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The Nutritional Soundness of Meat-Based and Plant-Based Pet Foods

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ABSTRACT

Objective
Global trends such as population growth, increasing competition for protein sources, environmental degradation, and farmed animal welfare concerns, are all driving plant-based pet food development. However, lack of evidence of nutritional sufficiency is inhibiting their uptake. This interferes with the ability of some consumers to adopt pet foods more aligned with their values, and the ability of the pet food sector to fully realise the potential of this emerging market, whilst concurrently reducing its environmental footprint. Yet, no systematic study has been published examining the prevalence of steps taken to ensure the nutritional soundness and quality of pet foods, and whether plant-based diets have lower standards in these respects. Accordingly, we designed a study to explore this.

Materials and methods
We surveyed pet food manufacturers producing 19 meat-based and 10 vegan, almost vegan or vegetarian pet foods.

Results
Although there were there were limited areas in which practices could be improved, most manufacturers had acceptable or superior standards at nearly all stages examined, throughout the design, manufacturing, transportation and storage phases, with plant-based diets slightly superior to meat-based diets overall.

Conclusion
A range of best practice steps should be implemented by companies and regulators, and a comprehensive range of communication modalities implemented, to reassure consumers about the nutritional soundness of products.

Keywords
Pet food, dog food, cat food, vegan, vegetarian, raw meat

Introduction

The global market for petfood is enormous, and growing. The world pet population was estimated as 3.5 billion dogs and cats in 2014 (Euromonitor International 2015a). Pet food sales were valued at Euro 131.7 billion (Euromonitor International 2015b). The US market for pet foods and treats was valued at USD 36.9 billion in 2019 (APPA, 2020), and the UK pet food market was expected to reach a value of £2.8 billion year's end, having risen 17% over the last five years (Mintel 2019).

The pet food market is not only growing, but changing, as the priorities of consumers evolve. A series of studies have demonstrated that pet owners are increasingly concerned about quality and nutritional content of pet food. A survey of 2,181 pet owners by Schleicher et al (2019) found that the characteristics considered most important were, in priority order, health and nutrition, quality, ingredients and freshness. Ninety seven per cent of respondents reported giving equal or greater priority to buying healthy food for their pets, compared with themselves.

Concerns about petfood quality may be increasing, due to growing 'humanisation' or anthropomorphism of pets by their owners (Kienzle & Mandernach 1998, Aylesworth et al 1999, Chen et al 2012). Pet owners most likely to view their pets anthropomorphically were also most likely to value nutrition and quality, along with related factors such as freshness, taste and variety within their pets' diets (Boya et al 2015).

Lack of trust in conventional pet foods may also be partly driving consumer concern about the nutritional soundness of pet foods. There have been multiple accounts over the years of commercial brands failing to meet labelling standards, guaranteed analysis, industry recommended nutrient profiles, or containing ingredients other than those listed on the packaging (Hill et al. 2009, Maine et al. 2015, Gosper et al. 2016).

This sector is also being affected by global trends. Predicted population growth and associated increasing demands for protein are placing increasing pressure on the human food system, and the pet food industry may need to adapt in order to avoid competition with the human food supply (Hill 2004, Pimentel & Pimentel 2004, Okin 2017). Consumers are also increasingly aware of, and concerned about, such issues, with growing numbers adopting alternatives such as plant-based diets and less consumptive lifestyle choices.

It is predicted that as the prevalence of plant-based human diets increase, the demand for plant-based pet foods will also increase, regardless of the expansion of 'ethically-raised' meat in the pet food market (PFI 2015, Lummis n.d.). In the USA alone, with its population of 325 million (US Census Bureau 2017) and a national a pet-owning rate estimated at 56% (AVMA 2002), there may be as many as 20 million vegetarian and vegan pet owners. Unsurprisingly, vegans are most interested in plant-based diets. 21% of vegan pet owners and 5% of vegetarian pet owners reported feeding a diet composed of less than 25% animal products (Rothgerber 2013).

However, a survey of 3,673 pet owners by Dodd et al (2019) found that the nutritional adequacy of plant-based pet foods was the most commonly reported concern about these diets. Although only 27% (58/212) of surveyed vegans reported feeding their pets a plant-based diet, 78% (131/ 168) indicated they would do so, if one were available which met their desired criteria. In total, 35% (1,083/3,130) of pet owners who did not already feed plant-based pet food indicated interest in doing so. However, 55% of those pet owners (599/1,083) stated further conditions needed to be met before they would do so. The most important - further evidence of nutritional sufficiency – was reported by 45% (269/599) of this group.

This concern is understandable, particularly for cats. Whilst dogs are biologically omnivorous, cats are obligate carnivores, meaning that in their natural environments they rely on meat-based diets to supply essential nutrients such as vitamins A and B12, and taurine (Morris 2002, Verbrugghe et al. 2012, Kanakubo et al 2015). To ensure they are nutritionally complete and balanced, commercial pet foods normally aim to comply with nutrient profiles published by authorities such as the Association of American Feed Control Officials and the European Pet Food Industry Federation, which have in turn been based on nutrient requirements established by the National Research Council (NRC 2006, AAFCO 2017, FEDIAD 2017).

However, an ever-increasing range of plant-based pet foods also aim to supply all of the nutritional requirements of dogs and cats. As noted however, concern about the nutritional soundness of such diets is a significant barrier to their wider uptake by consumers. In order for many consumers to adopt plant-based diets more in accordance with their values, and for the pet food industry to lower its ecological footprint (Okin 2017, Martens et al. 2019, Alexander et al. 2020), and to fully realise the potential offered by this emerging market, more information is needed about the nutritional soundness of pet food, and particularly plant-based diets, along with better communication of that information to consumers.

One way to achieve this, is to examine the health and longevity of cats and dogs maintained on such diets. This is a topic that warrants articles of its own. Limited studies in this area already exist (Wakefield et al. 2006, Brown et al. 2009). We have also addressed this in depth by another of our publications (Knight and Leitsberger 2016), and in a large-scale forthcoming study by the lead author.

The other way to study the nutritional soundness of pet food is to examine steps taken by manufacturers during diet formulation and creation. To date however, no systematic study has been published examining the prevalence of steps taken to ensure the nutritional soundness and quality of pet foods. Accordingly, we designed a study to explore such steps, and to ascertain whether such differences exist between the manufacture of plant- and meat-based diets. Our null hypothesis was that companies would have good compliance overall, with steps to ensure nutritional soundness and quality control, and there would be no significant difference between primarily meat- and plant-based diets. We also sought to examine the prevalence of various strategies used to communicate to consumers information about steps taken to ensure nutritional soundness of products.

Methods

Pet food companies were located within the UK, Europe, North and South America, Australia and New Zealand, Asia and Africa. This was achieved by online searches, and checks of industry association websites, including the Pet Food Manufacturers Association (UK), FEDIAF - the trade body representing the European Pet Food Industry, multiple European national pet food associations (https://fediaf.org/who-we-are/our-members.html), the American Feed Industry Association, and the International Feed Industry Federation.

