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READY, STEADY, CHOP! INVESTIGATING THE IMPACT OF CHOP SIZE ON ZOO FOOD NUTRITIONAL QUALITY

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ABSTRACT

It is common for animal keepers to chop food up for their animals into small pieces, yet there is limited information as to why this practice is done. Anecdotally, many collections also prepare their zoo animal diets the day before feeding and store them in the fridge overnight. The potential impact of these food preparation and storage methods on food nutritional quality is unknown. To address this, this study investigated the impact of preparing six types of produce into four sizes (0.5, 2, and 4 cm^3 cubes, or whole) on the desiccation, browning and pH scores. Samples were stored either under ambient, room temperatures, or stored in a fridge and analysis was conducted over a 24-hour period. The most severe desiccation levels occurred in finely chopped feeds, for both ambient and fridge-stored samples. Time significantly affected the rate of desiccation and browning, and food chop size was a significant predictor of both browning and pH. These results suggest that serious nutritional changes occur in chopped feeds, especially when they are finely chopped and especially when food is stored for more than a couple of hours prior to feeding. Practitioners who care for animals should consider whether their animals benefit from finely chopped feeds and should avoid the practice of storing chopped food overnight.

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GRAPHICAL ABSTRACT

RESEARCH HIGHLIGHTS

- Rapid changes in food pH, desiccation and browning occurred within 12 hours of chopping.
- Food chopped into small (0.5 cm^3) pieces resulted in desiccation levels of over 80%, even in the fridge.
- The act of chopping up zoo diets and storing them overnight may have serious consequences in terms of food freshness.

INTRODUCTION

Globally, over 26 billion animals from more than 10,000 species are held in captivity, with many of these species featuring in zoos and aquaria (Mason, 2010). From a nutritional standpoint, this vast array of species presents challenges in terms of dietary specialisms that zoos must tackle in order to maintain good animal welfare (Crissey, 2005). While zoo nutrition has developed as a discipline in its own right, historically it stems from an amalgamation of livestock and pet nutrition science (Das, 2018). Given the diversity of species, husbandry practices and unique problems in zoo nutrition, there remain many areas in need of evidence-based study (Melfi, 2009).

One area requiring further study is the field of food presentation. In zoos and aquaria, it is common practice for foods, especially fruits and vegetables, to be chopped up into small pieces for animals (Smith et al. 1989), even though wild animals would not find their food chopped up for them. It has been suggested that this practice could increase foraging opportunities for animals and reduce aggression (Waasdorp et al. 2021). However, observational study has demonstrated that aggression rates are actually reduced for some species, such as coatis (*Nasua nasua)* and macaques (*Macaca* spp.) when whole foods are provided (Smith et al. 1989; Sandri et al. 2017; Shora et al. 2018). In macaws (*Ara ararauna*), whole food provision was shown to be increase allofeeding; an important bonding behaviour in parrots (James et al. 2020), while there was no impact of food presentation on turaco (*Tauraco* spp.) behaviour and food intake (Griffin and Brereton, 2021). Clearly, there is no one-size-fits-all rule for zoo animal food presentation, but there is sufficient evidence to question whether chopping food is beneficial for all animal species.

The chopping of food has implications not only for animal behaviour, but also in terms of staff preparation time, food microbial contamination and nutrient value (Brereton, 2020). For example, James et al. (2020) demonstrated that keepers saved over three minutes of time when preparing whole food diets, as opposed to chopped foods, for parrots. The act of chopping increases the risk of microbial contamination through contact with knives and chopping boards, and the resulting moist food surfaces are more hospitable for microbes (Brackett, 1994; Redmond et al. 2004; Heaton and Jones, 2008). In the zoo environment, where food may stay within an animal exhibit for hours before being eaten, the nutritional consequences of chopping food are not well studied. Fortunately, however, some food presentation nutrient impacts are well studied in human food science (Hodges and Toivonen, 2008).

The term 'minimally processed' is commonly used to describe the practice of peeling or chopping up fruits and vegetables for human nutrition studies (Bansal et al. 2015). Minimally processed foods may be prepared for convenience (e.g. supermarket chopped salads) or as part of meal preparation (Hodges and Toivonen, 2008). Nutritionally, MP increases fruit and vegetable metabolism, as the act of cutting or blending is considered to be similar to wounding (Sasaki et al. 2006). The chopping process also destroys cell walls, thus liberating cell contents, and reduces the availability of vitamins (e.g. ascorbic acid) and antioxidants (Pyo et al. 2014; Picouet et al. 2016; Castillejo et al. 2017). These processes are generally increased with increasing temperature (as this increases metabolic rate), smaller chop sizes (which increase food surface area and degree of wounding) and time (Cocci et al. 2006; Sasaki et al. 2014). It is therefore important to find indicators of food nutrient breakdown that could be used by practitioners, particularly those working in the zoo kitchen or with animals. For example, desiccation could be used as an assessment of food quality, as it is affected by both chop size and ambient temperature (Hodges and Toivonen, 2008). However, indicators of nutrient value, such as vitamin and antioxidant availability are also required.

One quality that can be assessed for minimally processed fruits and vegetables is pH. In food science, pH changes are indicative of nutritional changes such as production or denaturing of acids. Some fruits and vegetables become more acidic as they degrade, largely as a result of ethylene production: examples include squash (*Curcubita moschata)* (Sasaki et al. 2014) and cantaloupe melon (*Cucumis melo*). As acidity increases, the palatability of food may decrease. On the other hand, some foods may become more alkaline as important acids, such as ascorbic acid (vitamin C) are denatured (Gramlich et al. 2002). This reduction in vitamin availability may reduce the resulting nutritional value of the food, and may mean that vitamin provision does not match the animal's nutritional needs. The assessment of food pH changes may therefore have merit in food presentation assessments.

Browning is commonly observed, particularly in pale fruits such as apples (*Malus domestica)* following chopping (Cocci et al. 2006). In human food preparation, browning of food is considered to be off-putting, and food production companies may spend money to chemically treat susceptible foods (Sasaki et al. 2014; Arnold and Gramza-Michałowska, 2022). Browning is caused by is caused by two enzymes: polyphenol oxidase and peroxidase, whose activities result in the breakdown of phenolic compounds and antioxidants (Arnold and Gramza-Michałowska, 2022). In addition to being a visual indicator, browning could be considered a proxy for underlying nutritional changes in foods that brown. Scientific browning indices are now available to assess this (Lunadei et al. 2011).

