Brereton JE, J Food Sci Nutr 2021, 7: 090
DOI: 10.24966/FSN-1076/100090

HSOA Journal of Food Science and Nutrition

Review Article

Size Matters: A Review of the Effect of Pellet Size on Animal Behaviour and Digestion

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Abstract

Pelleted diets are now available for animals housed in a wide range of captive conditions including as pets, in farms, laboratories, zoos and aquariums. These diets provide several benefits to fresh foods, in that they typically have a long shelf life, require minimal preparation, and nutritional values tend to stay similar between batches. However, pelleted feeds may provide fewer opportunities for species-specific feeding behaviours, such as food manipulation, peeling and tearing. As a result, pelleted foods are sometimes used in tandem with other, fresh food items.

The dimensions of animal feed pellets differ between brands, the species they are intended for, and sometimes between animal life stages. The size of a pellet has been shown to influence its digestion speed, with smaller pellets breaking down much more rapidly than larger items, even when the nutrient content is the same. Pellet size can therefore affect the nutrient bioavailability, and gut health of animals, with negative effects of very small pellet sizes for ruminants.

Pellet size is also known to have a considerable impact on the feeding behaviour of a range of species. For example, pigs (*Sus scrofa*), chickens (*Gallus gallus domesticus*) and orange-winged Amazon parrots (*Amazona amazonica*) show preference for larger pelleted items. In rodents such as rats (*Rattus spp*.), larger pellet sizes have been shown to encourage hoarding behaviour, thus changing the way in which the animals interact with their feed. For fish such as salmon (*Salmo salar*), pellet size can influence both feed conversion and motivation.

Despite considerable research on several commonly-housed species, there remain gaps in the field of pellet development and its effect on behaviour and digestion. Filling of such gaps would help feed manufacturers and animal caretakers to make more informed decisions about the pellets they provide for their subjects, and the potential behavioural and digestibility effects of these.

Keywords: Digestion; Food waste; Hoarding behaviour; Motivation; Pellet diameter; Preference testing

Introduction

Pelleted feeds are now widely available across a range of captive animal settings, including laboratories, in zoos and aquariums, farms, and for pets [1-3]. Pellets have many benefits for animal managers, as they typically have a long shelf life, have a stable nutritional value, and require minimal preparation before providing to animals [4,5]. They can also reduce issues associated with selective feeders [6,7] and can be produced to take into account species-specific, or even life-stage-specific, nutrient requirements [8].

However, pelleted rations also present several challenges for captive animals. For example, animals have evolved different strategies to obtain food in the wild. For example, pigs (*Sus scrofa)* in semi-wild conditions tend to root through soil in order to find their food [9]. This rooting behaviour is believed to be important and stimulating for the overall welfare of the pig [10]. The use of an entirely pelleted feed may therefore provide fewer opportunities for species-specific natural behaviours [7].

Pelleted diets vary considerably in their size, weight and dimensions (e.g. [11]). The pellet size often varies between brands, and also as a result of differences in target species [2] and sometimes between life stages [12,13]. Pellet size may have a considerable influence on both nutrient digestibility and animal feeding behaviour, such as food manipulation and feed-related aggression [14,15]. It is therefore important to investigate the potential effects of pellet dimensions on animal behaviour and digestibility, and to identify gaps in this field of study.

Methods

Relevant papers were identified using a literature search. The search engine Google Scholar was used to identify papers: the database was searched from January 1960 to January 2021, to identify any relevant papers. To find relevant papers, the search terms animal food and pellet or particle or biscuit, plus diameter or dimension or *size* were utilised. Papers were utilised if they included a comparison of two or more pellet sizes, or compared pellet feeds to other feed styles such as mashes. Papers were excluded if they did not contain information relating to pellet size (for example, many papers covering faecal pellet sizes were identified, yet were not relevant.) The papers that were identified could be broadly speaking divided into two categories: those that considered behaviour (e.g. feeding behaviour, preference and motivation), and those that considered physiology (e.g. gut health and feed conversion).

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Citation: Brereton JE (2021) Size Matters: A Review of the Effect of Pellet Size on Animal Behaviour and Digestion. J Food Sci Nutr 7: 090.