Online surveys were constructed within JISC Online Surveys, to explore the steps taken by pet food manufacturers to ensure nutritional soundness and quality control of their products. JISC Online Surveys complies with strict data security standards, the European General Data Protection Regulation, and was used by 88% of UK higher education institutions by 2019 (JISC 2020).

Manufacturers were invited by email to participate in an initial pilot survey during April 2020. Seven participated, representing small to medium-sized companies from most continental regions. A UK industry nutritionist was also consulted in detail. The survey was then adjusted, clarifying some questions and adding new questions relating to respondent role and relevant knowledge, manufacturing location, processing and nutritive and non-nutritive additive options, and post-manufacturing nutrient losses.

The final survey included stages covering company and respondent demographics, product formulation, ingredient sourcing, quality control during and after manufacturing, storage and shipping, and communication of information to wholesalers, retailers and consumers (Fig. 1). Companies were asked to provide information about a single dog or cat diet produced, other than a veterinary prescription or therapeutic diet. They were asked to choose a diet intended as a main diet, rather than as a treat or supplement. And in recognition that most formulations are conventional meat-based diets, limiting data on other options, companies were asked to choose another diet, if they produced any such alternative option.

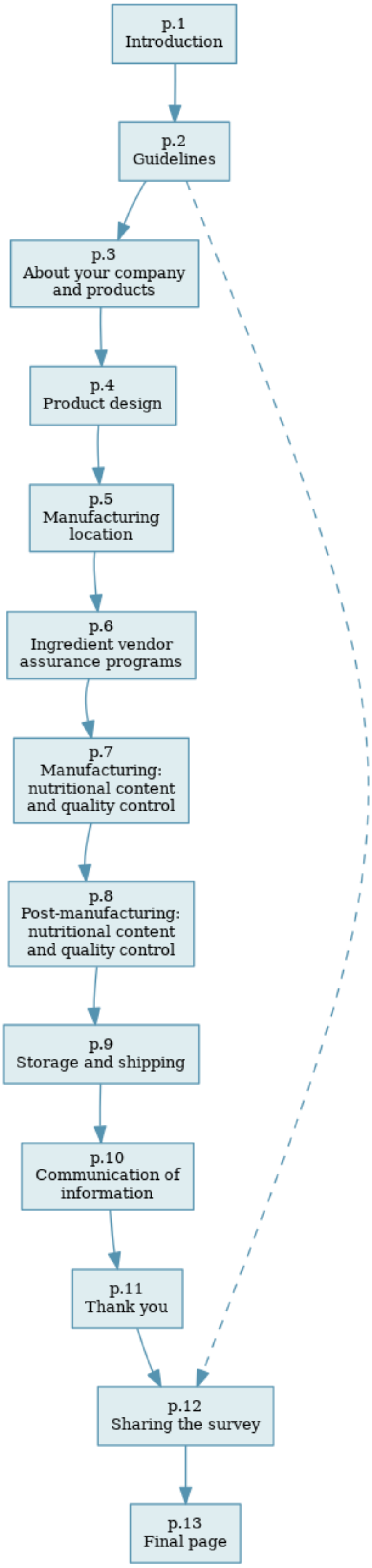

Figure 1. Survey of pet food companies – stages.

Vegetarian diets were defined as those including plants, milk and eggs, whereas vegan diets were defined as those excluding any animal products. For simplicity, and due to the relatively small sample size, in the following results and discussion, these two groups are jointly designated as plant-based diets ('V'), although in reality dry meat-based pet foods do also include considerable plant-sourced ingredients, with common examples including corn gluten meal, soybean meal, whole corn, whole wheat, barley and rice. Wet foods may also use plant-sourced proteins, but to a lesser extent (Thompson 2008).

From May to November 2020, invitations to participate in the final survey were distributed by email to around 688 pet food vendors considered likely to manufacture their own pet foods, or to have sufficient knowledge of manufacturing processes used for their products. An initial email was followed by a repeat invitation to non-responders, after at least one month. Finally, in November 2020, 48 companies thought likely to produce non-meat based diets were randomly selected using the random number generator www.randomized.org. These were contacted via personalised phone calls, email, Facebook or online chat messages, and invited to participate.

The steps taken by companies to ensure the quality and nutritional soundness of their pet food formulations were then examined and qualitatively assessed as inferior, acceptable, or superior at each stage, based on whether > 50% of the diets within each group (or 70% for 'superior') fulfilled the majority of criteria, or fulfilled those criteria indicating higher standards, as well as the presence of more significant differences between dietary groups. These assessments were made independently by both co-authors and then compared.

This research was conducted in compliance with the University of Winchester Research Ethics Policy (Scallan 2019).

Results

<u>Company demographics</u>

29 respondents confirmed their eligibility and participated in this study. Companies were primarily based in the UK and other European nations, with headquarters and production facilities primarily clustered in these regions, although North America and Australia/New Zealand/Oceania also featured significantly. Marketing regions were broader, however. Almost all global markets were targeted by many more companies than were based in them. The regions most targeted were the UK, other European nations, Asia, Australia/New Zealand/Oceania and North America (Table 1).

Table 1: Location of company headquarters, production facilities and marketing regions

Company	UK	Other European	North America	South America	Asia	Australia/ New Zealand/ Oceania	Africa
Headquarters	9	8	5	0	1	4	2
Production	9	13	7	2	4	6	2
Marketing	18	17	11	8	15	12	3

Compared to other pet food companies marketing in the same region(s), most considered their market share to be small (18) or medium (8). Three considered their market share to be large.

Respondents to the survey were primarily in technical/production/nutrition (16) roles, with 11 in management roles. One respondent covered all roles, also including ingredient procurement and marketing, and one worked in sales development.

<u>Diets produced by companies</u>

One company reported producing an 'other - organic meat' diet. For the purposes of this study, this was reclassified as 'meat-based conventional', as due to low respondent numbers more fine-grained discrimination into organic or not, was not advisable in this study.

Overall, surveyed companies produced diets that were most commonly meat-based (26 total: cooked - 18, raw - 8) or plant-based (14 total: vegan - 8, almost vegan – 4, vegetarian – 2). Two companies produced insect-based diets (Tab. 2). No companies reported producing in vitro meat-, fungi- or algal-based pet foods, or diets based on any other primary ingredient types.

Table 2: Diets classified by primary ingredients

notes: 'meat' includes land animals, poultry and fish. 'vegan' includes no animal products at all. 'Almost vegan' may include minimal animal products such as vitamin D3 derived from lanolin. Vegetarian includes eggs or milk, but not meat.

Diets	
Meat-based – cooked	18
Meat-based – raw	8
Vegan	8
Almost vegan	4
Vegetarian	2
Insect-based	3

Also produced were treats (16 companies), supplements such as amino acids, vitamins, minerals, enzymes, pro-/pre-biotics, fatty acids and joint health products (6 companies),
and premixes intended for use with additional items such as a fresh protein source (2 companies).

These diets were provided in a variety of moist and dry formulations. The 29 respondent companies produced moist formulations (canned, pouch, carton or raw) in 28 instances, and dry formulations (kibble or dehydrated raw) in 21 instances.