Zoo food presentation has the potential to affect animal welfare, well beyond its effects on behaviour. Anecdotally, many zoos are engaging in a practice whereby food is chopped up the day before feeding and kept in the fridge overnight. It has been suggested that this practice is undertaken to reduce workload during busy mornings. It is unclear what the impact of this practice is on food nutritional quality. In order to address these uncertainties, this study assessed changes in food pH, browning and desiccation commonly-fed fruits and vegetables. The study also investigated the nutritional impact of preparing food and storing it in the fridge prior to feeding.

MATERIAL AND METHODS

General Methods

This study was conducted at the laboratories at University Centre Sparsholt and took place between May and June 2022. Prior to study, he was granted ethical approval by the Sparsholt Ethics & Research Committee (Reference Number: UCSEC_9022). Two studies were conducted in order to investigate the types of food preparation being undertaken at the zoo: these consisted of an ambient temperature study, and a fridge storage study. To simulate the types of foods chopped up in a zoo kitchen, a range of commonly available fruits and vegetables were selected. For both studies, the fruits and vegetables used were sweet potato, parsnip, broccoli, pear, strawberry and banana (Table 1). For both studies, the fruits and vegetables were presented in four different formats: small (0.5cm^3), medium (2cm^3), large (4cm^3) and whole. All fruits and vegetables were chopped with a sharp steel knife at room temperature (which was recorded each day along with humidity prior to starting to chop). Once chopped, roughly 100 grams of food were placed into a silver bowl and was immediately weighed using a Precisa XB3200C scale (measured to the nearest 0.01 gram). Each food type was treated separately.

Table 1. Types of fruit and vegetable used in the study.

Common name	Scientific Name	Brand Used	Source
Pear	*Pyrus communis*	Tesco ripen at home	Tesco
Strawberry	*Fragaria × ananassa*	Taste the difference	Sainsburys
Banana	*Musa acuminata*	Tesco ripe and ready	Tesco
Sweet Potato	*Ipomoea batatas*	Tesco Sweet Potato Sweet and Smooth	Tesco
Parsnip	*Pastinaca sativa*	Tesco British Parsnip Sweet and Nutritious	Tesco
Broccoli	*Brassica oleracea*	Tesco Broccoli	Tesco

Ambient Temperature

For this study, food was prepared and was left in the laboratory under ambient conditions (to simulate a scenario where a keeper has prepared a diet but not yet placed the food in the exhibit). All size types of fruit and vegetable were used in this study. For each food type, three samples of food were prepared per chop size. For example, 12 samples of sweet potato were prepared overall, with three samples each prepared as 0.5cm^3, 2cm^3, and 4cm^3 cubes, and the final three samples prepared as whole potatoes. These samples were then left under ambient conditions. The temperature and humidity of the room was recorded using a digital thermometer and hygrometer each hour. After 2, 4, 6, 8, 10, 12 and 24 hours, the samples were tested for pH, browning and desiccation.

Desiccation was assessed by weighing the sample and deducting the weight of the sample from its original weight. Browning of browning-susceptible fruits and vegetables was assessed using a browning scale (0 to 10, where 0 indicates no browning and 10 indicates heavy browning) (Lunadei et al. 2011) and pH was assessed using pH indicator.

Fridge Storage

In this study, food was prepared using an identical method to that described in the 'ambient temperature' section, and the same quantities and types of foods were used. However, in this study, the food samples were placed in the fridge (temperature of 5^{o}C shortly after chopping, so as to simulate a keeper preparing food for the day after and storing it in the fridge. As for the ambient temperature study, the internal fridge temperature and humidity was recorded hourly. Care was taken keep the fridge door closed as much as possible when removing samples. At hours 2, 4, 6, 8, 10, 12 and 24, samples were removed and tested for desiccation, browning and pH as previously described.

Data Analysis

Data were collated using Microsoft Excel™ 2016, and Minitab version 21 was used for subsequent analysis. The ambient temperature and fridge storage studies were treated separately for the purposes of analysis. Percentage weight loss was calculated for each sample by deducting the sample's weight from its original weight, and then multiplying by 100. Fruit and vegetable types were pooled for the purpose of analysis.

To investigate the predictors of desiccation, a series of linear regressions were run, with percentage weight loss inputted as the response, and chop size, time (hours) inputted as categorical predictors, and temperature and humidity as continuous predictors. The Variance Inflation Factors (VIF) values were consulted in the resulting model, and where VIF values were high (above 10), the variables were removed. For example, food type was identified to have high VIF values for all ambient analysis, and as such this variable was removed from these analyses. For the browning and pH data, ordinal logistic regressions were run, as the pH and browning scales are ordinal rather than continuous. Chop size, food type and time (hours) were inputted as categorical predictors, and temperature and humidity were inputted as continuous predictors, with pH or browning inputted as the response.

RESULTS

Ambient Temperature

Overall, weight loss was most pronounced for the smallest chop size for all food types (Figure 1). Browning relationships were more complex for the four food types that browned (Figure 2). Time, temperature, humidity and size were significant predictors of food weight loss (Table 2). For pH, temperature, humidity and size were significant predictors, whereas for browning, only time and size were significant predictors.

Fridge Storage

Overall, small food sizes resulted in the greatest weight loss overall (Figure 3). Browning changes were more complex between food types but tended to change over time (Figure 4). There were significant effects of time, food size and food type on weight loss (Table 3). Browning was significantly impacted by time, size category and food type, and pH were impacted by size and food type only.

Table 2. Output of regression analysis for ambient temperature samples. * indicates a significant value.

Variable	R^2 (P)	Predictor	DF	SE Coefficient	T	P
Percentage weight loss	80.16% (P<0.001*)	Time	1	0.077	19.49	<0.001*
		Temperature ^{o}C	1	0.301	3.10	0.002*
		Humidity %	1	0.071	-4.03	<0.001*
		Size category	3			<0.001*
		Small-Medium		1.46	-26.10	<0.001*
		Small-Large		1.46	-31.99	<0.001*
		Small-Whole		1.45	-36.84	<0.001*
Browning	13.13% (P<0.001*)	Time	1	0.008	4.50	<0.001*
		Temperature ^{o}C	1	0.032	-1.45	0.148
		Humidity %	1	0.008	-1.63	0.103
		Size category	3			<0.001*
		Small-Medium		0.154	0.78	0.438
		Small-Large		0.154	0.87	0.383
		Small-Whole		0.153	-5.43	<0.001*

pH	6.85%	Time	1	0.002	1.57	0.117
	(P<0.001*)	Temperature °C	1	0.008	4.98	<0.001*
		Humidity %	1	0.019	2.53	0.012*
		Size category	3			0.068
		Small-Medium		0.039	0.61	0.541
		Small-Large		0.039	0.4	0.402
		Small-Whole		0.039	2.55	0.011*

