which have different biodiversity and place studied by researcher.

Habitat type	**Country (Site)**	**Animal species**	**Plant species(dominated)**	**References**
Pleistocene sandy deposits and mosaic habitat	Dellebuursterheide (Netherland)	Cattle,Pony	*Juncus effuses*	Mouissie A.M *et al. 2005*
Coastal ecosystem	South Westhoek	Cattle, pony	Perennial grasses.	Cosyns.E *el al. 2005*
Mediterranean Grassland	North Madird(Spain)	Cattle,red deer,Fallow deer,Rabbit	*Cistus ladanifer, thermophytic pastures*	Malo E.J & Suarez F.1995
Deciduous Forest	Finger lake (New york)	White tailed deer	*Trillium*	Myers.J.A *et al.* 2004
Conifer forest	Thetford Forest (England)	Four species of deer	*Chenopodium album, Urtica dioica and Agrostis stolonifera*	Eycott A.E *el al.* 2007
Heterogeneous dune landscape	Belgian coast (Westhoek)	Cattle, Horse	*Hippophae rhamnoides and Ligustrum vulgare*	Cosyns.E *el al. 2004*
Semi-arid climate	Knersvlakte (South Africa)	Domestic herbivores	Aizoaceae	Haarmeyer D.H .*et al.* 2009
Serengeti National Park	Tanzania	Thomson's gazelle. Topi and Grant's gazelle	*Acacia–Commiphora*	Anderson T.M. *et al.* 2014
Polana Biosphere Reserve	Slovakia	Red deer	Deciduous fores, coniferous woodland	Steyaert S.M.J.G.,*et al.* 2009
Temperate grassland	West European	Rabbit,sheep, donkey,horse	Poaceae, Juncaceae, Cyperaceae	COSYNS E. *et al.* 2005
calcareous grassland	Netherland, Belgium	Sheep	*Mesobromion erecti*	Kuiters A.T. 2010
semi-steppe rangelands	Iran	Sheep,Cattle	*Gramineae*	Fazelian S. *et al.* 2014
Island	Ryukyu Archipelago	Deer	*Castanopsis sieboldii, Machilus thunbergii*	Yamashiro A. 2006
Tropical rain forest	Costa Rica	Birds	Pasture, pine apple, coffe	Pejchar L. *et al.* 2008

3.1 Herbivory phase: which seeds are consumed and in which manner?

Herbivory phase depends on behaviors associated with seed preference, selection, manipulation and ingestion of seeds by herbivore dispersers. The type and quantity of seeds taken and dispersed by herbivores are determined during this phase and are primarily influenced by morphological (e.g. size), physiological (e.g. nutritional requirements) and behavioural (e.g. reproductive status, social interactions) characteristics of the animals relative to those of the dispersed plants which are mentioned in Table 2.

Table 2. Various Intrinsic and Extrinsic factors (biotic and abiotic) that may affect the herbivory and seed deposition phase.

Factors	Herbivores	Plants	Abiotic
Intrinsic	Body size	Fruit	NA
	Nutrient requirement	Crop size	_
	Age/Sex	Nutrient content	_
	Digestive system	Color	_
	Home range size/Territory	Accessibility	_
	Reproductive status	_	_
Extrinsic	Abundance	Abundance	Light incidence
	Competition	Plant aggregation	Temperature
	Predation	Community phenology	Topography
	_	Vegetation structure	Climate
	_	_	Soil

4.0 Role of endozoochory in seed dispersal and seed germination

4.1 Quantity and species composition of seed in dung

Herbivores disperse a large number of seeds through their dung. Table 3 shows the total amount of seeds germinating from herbivore dung, seed density in each dung sample, total plant species germinated, and the weight of dung sample used in the experiment.

Table: 3.This table shows the total amount of plants which were germinated from different dung samples. (-) indicate unknown value.