Diets chosen for this survey

The remainder of this survey focused on the steps taken to ensure nutritional soundness and quality control of products, and the communication of information about these factors. Companies were required to provide information about a single diet produced, which was the focus of most of the following results. Data on diets other than 'conventional meat-based' is limited; hence as mentioned previously, if companies produced any suitable alternative, they were asked to choose one. Nineteen of 29 (66%) of diets chosen were meat-based (11 conventional including one 'organic', six raw and two with meat base unclear), and 10 of 29 (34%) were plant-based (five vegan, one almost vegan e.g. with the exception of vitamin D3 derived from lanolin, one vegetarian, and three with plant base unclear).

Overall results

At almost all stages of the formulation, manufacturing and distribution processes, these companies were assessed as having acceptable or superior standards overall, with plant-based diets almost always produced to standards equal or superior to those of meat-based diets (Tab. 3). These assessments were independently confirmed by both co-authors, with no disagreements arising.

Table 3. Steps taken to ensure the quality and nutritional soundness of pet food formulations, meat-based (M), plant-based (V) and overall.

Steps to ensure formulation quality and nutritional soundness	M	V	Overall
Diet formulation – expertise	acceptable	superior	acceptable
Diet formulation – ensuring soundness	acceptable	acceptable	acceptable
Ingredients – ensuring quality	superior	superior	superior

Nutritional supplementation	superior	acceptable	superior
Preservation – physical	mixed	acceptable	mixed
Preservation – additives incl antimicrobials	inferior	mixed	inferior
Nutrient degradation – monitoring	acceptable	acceptable	acceptable
Nutrient degradation – adjustment	acceptable	superior	acceptable
Storage and shipping	acceptable	superior	acceptable

In the case of physical preservation methods, dry formulations were assessed as superior, and moist formulations as narrowly acceptable, hence a 'mixed' assessment was applied overall.

Each of these stages is examined in detail in the following.

<u>Diet formulation</u>

Two respondents used recipes designed elsewhere. Of the 93% (27: M – 18, V - 9) of 29 who designed their own formulations, all stated that they used nutritional specialists, but the levels of expertise differed (Tab. 4). A recognised veterinary specialist (i.e. board-certified) in nutrition, was used for 52% of diets overall (44% of M diets and 67% of V diets). A specialist in nutrition with different postgraduate nutrition qualifications at masters level or higher was used for 33% of diets overall (with 33% for both M and V diets). And a specialist in nutrition without such postgraduate nutrition qualifications was used for 15% of diets overall (22% of M, and no V diets).

Table 4. Highest levels of nutritional expertise utilised during diet formulation, among 27 companies who designed their own formulations.

Highest level of expertise	M	V	Total
Recognised veterinary specialist (i.e. board-certified) in nutrition	44% (8)	67% (6)	52% (14)
Other specialist in nutrition with postgraduate nutrition qualifications at masters level or higher	33% (6)	33% (3)	33% (9)
Other specialist in nutrition without the postgraduate nutrition qualifications above	22% (4)	0	15% (4)
Total	100% (18)	100% (9)	100% (27)

These 27 companies used a variety of methods to ensure their formulations were nutritionally complete (Tab. 5), including feeding trials, the family method (analyses conducted to ensure the product is a member of a product family, of which the lead member has successfully passed a feeding trial), the formulation method (formulated to meet nutritional requirements of national/regional bodies, such as the European Pet Food Federation (FEDIAF) or the Association of American Feed Control Officials (AAFCO)), and in house knowledge and experience (Zicker 2008).

Table 5. Steps taken by companies to ensure nutritional soundness during diet formulation. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 18, V – 9, Total – 27.

Steps to ensure soundness during diet formulation	M	V	Total
Feeding trials	22% (4)	22% (2)	22% (6)

Family method	11% (2)	11% (1)	11% (3)
Formulation method	94% (17)	100% (9)	96% (26)
Knowledge + experience	39% (7)	33% (3)	37% (10)

Feeding trials or the similar family method were jointly used in 17% (9 of 2 x 27 maximum possible instances) of diets. For both M and V diets this was also 17% (M: 6 of 2 x 18 maximum possible instances, V: 3 of 2 x 9 maximum possible instances). The formulation method was used by 96% of diets (M – 94%, V – 100%). In-house knowledge and experience was reportedly relied on in 37% (10/27) of diets (M – 39%, V – 33%).

Ingredients used
All 29 companies provided information about the steps they relied on to ensure the nutritional soundness and quality of ingredients used to create their diets (Tab. 6).

Table 6. Steps taken to ensure nutritional soundness and quality of ingredients used. One 'other' cited 'Independent ingredient certification'. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29.

Steps to ensure soundness of ingredients	M	V	Total
Tested for nutrients	68% (13)	80% (8)	72% (21)
Tested for risks	63% (12)	70% (7)	66% (19)
Visit ingredient factories	79% (15)	60% (6)	72% (21)
Contractual agreements, audited	74% (14)	70% (7)	72% (21)
Contractual agreements, not audited	11% (2)	40% (4)	21% (6)
Personal relationships	74% (14)	70% (7)	72% (21)
Other	0%	10% (1)	3% (1)
None	5% (1)	0%	3% (1)

The gold standard for ensuring nutritional soundness and quality of ingredients is to test incoming ingredients for (i) nutrient presence and purity, and (ii) for known risks and contaminants (e.g. residues of antibiotics, pharmaceuticals, pesticides, mycotoxins (fungal toxins), or heavy metals). Such tests were utilised for most diets overall (i - 72% and ii - 66%), although these steps were slightly more common for V diets (i - 80% and ii - 70%), than for M diets (i - 68% and ii - 63%).

Companies may also inspect ingredient factories, or rely on agreements with them, that may or may not be audited. 72% of companies overall inspected factories (M – 79%, V – 60%), with smaller numbers relying on contractual agreements (whether audited: overall – 72%, M – 74%, V – 70%; or not audited: overall – 21%, M – 11%, V – 40%). Strong person-to-person relationships with suppliers were also commonly relied on (overall – 72%, M – 74%, V – 70%). One company (V) cited 'independent ingredient certification', and one (M) reported normally assuming soundness of incoming ingredients, without utilising any additional verification steps.

Nutritional supplementation
In total, 79% of formulations (23/29) were supplemented with additional nutrients (Tab. 7).

For M diets this was 84% (16/19) and for V diets it was 70% (7/10). Nutrients supplemented were primarily (i) vitamins, pro-vitamins or chemically well-defined substances with similar effects, (ii) trace elements and their compounds, and (iii) amino acids, their salts or analogues.

In total, 76% were supplemented with vitamins or similar (M - 79%, V - 70%), 66% with trace elements or similar (M – 68%, V – 60%), and 52% with amino acids or similar (M - 53%, V - 50%). Hence, almost all formulations were supplemented, with vitamins or similar being most common, followed by trace elements or similar, and amino acids or similar, respectively. Most formulations were supplemented with all three. Supplementation in all three groups was slightly higher for M than for V diets.

