Essays on data-driven pet food marketing and buyer preferences

by

Elaheh Rabiee

B.S., Amirkabir University of Technology, 2013
M.A., Kansas State University, 2022

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
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Abstract

Pet food has become an increasingly important component of the global pet care industry as rising pet ownership, premiumization, and the humanization of pets continue to reshape consumer preferences and firm strategies. Despite rapid market growth, publicly available research in pet food economics and management has not kept pace with the industry's need for decision-relevant evidence on consumer behavior, product attributes, and market outcomes. This dissertation contains three essays designed to provide research-based insights into the relationships among pet health, consumer preferences, purchasing behavior, and ingredient positioning, with the objective of informing future research, product development, and marketing strategies in the pet food industry.

The first essay examines how reported feeding practices, exercise, product characteristics, and dog characteristics are associated with a breed-adjusted measure of canine weight deviation. The analysis integrates a nationwide survey of U.S. dog owners with product-level information and applies quantile regression to examine whether these associations differ across the conditional weight-deviation distribution. Total daily caloric intake is positively associated with weight deviation across important portions of the distribution, while dog age is also consistently associated with higher weight deviation. Treat frequency, feeding frequency, food form, breed size, and reproductive status are associated with weight outcomes in selected portions of the distribution, whereas reported exercise relationships are mixed. These findings indicate that canine weight outcomes are associated with a combination of feeding decisions, pet characteristics, and product-related factors rather than a single behavior or product characteristic.

The second essay investigates whether pet owners' stated attribute preferences are reflected in the characteristics of the food and treat products they report purchasing. The analysis

introduces a Match Index Score that measures preference-purchase alignment across health, ingredient, processing, and supply-chain attributes. The findings show that alignment varies substantially across attribute categories and between food and treats. Natural and Made in USA attributes display relatively strong visibility in both owner priorities and reported products, whereas larger gaps emerge for digestive-health, fresh, and minimally processed attributes. Alignment also varies with owner age, income, education, dog size, allergy status, and product price. In particular, higher product prices are associated with lower alignment in several specifications. These findings demonstrate that stated importance should not automatically be interpreted as realized demand because affordability, product availability, familiarity, palatability, and pet-specific needs may intervene between preference formation and purchase.

The third essay examines consumer preferences for sorghum relative to rice, barley, quinoa, corn, oat, and millet using survey-based grain-choice data and multinomial logit models. Sorghum is not the leading choice in any of the three comparison sets. Younger respondents are relatively more receptive to sorghum, whereas older respondents generally favor competing grains. Respondents who prioritize digestive health or weight control are less likely to select sorghum in several comparisons, suggesting that consumers do not yet strongly associate sorghum with these benefits. Avoidance of corn, soy, or wheat increases sorghum preference when corn is a competing alternative, while sustainability improves sorghum's position primarily when it is compared with rice and barley. These results show that sorghum's market potential depends on the competing ingredient, the consumer segment, and the benefit being communicated.

Taken together, these essays provide new insights into the economic and behavioral factors shaping pet food markets. The central lesson of the dissertation is that success in pet food depends on alignment, alignment between feeding behavior and canine health needs, between expressed preferences and feasible purchases, and between an ingredient's technical benefits and the meanings consumers attach to it. Pet food manufacturers and marketers must therefore consider not only what can be formulated or claimed, but also how owners understand, select, afford, and use products in everyday settings.

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entirely new meaning. Although she is too young to understand these words today, I hope that one day she will know that she was beside me, in her own special way, when I crossed the finish line. Becoming her mother made completing this degree even more meaningful and gave me a new reason to think about perseverance, growth, and the future.

To everyone who walked beside me through this experience- with guidance, friendship, patience, encouragement, or love- thank you. This dissertation carries a part of each of you with it.

Dedication

To Ali, my strength; to Lyanna, my sweetest chapter; and to my parents, my roots.

Chapter 1 - Introduction

The pet food market has become an increasingly important part of the broader pet care economy as rising pet ownership, premiumization, and the continued humanization of pets reshape consumer expectations and firm strategies. As pet owners place greater emphasis on health and nutrition, ingredient quality, naturalness, functionality, and sustainability, pet food companies face increasing incentives to develop products that respond to these preferences while also considering price, convenience, palatability, and other factors that shape purchasing decisions (Schleicher et al., 2019; Rombach & Dean, 2021; Ai et al., 2025). Despite the continued growth and diversification of the pet food market, research on consumer behavior toward commercial pet food remains fragmented and comparatively underexplored, particularly regarding how consumer preferences, product attributes, and real-world purchasing constraints interact (Ai et al., 2025). The central problem motivating this dissertation is therefore how to generate rigorous, decision-relevant evidence on the relationships among product attributes, buyer behavior, and market outcomes in the pet food industry.

This dissertation addresses this problem through three related essays examining pet food from the perspectives of canine weight outcomes, preference-purchase alignment, and ingredient positioning. Although each essay focuses on a distinct research question, all three are unified by a common concern: the gap between the attributes firms can formulate or promote and the attributes consumers ultimately recognize, value, purchase, and use in ways that shape market and health outcomes. The dissertation is therefore situated at the intersection of agricultural economics, marketing, consumer behavior, and companion-animal health.

The first essay, presented in Chapter 2, examines how feeding practices, exercise, dog characteristics, and pet food product attributes are associated with a breed-adjusted measure of canine weight deviation. The analysis uses an integrated dataset linking dog-owner survey responses with product-level market information. Quantile regression is employed to identify whether the relationships between feeding behavior, exercise, product characteristics, and weight deviation differ across the conditional NWD distribution. The essay connects these findings to product formulation, portion guidance, consumer education, and market segmentation strategies in the pet food industry.

The second essay, presented in Chapter 3, shifts the focus from canine weight outcomes to pet food purchasing behavior. It examines whether the attributes pet owners report prioritizing are reflected in the products they report purchasing. To measure this relationship, the essay develops a Match Index Score that compares owners' stated preferences with product attributes across four dimensions: health, ingredients, processing, and supply-chain characteristics. Using linked survey and product information, the analysis evaluates how owner, dog, and purchasing characteristics are associated with the degree of preference-purchase alignment. The results provide insight into the practical limitations of stated preferences and the roles of price sensitivity, product availability, household constraints, and established purchasing habits in shaping realized consumer choices.

The third essay, presented in Chapter 4, examines the market positioning of sorghum relative to competing grains used in pet food. Although sorghum possesses agronomic, nutritional, and sustainability-related advantages, it remains less familiar to many consumers than established ingredients such as rice, corn, and oat. Using survey-based grain-choice data and multinomial logit models, the essay compares sorghum with rice, barley, quinoa, corn, oat, and millet. It also identifies demographic characteristics, attitudes, and ingredient-related priorities associated with the likelihood of selecting sorghum. This analysis extends the dissertation's broader theme by demonstrating that technical or functional advantages do not automatically translate into consumer demand when buyers are unfamiliar with an ingredient or do not associate it with the benefits they prioritize.

This dissertation is organized into four remaining chapters. Chapter 2, which contains the first essay, investigates the relationships among feeding practices, exercise, dog characteristics, pet food product attributes, and breed-adjusted canine weight deviation. Chapter 3, which contains the second essay, evaluates the consistency between pet owners' expressed attribute preferences and the attributes of their reported purchased products. Chapter 4, which contains the third essay, analyzes consumer preferences for sorghum relative to competing pet food grains and identifies factors associated with sorghum choice. Chapter 5 summarizes the principal findings of the three essays, discusses their collective contributions to pet food economics and management, identifies limitations, and presents directions for future research. Supporting materials are provided in the appendices. Appendix A presents the pet food ingredient consumer survey instrument, Appendix B provides a detailed example of the product information collected from an online retailer, Appendix C reports descriptive information on dog owners and their dogs, Appendix D presents the distributions of preferred and purchased-product attributes, Appendix E reports the producer survey, Appendix F provides the average marginal effects from the multinomial logit models used in Chapter 4, and Appendix G provides supplementary machine-learning analyses for Chapter 2.