Received: February 08, 2021; **Accepted:** February 11, 2021; **Published:** February 20, 2021

Effect on behaviour

Preference and motivation: There is evidence to suggest that food pellet size, even when the nutritional breakdown is similar, can affect food-based motivation and preference for a range of avian and mammalian species. For example, Rozek & Millam [7], identified that Amazon parrots (*Amazona amazonica*) were willing to lift weights of up to 480g in order to gain access to oversized pellets, which were 20-30 times the size of standard pellets. The birds were willing to lift these weights even when the same food (in its normal size) was freely available in the exhibit [6].

Similar results in terms of motivation have been identified in the pigeon (*Columba livia domestica)*. In experiments, pigeons engaged more with trained key pecking and gaping behaviours when larger pellets were offered as rewards [14].

For farmed pigs, the situation is more complex. Comparative studies on pre- and post-weaning pigs were conducted, using pellet size as a variable [16]. Before weaning, piglets spent significantly more time engaged in trough-directed behaviours when a larger (5.0mm) versus a smaller (1.8mm) pellet was provided. However, after weaning, the effect of pellet size on behaviour disappeared. Similar findings were identified for piglets in a more recent study involving small (2.0mm) and larger (12.0mm) pellets. Both studies suggested that this effect suggests that larger pellet sizes increased interest in feeding for piglets, thus resulting in a higher intake of solid matter before weaning occurred [17].

Feeding behaviour, manipulation and hoarding: The up-scaling of pellet size necessarily presents handling challenges for many species. It may not always be possible to consume larger pellets without gnawing or breaking down the item. Over-sized pellets, such as those in Rozek et al's [6], parrot study, required species-relevant gnawing behaviours in order to be ingested.

Production of pellets of an ecologically relevant size may therefore provide animals with opportunities to express naturalistic behaviours. For example, experimental manipulation of dry food size for dogs (*Canis lupus domesticus)* revealed that larger pellets encouraged dogs to chew their food more [18]. This resulted in greater use of the molars, resulting in a 42% reduction in dental calculus when 50% larger pellets were provided.

In fish farming, some pellets may actually be close to the optimal size, or even exceed the optimum for encouraging feeding behaviour. A comparative study of pellet sizes for farmed Atlantic salmon (*Salmo salar)* identified that salmon were much more likely to capture larger food pellets [8]. However, the largest pellets were also the most likely to be rejected once they had been captured, resulting in a much greater wastage of food. There may therefore be an optimal size for food particles, which is likely to be both captured and accepted by the fish [8,12].

The modification of food pellet size might change food processing behaviour entirely [19]. Some animals practice hoarding behaviour in order to ensure a supply of food during periods of shortage: hoarding behaviour is well recognised throughout many rodent species. One species that has received considerable attention in food pellet size behavioural research is the rat (*Rattus norvegicus)*. When provided with small food items, captive rats generally close to the food resource and swallow the pellets at the source [20]. However, when medium sized food items were provided, the rat often changed posture, sitting on its haunches to feed. When provided with large food items, hoarding behaviour occurred most commonly: the rat tended to take the food pellet and move it to a refuge for caching [20]. These findings have been identified by multiple studies: increasing difficulty to travel to the refuge reduced but did not eliminate the hoarding behaviour [21-23]. Rats were also more likely to hoard when hungry [24].

The potential value, or issues, with hoarding behaviour, have not been investigated fully in terms of animal welfare. On one hand, hoarding occurs naturally in a wide range of rodents and other taxa [25] and therefore expression of the behaviour may be valuable to animals. On the other hand, food hoarding might present a management challenge, particularly when animals are on a strict diet. Hoarding behaviour occurs in a wide range of commonly housed animals (e.g. hamsters (*Mesocricetus auratus*) and mice (*Mus musculus*) so more research onto its potential welfare value would have merit [2].

Social behaviour: Many animals housed in farms, zoos and aquaria are held, and also fed, in groups. Group housing can pose challenges when feeding animals, as hierarchy might dictate that some animals feed last, or are subject to feed-related aggression [3,26].