Table 7. Nutritional supplementation of formulations. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29. One 'other' was 'fish oil and organic sunflower oil to comply with AAFCO requirements'.

Nutritional supplementation	M	V	Total
Vitamins or similar	79% (15)	70% (7)	76% (22)
Trace elements or similar	68% (13)	60% (6)	66% (19)
Amino acids or similar	53% (10)	50% (5)	52% (15)
Other	5% (1)	0%	3% (1)

Preservation

Physical preservation processes vary for dry and moist/semi-moist/raw formulations. There were 17 of the former (M – 8, V – 9), and 12 of the latter (M – 11, V – 1) formulations studied.

Of the 17 dry formulations, high temperature sterilisation was used for 88% overall (M – 100%, V – 78%). High pressure sterilisation was used for 59% overall (M – 88%, V – 33%). Drying sufficient to inhibit mould formation and bacterial growth was used for 53% of diets overall (M - 38%, V - 67%). All formulations utilised at least one of these options, and no formulations utilised freeze-drying (Tab. 8).

Table 8. Physical treatments used to preserve dry formulations. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 8, V – 9, Total - 17.

Dry formulations: physical preservation	M	V	Total
High temperature sterilisation	100% (8)	78% (7)	88% (15)
High pressure sterilisation	88% (7)	33% (3)	59% (10)
Drying sufficient to inhibit mould formation and bacterial growth	38% (3)	67% (6)	53% (9)

Among the 12 moist/semi-moist/raw formulations, only one was plant-based. This formulation relied solely on cold sterilisation as a physical preservation method. Among the 11 meat-based formulations, steam and high temperature sterilisation were jointly used by 45% (5/11) and cold sterilisation by 18% (2/11) of formulations. 45% (5/11) of these formulations did not use any physical preservation method (Tab. 9).

Table 9. Physical treatments used to preserve moist or raw formulations. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 11, V – 1, Total - 12.

Moist formulations: physical preservation	M	V	Total
Steam sterilisation	36% (4)	0%	33% (4)
High temperature sterilisation	9% (1)	0%	8% (1)
Cold sterilisation	18% (2)	100% (1)	25% (3)
None of the above	45% (5)	0%	42% (5)

Fifty two percent (15: M – 8, V - 7) of the 29 formulations also used one or more additional (non-nutritive) additives to (i) preserve nutrients, (ii) preserve or enhance flavour or colour, or (iii) impede colonisation by bacteria or mould (Tab.10).

Preservatives were used in 48% of formulations overall (M – 42%, V – 60%). These were most commonly antioxidants - 48% (14 of 29 formulations), unspecified preservatives – 14% (4/29), and least commonly, acidity regulators – 10% (3/29).

Colourants and flavourants were used in 21% of formulations overall (M – 26%, V – 10%). These were most commonly flavouring compounds – 14% (4 of 29 formulations). Two colorants (7% - 2/29) were also used.

Antimicrobials were used in 14% of formulations overall (M – 16%, V – 10%). These were most commonly mould inhibitors – 14% (4 of 29 formulations). In two cases (7% - 2/29) bacterial inhibitors were used.

In summary, a minority of formulations overall used preservatives, and this became a small minority, in the case of colourants and flavourants, and antimicrobials. Preservatives were slightly more likely to be used in the V formulations studied, and the other additives, likely slightly more likely to be used in the M formulations.

Table 10. Additives included to preserve nutrients, impede microbial colonisation, and to preserve or enhance flavour or colour. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29.

Additives: non-nutritive	M	V	Total
Preservatives	42% (8)	60% (6)	48% (14)
Colourants and flavourants	26% (5)	10% (1)	21% (6)
Antimicrobials	16% (3)	10% (1)	14% (4)

Companies also reported a range of other measures to preserve the nutritional content and palatability of formulations during manufacture. Blast freezing was reported in 3 cases, other temperature control in 6 cases, and minimisation of atmospheric O2 in one case.

<u>Nutrient degradation over time</u>
Four of 29 (14%) companies overall reported not normally attempting to predict post-manufacturing nutrient loss over time (Tab. 11). For companies producing an M formulation this was 16% (3/19), and for those producing a V formulation, this was 10% (1/10). Three of these four companies provided reasons, including short timeframe from manufacture to sale (max. 10 days), raw product frozen to -20F until shipped and all shipped within a maximum of six months, and confidence (based on prior testing) of food storage containers, with food all shipped prior to expiry dates.

The remaining 86% (25/29) of companies attempted to predict nutrient degradation over time, either by conducting post-manufacture testing to determine nutrient levels (e.g. accelerated shelf-life or other testing) – 69% overall (M – 68%, V – 70%), or by extrapolating from known characteristics (e.g. published data), and from historical experience – 55% overall (M – 58%, V – 50%).

Table 11. Steps normally taken by companies to predict post-manufacturing nutrient loss over time. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29.

Nutrient loss monitoring	M	V	Total
Nutrient testing	68% (13)	70% (7)	69% (20)
Extrapolation and experience	58% (11)	50% (5)	55% (16)
None	16% (3)	10% (1)	14% (4)

When considering post-manufacture nutrient testing, 52% (M – 47%, V – 60%) chose to use an external laboratory, certified by a professional or regulatory body. 28% (M – 26%, V – 30%) conducted their own In-house nutrient testing (Tab. 12).

Table 12. Facilities used for post-manufacture nutrient testing. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29.

Post-manufacture nutrient testing	M	V	Total
External laboratory	47% (9)	60% (6)	52% (15)
In-house	26% (5)	30% (3)	28% (8)

These 20 companies tested most commonly for protein and fat content, slightly less often for ash content and rancidity (e.g. thiobarbutyric acid (TBA) number to measure oxidative rancidity), and least often for pH level (i.e. acidity/alkalinity), or for more specific nutrients (Fig. 2). The latter included amino acid, fatty acids, vitamins and minerals.

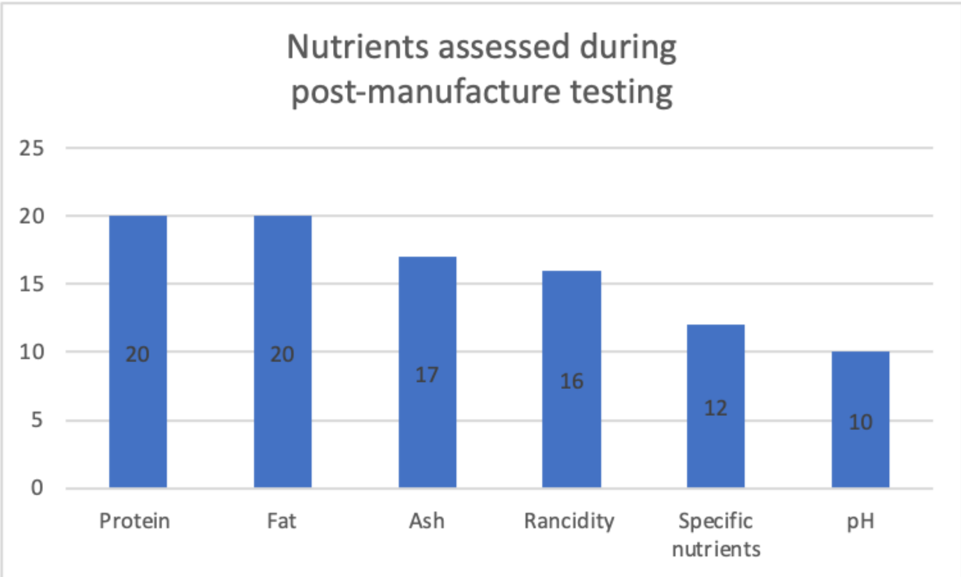

Figure 2. Prevalence of nutrients assessed during post-manufacture testing.