Chapter 2 - Pet Obesity Trends and Their Impact on Business Strategies in the Pet Food Industry

2.1 Introduction

On a typical evening, a dog sits by the dinner table, watching each bite its owner takes. A small piece of meat drops to the floor, a snack appears "because he looks hungry" and an extra treat is given "because he was such a good boy today". For the owner, these are everyday acts of affection. For the dog, repeated thousands of times over its lifetime, they become a steady push toward overweight and, eventually, obesity. This familiar scene is now replicated in millions of households worldwide. Pet obesity is a growing animal-health and economic concern. The Association for Pet Obesity Prevention reports that approximately 59% of dogs and 61% of cats in the United States are overweight or obese, while UK estimates also indicate that excess weight affects a substantial share of companion animals (Association for Pet Obesity Prevention, 2022; UK Pet Food, 2024). Excess weight is associated with diabetes, orthopedic disorders, cardiorespiratory problems, reduced quality of life, and shorter lifespan (German, 2006; Laflamme, 2012). These health consequences also create financial burdens for households and insurers; These health consequences can also create financial burdens for pet owners. Among insured pets, Nationwide P&C Group, one of the largest pet insurance providers in the United States, reported more than $90 million in obesity-related veterinary claims during a twelve-month period (Nationwide, 2021). Because only a small proportion of U.S. pets were insured at that time, this figure represents costs within Nationwide's insured population rather than the total economic burden of pet obesity.

The obesity problem is closely connected to household feeding decisions and to the products and information supplied by the pet food industry. Canine weight outcomes reflect energy intake and expenditure, conditional on breed, age, sex, reproductive status, and other biological characteristics (German, 2006; Robertson, 2003). Owners determine food portions, feeding frequency, treat use, and exercise, while manufacturers influence the choice environment through product formulation, caloric density, package design, feeding instructions, and health-related claims. Pet obesity is therefore not only a veterinary issue; it is also relevant to product development, labeling, consumer education, and market segmentation. Hobbs et al. (2024) similarly identify opportunities for differentiation through lower-calorie products, breed- or size-specific positioning, and services that help owners make more appropriate feeding decisions.

Despite a substantial veterinary literature on canine obesity, several empirical gaps remain. Many studies rely on veterinary-clinic samples or specialized owner populations, limiting generalizability. Owner behavior and product characteristics are also frequently studied separately, even though weight outcomes may reflect their interaction. In addition, categorical body condition scores can be affected by owner misperception and may conceal variation within broad weight categories (Courcier et al., 2010; White et al., 2011). Finally, relatively little work uses distribution-sensitive econometric methods to examine whether feeding, activity, product, and breed-related factors are associated differently with canine weight outcomes across the weight-deviation distribution.

This chapter addresses the following questions: How are owner feeding decisions, treat practices, exercise, product attributes, and dog characteristics associated with canine weight deviation after accounting for breed-related differences? Canine weight deviation is measured using Normalized Weight Deviation (NWD), defined as the difference between a dog's reported weight and the mean reference weight for its breed, divided by that breed reference weight. Do these associations vary across the lower, middle, and upper portions of the weight-deviation distribution? These questions are examined using a nationwide online survey of U.S. dog owners linked to product information collected from Chewy.com. Product names reported by respondents were standardized and matched to product-level information collected from Chewy.com, resulting in a novel integrated dataset of 5,211 matched owner-dog-product records. A key contribution of this study is the construction of this novel linked dataset, which allows owner-reported feeding behavior and dog characteristics to be examined jointly with detailed characteristics of the products actually reported as being fed.

The primary outcome is Normalized Weight Deviation (NWD), a continuous breed-adjusted measure based on the difference between a dog's reported weight and its breed-standard reference weight. NWD adjusts for differences in typical body weight across breeds but does not fully account for within-breed variation in individual body size, genetics, or clinically ideal weight. Environmental and behavioral factors, including feeding practices and physical activity, are not incorporated directly into the NWD calculation but are included separately as explanatory variables in the empirical models. NWD is used as a proxy for relative weight status rather than as a clinical body condition score. Quantile regression estimates how the conditional relationships between NWD and feeding, exercise, product, and dog characteristics differ across the NWD distribution. Specifically, the 25^{th}, 50^{th}, and 75^{th} percentiles represent dogs with relatively lower, median, and higher weight deviations from their breed-standard reference weight, respectively. A supplementary machine-learning analysis exploring nonlinear predictive patterns is provided in Appendix G.

This research is important because canine excess weight is not only an animal-health concern but also a business and consumer-decision problem. Owners determine how much and how often dogs are fed, how frequently treats are provided, and how much physical activity dogs receive, while pet food companies influence these decisions through product formulation, caloric density, package design, labeling, feeding instructions, and marketing communication. Answering the chapter's research questions therefore matters because it helps explain how owner behavior, product characteristics, and dog-specific factors operate together and whether their relationships with weight deviation differ across dogs at lower and higher points of the NWD distribution. Building on Hobbs et al. (2024), this chapter contributes by using a substantially larger linked owner-dog-product dataset and incorporating product-level measures of crude protein, crude fat, and crude fiber in addition to owner feeding practices, activity, and dog characteristics. It also constructs a continuous breed-adjusted measure of relative weight status and examines heterogeneity across the NWD distribution using quantile regression.

Pet food manufacturers and product developers can use the findings to identify segments that may require more tailored support, including older dogs, extra-small breeds, spayed or neutered dogs, and dogs receiving substantial calories from treats. Marketing managers and retailers can use the evidence to develop clearer and more relevant communication, such as calories per serving, the contribution of treats to total daily intake, and instructions for adjusting portions when treats are given, rather than relying only on broad weight-management claims. Veterinarians and consumer educators may benefit by using the findings to support individualized feeding discussions that account for the dog's diet, age, activity, breed size, and reproductive status. Pet owners ultimately benefit from clearer product information and more practical guidance that can improve feeding decisions. However, because the data are cross-sectional and several measures are self-reported, the findings should be interpreted as conditional associations rather than causal effects.

The remainder of this chapter is organized as follows. Section 2.2 reviews the relevant literature. Section 2.3 presents the conceptual framework, describes the consumer survey and web-scraped product datasets, explains the data-integration process, and details the econometric approach used in the analysis. Section 2.4 reports and discusses the quantile-regression results. Finally, Section 2.5 concludes with key findings, implications, limitations, and directions for future research. Supplementary machine-learning analyses are reported in Appendix G.

2.2 Literature Review

2.2.1 Pet Obesity Trend

Pet obesity is widely documented as a health and welfare concern. Excess weight is associated with diabetes, orthopedic disease, reduced mobility, and shorter lifespan (German, 2006, 2016; Laflamme, 2012; Courcier et al., 2010). A persistent challenge is that owners often underestimate their dog's body condition. U.S. and UK evidence indicates that many owners classify overweight pets as being at a healthy weight, reducing the likelihood that they will seek veterinary guidance or adopt weight-management practices (Association for Pet Obesity Prevention, 2022; UK Pet Food, 2024; Eastland-Jones et al., 2014).

Canine obesity is shaped by biological, behavioral, and household factors. Age, breed, reproductive status, energy intake, treat use, and physical activity have all been associated with weight outcomes (Robertson, 2003; Courcier et al., 2010; German, 2016). Owner behavior is central because food portions, feeding frequency, treat use, and exercise are controlled within the household. Socioeconomic constraints may also influence access to veterinary care, suitable products, and exercise opportunities, although these relationships should not be interpreted as deterministic (Bomberg et al., 2017). The literature therefore supports an integrated framework in which weight outcomes reflect the interaction of biology, owner decisions, and the available product environment.

2.2.2 Market Strategy

The pet food industry has responded to weight-related concerns through calorie-controlled foods, high-satiety formulations, life-stage products, feeding guides, and digital tools. These products allow firms to differentiate on health and wellness attributes while addressing a recognized consumer need. Hobbs et al. (2024) show that product reformulation, perceptual positioning, and complementary services can support differentiation in the healthy-weight segment. Nielsen (2021) similarly documents growing consumer interest in health- and wellness-oriented pet food attributes, as reflected in in-store sales and online search behavior during 2020-2021.

However, the effectiveness of weight-management products depends on owner recognition and adherence. A technically appropriate formulation will have limited effect if portions are not measured, treats are excluded from the daily calorie budget, or owners do not recognize excess weight. Product strategy must therefore extend beyond formulation to include clear calorie information, practical portion guidance, and communication that helps owners translate recommendations into routine behavior (German et al., 2018; Zoran, 2010).

2.2.3 Buyer Behavior

Pet owners express strong concern for health, ingredient quality, and freshness when choosing food (Schleicher et al., 2019), but purchasing and feeding behavior are also shaped by price, convenience, habit, palatability, and the owner-pet relationship. Owners may use food and treats as expressions of affection, respond to begging as evidence of hunger, or rely on visual familiarity when evaluating body condition. These tendencies can weaken portion control even when owners intend to support health.