Germinated seeds(seedlings)	**Seed density (Average of all species/each dung sample)**	**Total plant species**	**Samples (grams)**	**References**
6557	-	85	1	Mouissie A.M *et al. 2005*
29782	-	99	2.5	Cosyns.E *el al. 2005*
11967	28.8	107	3	Malo E.J & Suarez F.1995
3431	3	72	18-25	Myers.J.A *et al.* 2004
9648	1.8	101	0.01	Eycott A.E *el al.* 2007
59,049	31	117	2.5	Cosyns.E *el al. 2004*
909	31	152	10	Haarmeyer D.H *.et al.* 2009
700	4.9	53	40	Anderson T.M. *et al.* 2014
2834	-	43	200-400	Steyaert S.M.J.G.,*et al.* 2009
-	-	19	150	COSYNS E. *et al.* 2005
11 130	10.2	72	611	Kuiters A.T.& Huiskes H.P.J. 2010

	-	39	-	Fazelian S. *et al.* 2014
19,273	-	35	2.5	Yamashiro A. 2006
-	112.5	65	-	Pejchar L. *et al.* 2008

4.2 Seed dispersal success rate of gut passed seed species

Table 4 shows the different plant families dispersed by in the dung of six different animals (deer, horse, cattle, sheep, rabbit and herbivore birds). Seeds from a total of 31 plant families were found in dung from these five animals based on research papers of the last 20 years. Of these 06 herbivores, cattle dispersed the most; 25 plant families were germinated from cattle dung. Sheep dispersed 24 plant families, while from horse, rabbit and birds dung 14, 12 and 09 plant families were dispersed, respectively. Deer was the poorest disperser among all by which 06 plant families were dispersed or germinated.

Table 4: Shows the different type of plant families disperse by herbivores. (+) indicates the plant families dispersed by herbivores, while (-) indicates that plant families not dispersed by that herbivores dung.

Plant Families	Seed size	Herbivores						References
		Deer	Horse	Cattle	Sheep	Rabbit	Birds	
Caryophyllaceae	S	+	-	+	+	+	+	Malo E.J & Suarez F.1995, Haarmeyer D.H. 2009, Mouissie A.M *et al*. 2005; Whelan J.C. *et al.* 2008
Leguminosae	S	+	-	+	+	-	+	Malo E.J & Suarez F.1995, Kuiters A.T.& Huiskes H.P.J. 2010, Whelan J.C. *et al.* 2008
Brassicaceae	S/M	-	-	+	+	+	+	Malo E.J & Suarez F.1995, Haarmeyer D.H .*et al.* 2009, Whelan J.C. *et al.* 2008
Geraniaceae.	S/L	+	-	-	-	-	-	Malo E.J & Suarez F.1995
Asteraceae	S	-	+	+	+	+	-	Malo E.J & Suarez F.1995, COSYNS E. *et al.* 2005, Haarmeyer D.H. 2009
Poaceae	S	+	+	+	+	+	+	Malo E.J & Suarez F.1995, Cosynse. *et al.* 2005, Haarmeyer D.H .*et al.* 2009, Mouissie A.M *et al*. 2005, Whelan J.C. *et al.* 2008
Cystaceae	S	-	+	+	+	+	-	COSYNS E. *et al.* 2005

Cyperaceae	S	+	+	+	+	+	+	Cosynse. *et al.* 2005, Yamashiro A. 2006, Whelan J.C. *et al.* 2008
Fabaceae	S/M	-	+	+	+	+	+	Cosynse. *et al.* 2005, Haarmeyer D.H .*et al.* 2009, Whelan J.C. *et al.* 2008
Gentianaceae	S	-	+	+	+	+	-	Cosynse. *et al.* 2005
Juncaceae	M	-	+	+	+	+	-	Cosynse. *et al.* 2005, Mouissie A.M *et al*. 2005
Lamiaceae	S	-	+	-	+	+	-	Cosynse. *et al.* 2005
Plantaginaceae	S	-	+	+	+	+	-	Cosynse. *et al.* 2005
Rubiaceae	S/M	-	+	+	+	-	-	Cosynse. *et al.* 2005
Scrophulariaceae	S	-	+	+	+	+	-	Cosynse. *et al.* 2005, Haarmeyer D.H .*et al.* 2009
Aizoaceae	S/L	-	-	+	+	-	-	Haarmeyer D.H .*et al.* 2009
Chenopodiaceae	S	-	-	+	+	-	-	Haarmeyer D.H .*et al.* 2009, Kuiters A.T.& Huiskes H.P.J. 2010, Fazelian S. et al. 2014
Solanaceae	S	-	-	+	+	-	-	Haarmeyer D.H .*et al.* 2009
Ericaceae	S	-	+	+	+	-	-	Mouissie A.M *et al*. 2005
Ranunculaceae	S	-	+	+	+	-	-	Mouissie A.M *et al*. 2005