To account for post-manufacturing nutrient loss over time, 62% (18/29) companies reported normally including an oversupply of nutrients. For M diets this was 53% (10/19), and for V diets, 80% (8/10).

These were most commonly vitamins, with specific amino acids, overall fat and protein, and fatty acids, also being reported (Fig. 3). The most commonly reported vitamins were Vitamins A, B vitamins, D and E vitamins. Some reported a fuller range, e.g. “All essential vitamins, particularly those known to be heat labile or degrade with time.” Amino acids reported included Taurine, Methionine and “all”, and fatty acids included Omega DHA, Arachidonic Acid EPA and Linoleic Acid.

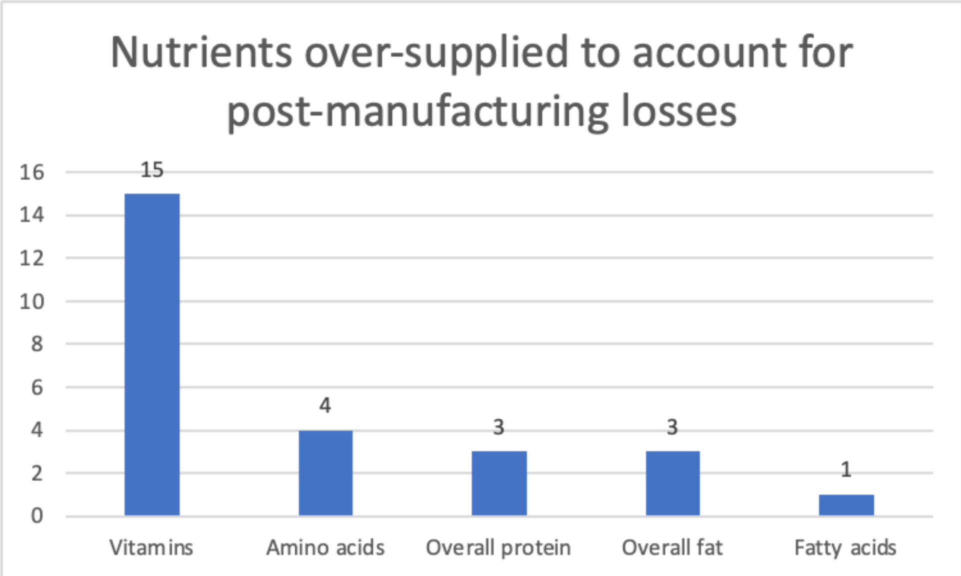

Figure 3. Nutrients over-supplied to account for post-manufacturing losses.

Storage and shipping

All but one company (producing an M formulation) reported the use of standardised protocols to safeguard nutritional quality or prevent degradation, at different stages during the storage and shipping process (Tab. 13). These most commonly covered recommended temperatures (86% - 25/29), the use of 'best before', 'use by' or similar expiry dates (83% - 24/29) and recommended humidity levels (59% - 17/29). Four companies also reported the use or recommendation of specialised storage and handling protocols, e.g. relating to refrigeration, hygiene or avoidance of exposure to light.

Such standardised protocols were most commonly applied to the in-house storage phase, being used for 90% of formulations overall (M – 89%, V – 90%). For 72% of companies (M – 63%, V – 90%) these covered shipping to wholesalers or retailers. Once at these locations, protocols were supplied by 66% of companies overall (M – 63%, V – 70%). Finally, recommendations for consumers were supplied by 69% of companies (M – 68%, V – 70%). Hence, protocols coverall all stages were applied or supplied by most companies; however, at every stage companies supplying V formulations were more likely to provide these, although differences were usually small.

Table 13. Standardised protocols to safeguard nutritional quality or prevent degradation, applied at stages of the supply chain. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29.

Protocols minimising degradation	M	V	Total
In-house storage	89% (17)	90% (9)	90% (26)
Shipping	63% (12)	90% (9)	72% (21)
Wholesalers/retailers	63% (12)	70% (7)	66% (19)
Consumers	68% (13)	70% (7)	69% (20)
None	5% (1)	0%	3% (1)

Additional quality checks

Several companies reported additional steps taken to ensure nutritional soundness and quality control during the manufacturing stage. Laboratory testing to check nutrient levels seemed apparent in eight cases. These varied from random, each batch, to annual testing, and was done both in-house and by external laboratories. Testing product or ingredients for bacteria were reported in two cases (in one case, hourly during manufacturing), and testing for toxins was reported in one case. These included pesticides such as Dioxin and PCBs, the herbicide Glyphosate, and metals and minerals such as Lead, Mercury, Cadmium and Arsenic.

Communication of protocols to retailers and/or consumers
Companies used a variety of information channels to communicate to retailers and/or consumers the steps they take to ensure the nutritional soundness and quality control of their products, beyond general advertising (Tab. 14). Most common were the use of product labelling to provide information beyond minimum legal requirements, and company websites – both used in 93% of cases, with V diets slightly more likely to use product labelling (100% vs. 89%), and M diets slightly more likely to use websites (95% vs. 90%). Also very common was the use, for this purpose, of a product information sheet for retailers (72% overall; M – 79%, V – 60%). Around a third of companies also used external publications such as industry journals (31% overall; M – 37%, V – 20%).

Hence, with the exception of external publications, most companies used most surveyed modalities, although with the exception of enhanced product labelling, companies producing M formulations seemed to make use of these modalities, more often.

Three companies also reported the use of additional communication methods. One reported the use of campaigns about product quality combined with educational materials within veterinary schools about their products and nutrition overall, and publication of related research within scientific journals. And one company each reported the use of YouTube video(s), and an email and 24 hour telephone inquiry service.

Table 14. Methods used to communicate information about product nutritional soundness and quality control to retailers and/or consumers. nb: multiple answers were possible, and percentages are proportions within each diet group: M – 19, V – 10, Total - 29.

Communication of information	M	V	Total
Product labelling	89% (17)	100% (10)	93% (27)
Website	95% (18)	90% (9)	93% (27)
Retailer guide	79% (15)	60% (6)	72% (21)
External publication	37% (7)	20% (2)	31% (9)

Discussion

Company demographics
Among the 29 responding companies, socioeconomically developed nations were over-represented. This was unsurprising however, consistent with greater pet ownership in societies with greater disposable incomes, and hence, greater petfood marketing opportunities.