When owners recognize a weight problem, reducing portions or treats may be more acceptable than switching to a therapeutic diet because these actions are less costly and require less adjustment. Specialized products may face barriers related to price, access, palatability, and uncertainty about effectiveness. Price sensitivity is heterogeneous: some owners display strong brand loyalty and willingness to pay for perceived quality, whereas budget-constrained households may rely more heavily on lower-cost products or zero-cost changes to feeding routines (Schleicher et al., 2019; Bomberg et al., 2017).

Veterinarians can reduce information gaps by providing body-condition assessment, calorie targets, and feeding guidance. Yet owner recall of weight-related counseling is incomplete, and advice may not be implemented consistently (Association for Pet Obesity Prevention, 2022). Buyer behavior is therefore best understood as the outcome of health intentions, household constraints, emotional attachment, product characteristics, and professional guidance rather than as a simple response to nutritional information.

2.2.4 Summary of Literature Gaps and Contribution

The literature establishes the prevalence and clinical consequences of canine obesity, but it provides less evidence on how owner behavior and the attributes of the products owners report feeding operate jointly. Existing work also relies heavily on categorical or owner-reported body condition and often emphasizes average relationships. This chapter addresses these gaps by linking a large owner survey to product-level information, constructing a continuous breed-adjusted weight-deviation measure, and estimating heterogeneous relationships across the NWD distribution. This design connects veterinary evidence on weight risk to questions of product formulation, feeding guidance, and consumer use.

2.3 Data & Methodology

2.3.1 Conceptual Framework

The conceptual framework links canine weight deviation to three broad components: caloric intake, caloric expenditure, and biological predisposition. These components are influenced by owner decisions, product characteristics, and dog-specific factors. The framework is not intended to imply that any single variable determines obesity; rather, it organizes the mechanisms through which household behavior and the product environment may be associated with relative weight status. This relationship has been conceptually modeled in previous research (German, 2006; Robertson, 2003) and is further supported by Hobbs (2023), who emphasizes the interaction among diet, exercise, and genetic factors in determining pet body condition. Mathematically, this relationship can be expressed as:

(2.1)

Dog Body Condition = f (caloric intake, caloric output, genetic predisposition)

In this framework, caloric intake includes calories from the primary food and treats. It is shaped by food type, caloric density, portion size, feeding frequency, treat frequency, and the rules owners use to determine portions. Owners directly determine how much and how often a dog is fed. Manufacturers influence these decisions through formulation, serving recommendations, package size, calorie disclosure, and labeling. Consequently, observed intake reflects both household behavior and the characteristics of the selected product.

Caloric expenditure is represented by the frequency and duration of low-, moderate-, and high-intensity activity. Exercise is primarily controlled by the owner and may vary with time constraints, dog age, breed, health, and living environment. Although firms do not directly determine activity, they may influence awareness through feeding calculators, weight-management guidance, and educational materials. Intake and activity must be considered jointly because the same intake level may have different implications for dogs with different activity patterns.

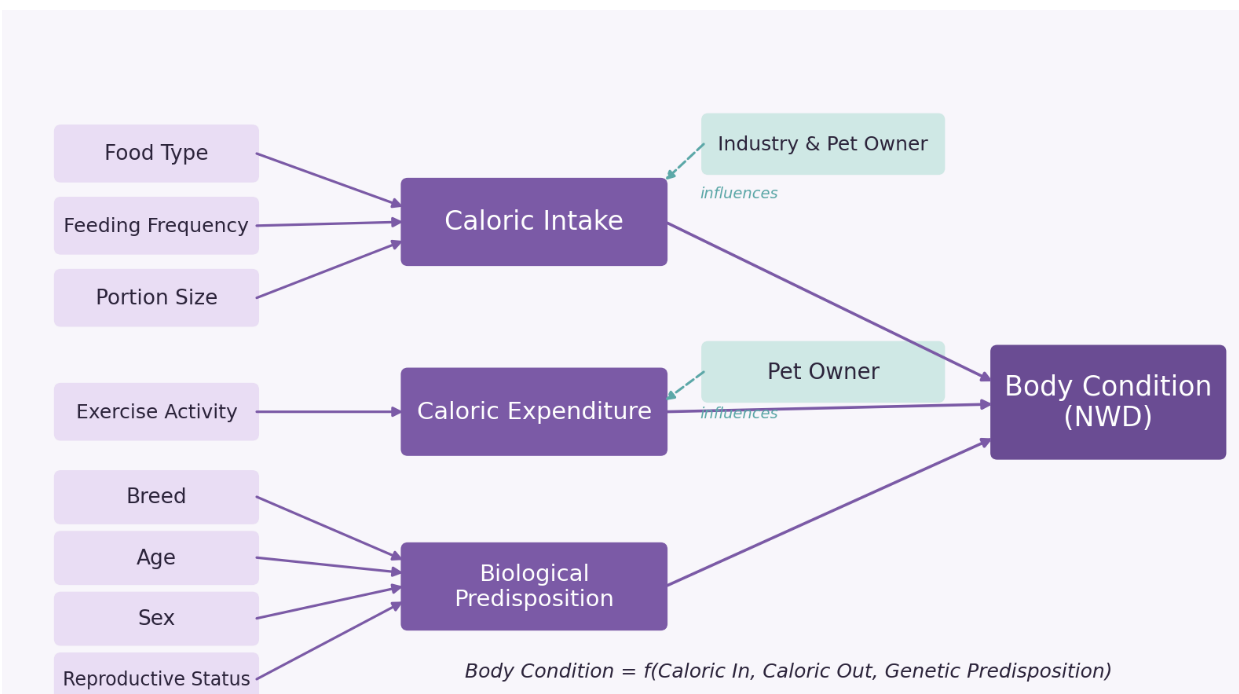
Biological predisposition includes breed size, age, sex, and reproductive status. These factors affect expected body size, maintenance energy requirements, and susceptibility to weight gain. Breed-adjustment is especially important because an absolute weight difference has different meaning for a toy breed and a large breed. The framework therefore motivates breed-size controls and interactions between caloric intake and breed-size categories.

Owner perception and information operate across all three components. Owners may misclassify body condition, underestimate the caloric contribution of treats, or depart from package and veterinary recommendations. These behaviors can mediate the relationship between the available product information and realized feeding practices (Courcier et al., 2010; White et al., 2011; German et al., 2016).

The conceptual framework presented in this chapter illustrates the relationships between the chapter's objective and its research questions. The first research question asks how feeding decisions, treat practices, physical activity, product characteristics, and dog-specific factors are associated with canine weight deviation. The framework guides this analysis by organizing the explanatory variables into three mechanisms: caloric intake, caloric expenditure, and biological predisposition. Food and treat calories, feeding frequency, food type, nutrient composition, and portion-decision rules represent the caloric-intake channel; low-, moderate-, and high-intensity activity represent the caloric-expenditure channel; and breed size, age, sex, and reproductive status represent biological predisposition. Normalized Weight Deviation serves as the outcome because it expresses reported weight relative to a breed-based reference and therefore allows breed-related differences to be incorporated directly into the analysis.

The second research question asks whether these associations differ across the lower, middle, and upper portions of the NWD distribution. The framework suggests that the same feeding practice or calorie level may have different implications depending on a dog's breed size, age, reproductive status, activity, and existing position in the weight-deviation distribution. It also motivates the use of quantile regression to estimate associations at different points of the conditional NWD distribution. Figure 2.1 summarizes these relationships and shows how the conceptual components are translated into the variables and empirical methods used in the empirical analysis.

Figure 2.1. Conceptual Framework of Canine Body Condition



2.3.2 Data Collection & Integration

This study is based on a unified dataset created by integrating information from two sources: a consumer survey and web-scraped data, providing a comprehensive analysis of pet owners' behaviors, preferences, and market trends in the pet food industry. The first dataset was collected through an online consumer survey administered using the Qualtrics platform, targeting dog owners in the United States. Survey respondents were recruited through Dynata, a leading provider of survey sample services. This dataset provides insight into pet owners' feeding habits, purchasing decisions, and demographic characteristics. The second dataset was compiled through web scraping of Chewy.com, one of the largest online pet food retailers in the U.S. This dataset includes detailed product information on dog food and treats, capturing specifications such as product name, flavor, pricing, nutritional content, and feeding instructions. The integration of these datasets allows for an in-depth exploration of the intersection between consumer decision-making and the real-world pet food market and its response to obesity-related trends.

2.3.2.1 Online Consumer Survey

The primary dataset was collected through an online survey specifically designed to target dog owners across the United States. The survey aimed to gather extensive insights into dog owners' feeding practices, purchasing behaviors, perceptions of ingredients, particularly plant-based ingredients such as sorghum, and demographic characteristics. Dog owners' behaviors provide valuable insights for product development and marketing strategies.