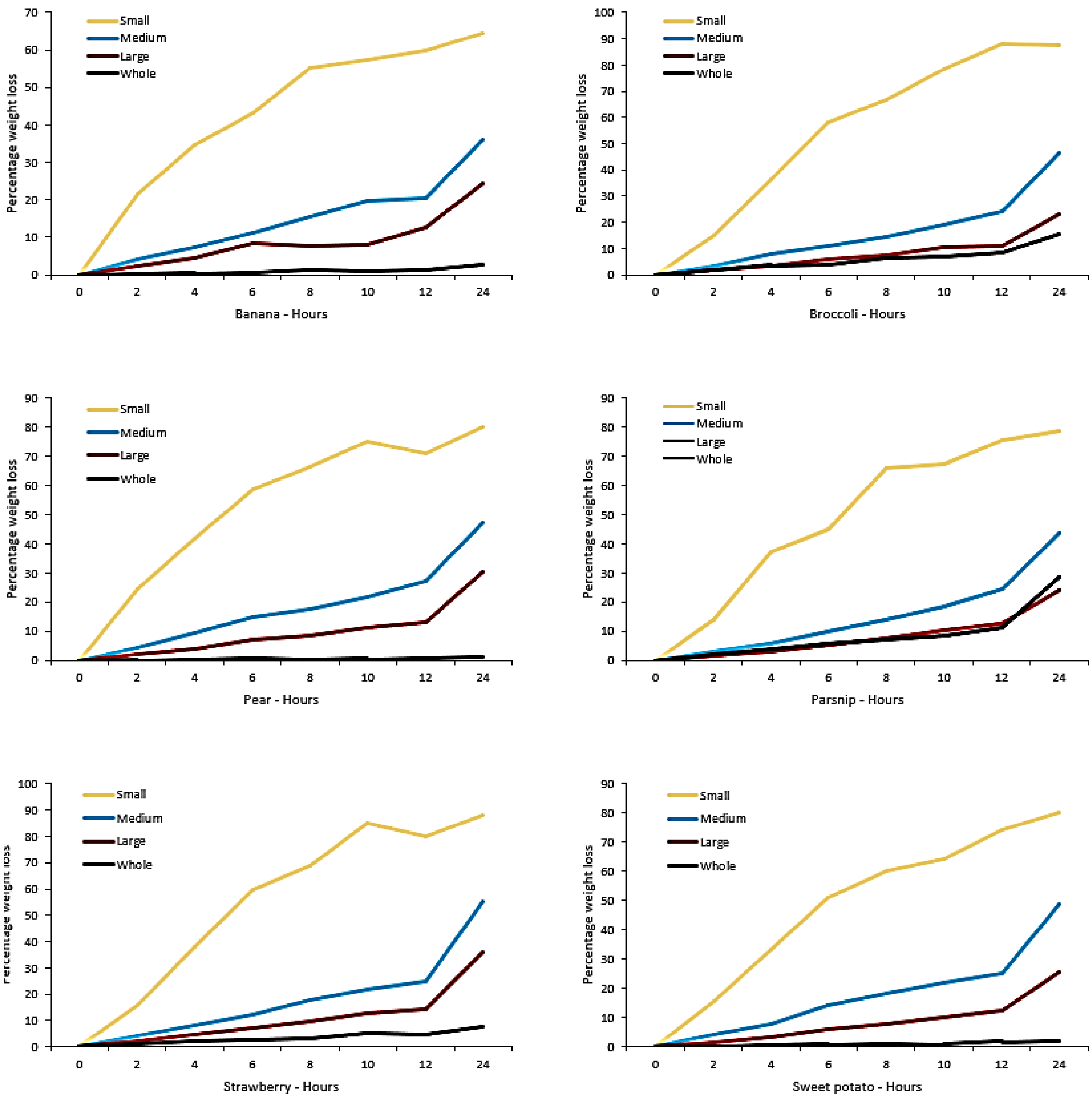

Figure 1. Percentage weight loss for all six food types over time, as separated by food size.

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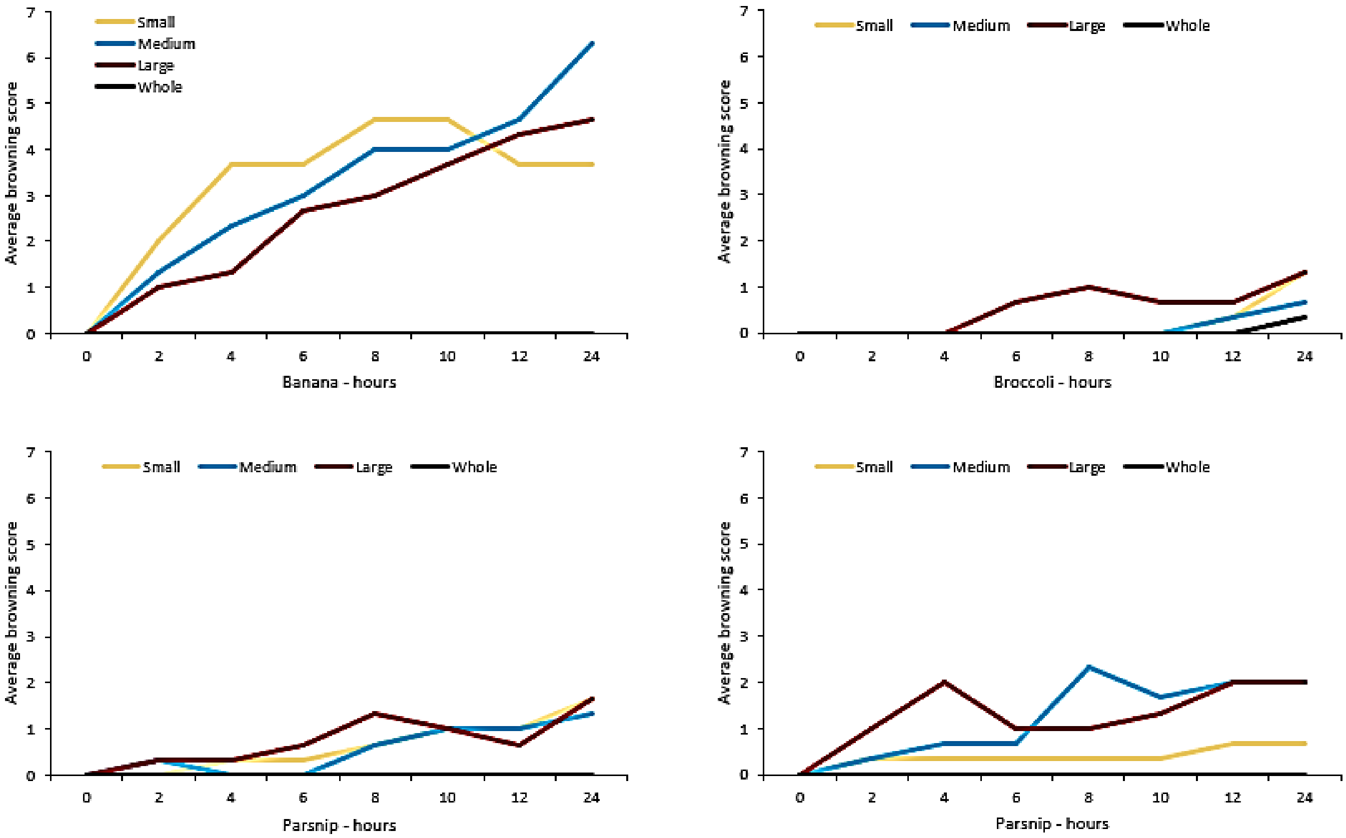

Figure 2. Browning changes over time for food size categories under ambient temperatures.