Lythraceae	M	-	+	+	+	-	-	Mouissie A.M *et al*. 2005
Urticaceae	M	-	+	-	+	-	-	Mouissie A.M *et al*. 2005, Kuiters A.T.& Huiskes H.P.J. 2010
Onagraceae	?	-	-	+	-	-	-	Mouissie A.M *et al*. 2005
Labiatae	S/M/L	-	-	+	-	-	-	Mouissie A.M *et al*. 2005, Kuiters A.T.& Huiskes H.P.J. 2010, Fazelian S. et al. 2014,
Gramineae	S	+	-	+	+	-	-	Kuiters A.T.& Huiskes H.P.J. 2010, Fazelian S. *et al.* 2014, Yamashiro A. 2006
Guttiferae	?	-	-	-	+	-	-	Kuiters A.T.& Huiskes H.P.J. 2010
Compositae	S	-	-	+	+	-		Kuiters A.T.& Huiskes H.P.J. 2010
Cruciferae	?	-	-	-	+	-	+	Kuiters A.T.& Huiskes H.P.J. 2010, Whelan J.C. *et al.* 2008
Papilionace Ae	M	-	-	+	-	-	-	Fazelian S. et al. 2014, Kuiters A.T.& Huiskes H.P.J. 2010
Rosaceae	S/M	-	-	+	-	-	+	Fazelian S. et al. 2014, Kuiters A.T.& Huiskes H.P.J. 2010,Gracia D.*et al*.2009, Whelan J.C. *et al.* 2008
Moraceae	S	+	-	-	-	-	+	Yamashiro A. 2006, Whelan J.C. *et al.* 2008
Total plant families: **31**		**07**	**15**	**25**	**24**	**12**	**09**	

Figure (3) shows the dispersal of the seeds of different plant families by herbivores (deer, horse, cattle, sheep and rabbit). Poaceae and Cyperaceae are the most common families dispersed and germinated from dung of all six herbivores, followed by Fabaceae and Caryophyllaceae which are dispersed by five herbivores. Asteraceae, Cystaceae, Gentianaceae, Plantaginaceae, Scrophulariaceae. is dispersed and germinated through the dung of four herbivores. Onagraceae, Papilionaceae and Labiatae was only found in cattle dung and Moraceae only dispersed by the deer and birds dung.