First, specific eligibility criteria were established for the online survey respondents. Participants had to be at least 18 years old and own a dog. Those who did not meet these conditions were prevented from continuing the survey. The survey included a structured questionnaire comprising demographic items (e.g., gender, age, income, education, geographic location), detailed pet characteristics (e.g., breed, age, weight, sex, reproductive status, body condition), pet food feeding habits (allergy, primary food/treat type, food/treat portion, food/treat frequency, decision-making on food amount, brand name, product name, formulation type, and monthly expense on food/treat), pet exercise habits (intensity activity including low, medium, and high, frequency time of per week, and duration per time), pet food buying habits (most preferred criteria among price, ingredient, and attribute, most preferred attributes for each attribute containing health, ingredient, processing, and supply-chain), preference of plant based ingredients using Best Worst Scaling (BWS) among seven ingredient, and specific inquiries into preference of sorghum benefit using BWS among seven important benefit.

An initial sample size target of 5,000 respondents was established in June 2023. The survey underwent a preliminary soft launch with 50 participants, followed by a partial launch of approximately 2,500 responses. The responses were reviewed for completeness, and observations with substantial missing information were removed. No changes were made to the questionnaire between data-collection waves. The final survey resulted in 6,310 completed responses, providing broad coverage across demographic groups and geographic locations in the United States.

To ensure data quality, a thorough data-cleaning process was implemented. First, irrelevant entries were removed from the open-ended responses. ZIP codes that were not exactly five digits long were excluded. Cleaning dog breed names posed a unique challenge because of variations in spelling, as breed names are often difficult for respondents to spell correctly. To improve consistency, all breed names were converted to lowercase. Each entry was then manually reviewed and corrected by cross-referencing it with official breed names from sources such as the American Kennel Club. Typos were standardized to their correct breed names, for instance, entries like beagal, begal, begel, and begle were all corrected to “beagle”. A similar approach was applied to brand names, product names, and formulation types. For example, variations such as pedegree, predigre, pedergree, pedrigree, and pefigree were all standardized to “pedigree” to ensure consistency across the dataset. (questionnaire survey in Appendix A)

2.3.2.2 Web Scraping Dataset

The second dataset complements the consumer survey through comprehensive web scraping of Chewy.com, one of the largest online pet food retailers in the United States. The web scraping was conducted on two separate occasions: initially capturing URLs for food products on March 21, 2024, followed by treat products on June 4, 2024. A Python script utilizing Beautiful Soup and Selenium WebDriver were used to systematically extract detailed product information from each URL, including product names, categories, flavors, pricing, nutritional content, and feeding instructions (Richardson, n.d.; Selenium Project, 2024).

After eliminating duplicate URLs, the finalized dataset contains 7,125 unique observations spanning different product categories such as dry food, wet food, and treats. Each entry captures detailed specifications, including product name, brand, product size, pricing, flavor profile, nutritional details (e.g., caloric content, crude protein, crude fat, fiber, moisture, etc.), and recommended feeding guidelines. An example from this dataset is “Purina ONE Natural Adult Chicken & Rice Formula Dry Dog Food”. Detailed visuals of this product are provided in Appendix B for better readability.

To clean the dataset, the scraped text was first extracted from a single column and organized into specific columns to improve data organization and usability. Primary columns were created for Product Name, Category, Details, Ingredient Information, and Feeding Instructions. The Details column was further divided into sub-columns, including Text Part, Item Number, Weight, Dimensions, Package Size, Season, Sourced From, Made In, Shop Conscious, Packaging Type, Lifestage, Breed Size, Food Form, and Special Diet. Additionally, the Ingredient Information section was separated into three specific columns: Ingredients, Caloric Content, and Guaranteed Analysis. The Caloric Content column was further divided into specific sub-columns based on measurement units. For food products, the caloric values were categorized as kcal/kg, kcal/cup, kcal/pack, kcal/12.5oz can, and kcal/oz. For treats, additional sub-columns were created, including kcal_treat, kcal_piece, kcal_each, kcal_bit, kcal_hoof, kcal_chew, and kcal_tray to capture different portion sizes and packaging formats. For the Guaranteed Analysis section, separate columns were created for all nutritional values and vitamins reported for each product. Some examples include Crude Protein, Crude Fat, Crude Fiber, Moisture, Methionine, Docosahexaenoic Acid, Linoleic Acid (Omega 6 Fatty Acid), Linoleic Acid (Omega 3 Fatty Acid), Zinc, Selenium, Vitamin A, Vitamin E, and others. The most challenging part was structuring the Price column, as pricing varied significantly based on different packaging formats. Products came in various bag sizes (e.g., 18-lb bag, 30-lb bag, 8-oz bag), can sizes (e.g., 13.2-oz can, 22-oz can), box sizes (e.g., 4-lb box - makes 16 lbs, 7-lb box - makes 28 lbs), and count-based formats (e.g., 7 count, 14 count, 70 count). Prices were recorded per pound (lb), ounce (oz), or unit (each). Additionally, for some product variations, pricing was unavailable at the time of web scraping. Finally, it is important to note that not all products contain information for every column. The general structure was created to accommodate all possible details, but individual products may only include a subset of these attributes. (Sample of product information in Appendix B)

2.3.2.3 Matching and Final Analytical Sample

Integrating these two datasets was a critical step in creating a cohesive analytical foundation. Survey-reported brand names, product names, formulation types, and food types were first standardized to reduce differences in spelling and formatting. The actual matching was performed by comparing the product name reported by each respondent with the product title displayed on the corresponding Chewy.com product page. The full product description, ingredient list, nutritional information, and other webpage content were not used to calculate the matching score.

This matching process represents a practical application of text mining, as it involves extracting, cleaning, and comparing unstructured textual information from two independent data sources to identify meaningful correspondences between survey responses and scraped product listings. To match respondent-reported product names with Chewy.com product titles, the Python library FuzzyWuzzy was employed (Cohen, 2011). FuzzyWuzzy uses fuzzy string-matching algorithms based on Levenshtein distance to calculate the similarity between two strings. Levenshtein distance quantifies the number of edits (insertions, deletions, or substitutions) required to convert one string into another, generating a similarity score ranging from 0 to 100, where higher scores represent greater similarity between two strings (Bosker, 2021).

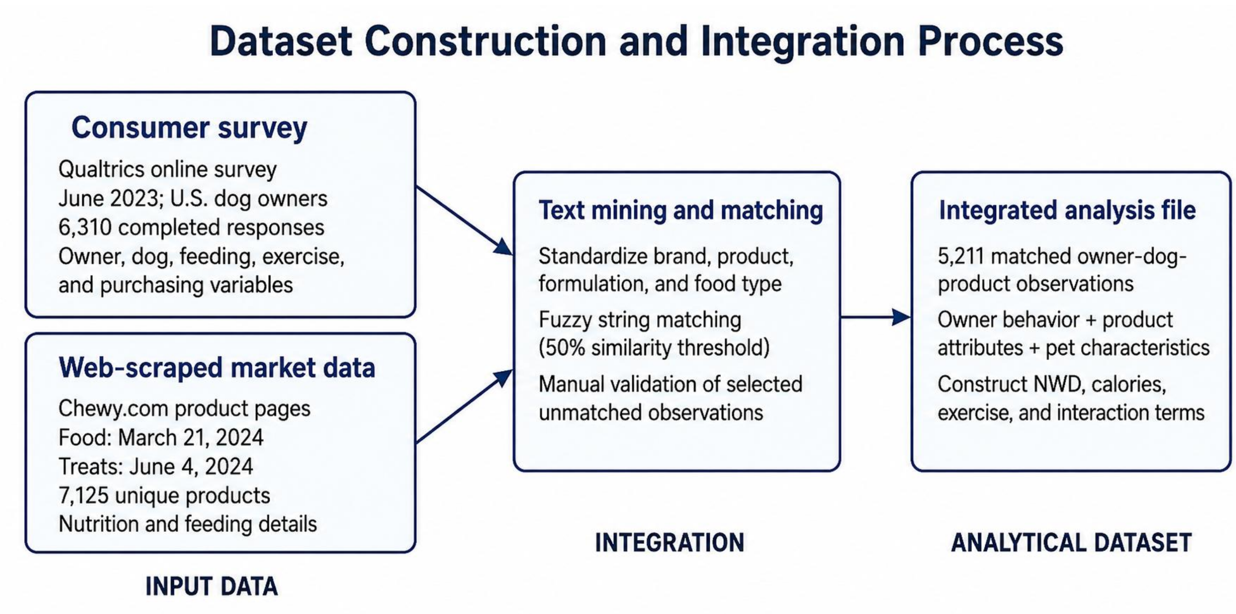
This text-mining approach enables the systematic handling of inconsistencies in spelling, phrasing, and formatting between survey-reported product information and Chewy.com product titles. Before matching, the text was standardized by converting it to lowercase and removing spaces and selected punctuation. FuzzyWuzzy's "fuzz.ratio" was then used to generate a similarity score ranging from 0 to 100 between the cleaned survey string and the cleaned Chewy.com product title. This score does not represent the percentage of words matched in either string; rather, it measures the overall character-level similarity between the two cleaned strings. A score of 100 indicates that the two cleaned strings are identical. A similarity-score threshold of 50 was selected after evaluating higher thresholds of 60, 70, and 80. Higher thresholds substantially reduced the number of matched observations because respondents often reported abbreviated or less detailed product information, whereas Chewy.com product titles were typically more specific. For example, a respondent might report a product as "Purina Chicken", while the corresponding Chewy.com title could contain additional information about the product line, flavor, life stage, or food form. Therefore, the 50-point threshold was used to retain plausible matches despite differences in the level of detail between the two data sources.