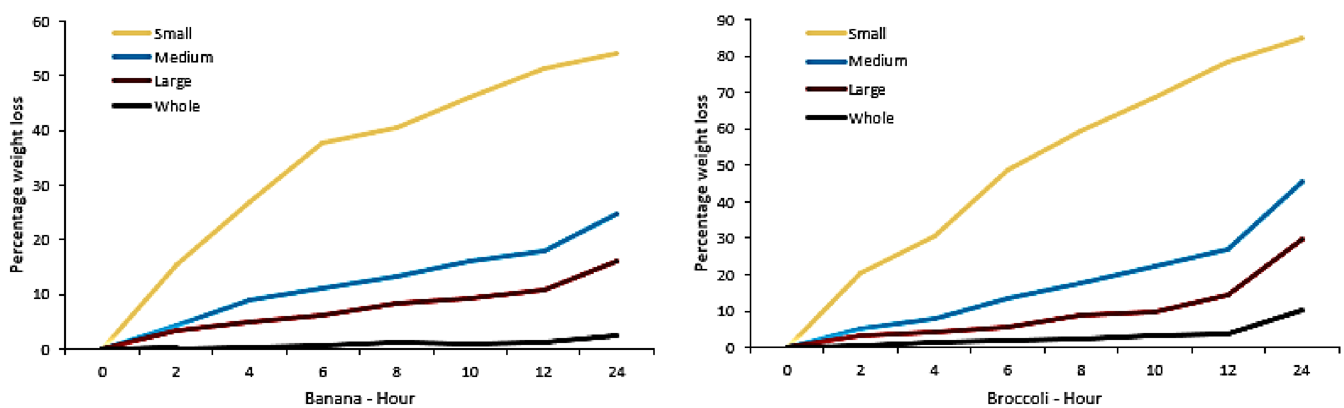

Figure 3(a). Percentage weight loss for all six food types over time for fridge-stored sampled, as separated by food size.

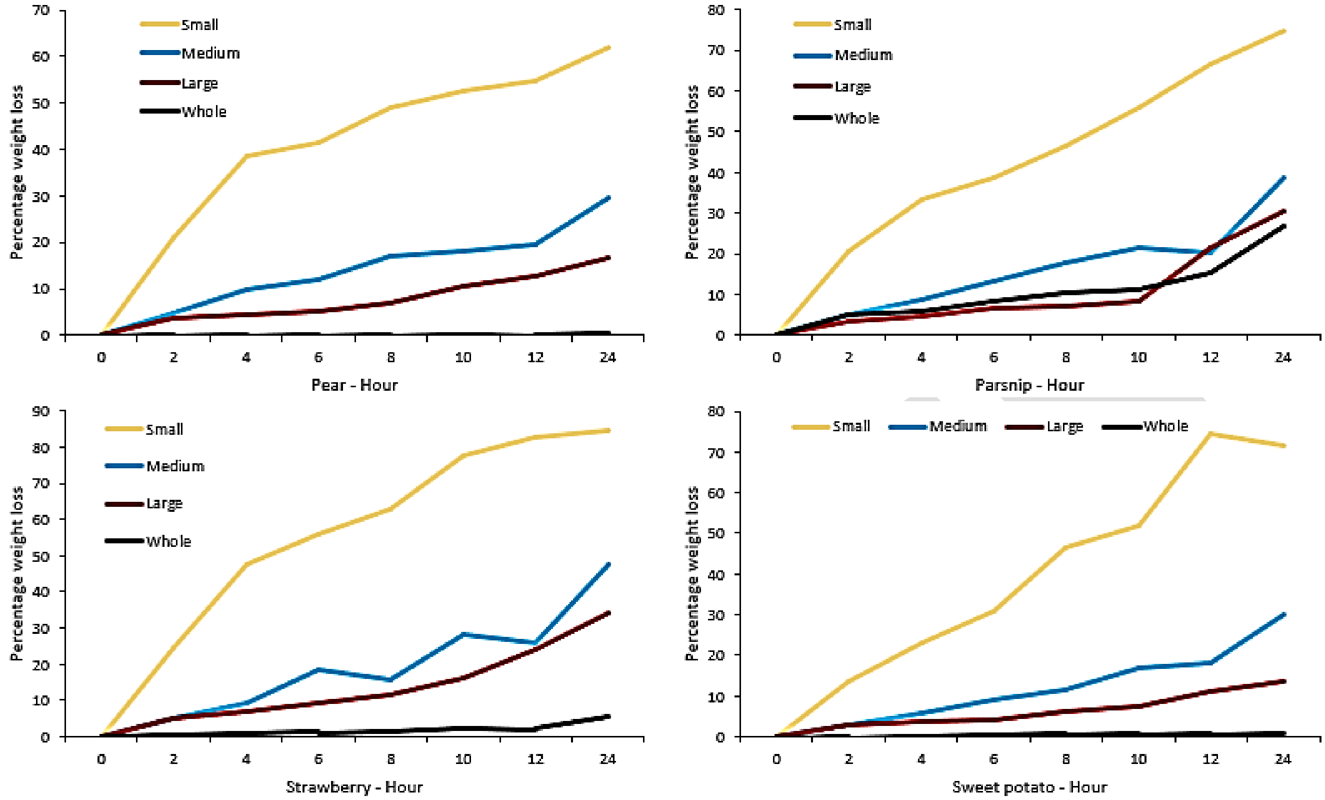

Figure 3(b). Percentage weight loss for all six food types over time for fridge-stored sampled, as separated by food size.