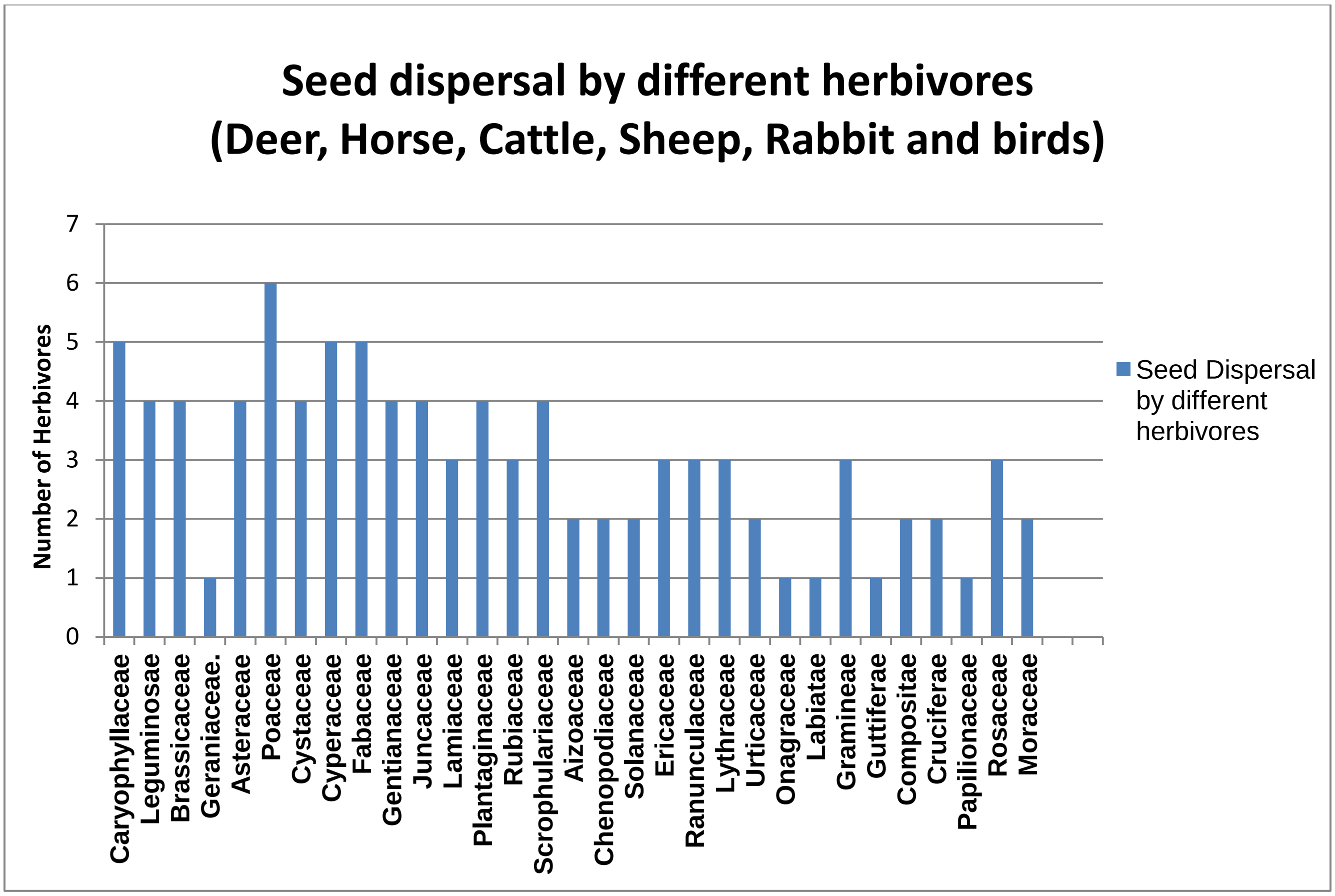

Figure 3: This bar graph describes the dispersal rate of different plant families by herbivores**.**