Several additional steps were used to reduce the likelihood of incorrect matches. Before calculating the fuzzy-matching score, candidate Chewy.com products were restricted to titles containing the brand name reported by the respondent, thereby preventing comparisons across unrelated brands. Product names were also standardized before matching by converting text to lowercase and removing selected spaces and punctuation. In addition, higher similarity-score thresholds of 60, 70, and 80 were evaluated to examine the trade-off between match strictness and sample retention. Finally, approximately 100 observations were manually verified, and targeted searches were conducted for products and brands that were not successfully identified through the automated procedure.

Consequently, a similarity-score threshold of 50 was selected to balance the retention of plausible matches with the risk of incorrect product identification. This merging process resulted in 5,211 matched observations. To further enhance the dataset completeness, additional targeted searches were conducted for products initially missed by the automated fuzzy matching process (e.g., brands like Fromm, Member's Mark, and 4Health).

The integrated dataset uniquely positions this research to significantly contribute to both academic literature and industry practices. By matching consumer behavior and perceptions directly with specific market offerings, the study provides deeper insights into the effectiveness of existing product strategies and consumer adherence to weight-management guidelines. Such comprehensive data integration offers robust evidence that can guide strategic business decisions, inform targeted marketing plans, and inspire innovative product development, particularly for pet food brands aiming to align with increasing consumer demand for obesity-management solutions. Figure 2.2 summarizes how the consumer survey and product-level web-scraped data are cleaned, standardized, matched, and transformed into the final analytical dataset used for empirical analysis.

Figure 2.2. Dataset Construction and Integration Process



2.3.2.4 Data Description

The integrated dataset contains 5,211 matched owner-dog-product records. Respondents are nearly evenly divided by gender and cover a broad range of ages, incomes, education levels, and states. The largest age groups are 33-40 and 49-56 years, and responses are concentrated in populous states including California, Texas, and Florida. The demographic composition of the analytical sample was compared with available national evidence on U.S. dog owners. The gender composition is broadly similar to estimates from a nationally representative U.S. sample of dog owners, although the present sample contains a larger proportion of respondents with college or graduate education (Mueller et al., 2021). The sample also covers a broad range of ages, household incomes, and geographic locations. However, because respondents were recruited through an online panel and inclusion in the analytical sample required successful matching with Chewy.com product information, the sample should not be interpreted as statistically representative of the entire U.S. dog-owner population. Rather, it provides a large and demographically diverse sample of U.S. dog owners. Full demographic distributions are presented in Appendix Figures C.1-C.5.

In terms of dog owners, the majority of participants reported owning a single dog (61.04%), while 26.92% had two dogs. Fewer respondents reported owning three or more dogs, indicating most pet owners manage smaller pet households (Appendix Figure C.6).

One of the most critical aspects of pet care is health management, and reproductive status plays a role in this. A strong majority (65.87%) of dogs in the survey were spayed or neutered. (Appendix Figure C.7).

Appendix Figure C.8 presents the distribution of owner-reported body condition scores. Because these scores reflect owners' perceptions and may differ from breed-standard weight classifications, they are used only for descriptive purposes and not as the primary outcome in the analysis.

Feeding practices reveal intriguing patterns in pet nutrition choices. Dry kibble is the primary food for 73.3% of respondents, followed by wet food, fresh cooked food, and raw food. Most owners feed twice per day. How often dogs eat also varies. Most owners adhere to a structured routine, feeding their pets twice daily (59.91%), while a smaller percentage follow a once-daily schedule (16.2%) or more frequent feeding patterns (12.95% feed three times daily). Interestingly, 9.98% of dog owners allow free feeding, granting constant access to food.

When determining portion sizes, pet owners rely on a mix of expert advice and personal intuition. Veterinarian recommendations and package instructions are the most frequently reported bases for determining portions, although many respondents also rely on hunger cues, body condition, or personal judgment.

Treats are more than just a reward; they play a role in training, dental health, and emotional bonding. The most popular choices among dog owners include dental treats (44.58%), crunchy treats (41.85%), soft moist treats (37.09%), and jerky treats (32.06%). Notably, nearly a quarter (24.37%) of respondents admit to offering table scraps, a practice that may contribute to weight-related concerns.

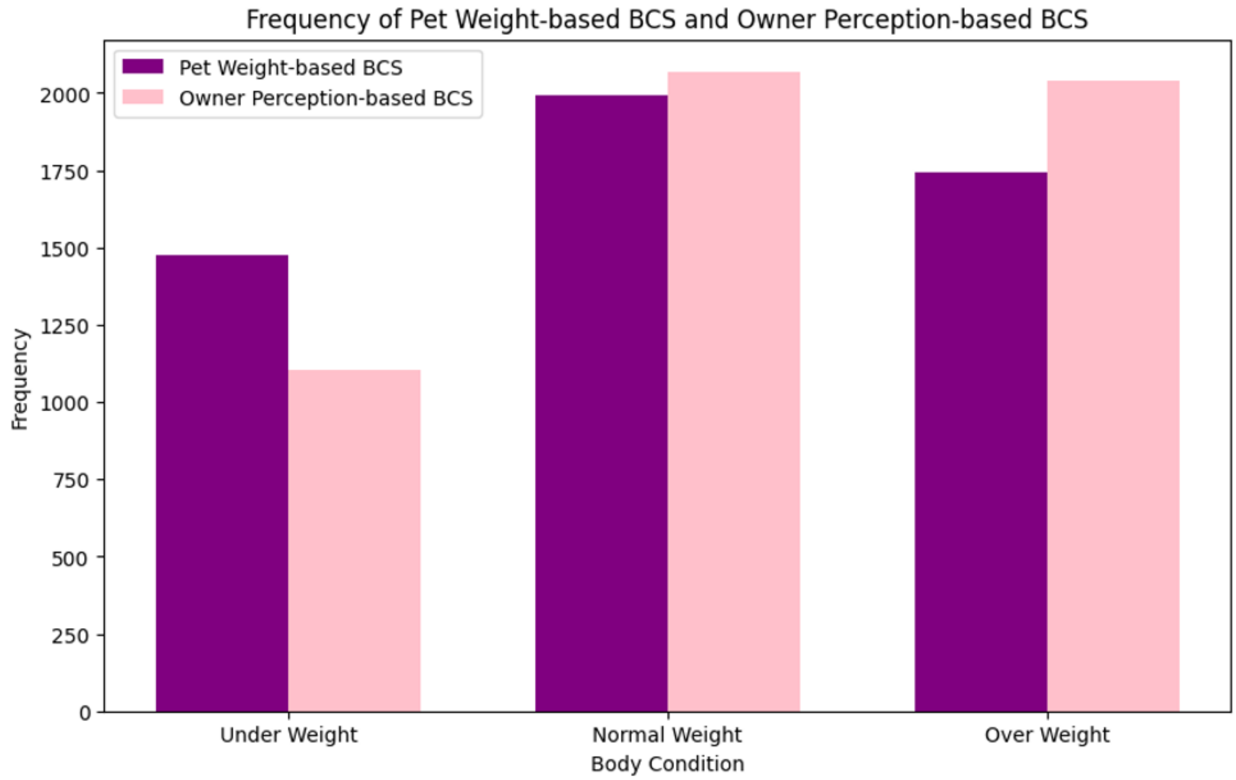
The frequency of treat feeding shows that moderation is key. The majority of owners offer treats once (32.74%) or twice daily (33.39%), with controlled portions, 41.78% typically giving one treat per feeding event, while 28.22% provide two. This suggests that while treats are a regular part of dogs' diets, owners are often mindful of portion control.