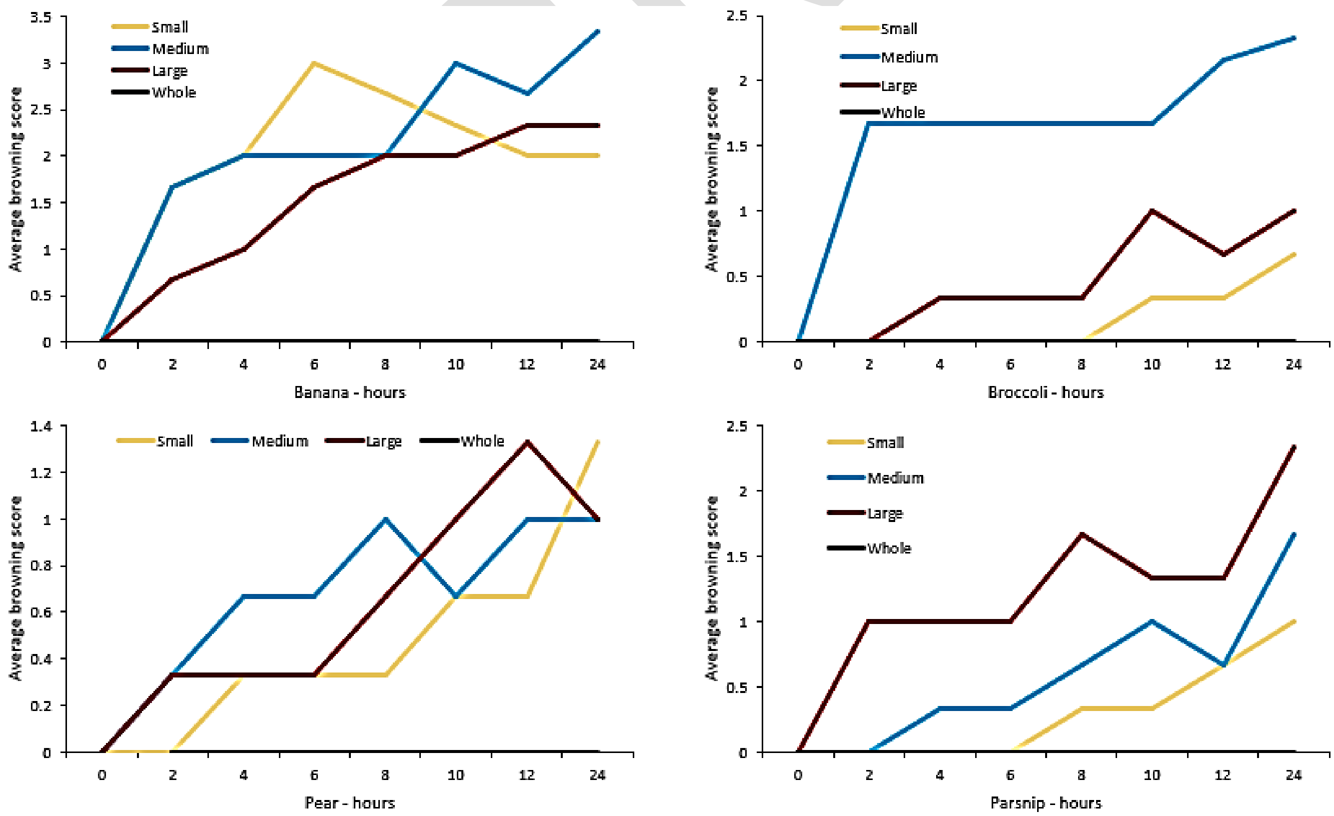

Figure 4. Browning changes over time for food size categories under fridge temperatures.

Table 3. Output of regression analysis for fridge storage samples. * indicates a significant value.

Variable	R^2 (P)	Predictor	DF	SE Coefficient	T	P
Percentage weight loss	56.24% (P<0.001*)	Time	1	0.109	11.18	<0.001*
		Humidity %	1	1.25	0.91	0.361
		Size category	3			<0.001*
		Small-Medium		2.08	-14.21	<0.001*
		Small-Large		2.08	-17.87	<0.001*
		Small-Whole		2.08	-20.67	<0.001*
		Food type	5			<0.001*
		Banana-broccoli		2.61	1.97	0.049*
		Banana-parsnip		2.61	1.77	0.077
		Banana-pear		2.55	0.26	0.792
		Banana-strawberry		2.55	3.31	0.001*
		Banana-sweet potato		2.61	-1.02	0.306
Browning	40.52% (P<0.001*)	Time	1	0.005	4.38	<0.001*
		Humidity %	1	0059	-0.86	0.392
		Size category	3			<0.001*
		Small-Medium		0.099	4.17	<0.001*
		Small-Large		0.099	2.00	0.046*
		Small-Whole		0.099	-5.45	<0.001*
		Food type	3			<0.001*
		Banana-broccoli		0.124	-7.12	<0.001*
		Banana-parsnip		0.124	-7.80	<0.001*
		Banana-pear		0.121	-9.04	<0.001*
pH	12.25% (P<0.001*)	Time	1	0.004	0.89	0.372
		Humidity %	1	0.048	-0.81	0.417
		Size category	3			0.001*
		Small-Medium		0.080	-2.68	0.008*
		Small-Large		0.080	1.14	0.255
		Small-Whole		0.080	-0.05	0.961
		Food type	5			<0.001*
		Banana-broccoli		0.100	-0.31	0.759
		Banana-parsnip		0.100	1.47	0.141
		Banana-pear		0.098	1.09	0.275
		Banana-strawberry		0.098	-2.43	0.016*
		Banana-sweet potato		0.100	5.15	<0.001*

DISCUSSION

This study investigated the impact of food presentation and storage on several aspects of food nutrition. Overall, the study revealed that finely chopped feeds resulted in the most rapid desiccation for all food types, under both ambient and fridge settings. Chopping food also influenced the browning of food and resulted in pH changes in both ambient and fridge-stored samples. These results have implications for the nutrition of zoo-housed animals in scenarios where food is chopped up and stored prior to feeding.

Desiccation

Chop size had a significant, substantial impact on the desiccation of food stored under both ambient and fridge conditions. Under both conditions, the smallest chop sizes resulted in the most severe desiccation levels, whilst minimal desiccation occurred when foods were left in a whole state. For both the ambient and fridge samples, desiccation (percentage weight loss) levels were comparable, with percentage weight loss reaching over 80% for some food types. This may have potentially negative consequences for captive animals, particularly those that rely on their food as a source of water. For example, many birds, such as tawny frogmouths (*Podargus strigoides)* are not believed to drink in the wild, but rather obtain fluid from food (Snow, 2008). Guidelines for feeding, therefore, often involve soaking food in water in order to increase the moisture content (Snow, 2008). The cutting of food into sizes that rapidly desiccate is therefore counterproductive for many avian species.