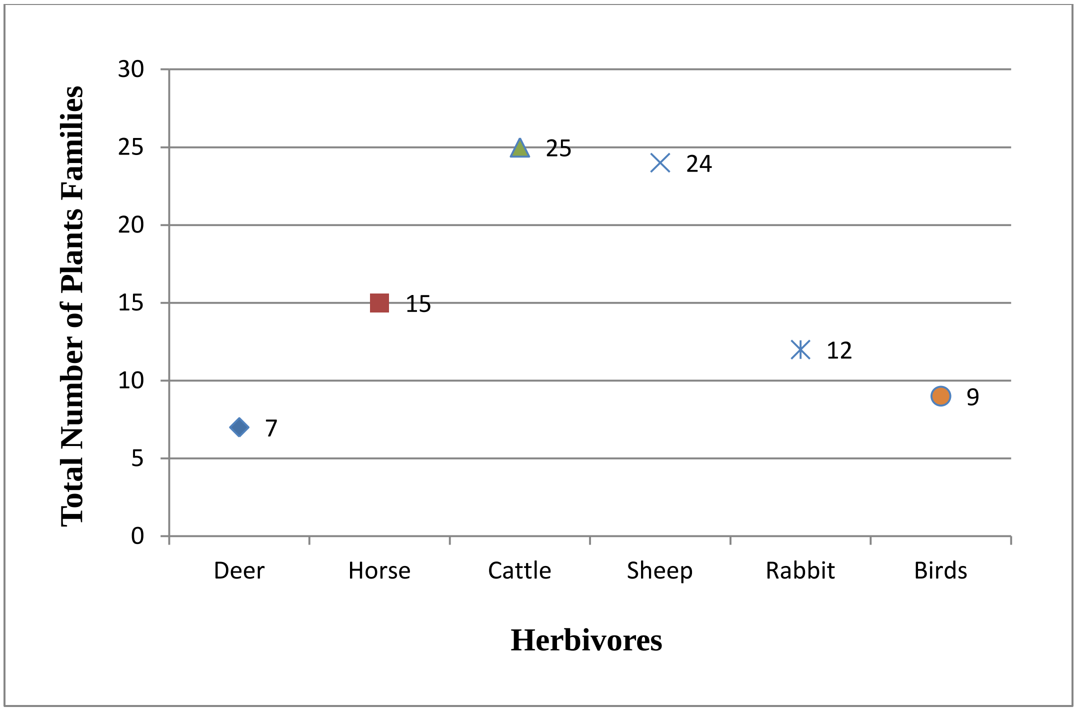

Figure 4: This graph shows the total number of the plant families which are dispersed from herbivore dung. (♦) represents plant families disperse by deer, (▪) represent the plant families disperse by horse, (◄) represents the plant families disperse by cattle, (x) represents the plant families disperse by sheep and (*) represents the plant families disperse by rabbit and (●) represents the plants families disperse by birds.

4.3 Role of endozoochory on seed germination and seed survival rate

Seed germination and survival rate depends on the seed mass and impermeability of the seed coat. Table 05 describes difference in seed survival, seed germination rate in both treated and controlled samples.

Table 05: This table describes the percentage of seed survival both (treated and controlled), percentage germination of seeds and percentage speed of seed germination of both (treated and control), While *P* value indicate the difference between two treatments.

Plant species	**Plant Family**	**Survival percentage**			**Germination percentage**			**Germination speed(T50)**			**References**
		Treated	**Control**	***P***	**Treated**	**Control**	***P***	**Treated**	**Control**	***P***	
A. arvensis	Compositae	14.67	95.33	0.002	14.17	85.67	0.002	4.5	2.50	1.000	Peco. B *et al.*2006
A. granatense	Cruciferae	40.17	99.50	0.002	0.50	93.17	0.002	20.50	6.50	0.1000	Peco. B *et al.*2006
A. integrifolia	Compositae	17.33	100.00	0.002	0.33	67.33	0.002	13.00	11.33	0.611	Peco. B *et al.*2006
A. pelecinus	Leguminosae	67.17	100.00	0.002	1.50	3.00	0.093	21.40	8.17	0.063	Peco. B *et al.*2006
B. barrelieri	Cruciferae	11.00	100.00	0.002	1.50	72.17	0.002	31.40	2.50	0.005	Peco. B *et al.*2006
C. rapunculus	Campanulaceae	5.83	80.33	0.002	2.50	42.50	0.002	33.80	10.17	0.005	Peco. B *et al.*2006
C. mixtum	Compositae	39.00	98.67	0.002	37.17	97.83	0.002	6.50	6.50	1.000	Peco. B *et al.*2006
F. lutescens	Compositae	2.50	76.83	0.002	0.67	67.67	0.002	29.33	6.00	0.016	Peco. B *et al.*2006
J. Montana	Campanulaceae	62.00	100.00	0.004	0.00	82.50	0.004	-	6.67	-	Peco. B *et al.*2006

J. bufonius	Juncaceae	45.67	95.17	0.002	25.33	12.33	0.18	5.00	9.50	0.241	Peco. B *et al.*2006
L. stoechas	Labiatae	61.50	100.00	0.015	0.50	62.33	0.002	19.67	7.00	0.039	Peco. B *et al.*2006
O. compressus	Leguminosae	49.00	100.00	0.004	0.60	62.33	0.004	7.00	6.83	0.783	Peco. B *et al.*2006
P. latifolia	Scrophulariaceae	4.50	100.00	0.002	0.00	0.00	-	-	-	-	Peco. B *et al.*2006
P. nanteuilii	Caryophyllaceae	39.67	100.00	0.002	20.67	98.33	0.002	7.17	7.00	0.799	Peco. B *et al.*2006
P. coronopus	Plantaginaceae	24.67	84.17	0.002	21.83	55.67	0.002	7.17	4.00	0.288	Peco. B *et al.*2006
P. lanceolata	Plantaginaceae	51.83	94.67	0.002	46.33	54.33	0.132	6.83	12.50	0.012	Peco. B *et al.*2006
R. acetosella	Polygonaceae	9.33	100.00	0.002	0.33	0.17	0.937	17.00	20.00	0.317	Peco. B *et al.*2006
S. gallica	Caryophyllaceae	11.33	100.00	0.002	7.67	69.00	0.002	20.00	2.50	0.005	Peco. B *et al.*2006
S. purpurea	Caryophyllaceae	8.5	75.50	0.002	2.50	34.83	0.002	7.20	12.00	0.029	Peco. B *et al.*2006
T. barbata	Compositae	45.83	100.00	0.002	0.50	69.50	0.002	43.00	6.50	0.105	Peco. B *et al.*2006
T. subterraneum	Fabaceae	41.25	97.00	0.05	30.00	97.00	0.05	-	-	-	Leyton J.M. &Vicente A., 2011