2.3.3 Analytical Framework

Guided by the conceptual framework, the analytical framework translates the conceptual mechanisms into measurable variables and empirical relationships. Figure 2.3 illustrates a comparison between breed-standard weight classification and owner-reported body condition. The first is owner-reported body condition, obtained from the survey question that asked respondents to select the image that most closely represented their dog's current body condition. These responses reflect the owner's visual assessment and were grouped into underweight, normal-weight, and overweight categories. The second is breed-standard weight classification, constructed by comparing each dog's owner-reported weight with the American Kennel Club (AKC)-based reference weight range assigned to its reported breed. Dogs were classified as below, within, or above the applicable breed reference range. This measure may contain measurement error because both dog weight and breed are owner-reported, and the AKC breed reference range may not reflect the ideal weight of every individual dog.

These measures capture different concepts. Owner-reported body condition reflects the owner's perception of the dog's physical condition, whereas breed-standard classification compares reported weight with an external breed reference. Figure 2.3 descriptively suggests disagreement between the two measures, including cases in which owners describe their dogs as normal weight even though the breed-based classification places them above the reference range. However, neither measure is equivalent to a veterinarian-assessed body condition score because both depend on owner-reported information, and breed standards may not represent the clinically ideal weight of every individual dog. To reduce reliance on broad categorical classifications and retain variation in relative weight status, this study constructs Normalized Weight Deviation (NWD).

Figure 2.3. Frequency of Pet Weight-based and Owner Perception-based BCS



The primary outcome is Normalized Weight Deviation (NWD), defined as the difference between the dog's reported weight and the midpoint of the sex-specific breed reference weight range, divided by that midpoint (Hobbs et al., 2024). The midpoint is calculated as the average of the minimum and maximum reference weights for the dog's reported breed and sex. NWD is a continuous outcome with a distribution across dogs rather than a single measure centered only on its mean. Focusing only on the conditional mean of NWD could mask differences in the associations between feeding, activity, and dog characteristics and relative weight status at different points of the distribution. Therefore, this study examines the lower, median, and upper portions of the NWD distribution using quantile regression.

(2.2)

$$NWD_i = \frac{ActualWeight_i - BreadMeanWeight_i}{BreadMeanWeight_i}$$

Positive values indicate reported weight above the breed reference midpoint, negative values indicate reported weight below the reference midpoint, and values near zero indicate proximity to the reference midpoint. NWD is a breed-adjusted proxy for relative weight status. Because breed and weight are reported by owners and breed standards describe population ranges rather than an individual dog's clinical ideal weight, the measure may contain classification and measurement error. Two measurement issues are important when interpreting NWD. First, the breed reference weights used to construct NWD represent adult breed standards and do not vary with the dog's stage of growth. Consequently, NWD may understate relative weight status for puppies and adolescent dogs that have not yet reached adult size. Second, breed-specific reference weights are less precise for mixed-breed dogs because a single breed standard may not adequately represent their expected body size. These issues may introduce measurement error into NWD.

Figure 2.4. Distribution of Normalized Weight Deviation (NWD) Using the Midpoint Reference Weight

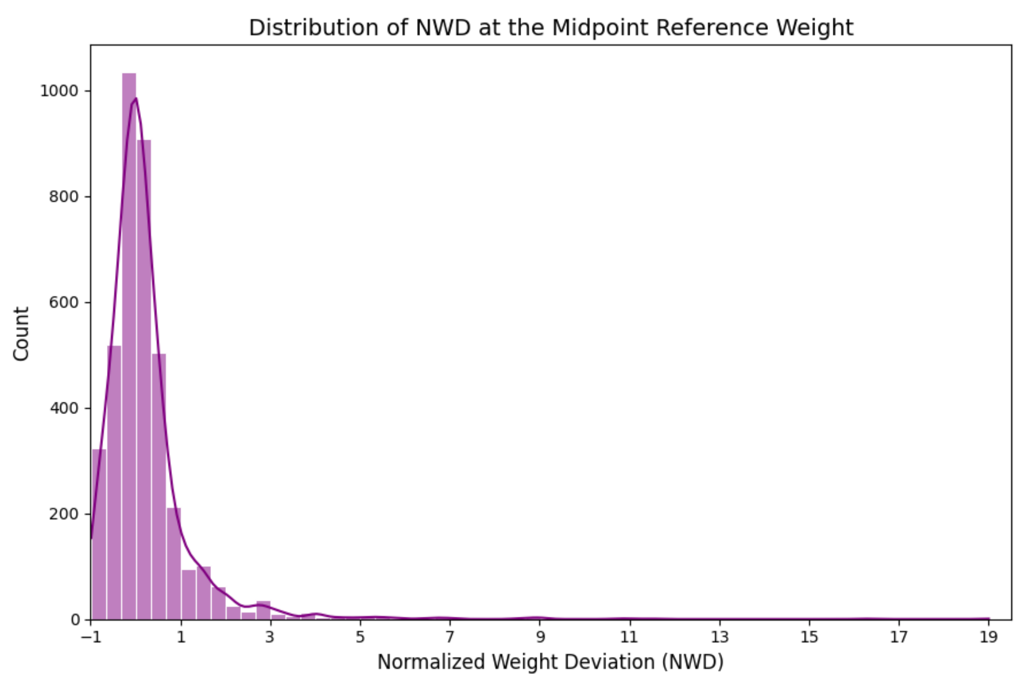


Figure 2.4 illustrates the distribution of NWD based on the midpoint of the sex-specific breed reference weight range. The distribution is right-skewed, with most observations concentrated at relatively lower NWD values and a smaller number of observations exhibiting large positive deviations. The 25th, 50th, and 75th quantiles represent the lower, median, and upper portions of the NWD distribution, respectively. These quantiles describe relative positions in the NWD distribution rather than clinical underweight, normal-weight, or overweight categories. This continuous metric enables the application of quantile regression, specified as:

(2.3)

$$NWD_i = \alpha + \beta X_i + \gamma Z_i + \delta W_i + \varepsilon_i$$

Where:

- NWD_i is the dependent variable underlying the observation for the respondent i.
- X_i is a vector of variables including total caloric intake, primary food type (dry kibble, wet food, fresh food, raw food), frequency of daily feeding, frequency of daily treat, proportion of treat-based calories, feeding based on weight, feeding based on veterinary recommendation, and caloric output including low, medium, and high exercise activity.
- Z_i includes pet-specific attributes such as breed type, reproductive status (intact vs. neutered/spayed), age, and sex.
- W_i incorporates interaction terms designed to capture nuanced relationships, including interactions between total calories and feeding based on veterinary recommendations, breed sizes, and feeding based on weight (Hobbs, 2023).
- ε_i represents unobserved variation. Quantile regression is a semiparametric approach that does not require a specific distribution, such as normality, for the error term. Instead of modeling the conditional mean of NWD, it directly estimates specified conditional

quantiles by minimizing an asymmetrically weighted sum of absolute residuals. This allows the associations between the explanatory variables and NWD to vary across different points of the conditional NWD distribution (Koenker and Bassett, 1978; Koenker, 2005).

The final model can be formulated as follows:

(2.4)

$$
\begin{aligned}
NWD_i = \; & \beta_0 + \beta_1 Total\ calories\ per\ week + \beta_2 Total\ calories\ * weight\ recommendation \\
& + \beta_3 Total\ calories\ * vet\ recommendation + \beta_4 Food\ frequency \\
& + \beta_5 Food\ type + \beta_6 Treat\ frequency + \beta_7 Treat\ calories\ percentage \\
& + \beta_8 Low\ exercise\ per\ week + \beta_9 Medium\ exercise\ per\ week \\
& + \beta_{10} High\ exercise\ per\ week + \beta_{11} Dog's\ breed + \beta_{12} Total\ calories \\
& * Dog's\ breed + \beta_{13} Dog's\ reprostatus + \beta_{14} Dog's\ sex \\
& + \beta_{15} Dog's\ age\ (in\ months) + \beta_{16} Feeding\ based\ on\ weight \\
& + \beta_{17} Feeding\ based\ on\ vet \\
& + \beta_{18} Crude\ protein + \beta_{19} Crude\ fat + \beta_{20} Crude\ fiber + \varepsilon_i
\end{aligned}
$$

The quantile regression models are estimated separately at the 25th, 50th, and 75th quantiles. Unlike ordinary least squares, which minimizes the sum of squared residuals, quantile regression estimates the coefficients by minimizing an asymmetrically weighted sum of absolute residuals (Koenker and Bassett, 1978; Koenker, 2005). Statistical inference is conducted separately at each quantile using heteroskedasticity-robust standard errors. The associated p-values are used to test the null hypothesis $H_0: \beta = 0$ for each coefficient at each quantile. Statistical significance is evaluated at the 1%, 5%, and 10% levels. The definitions and descriptive statistics of specific variables are presented in Table 2.1 below. Categorical variables are entered using indicator variables. For primary food type, dry kibble is the reference category; therefore, coefficients for wet, fresh, and raw food are interpreted relative to dry kibble. For breed-size group, medium-sized dogs are the reference category; therefore, coefficients for extra-small, small, large, and extra-large breeds are interpreted relative to medium-sized dogs. The definitions and descriptive statistics of specific variables are presented in Table 2.1 below.