The majority of responding companies were small. Such companies are likely to have less developed processes for ensuring nutritional soundness and quality control. Accordingly, industry-wide practices may sometimes be superior to those determined within this limited study. Hence, its results may be presumed to be conservative.

The majority of respondents were in technical/production/nutrition roles – those most likely to be knowledgeable about the steps taken by their companies to ensure nutritional soundness and quality control. Accordingly, this study can be assumed to be a generally reliable representation of practices within the surveyed companies.

The companies produced a wide range of cooked or raw meat-based, vegetarian, vegan or almost vegan, and a small number of insect-based products, in an array of wet and dry formulations. Companies each chose to describe one complete diet within this survey, of which 19 were meat-based (cooked or raw - M), and 10 plant-based (vegetarian, vegan or almost vegan - V). It had been hoped that additional alternative diets might have been included in sufficient numbers for study. However no companies reported producing in vitro meat-, fungi- or algal-based pet foods, or those based on other primary ingredient types.

Diet formulation
Of the 93% of companies who designed their own formulations, all stated that they used nutritional specialists, but the levels of expertise differed. The highest level of nutritional expertise is provided by veterinary specialists board-certified in nutrition, followed by specialists with other postgraduate nutrition qualifications at masters level or higher. Whilst all companies stated they used nutritional specialists, the expertise utilised during the creation of the V diets exceeded that of the M diets overall (Tab. 4).

Similarly, feeding trials are considered the gold standard to ensure nutritional soundness of new formulations (Morris and Rogers 1994, Zicker 2008). Other methods are considered less reliable. These include formulation to meet nutritional requirements of national/regional bodies, and reliance on in-house knowledge and experience.

The formulation method simply requires application of nutritional standards supplied by national/regional bodies. This is the minimum requirement needed to ensure a formulation is likely to be nutritionally complete and balanced, and is required for product licencing and marketing in most jurisdictions. Almost all diets were found to use this method (Tab. 5).

Use of feeding trials, either directly, or indirectly via the family method, supplies the best information about actual effects on the target species. Hence feeding trials are considered the gold standard (Morris and Rogers 1994, Zicker 2008). In the closely related family method, the new formulation is established through analysis to be a member of a product family, of which the lead member has successfully passed a feeding trial. Such direct or indirect feeding trials were used for only 17% of both M diets and V diets.

In-house knowledge and experience is the least reliable means of ensuring nutritional soundness, and would normally be used in conjunction with other methods. This method was reportedly used for around a third of diets overall. In short, all companies used methods meeting or exceeding the nutritional requirements of national/regional bodies, and standards barely differed between M and V diets.

Ingredients used
Best practice, and in some cases regulatory and industry policy, requires verification of nutrient content and purity, and freedom from toxins or contaminants (Zicker 2008). Potentially hazardous contaminants can arise from a variety of sources, including free radicals, trans fatty acids, and other toxins from restaurant grease used as a fat source, hormonal residues and some chemical preservatives (Knight and Leitsberger 2016).

Pharmacologically active residues may derive from farm practices, such as prophylactic antibiotic use during intensive animal farming. Ionophore antibiotics, for example, are included within feed additives administered to poultry for control of coccidiosis, and to beef cattle and pigs for improved feed conversion efficiency and growth rates. These include salinomycin, lasalocid, monensin sodium, narasin and others. However, they can be toxic to cardiac and skeletal muscles and peripheral nerves, resulting in paralysis and even death, in dogs and cats (Carrión et al. 2014). Dosing levels and withholding periods prior to slaughter are intended to prevent excessive drug residues in food-producing animals that may be used within pet foods (Zicker 2008). Nevertheless, some of the most severe toxicity incidents have resulted from cross-contamination of feed ingredients with medicated feeds during feed or premix processing, handling or delivery (Carrión et al. 2014). Fish are also commonly used within pet food. However, they are unable to excrete modern oceanic pollutants, such as mercury and PCBs. These can accumulate in their tissues, reaching hazardous levels (Boyer et al. 1978, Houpt et al. 1998).

Most companies relied on a variety of steps to ensure nutritional soundness and quality of ingredients used. Gold standard steps of testing incoming ingredients for (i) nutrient presence and purity, and (ii) for known risks and contaminants, were utilised by most companies, although such steps were slightly more commonly utilised for V diets. Additionally, and in accordance with best practice (Thompson 2008), most companies inspected ingredient factories (although slightly less for V diets), and relied on contractual agreements with vendors. Most of the latter were audited to verify compliance, although significantly more were not audited in the case of V, than for M diets (40% vs. 11%). It was concerning that one company (M) normally assumed soundness of incoming ingredients, without any additional verifying steps.

Nutritional supplementation

Almost all (79%) of formulations were supplemented, with vitamins or similar being most common, followed by trace elements or similar, and amino acids or similar, respectively. Most formulations were supplemented with all three. However, supplementation in all three groups was slightly higher for M than for V diets (Tab. 7).

Preservation

Preservation processes were studied for 17 dry (M – 8, V – 9), and 12 moist/semi-moist/raw (M – 11, V – 1) formulations.

Dry foods rely their low water content to protect against spoilage, with antioxidants such as vitamin E, BHA and BHT added to counteract oxidative damage (Zicker 2008). For the dry formulations studied, physical methods to preserve formulations were used by all 8 M formulations. Sterilisation using high temperature or pressure was most commonly used, followed by drying sufficient to inhibit mould formation and bacterial growth. This is encouraging, as sterilisation (killing pathogens) is more effective than inhibiting their growth. However, there was a partial reversal of this trend for the 6 V diets, with drying being used for 67% of diets, compared to sterilisation (high temperature - 78% or high pressure - 33%).

Canned moist foods should be sealed under steam, which displaces air, resulting in an anaerobic environment, preventing aerobic bacterial survival. Cans should then be sterilised in a 'retort' using temperatures of 121°C for at least three minutes, which kills virtually all pathogens (Zicker 2008). Physical methods were less utilised to preserve the 12 moist, semi-moist or raw formulations, with 42% not utilising any physical treatments. The single V formulation relied solely on cold sterilisation as a physical preservation method. Among the M formulations, sterilisation by steam (36%) was twice as frequent as sterilisation by cold (18%). This is good, given the effectiveness of steam as a penetrative sterilising agent (Zicker 2008).

Considered overall, almost all dry formulations used more effective sterilisation methods, although less effective methods were more commonly used for V formulations. Nearly half of moist, semi-moist or raw formulations (which were almost entirely meat-based) did not utilise any physical treatments however. Clearly, significant scope exists to increase the use of physical sterilisation methods within this group, and steam sterilisation is the preferred option, where possible.

Additionally, just under half of all formulations used at least one additional (non-nutritive) additive to (i) preserve nutrients, (ii) preserve or enhance flavour or colour, or (iii) impede colonisation by bacteria or mould. When considered individually, these additive classes were used by just under half of formulations in the case of preservatives, dropping to a small minority, in the case of colourants and flavourants, and antimicrobials.