L. rigidum	Apiaceae	68.78	94.00	0.05	58.33	90.00	0.05	-	-	-	Leyton J.M. &Vicente A., 2011
Arenaria serpyllifolia	Caryophyllaceae	-	-	-	1.59	19.3	0.009	-	-	-	Wessels, S.C 2007
Medicago minima	Fabaceae	-	-	-	1.19	39.3	0.009	-	-	-	Wessels, S.C 2007
Phleum arenarium	Poaceae	-	-	-	0.20	82.1	0.009	-	-	-	Wessels, S.C 2007

Most species showed the less survival rate after ingestion. However, some species (*Lavandula stoechas, Astragalus pelecinus, Jasione montana, Plantago lanceolata, rigidum*) showed more than 50 % survival rate due to increase seed mass. Seed germination and germination speed also decreased of most plant species after the gut passage.The germination speed of some species like *B. barrelieri, C. rapunculus, F. lutescens, S. gallica,* and *L. stoechas* decreased after the treatment, while the germination speed of *S. purpurea and P. lanceolata, R. acetosella* increased after the germination due to impermeability of the seed coat. The rate of seed germination depends on seed size, seed shape, seed longevity and how the seed coat is impermeable; because ingestion may reduce the hardness of seed coat which may increase the germination speed.

Mean retention time in the gut also play an important role in seed survival rate and germination rate. For example, the percentage emergence of *T. subterraneum* was 33 % after 48 h (P = <0.05), which was reduced to 11.25 % after 72 h (P = <0.05) (Leyton &Vicente, 2011).

5.0 Conclusion

Herbivore dung is an important vector for seed dispersal of many plant species in different ecosystems, in term of both species composition and quantity. The number of viable seeds that are dispersed by herbivores is very high, which indicates that seed dispersal process by herbivores is important for plant communities (Janzen 1984). According to Welch (1985), cattle disperse 2.6 million seeds per animal, horse 0.5 million seeds per animal while sheep disperse 40 thousand seeds per animal every year. This high quantity and species diversity of seeds in herbivore dung indicates that endozoochory may affect plant community dynamics (Janzen, 1984). Some plant species may gain cover through endozoochorous seed dispersal, such as *Arenaria serpyllifolia* in limestone grassland (Dai, 2000) and *Biserrula pelecinus* in Mediterranean grasslands (Malo & Suarez, 1995). In Meditereanean dehesa Leguminosae is the most preferential plant family which is endozoochorously dispersed by herbivores (Malo & Suarez, 1995). In my review study, Poaceae and Cyperaceae are most common families which are dispersed and germinated by the herbivore dung, followed by, Caryophyllaceae, Fabaceae (Figure 3). Poaceae is also preferentially dispersed in heather grassland mosaics (Welch 1985) and also in Pleistocene sandy deposits and mosaic habitat (Mouissie *et al*. 2005).

Cosyns et al. (2005) recorded about 27% of plant species in the coastal dune grassland, which had viable seeds content in cattle and horse dung, while (Pakeman *et al*. 2002) recorded that 37% of the local plant species found in acidic grassland as viable seeds in sheep and rabbit dung. However, in Mediterranean grassland, the seed percentage of the local plant species varies from 30% (Malo & Suarez 1995) to 50% (Traba *et al*. 2003) which are endozoochorously dispersed by herbivores. The annual deposition of seeds by herbivores in Mediterranean grasslands is 30,000–40,000 seeds per m^2 in normal years, and can surpass 100,000 seeds per m^2 in years of high production (Ortega *et al*. 1997), while woody communities have 800–66,000 seeds/m^2 (Parker and Kelly 1989).