The linear regressions for percentage weight loss under ambient and fridge conditions showed high predictive power, with over 80% and 56% of variation explained by the models respectively. This suggests that time, temperature, humidity and food size were strong predictors of changes in food weight. Higher temperatures, lower humidities and longer time periods tended to result in greater amounts of weight loss in all samples, though it should be noted that weight loss was most extreme during the first 8-10 hours of study. During the last hours of study, weight loss tended to reduce. It should be noted that within 12 hours, the majority of small (0.5 cm^3) samples had lost over 60% of their weight, whereas the medium size (2 cm^3) had lost only 20%. For fridge-based samples, the pattern is similar: most small samples had lost 50% of their weight by 12 hours, whereas medium samples had lost less than 20%. In some respects, these changes are intuitive, as smaller chop sizes result in much greater fruit and vegetable surface area for evaporation to take place (Perera, 2020). Finer chopping also results in breakage of a much greater number of plant cell walls, allowing fluids to coat the outside of the fruit or vegetable particle (Rolle and Chism, 1987). In human food science, attempts to reduce desiccation centre around the use of coating of food (e.g. in plastic packaging, or through the development of edible food coatings, Lin et al., 2007). Unfortunately these practices are rarely feasible in a zoo setting, and as such practitioners should consider the wider impact of food presentation and storage on its quality.

The potential impact of food type should also be taken into account. For model development for ambient temperatures, food type was removed due to high VIF values, but was maintained for the fridge sample model. There was a significant difference in desiccation levels between some fridge-stored food types (e.g. banana-strawberry and banana-sweet potato) but not others: similar has been shown in the wider literature (Bansal et al. 2015). This suggests that the cellular structure of the food type may have an impact on desiccation: some food types may desiccate more slowly than others.

Storing food in a fridge had a limited impact on desiccation values, with desiccation levels being only a little lower in the fridge. Chop size, by comparison, had a much greater impact on desiccation levels. If preparing foods for animals that rarely drink, zookeepers, should therefore consider either using a larger chop size (e.g. 2 cm^3 or larger), or prepare the food shortly before it is fed.

Browning

Browning occurred for four of the six types of fruits and vegetables tested under the current study (banana, pear, parsnip and sweet potato). Browning is caused by exposure to air following cutting, and results in decreased palatability, and decreased nutritional value to foods (Singh et al., 2018). Browning therefore acts as an useful visual assessment for fruit quality and senescence Overall, time and food particle size were significant predictors of browning, as were food type for the fridge storage study. The predictive power of the ambient model for food browning was poor (13% of variation explained) but was comparatively higher for the fridge storage test (40% of variation explained). The poorer explanatory power for the ambient model is likely a result of the fact that food type was removed from the models due to high VIF scores.

For browning, the effect of food particle size is complex. For example small chop sizes did not always result in the highest grades of browning. The whole food items did not brown: this is because no surfaces were cut for these items, so no browning reaction took place (Singh et al., 2018). In many cases, the medium (2 cm^3) food sizes resulted in greater browning than did the smallest chop sizes. This may be because these food items had longer surfaces for browning to take place. However, it should be noted that due to the increased amount of surface area in small chopped foods, the actual amount of browning may have been higher, even if the severity was lower.

In human food science, browning is often ameliorated by using natural substances (e.g. lemon juice) or chemical treatments (Sommano et al., 2020). These methods may reduce some of the biochemical impacts of chopping and reduce colour change impacts (Wiley, 1994). However, these treatments may also have unknown impacts on animals, and could affect the nutritional value of the feeds being provided. It is unlikely, therefore, that attempts to reduce browning will be practiced in a zoo environment. Browning of feeds could be used by researchers to identify the potential level of nutritional breakdown of feeds, especially when quantified in a standardised way Lunadei et al., 2011). While browning is a key part of this paper, consideration towards other forms of change such as whitening and softening could be considered, especially in whole fruits or even in donated fruit and vegetables which many smaller zoos may receive (Brereton 2020; Cocci 2006).

pH

Acid changes in food occur as a result of production or breakdown of acidic products and as such, they should be of concern to zoo nutritionists. Of all tests run for this study, the pH models had the lowest predictive power, explaining only 6% of variation in values for ambient samples, and 12% for fridge-stored samples. For pH, time did not significantly predict pH changes in either model, but food particle size and food type (for fridge-stored samples) did. Clearly, there are other, unmeasured predictors that would better explain the variance in browning between samples. These could include the time since the fruit or vegetable was originally harvested. Differences in pH change direction between fruits and vegetables (e.g. as a result of production of ethylene or destruction ascorbic acid) are likely to increase the variance in the data.

While time was not a significant predictor of pH change, food particle size was a predictor. Small food sizes showed significantly different values to whole (for ambient) and medium (for fridge-stored) samples. It seems likely, therefore, that the degree of wounding via chopping speeds up the chemical reactions associated with pH change (Wiley, 1994). These pH changes may reduce the palatability of food as fruits may become more acidic (Varroquaux and Wiley, 2017). Alternatively some fruits may become sweeter as complex carbohydrates break down into simple sugars (Ali et al., 2017).

Animal welfare implications

Given the negative nutritional impacts of zoo food presentation, the wider practice of chopping food for zoo animals, especially into very small pieces and especially when the food is to be stored before feeding, should be questioned. Chopping food already incurs costs in terms of keeper time (James et al., 2021; Quintanilla et al. 2023) and increases the risk of microbial contamination. In order to determine whether this practice of chopping food should be continued, researchers should focus on the purported benefits to animals in terms of behaviour, and whether these outweigh the nutritional, time and microbial costs. For some species, a smaller chop size may be beneficial. Waasdorp et al. (2022), for example, identified that larger chop sizes were associated with greater stealing in mangabey (*Cercocebus lunulatus)*, and so for this species, chopping food may be well-justified. Similarly, it may be argued that chopped food increases opportunities for foraging when it scattered across an exhibit. On the other hand, many species, including macaques (Smith et al., 1989; Sandri et al., 2017), macaws (James et al., 2021; Quintanilla et al., 2023) and carnivorans (Shora et al., 2018) have been shown to benefit from whole food in terms of increased opportunities for natural feeding. In some birds, such as Amazon parrots (*Amazona amazonica) and rats* (*Rattus norvegicus*), larger food particle sizes have been shown to elicit greater food motivation (Whishaw and Tomie, 1989; Rozek and Millam, 2011). In these cases, there appears to be only costs in the cost: benefit analysis.

When selecting species for study, collections should consider the species with the greatest welfare concerns, but also those that feature most commonly in collections. For example, while mammals are the best studied taxonomic group (Melfi, 2009), birds are actually more speciose in animal collections, as are fish (Brereton & Brereton, 2020, 2023). Research therefore has a greater potential impact if it focuses on these highly speciose groups. Of these taxa, aquarium fish have not been the focus of much food presentation research, so future research in this field would be especially meaningful.