While there is currently limited evidence on food pellet size effects in zoological collections, parallel research on food particle size has been undertaken for a range of species. One primate genus, *Macaca*, has received considerable research focus [27]. For two studies, increasing the size of food particles also reduced aggression between members of the group [19,27], whereas one study revealed a positive correlation between food size and aggression [28]. However, there were differences in methodology: Mathy & Isbell's [28], project involved providing only a couple of food items at a time to a group of macaques, whereas other studies involved providing enough food for all individuals. If enough food is provided that all animals can access items, it appears that in macaques, aggression is reduced.

Similar findings were identified in a group-housed carnivore, the coati (*Nasua nasua*) [15]: when larger items were provided, aggressive interactions decreased. This initially appears to match the findings of the earlier rodent studies [22]: When larger food items were provided, animals took the items to refuges where they could eat the meal. This then indirectly reduced aggression because animals were not directly competing over food resources (Table 1).

Effect on physiology

Effect of pellet size on digestibility: It appears counterintuitive that pellets that are made from identical ingredients might differ in their digestibility. However, pellet size does influence the ease with which animals can gain nutrients from their food. In general, smaller food items are often digested more rapidly [29,30]. This is because smaller items have a proportionately much higher surface area: mass ratio, resulting in absorption of nutrients potentially occurring more quickly [29]. As a result, the nutrients and energy from small-sized pellets may become available faster to animals than larger items [29]. Chewing action may, however, buffer this effect as large pellet items are fragmented into smaller particles.

Species	Study type	Effect	Citation
Rat (*Rattus norvegicus*)	Small versus large pellets	Small pellets were eaten at source. Large pellets were hoarded.	[20]
	Small versus large pellets	Increasing the distance between refuge and food reduced hoarding behaviour.	[21]
	Small versus large pellets	Hoarding behaviour additionally increased when rats were hungrier.	[25]
	Smallversus medium and large pellets	Medium sized pellets resulted in change in posture.	[22]
Pig (*Sus scrofa*)	Small versus large pellets	Pre-weaned pigs spent more time at the trough when provided with larger pellets. No effect on post-weaned pigs.	[16,26]
Amazon parrot (*Amazona amazonica*)	Oversized pellets versus normal pellets	Strong preference shown for oversized pellets. Birds were willing to lift weights to gain access to oversized pellets.	[6,7]
Atlantic salmon (*Salmo salar*)	Range of pellet sizes	Salmon were most likely to capture large food items. However, rejection was also high for the largest pellet sizes.	[8]

Table 1: Effect of pellet types on behaviour.

For ruminants, the pellet digestibility is of particular significance. Many ruminants such as cattle (*Bos tauros*) are adapted to high-fibre diets that require fermentation by rumen microbes as part of their digestion [31]. In farms, the animals may be provided with a concentrate feed in addition to high-fibre foods such as hay, in order to provide sufficient energy [32]. Concentrates, due to their greater digestibility, often pose a risk of rumen acidosis when provided in large amounts [31]. Additionally, risks are increased because many domestic and exotic ruminants preferentially select concentrates over high-fibre foods, resulting in an exacerbation of physiological issues [33].

Smaller pellet sizes may therefore accentuate digestibility problems in foregut fermenting species such as ruminants [34]. Whilst pellets may not be the most appropriate food item nutritionally for ruminants, a larger pellet may help to buffer against some of the effects of rumen acidosis.

Feed conversion and waste: Feed conversion is of particular importance in the farming industry: strategies to reduce waste and improve feed conversion can directly translate into profit [1]. Similarly, animal farmers may measure performance of animals (how quickly they reach a predetermined weight) as a measure of diet success. Pellet size effects have been studied in a range of farmed species including pigs, chickens [13] and fish [12].

The evidence on pellet size effects on feed conversion is complex and is sometimes at odds with the behavioural motivation literature. For example, in pigs there was no effect of larger or smaller pellet sizes on piglet performance [9,16,26], even though the animals showed a preference for larger items.