5.1 Factor determining the endozoochorous seed dispersal

There is very little experimental testing on ‘foliage is the fruit hypothesis’ published since Janzen’s publication (1984). This is may be due to the appealing character of this hypothesis, placing the large number of plant species, without any apparent adaptation for endozoochorous dispersal, into evolutionary perspective. Secondly, its formulation is not very specific, because all plant species do not have all those traits, which make the hypothesis difficult to test. Most of the aspects of ‘foliage is the fruit hypothesis’ cannot be argued. It has been experimentally proven that many plant species which have small seeds are dispersed via dung of herbivores (Welch 1985, Malo & Suarez 1995b, Pakeman *et al*. 2002). Moreover, Janzen’s statement is little arguing that seeds which are aggregated with attractive foliage are more often eaten by herbivores than the seeds which are not aggregated with the foliage. This controversial part of hypothesis suggests that foliage palate has been co-evolved with the ability of seed survival in the gut of herbivores.

According to my review, those plants which have smaller seeds are more likely to disperse by herbivores dung than those plants which have large seeds (Table 4). This is consistent with the other studies (Pakeman *et al*., 2002; Couvreur *et al*., 2004). This is due to positive relationship between the seed size and production, but not due to that they are better adapted to surviving during gut passage (Erikson & Jakobsson, 1998).

5.2 Germination success rate after gut passage

The seed passage through the animal gut may affect the fraction of seed germination. Seed dispersal process can be costly if it reduces the process of seed germination. Such reduction can occur, if the passage through the gut reduces the mechanical protection of seed coat. According to (Lennartz 1957; Özer 1979; Gardener *et al*. 1993) seed germination of all studied plant species is significantly reduced after gut passage of herbivores. However, on the other hand this cost can be offset, e.g. if animal deposit the seeds in very favorable microhabitats. Gut passage may also influence the germination process by effecting seed coats. In herbivore birds, there are some secondary compounds present in fruits like capsaicin which may increase the retention time of seed in gut due to constipative effect which may only occurs after the 80 minutes time lag. But longer retention in gut may reduce the germination of seeds; on the other hand this constipative effect may help to disperse the seeds at longer distances (Tewksbury *et al* 2008). Plant species with impermeable seeds also seemed to be indifferent to the treatment. In my studies I reviewed the germination success rate of six herbivores species (deer, horse, cattle, sheep, herbivores birds and rabbit). To check the dispersal/germination success rate I reviewed the past papers, all herbivores are involved in endozoochorous seed dispersal and according to my results, cattle are among the most seed disperser as compared to other herbivores (Figure 4), which is supported by the results of (Welch 1985).

According to (Illius & Gordon 1992), there is no relationship between mean retention time and germination success. Retention time of seeds is lowest in rabbit gut which is 31 hours while in cattle it is 71 hours, sheep 41 hours and in horse it is 66 hours. While birds can disperse the seeds at longer distances then other herbivores over short (0–100 m) to medium (100–20,000 m) distances which have mostly been recorded in terrestrial ecosystems. However, long-distance dispersal by birds is (20–1000 km or more), which is considered as a rare event because many herbivore bird which fed on plants generally migrate over longer distances than do other herbivores (Wenny & Levey, 1998). Seed germination success rate depends on the mastication and rumination by the herbivores (Mueller *et al*. 1998). Seeds which are ingested by herbivores can be damaged during rumination and also during mastication, and larger seeds have greater chance to damage during the molar grinding (Gardener *et al*, 1993).

6.0 Future Research Directions

Past research on the seed dispersal by herbivores has contributed greatly to my understanding of the roles of herbivores as seed dispersers. However, seed dispersal process by herbivores and their effect on seed germination deserve substantially more research (Richardson *et al*., 2000). According to my opinion a functional approach to this issue could be particularly valuable to understand the process of seed dispersal. By detailed analyses of fruits (chemistry, morphology and phenology), animal fruit choice and handling, and gut passage combined with herbivore movements and seed deposition, we may better understand the plant and animal relationship and also provide the better understanding in relation to seed dispersal patterns and plant spread (Pizo, 2002). Research in these areas is also likely to enable better prediction of the likelihood of adoption of fruit of new plant introductions by herbivores dispersers and their invasive potential.

In addition, long - term studies should be established and maintained, to understand and examine the temporal variations in seed dispersal mechanisms and the dynamics of plant recruitment to improve our understanding of the effects of seed dispersers on plant populations. Because there are several biotic factors and abiotic factors that could influence the establishment process of deposited seeds.

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