The costs incurred by preparing and storing food for longer periods increase in terms of food nutritional value. While it is unlikely that keepers would deliberately prepare food and then leave it out under ambient conditions, this may happen under certain circumstances, such as when there is a centralised kitchen and delays before keepers pick up their food, or when food is provided for animals but they do not immediately eat it. It should be noted that chop size and temperature catalyses the chemical changes in the feed, so food quality is likely to deteriorate more rapidly under hot conditions with small chop sizes.

The greater concern relates to fridge storage of food overnight. While less than those for ambient foods, the changes in food desiccation were severe in fridge samples, and this could impact the health of animals being regularly fed in this way. The fridge storage of zoo diets does not feature in the zoo literature, and as such it is difficult to determine the underlying motivations for this practice. The results of this demonstrate that it is not in the best interest of the animals to prepare diets and store them overnight, especially where small chop sizes are being used.

FUTURE DIRECTIONS

To advance this field, researchers could consider the following areas for further study:

- Food presentation across a wider range of species. While several food presentation studies are available, there appears to be a taxonomic bias in the types of animal being studied, with many studies focusing on mammals. Investigation of the food presentation impact on the behaviour of a much wider array of species would therefore have merit.
- Nutritional impacts across a wider range of feeds. This study has investigated common fruit and vegetable species, but zoos feed many other food types, such as carcasses (Gaengler and Clum, 2015). Investigations of the wider effects of food storage on the nutritional values of other common foods would therefore be useful.
- Microbial effects. Currently there are no published studies on the microbial consequences of zoo food preparation. Further study in this field could quantify the potential risks incurred during food preparation and could identify methods to mitigate these concerns.

CONCLUSIONS

This study is one of the first investigations of the nutritional impacts of zoo food presentation and storage styles. While storage under ambient conditions resulted in the most severe desiccation, browning and pH changes, it should be noted that the effects of chopping were considerable even under fridge conditions. The effects of chopping, especially to small sizes, on the desiccation, browning and pH of fruits and vegetables demonstrates that there is considerable physiological change in food following its preparation. From an zoo perspective, practitioners have a duty to ensure that their animals receive nutritionally adequate diets. As such, further scrutiny should be placed on the practices of chopping food, especially if the diet is then stored for prolonged periods, even in fridge conditions. If there is evidence that animals benefit from a chopped food diet, feeds should be prepared fresh, and should be fed out to the animals as rapidly as possible (i.e. within a few hours of preparation).

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CREDIT STATEMENT

Conceptualization: JEB; data curation: CW; formal analysis JEB; funding acquisition CW; investigation CW, JEB; methodology CW; project administration GAP; resources JEB, CW; software JEB; supervision JEB, GAP; validation CW, JEB; visualization JEB; writing – original draft JEB; and writing – review and editing CW, GAP.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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REFERENCES

Ali, A., Yeoh, W.K., Forney, C., Siddiqui, M.W., 2018. Advances in postharvest technologies to extend the storage life of minimally processed fruits and vegetables. Critical Reviews in Food Science and Nutrition 58, 2632–2649. https://doi.org/10.1080/10408398.2017.1339180

Arnold, M., Gramza-Michałowska, A., 2022. Enzymatic browning in apple products and its inhibition treatments: A comprehensive review. Comp Rev Food Sci Food Safe 21, 5038–5076. https://doi.org/10.1111/1541-4337.13059

Bansal, V., Siddiqui, M.W., Rahman, M.S., 2015a. Minimally Processed Foods: Overview, in: Siddiqui, M.W., Rahman, M.S. (Eds.), Minimally Processed Foods: Technologies for Safety, Quality, and Convenience, Food Engineering Series. Springer International Publishing, Cham, pp. 1–15. https://doi.org/10.1007/978-3-319-10677-9_1

Bansal, V., Siddiqui, M.W., Rahman, M.S., 2015b. Minimally Processed Foods: Overview, in: Siddiqui, M.W., Rahman, M.S. (Eds.), Minimally Processed Foods: Technologies for Safety, Quality, and Convenience, Food Engineering Series. Springer International Publishing, Cham, pp. 1–15. https://doi.org/10.1007/978-3-319-10677-9_1

Brackett, R.E., 1994. Microbiological Spoilage and Pathogens in Minimally Processed Refrigerated Fruits and Vegetables, in: Wiley, R.C. (Ed.), Minimally Processed Refrigerated Fruits & Vegetables. Springer US, Boston, MA, pp. 269–312.

https://doi.org/10.1007/978-1-4615-2393-2_7

Brereton, S. R., & Brereton, J. E. (2020). Sixty years of collection planning: what species do zoos and aquariums keep?. International Zoo Yearbook, 54(1), 131-145. https://zslpublications.onlinelibrary.wiley.com/doi/abs/10.1111/izy.12264

Brereton, S. R., & Brereton, J. E. (2023). Investigating Market and Conservation Education Influences on Global Zoo and Aquarium Animal Collections. Journal of Research in Social Science and Humanities, 2(1), 25-34. https://www.pioneerpublisher.com/jrssh/article/view/117

Brereton, J.E., 2020. Challenges and Directions in Zoo and Aquarium Food Presentation Research: A Review. Journal of Zoological and Botanical Gardens 1, 13–23. https://doi.org/10.3390/jzbg1010002

Castillejo, N., Martínez-Hernández, G.B., Monaco, K., Gómez, P.A., Aguayo, E., Artés, F., Artés-Hernández, F., 2017. Preservation of bioactive compounds of a green vegetable smoothie using short time–high temperature mild thermal treatment. Food sci. technol. int. 23, 46–60. https://doi.org/10.1177/1082013216656240

Cocci, E., Rocculi, P., Romani, S., Dalla Rosa, M., 2006. Changes in nutritional properties of minimally processed apples during storage. Postharvest Biology and Technology 39, 265–271. https://doi.org/10.1016/j.postharvbio.2005.12.001

Crissey, S., 2005. The complexity of formulating diets for zoo animals: a matrix. International Zoo Yearbook 39, 36–43. https://doi.org/10.1111/j.1748-1090.2005.tb00003.x

Das, A., 2018. Current trends in feeding and nutrition of zoo animals: A review. Ind. Jour. of Anim. Nutr. 35, 242. https://doi.org/10.5958/2231-6744.2018.00038.5

Gramlich, G., Zhang, J., Nau, W.M., 2002. Increased Antioxidant Reactivity of Vitamin C at Low pH in Model Membranes. J. Am. Chem. Soc. 124, 11252–11253. https://doi.org/10.1021/ja026927b