In chickens, larger pellets appeared to result in better performance overall [1]. Pellets appeared to be taken in larger quantities than mash [13]. Improved performance was also observed in comparative studies when chickens were provided with either a mash or pellet: pellet use was positively correlated with greater fat deposition [35,36]. Overall, inclusion of a greater amount of pelleted feed resulted in the development of a more muscular gizzard. This improved the bird's ability to break down, and therefore digest food [35,26,37].

In aquaculture, several studies have been conducted focusing on salmon. On one hand, some studies identified no effect of pellet size on growth of salmon, suggesting some plasticity in being able to take different pellet sizes [12]. In others, there was an optimal pellet size for good growth: however, this optimal size changed alongside the size of the fish [4]. Further research in this area is therefore beneficial.

Future directions

Species gaps: There remain may gaps in the scientific study of pellet size effects, particularly with regards to species representation. For example, species commonly housed in farms and in laboratories are well represented [20,35]. However, common household pets such as cats and dogs, both of which are commonly fed dry foods such as pellets and biscuits, appear rarely in the pellet size literature [18]. The potential effects of pellet size on behaviour preference and aggressive interactions therefore have yet to be fully explored. Similarly, pellet studies on exotic animals in the zoo and aquarium community remain rare, despite the wide range of species that housed in captivity and are fed pellets as part of their diet [2,11,38]. Without such studies, it is difficult to determine whether existing pellets are the optimal size for health, behaviour and that best meet the preferences of captive animals. Further research, to be shared with the animal-keeping and feed manufacturing communities, therefore could enhance animal welfare.

At current, there is insufficient data across a wide range of subjects to draw conclusions as to which species might benefit most from larger, or smaller, pellet styles. For example, the literature seems to suggest that Amazon parrots show a distinct preference for larger pellet styles. Further research, focusing on a wider range of Psittaciformes, could help to identify whether this trend occurs throughout the entire taxonomic class. Similarly, research covering a wider range of species in Rodentia would identify whether the trend toward hoarding large pellets is uniform across Order.

It is possible that the trends in behaviour observed may actually represent a more generic response to food size that is withheld across a range of taxa. Species of fish, primates, parrots chickens piglets and hamsters showed some similarity in that generally, larger pellets resulted in more interest in feeding. In the studies where the largest pellet sizes were provided (in proportion to animal body size), animals tended to take the food item to a refuge before either hoarding or eating the meal. This change of response alongside food particle size (small items are eaten *in situ*, and larger are transported) could represent a behavioural mechanism that has been withheld across many taxa. Further diversification of species covered, along with a greater diversity of pellet sizes (extra small versus oversized) would help to identify whether this trend exists.

Diversifying study outcomes: At current, there is limited crossover in terms of the types of pellet research practiced by each animal industry. For example, laboratory research has primarily focused

on behavioural research, particularly on hoarding behaviour and motivation [24]. In farming, the focus has been more on feed intake and performance. Diversifying the types of project that are conducted in each industry would be beneficial. For example, studies in the laboratory tended to use a repeated measures design, in which all study subjects were exposed to difference sizes of pellet [20]. By contrast, farming studies methods tended to separate animals into different groups, each of which received a different size pellet [8]. Mixing these methodological designs could provide greater insight into best practice pellet manufacture: preference tests in piglets or chickens would help to identify what animals consider most suitable (and how willing they are to work for different food sizes).

Conclusion

Whilst the effects of pellet size have been studied well for some species, notably those under farmed conditions, there remain major gaps in the literature on animal pellet size and its effects on behaviour and digestion. Finding the optimal pellet size for captive animals may improve social group cohesion by reducing opportunities for aggressive interactions, whilst also encouraging species-specific feeding behaviours. Examples that have been identified so far include the food manipulation and chewing behaviours seen in parrots and the hoarding behaviours identified in a range of rodents. To develop evidence-based decisions on optimal pellet size, feed manufacturers are encouraged to carry out and publish preference tests for a range of captive species, ideally using the same food but in different sized pellet rations. The results of these studies should be shared with the feed manufacturing community, allowing both keepers of animals and feed companies to produce pellets that not only promote good health, but also encourage animals to behaviour in a species-relevant manner. Further sharing and mainstreaming of this 'feedback' from animals on pellet design could therefore aid in reducing waste, and potentially enhancing performance in a range of species.

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