The slight minority use of preservatives may reflect either an expectation most produce is consumed, prior to preservation becoming a significant need. But it could also indicate lack of knowledge or prioritisation of nutrient preservation.

The lack of colourant and flavourant use likely reflects a lack of need – presumably these are considered unnecessary to produce palatability sufficient to sell produce.

The even lower levels of antimicrobial use may reflect a reliance on the physical sterilisation methods noted previously. These were used for a clear majority of dry formulations, but only a minority of moist formulations. Lack of antimicrobial use may also reflect a lack of knowledge concerning the need, or a lack of prioritisation. Microbial risks associated with meat-based diets include contamination with Salmonella, Listeria, and a range of other potentially pathogenic microorganisms, prion proteins (which cause transmissible spongiform encephalopathies, such as feline spongiform encephalitis), and mycotoxins (fungal toxins), such as aflatoxins produced by Aspergillus flavus and A. parasiticus, and vomitoxin produced by Fusarium moulds (Carrión et al. 2014). The dominance of mould inhibitors within the category of antimicrobials used, presumably reflects concerns about mould colonisation of produce warehoused for prolonged periods.

In all cases lack of (non-nutritive) additives may reflect a belief that consumers prefer formulations in which such additives are minimised. This contrasts markedly with nutritive additives, which were included in 79% of formulations overall. Consumers seem to prefer formulations that are both as nutritious, and also 'natural' – i.e. with minimisation of non-nutritive additives (Buff et al. 2014). Clearly, scope exists for greater use of various preservatives, and this would enhance product quality and the preservation of nutritional soundness. However, to address consumer concern it would be important to clearly signpost the benefits provided by such additives, within product branding.

Nutrient degradation over time

Best practice within post manufacture quality control involves nutrient testing to determine nutrient losses, in the short- and long-term storage, and assessment of product stability under differing environmental conditions (Zicker 2008).

Four of 29 (14%) companies reported that they don't normally attempt to predict post-manufacturing nutrient loss over time, with three of these four producing an M formulation. In one case a very short timeframe from manufacture to sale meant nutrient degradation would have been minimised. In the other cases, despite some steps taken to ensure product preservation, potentially prolonged timeframes left open the possibility of some nutrient degradation.

It was encouraging that the vast majority (86%) of companies reported normally attempting to predict post-manufacturing nutrient loss over time. Reliance on post-manufacture testing to determine nutrient levels was most common, with extrapolation from known characteristics (e.g. published data) and historical experience being the other method used. Both methods were used by the majority of companies.

Nutrient testing is most reliable when conducted by an external laboratory, certified by a professional or regulatory body. These were used by just over half of companies overall, with in-house testing utilised by just over one quarter (Tab. 12). These methods were not mutually exclusive. Companies producing V formulations appeared slightly more likely to use both types of testing.

Of the 20 companies conducting post-manufacture nutrient testing, all tested for overall protein and fat levels, and most also tested for ash content and rancidity. pH and specific nutrients were tested for, in close to half of cases. These tended to be amino acid, fatty acids, vitamins and minerals, in some cases apparently to check compliance with AAFCO or FEDIAF nutritional guidelines. These measures were welcome, but as with the use of laboratory testing, and importantly, external laboratory testing, compliance with these measures could be improved.

It was encouraging to see that 18 companies reported over-supplying vitamins to account for degradation over time. Vitamins are among the nutrients most vulnerable to degradation and loss of biological activity, and were added in 15 cases. Very few companies oversupplied other nutrients, although processing can result in other nutritional losses, e.g. heat treatment during extrusion can cause protein denaturation (Akhtar and Khan 2015). However, a more consistent, evidence-based approach, seems warranted.

Storage and shipping

It was encouraging that all but one company reported the use of standardised protocols to safeguard nutritional quality or prevent degradation, at different stages during storage and shipping. These were most commonly recommendations about storage temperatures and humidity levels, and expiry dates. Recommendations were most commonly applied to the in-house storage stage, followed by the shipping stage and recommendations for consumers, with specific recommendations for wholesalers and retailers being least common, but still applicable in around two thirds of diets overall. Companies producing V formulations were more likely to supply such recommendations, although differences were usually small.

Additional quality checks

A variety of additional quality steps were undertaken to ensure nutritional soundness and quality control during manufacturing. However, their prevalence, and application, varied significantly. Laboratory testing was applied to ingredients and products, by in-house and external laboratories. Tests were undertaken for nutrient levels, toxins including pesticides, a herbicide and metals. Testing frequency varied from non-existent, through annual, to each batch, and was pre-determined or random. Bacteriological testing was rare, but in one of two reported cases, occurred hourly during manufacturing.

Clearly, greater consistency in adherence to best practice standards would be desirable. These include regular predetermined and some random testing, of both ingredients and final products, for appropriate nutrients, toxins and pathogens. For optimal accuracy and transparency, a significant level of testing should be conducted by independent, external laboratories, certified by a professional or regulatory body.

Communication of protocols to retailers and/or consumers

Arguably, taking steps to ensure the nutritional soundness and quality control of products produced, is only part of the solution, to the problem of lack of confidence among some consumers. The other key step is the successful communication of information about these measures, using all appropriate communication channels. Most surveyed companies were using most of the channels included within this survey; namely, the use of company websites, information beyond minimum legal requirements on product labelling, and product information sheet for retailers, although 60% of those producing V formulations did not use the latter. Around 2/3 of companies producing M diets, and 80% of those producing V diets, did not make use of external publications such as industry journals. The use of additional modalities, provision of educational materials within veterinary schools, YouTube videos, email and 24 hr telephone enquiry services, were reported only once each.

Provision of educational materials within veterinary schools is obviously an ideal way to educate veterinarians, who will then go on to educate their clients about pet food choices. Access is limited however, and restricted by concerns about commercial sponsorship of professional veterinary curricula (Dowers et al. 2015).

A 24 hr telephone enquiry service is clearly expensive to staff. However, social media modalities such as YouTube and Facebook are clearly not expensive to set up – particularly given the increasing availability of 'screen casting' software, and webcams for recording videos. Optimisation of these social media communication channels requires ongoing engagement with users, and monitoring of pages, e.g. for inappropriate posts, although to some degree (e.g. software blocking of spam or abusive posts) these can be automated. However, more cost-effective measures may still allow a degree of optimisation, such as simple in-house video recording, once daily social media channel monitoring, and restricting general posting. It is surprising that such modalities are not more widely utilised. This suggests significant scope for their increased use. The use of external publications such as industry journals, e.g. through articles or paid advertising, could also help increase awareness of retailers. All of these would ultimately lead to increased consumer awareness of steps taken by manufacturers to ensure the nutritional soundness and quality control of their products.

Recommendations

This study found that for almost all stages within the formulation, manufacturing and distribution processes, the assessed companies had acceptable or superior standards overall, with plant-based diets slightly superior to meat-based diets (Tab. 3). However, in all dietary groups, there were occasional areas of concern, especially in the application of preservatives. To ensure more uniform compliance with best practice standards, companies, consumers and regulators could all assist.