Table 2.1. Variable Descriptions

Variable	Description	Min.	Max.	Mean	Std. Dev.	Obs. (n)
Food calories per day	Amount of food calories given to dog per day (food frequency * food amount * food calories)	4.25	5087.5	689.5	921.28	5,027
Food type	(1=Dry kibbles **(Reference)** 2=Wet food (canned, pouch, or tray) 3=Fresh (cooked) food (commercial or home) 4=Raw food (commercial or home prepared) 5=Other)	1	5	1.47	0.93	5,211
Food frequency	Number of times per day dog is fed primary food (1=once, 2= twice, 3=three times, 4=four times, 5=free feed or constant access to food)	1	5	2.29	1.07	5,211
Treat frequency	Number of times per day dog is fed treats (31=more than 30)	0	31	2.15	1.77	5,146
Treat calories per day	Amount of treat calories given to dog per day (treat frequency * treat amount * treat calories)	0	2120.0	290.54	392.77	4,148
Total calories per day	Amount of calories given to dog per day (food calories per day + treat calories per day)	4.25	7207.5	1243.28	1032.64	3,996

Treat calorie percentage	Percentage of total calories derived from treat calories. (treat calories / total calories) * 100	0	99.03	25.4	22.61	3,996
Feeding based on weight	Identifier if pet owner determines feeding amount based on dog's weight (0= does not determine feeding amount based on weight, 1= determines feeding amount based on weight)	0	1	.16	.37	5,211
Feeding based on vet recommendation	Identifier if pet owner determines feeding amount based on vet recommendation (0= does not determine feeding amount based on vet recommendation, 1= determines feeding amount based on vet recommendation)	0	1	.27	.44	5,211
Low intensity activity	Number of times that dog participates in a **low intensity** activity per week (181=more than 180)	0	35	6.91	6.31	5,116
Low intensity duration	Duration of time that dog participates in a **low intensity** activity per occasion (181=more than 180minutes)	0	125	20.11	18.67	5,116
Medium intensity activity	Number of times that dog participates in a **medium intensity** activity per week (181=more than 180)	0	30	4.69	4.68	5,116
Medium activity duration	Duration of time that dog participates in a **medium intensity** activity per occasion (181=more than 180minutes)	0	120	14.29	16.53	5,116

High intensity activity	Number of times that dog participates in a **high intensity** activity per week (181=more than 180)	0	35	3.23	4.58	5,116
High activity duration	Duration of time that dog participates in a **high intensity** activity per occasion (181=more than 180minutes)	0	110	11.19	16.36	5,116
Dog's sex	0= male, 1=female	0	1	0.43	0.50	5,211
Dog's age	Dog's age (in month)	1	210	72.72	49.07	5,159
Dog's breed type	1=extra small, 2= small, 3=medium **(Reference)**, 4=large, 5=extra large	1	5	2.56	1.17	5,188
Dog's reproductive status	0=spayed/neutered, 1=intact	0	1	0.35	0.48	5,211
Crude protein	Minimum crude protein in percentage	0.24	65	21.02	8.25	5,052
Crude Fat	Minimum crude fat in percentage	0.1	38	11.31	5.02	5,051
Crude Fiber	Maximum crude fiber in percentage	0.04	17	3.55	1.90	5,052

Continuous weight deviation normal($NWD_{midpoint}$)	(Dog weight – $Avg.Breed\ weight_{sex,breed}$)/ $Avg.Breed\ weight_{sex,breed}$	-.99	19	.21	1.02	5,188
Continuous weight deviation normal (NWD_{lower})	(Dog weight – $Lower\ bound.Breed\ weight_{sex,breed}$)/ $Lower\ bound.Breed\ weight_{sex,breed}$	-.98	39	.81	1.98	5,188
Continuous weight deviation normal (NWD_{upper})	(Dog weight – $Upper\ bound.Breed\ weight_{sex,breed}$) / $Upper\ bound.Breed\ weight_{sex,breed}$)	-.99	12.3	-0.036	.74	5,188

This study extends the earlier analysis of Hobbs et al. (2024) in two important ways. First, it uses a substantially larger analytical dataset, with 5,211 matched owner-dog-product records compared with 1,173 dog owners in Hobbs et al. (2024). Second, the linked product-level data allow the analysis to incorporate three measures of nutritional composition: crude protein, crude fat, and crude fiber, which were obtained from the reported products' nutritional information.

2.3.4 Empirical Analysis and Estimation Approach

Following the analytical framework, the primary empirical approach is quantile regression, which estimates the conditional relationship between the explanatory variables and different points of the NWD distribution rather than focusing only on the conditional mean. This approach is appropriate because the relationships between feeding practices, activity, product characteristics, dog characteristics, and NWD may differ across the conditional distribution. Quantile regression is well established for studying heterogeneous relationships and distributional outcomes (Koenker and Bassett, 1978; Koenker, 2005).

This approach directly aligns with the research questions by identifying whether caloric intake, exercise, feeding guidance, product attributes, and dog characteristics are associated differently with NWD at the 25^{th}, 50^{th}, and 75^{th} quantiles. Because the data are observational and cross-sectional, the estimated relationships are interpreted as conditional associations rather than causal effects. A supplementary machine-learning analysis examining predictive nonlinearities is provided in Appendix G.

As a robustness check, the quantile regression models are also estimated using two alternative definitions of NWD. While the primary specification uses the midpoint of the sex-specific breed reference weight range, the alternative measures use the lower and upper bounds of the same reference range. The same explanatory variables and analytical sample are maintained across specifications. This sensitivity analysis evaluates whether the main findings depend on the reference weight used to construct NWD. The distributions of the lower- and upper-bound NWD measures are presented in Appendix Figures C.9 and C.10.

The next section presents the empirical results and evaluates how these relationships vary across the distribution of canine weight outcomes.

2.4 Result and Discussion

2.4.1 Quantile Results

The results are organized to mirror the conceptual and analytical frameworks. Table 2.2 reports the conditional quantile estimates at the 25^{th}, 50^{th}, and 75^{th} percentiles of NWD. The results indicate that caloric intake, feeding frequency, treat frequency, food type, breed size, age, reproductive status, and veterinary-based feeding decisions are associated with NWD, but several relationships differ across quantiles.

Table 2.2. Quantile Regression Estimation

	Quantile = 0.25	Quantile = 0.5	Quantile = 0.75
Variable			
Intercept	**-0.2698****** (.009)	**0.0734****** (.010)	**0.5222****** (0.012)
Total calories per day	**0.0432**** (0.021)	**0.0730****** (.021)	**0.0377*** (0.026)
Total calories *weight recommendation	-0.0006 (0.016)	-0.0064 (0.016)	0.0036 (0.020)
Total calories *vet recommendation	0.0038 (0.016)	-0.0026 (0.016)	**0.0167*** (0.021)
Treat calories percentage	**-0.0444****** (0.010)	**-0.0233**** (.011)	-0.0090 (0.013)
Food frequency	**-0.0620****** (0.011)	**-0.0495****** (.012)	**-0.0424****** (0.014)
Treat frequency	**0.0254**** (0.010)	**0.0182*** (.010)	0.0111 (0.014)
Low exercise per week	0.0199 (0.012)	0.0052 (.011)	-0.0106 (0.015)
Medium exercise per week	**0.0125**** (0.013)	**0.0271**** (.013)	**0.0302*** (0.016)
High exercise per week	-0.0199 (0.013)	-0.0162 (.012)	0.0219 (0.016)
Dog's sex	0.0106 (0.010)	-0.0022 (.010)	-0.0130 (0.012)
Dog's reprostatus	**-0.0589****** (0.010)	**-0.0503****** (.010)	**-0.0638****** (0.013)
Dog's age (in months)	**0.0812****** (0.011)	**0.0828****** (.010)	**0.0828****** (0.012)
Feeding based on weight	0.0085 (0.016)	0.0118 (.016)	0.0011 (0.019)
Feeding based on vet	-0.0043 (0.016)	0.0016 (.016)	**-0.0482****** (0.020)
Crude protein	0.0231 (0.021)	-0.0007 (.022)	-0.0151 (0.027)
Crude fat	-0.0216 (0.019)	0.0004 (.020)	0.0143 (0.025)
Crude fiber	-0.0105 (0.011)	0.0081 (.012)	0.0059 (0.014)
Food type (wet)	**-0.0607****** (0.011)	**-0.0287****** (.011)	**-0.0210*** (0.014)
Food type (fresh)	**-0.0325****** (0.010)	**-0.0181**** (.010)	-0.0061 (0.012)
Food type (raw)	**-0.0217*** (0.010)	-0.0082 (.010)	0.0126 (0.012)
Food type (other)	0.0083 (0.010)	0.0028 (.010)	0.0031 (0.012)