Griffin, B., Brereton, J.E., 2021. Should Zoo Food Be Chopped for Captive Turacos? Birds 2, 415–426. https://doi.org/10.3390/birds2040031

Heaton, J.C., Jones, K., 2008. Microbial contamination of fruit and vegetables and the behaviour of enteropathogens in the phyllosphere: a review. J Appl Microbiol 104, 613–626. https://doi.org/10.1111/j.1365-2672.2007.03587.x

Hodges, D.M., Toivonen, P.M.A., 2008. Quality of fresh-cut fruits and vegetables as affected by exposure to abiotic stress. Postharvest Biology and Technology 48, 155–162. https://doi.org/10.1016/j.postharvbio.2007.10.016

James, C., Nicholls, A., Freeman, M., Hunt, K., Brereton, J.E., 2021. Should zoo foods be chopped: macaws for consideration. Journal of Zoo and Aquarium Research 9, 200–207. https://doi.org/10.19227/jzar.v9i4.507

Lin, D., Zhao, Y., 2007. Innovations in the Development and Application of Edible Coatings for Fresh and Minimally Processed Fruits and Vegetables. Comp Rev Food Sci Food Safe 6, 60–75. https://doi.org/10.1111/j.1541-4337.2007.00018.x

Lunadei, L., Galleguillos, P., Diezma, B., Lleó, L., Ruiz-Garcia, L., 2011. A multispectral vision system to evaluate enzymatic browning in fresh-cut apple slices. Postharvest Biology and Technology 60, 225–234. https://doi.org/10.1016/j.postharvbio.2011.02.001

Mason, G.J., 2010. Species differences in responses to captivity: stress, welfare and the comparative method. Trends in Ecology & Evolution 25, 713–721. https://doi.org/10.1016/j.tree.2010.08.011

Melfi, V.A., 2009. There are big gaps in our knowledge, and thus approach, to zoo animal welfare: a case for evidence-based zoo animal management. Zoo Biol. 28, 574–588. https://doi.org/10.1002/zoo.20288

Perera, C.O., 2020. Minimal Processing of Fruit and Vegetables, in: Handbook of Food Preservation. CRC Press.

Picouet, P.A., Hurtado, A., Jofré, A., Bañon, S., Ros, J.-M., Guàrdia, M.D., 2016. Effects of Thermal and High-pressure Treatments on the Microbiological, Nutritional and Sensory Quality of a Multi-fruit Smoothie. Food Bioprocess Technol 9, 1219–1232. https://doi.org/10.1007/s11947-016-1705-2

Pyo, Y.-H., Jin, Y.-J., Hwang, J.-Y., 2014. Comparison of the Effects of Blending and Juicing on the Phytochemicals Contents and Antioxidant Capacity of Typical Korean Kernel Fruit Juices. JFN 19, 108–114. https://doi.org/10.3746/pnf.2014.19.2.108

Quintanilla, B., Diana, A., Salas, M., 2023. Enhancing welfare in a mixed exhibit: The impact of dispersed whole food on activity levels and feeding behaviours of Mexican military macaws and red-billed curassows. Journal of Zoo and Aquarium Research 11, 366–375. https://doi.org/10.19227/jzar.v11i4.771

Redmond, E.C., Griffith, C.J., Slader, J., Humphrey, T.J., 2004. Microbiological and observational analysis of cross contamination risks during domestic food preparation. British Food Journal 106, 581–597. https://doi.org/10.1108/00070700410553585

Rolle, R.S., Chism, G.W., 1987. Physiological consequences of minimally processed fruits and vegetables. Journal of Food Quality 10, 157–177. https://doi.org/10.1111/j.1745-4557.1987.tb00856.x

Sandri, C., Regaiolli, B., Vespiniani, A., Spiezio, C., 2017. New food provision strategy for a colony of Barbary macaques (Macaca sylvanus): effects on social hierarchy? Integr Food Nutr Metab 4. https://doi.org/10.15761/IFNM.1000181

Sasaki, F.F., Aguila, J.S. del, Gallo, C.R., Ortega, E.M.M., Jacomino, A.P., Kluge, R.A., 2006. Physiological, qualitative and microbiological changes in minimally processed squash submitted to different cut types. Hortic. Bras. 24, 170–174. https://doi.org/10.1590/S0102-05362006000200009

Shora, J., Myhill, M., Brereton, J.E., 2018. Should zoo foods be coati chopped. Journal of Zoo and Aquarium Research 6, 22–25. https://doi.org/10.19227/jzar.v6i1.309

Smith, A., Lindburg, D.G., Vehrencamp, S., 1989. Effect of food preparation on feeding behavior of lion-tailed macaques. Zoo Biol. 8, 57–65. https://doi.org/10.1002/zoo.1430080108

Sommano, S.R., Chanasut, U., Kumpoun, W., 2020. 3 - Enzymatic browning and its amelioration in fresh-cut tropical fruits, in: Siddiqui, M.W. (Ed.), Fresh-Cut Fruits and Vegetables. Academic Press, pp. 51–76. https://doi.org/10.1016/B978-0-12-816184-5.00003-3

Snow, J., (2008). Husbandry Guidelines for Tawny Frogmouth. Accessed at http://nswfmpa. org/Husbandry% 20Manuals/Published% 20Manuals/Aves/Tawny, 2.

Varoquaux, P., Wiley, R.C., 2017. Biological and Biochemical Changes in Minimally Processed Refrigerated Fruits and Vegetables, in: Yildiz, F., Wiley, R.C. (Eds.), Minimally Processed Refrigerated Fruits and Vegetables, Food Engineering Series. Springer US, Boston, MA, pp. 153–186. https://doi.org/10.1007/978-1-4939-7018-6_5

Waasdorp, S., Tuffnell, J.A., Sonsbeek, L.B., Schilp, C.M., van Zeeland, Y.R.A., Sterck, E.H.M., 2021. Chopped and dispersed food enhances foraging and reduces stress-related behaviours in captive white-naped mangabeys (Cercocebus lunulatus). Applied Animal Behaviour Science 241, 105392. https://doi.org/10.1016/j.applanim.2021.105392

Whishaw, I.Q., Tomie, J.-A., 1989. Food-pellet size modifies the hoarding behavior of foraging rats. Psychobiology 17, 93–101. https://doi.org/10.3758/BF03337821

Wiley, R.C., 1994. Preservation Methods for Minimally Processed Refrigerated Fruits and Vegetables, in: Wiley, R.C. (Ed.), Minimally Processed Refrigerated Fruits & Vegetables. Springer US, Boston, MA, pp. 66–134. https://doi.org/10.1007/978-1-4615-2393-2_3