Companies could aim for compliance with best practice standards, at all stages of the product design, manufacturing, storage and shipping processes. For companies formulating their own diets, nutritional expertise should ideally come from a veterinary specialist board-certified in nutrition, or failing that, by specialists with other postgraduate nutrition qualifications at masters level or higher. As well as being designed to meet the nutritional standards of national/regional bodies such as FEDIAF and AAFCO, companies could aim to ensure nutritional soundness through use of feeding trials, or the closely related family method.

Manufacturers should ensure incoming ingredients are tested for (i) nutrient presence and purity, and (ii) for known risks and contaminants, as well as physically inspecting ingredient production locations, and auditing contractual agreements with suppliers. Strong person-to-person relationships should be maintained. To account for nutritional degradation caused by manufacturing processes, manufacturers should supplement vitamins, trace elements and amino acids as appropriate to the formulation and intended species.

Manufacturers should implement best practice steps to ensure the preservation of products produced, ideally including, for dry products, high temperature and pressure sterilisation, and drying, and for wet products, high temperature steam. Appropriate preservatives and antimicrobials should also be used.

Manufacturers could more consistently test for the degradation over time of key nutrients, such as overall protein and fat levels, specific amino acid, fatty acids, vitamins and minerals, as well as ash content, rancidity and pH. Testing for both incoming nutrients and final products should utilise both regular and random frequencies. For optimal accuracy and transparency an external laboratory, certified by a professional or regulatory body, should be used, although supplementation with in-house testing may allow increased testing frequency.

Standardised protocols to safeguard quality and minimise degradation should be communicated and complied with during storage, shipping/transportation, and final use by consumers. These should cover temperature and humidity requirements, 'best before'/'use by' dates, handling and any other requirements.

The steps taken by companies to ensure nutritional soundness and quality control through the production and supply chain should be communicated to retailers and consumers using a full array of communication modalities. These should include information beyond minimum legal requirements on product labelling, product guides for retailers, company websites. Serious consideration should be given to the use of additional modalities, such as YouTube videos and other social media channels, external publications such as pet care or industry journals, email, online chat and telephone enquiry services, and, to the extent reasonably possible, provision of educational materials within veterinary schools. To address consumer concerns about 'unnatural' additives such as preservatives, the benefits provided by such additives should be clearly communicated.

Regulators could assist, by taking steps to ensure companies provide such information more transparently. Finally, consumers could encourage companies to aspire to such best practice standards, by requesting information about the steps they take to ensure the nutritional soundness and quality control of their products.

Conclusions

The nutritional soundness of pet foods has been repeatedly cited by consumers as one of their top concerns, especially in relation to plant-based diets. Such concerns are understandable, given both a history of contaminated product recalls and studies demonstrating nutritional deviations among pet foods generally, and also the biological requirements of cats in particular, who are naturally obligate carnivores. These concerns can impede the marketability and uptake of such diets, especially by the sizeable and growing proportion of consumers who follow plant-based diets themselves. This also limits the diversification of the pet food product range, and the ability of the pet food industry to use such diets to help lower its ecological footprint.

To our knowledge, this is the first systematic study to be published, examining the prevalence of steps taken to ensure the nutritional soundness and quality of pet foods. It demonstrated that at almost all stages within the formulation, manufacturing and distribution processes, these 29 surveyed companies had acceptable or superior standards overall, with plant-based diets slightly superior to meat-based diets (Tab. 3).

The majority of responding companies were small. Larger companies are likely to have a greater market share, and also more developed processes for ensuring nutritional soundness and quality control. Accordingly, industry-wide practices may sometimes be superior to those determined within this limited study.

Despite the good standards evident overall, there were limited areas in which practices could be improved, especially in the application of preservatives. And as Zicker (2008) noted, "Long-lived, healthy consumers (pets) contribute to greater sales, so breakdowns in product quality can have catastrophic effect on profits or even company viability." He noted that contamination incidents, that whilst often affecting only a small percentage of commercial pet foods, have adversely impacted the entire industry (Anon 1995, Dobson et al. 2008, Petful 2021).

A range of steps could, and should, be broadly implemented by manufacturers, and even regulators, to encourage best practice throughout the production and supply chain. Consumers can also assist, by inquiring of companies what steps have been taken, to ensure the nutritional soundness and quality of the products they sell.

Utilisation of a more comprehensive range of communication modalities, summarising quality control steps implemented, would help to reassure consumers at large, and particularly the sizeable minority interested in plant-based pet foods.

Through ensuring higher quality diets, and better transparency of information, such steps would enhance the welfare of cats and dogs, the market shares of companies producing high quality diets, and would satisfy the concerns of consumers about the nutritional soundness of both conventional and plant-based pet foods.

Limitations and Future Studies

Study limitations

As noted, we qualitatively assessed steps taken by companies to ensure the quality and nutritional soundness of their pet food formulations as inferior, acceptable, or superior. In doing so we studied the proportion of diets fulfilling the various criteria within each group, and focused on more significant differences between dietary groups. Although we believe our assessments are supported by these data, we acknowledge that qualitative assessments may vary between assessors. In our case however, no disagreements arose between the two co-authors after independent assessment.

We would also like to have tested the statistical significance of the apparent differences in outcomes, based on diet type M or V. The main statistical method for investigating such differences is the two-way chi-square test. However, chi square tests are not valid when table cells have expected counts < 1, or 20% or more cells have expected counts < 5, as commonly occurred in this study. Additionally, even the most optimal tables (one degree of freedom) require sample sizes of 32 to 785 respectively, depending whether effect sizes are large or small (Hawkins 2019: 114-115). Hence unfortunately chi-square significance testing was not possible, with our sample size of 29. Hence, although our results are indicative, we acknowledge our participant numbers are not adequate for reliable extrapolation of results to all pet foods companies in general.

Suggestions for further research

To allow statistical testing of the significance of apparent differences between dietary groups, further research should aim to recruit greater participant numbers. We did make extensive efforts to recruit study participants, in an effort to achieve a sample size sufficient for statistical analysis. Steps taken included ensuring the survey was fairly quick to complete, and inviting participation from nearly 700 companies, twice, and making additional personalised requests to nearly 50 companies. One major industry association kindly encouraged its numerous members to participate, also repeatedly, and the survey was advertised in one industry newsletter. All were offered a free copy of the resultant published report, which was expected to be of benefit to them. However our participation rate was 29 of 688 companies, or 4%. Such low participation rates are common for online surveys. Future research should aim to address this by including a budget to recompense participants for their time. As noted by Conn et al (2019), "… relative to monetary incentives, altruistic appeals are ineffective in increasing survey response and that offering additional monetary incentives is always desirable". £6,000 would allow payments of £30 to 200 individuals, for the 15 mins estimated necessary. This would be sufficient to detect large to medium-sized differences between dietary groups. Small differences would require sample sizes closer to 1,000 or above (Hawkins 2019: 114).

We also note the ongoing development of novel protein sources, including in vitro meat. Future studies, with greater participant numbers, may also allow examination of a greater diversity of dietary groups.

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