ExtraSmall breed	**0.0380**** (0.018)	**0.2013***** (.018)	**0.4252***** (0.022)
Small breed	-0.0160 (0.019)	0.0058 (.019)	0.0035 (0.023)
Large breed	-0.0127 (0.019)	-0.0054 (.019)	**-0.0465**** (0.024)
ExtraLarge breed	**-0.0386**** (0.018)	**-0.0355**** (.018)	**-0.0668***** (0.022)
Totalcal* ExtraSmall	-0.0135 (0.017)	**-0.0811***** (.017)	**-0.0326**** (0.021)
Totalcal* Small	0.0027 (0.018)	-0.0018 (.018)	0.0191 (0.022)
Totalcal* Large	-0.0009 (0.021)	**-0.0232*** (.020)	-0.0039 (0.026)
Totalcal* ExtraLarge	0.0184 (0.019)	0.0049 (.019)	0.0247 (0.022)
Observation	3902	3902	3902
Pseudo R-squared	0.05	0.041	0.11

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$ (Standard error in parentheses)

2.4.1.1 Dietary Intake and Feeding Habits

2.4.1.1.1 Daily Calorie

As expected, total daily calories are positively associated with NWD at all three quantiles. The estimated coefficient is 0.0432 at the 25th percentile, 0.0730 at the median, and 0.0377 at the 75th percentile. The relationship is statistically strongest at the lower and middle quantiles and is significant at the 10% level at the upper quantile. These results support the central role of intake in relative weight status, but they do not show that the effect increases monotonically toward the upper tail.

2.4.1.1.2 Feeding Frequency

The number of meals per day (feeding frequency) by itself showed a more subtle influence on weight. Food frequency is negatively associated with NWD at each quantile after total calories are held constant. This suggests that how many meals a pet receives in a day also matters along with how much it eats in total. For instance, whether an owner feeds the daily ration in three meals made little difference in the pet's weight deviation, so long as the overall calorie intake was the same. One interpretation is that dividing calories into smaller, more frequent meals could modestly help in weight management by preventing overeating and begging behaviors, thereby slightly mitigating weight gain in prone animals.

2.4.1.1.3 Treat Frequency

Treat frequency is positively associated with NWD primarily in the lower and middle portions of the conditional distribution. At the 25th quantile, an additional daily treat is associated with a 0.0254 increase in NWD, and the relationship is statistically significant. The association remains positive but smaller at the median (0.0182), while at the 75th quantile the coefficient decreases to 0.0111 and is not statistically significant. Because the lower quantile represents dogs toward the lower end of breed-adjusted weight deviation, this pattern suggests that treat frequency is more strongly associated with differences in relative weight among dogs in the lower and middle portions of the NWD distribution than among dogs already at the upper end. This finding is consistent with previous evidence identifying snack and treat frequency as an environmental factor associated with canine overweight (Courcier et al., 2010). From a practical feeding-management perspective, treats should also be considered as part of total daily caloric intake; nutrition guidelines recommend that treats and other nutritionally incomplete foods contribute no more than approximately 10% of a dog's daily calories (Cline et al., 2021).

2.4.1.2 Physical Activity

Physical activity shows mixed associations with NWD. In the survey, owners reported their dog's current exercise habits separately for low-, medium-, and high-intensity activities, including the number of activity sessions per week and the duration of each occasion. Medium-intensity activity frequency is positively associated with NWD across the three quantiles, with coefficients of 0.0125, 0.0271, and 0.0302 at the 25th, 50th, and 75th quantiles, respectively. In contrast, low- and high-intensity activity frequencies are not statistically significant. The positive association for medium-intensity activity should not be interpreted as evidence that exercise increases weight deviation. Because the survey measures current weekly exercise habits at the same time that weight is reported, the temporal ordering cannot be established. For example, owners of dogs with higher weight deviation may have increased activities such as walking or playing fetch in response to concerns about their dog's weight. In addition, frequency per week does not fully capture total exercise exposure because the duration of each activity session may vary across dogs.

2.4.1.3 Food Type and Nutrient Composition

Beyond how much pets eat, what they eat also contributes to weight outcomes. Relative to dry food, wet food is associated with lower NWD at all three quantiles, although the magnitude declines toward the upper tail. Fresh food is associated with lower NWD at the 25th and 50th percentiles but not at the 75th percentile. Raw food is weakly negative only at the 25th percentile. Crude protein, fat, and fiber are not statistically significant.

These factors yielded insightful trends. Notably, pets on diets other than dry kibble, such as canned (wet) food or possibly fresh homemade diets, tended to have lower NWD on average, with the differences most visible at lower weight quantiles. They suggest that diet form and quality can influence propensity for weight gain. One plausible explanation is caloric density; dry kibble is typically more calorie-dense than wet food. Because wet food generally has a higher moisture content and lower energy density than dry kibble, a dog may consume a larger amount of food for the same caloric intake. Thus, owners feeding wet or fresh diets might inadvertently be controlling calories simply because the pet feels full with less energy intake. Our findings are emerging evidence from industry research that dogs eating primarily kibble tended to have higher obesity rates than those on fresh or less processed diets (Pet Food Industry, 2020).

2.4.1.4 Breed Size and Caloric Interactions

The analysis also reveals significant differences by breed size, both as main effects and in interaction with caloric intake. Using medium-sized breeds as the reference group, extra small breed dogs have higher NWD on average, while large and extra large breed dogs have lower NWD, holding other factors constant. Specifically, extra small breeds showed a tendency toward greater weight deviation, particularly at the 75th percentile (.4252). Many veterinarians report that toy and small breeds often struggle with weight issue, whether due to owners indulging them or the dogs' lower energy requirements. Our results similarly suggest that being a small dog is a risk factor for obesity in and of itself (possibly because small dogs are more likely to be kept indoors, less exercised, and over-fed relative to their tiny size). Large and extra-large breeds in our study, on the other hand, did not show a propensity for high NWD.

The interaction between total calories and extra-small breed is negative at the median and at the 75th percentile, indicating that the effect of extra calories on weight depends on the size of the dog. Extra-small breed dogs are far more sensitive to caloric surplus than large or extra-large breeds. What might be an insignificant treat for a big dog could be a meal's worth of calories for a toy breed. Conversely, the interaction term for large breeds suggests that large dogs gain less weight per extra calorie. In practice, a large breed might require a more substantial absolute excess to become equally overweight as a small dog fed just slightly too much.

2.4.1.5 Feeding Based on Veterinary Advice

Feeding amount based on veterinary recommendation shows a significant relationship with NWD only at the 75th quantile. However, this relationship must be interpreted together with the interaction between veterinary-based feeding and total caloric intake. At the 75th quantile, the coefficient for veterinary-based feeding is negative (-0.0482), while the interaction between total calories and veterinary-based feeding is positive (0.0167). Thus, the association between veterinary-based feeding and NWD varies with caloric intake rather than representing a constant difference between owners who do and do not use veterinary recommendations. The positive interaction indicates that the relationship between caloric intake and NWD is more positive among dogs whose owners report using veterinary recommendations to determine feeding amounts.

2.4.1.6 Dog Characteristics

2.4.1.6.1 Dog Age (Months)

Dog age is positively associated with NWD across the estimated quantiles. However, this relationship should be interpreted cautiously because NWD is constructed using adult breed-reference weights. For younger dogs that have not yet reached adult size, lower NWD values may partly reflect normal growth rather than low body condition. Therefore, part of the positive relationship between age and NWD may arise as dogs mature toward their adult breed-reference weight. Among adult dogs, the positive association may also reflect differences in metabolism, activity, health, or feeding practices associated with aging. This indicates that weight problems increase with age, a trend widely observed in epidemiological studies where obesity is more common in dogs older than about 5-6 years (Suarez et al., 2022).

2.4.1.6.2 Reproductive Status (Neutered/Spayed vs Intact)

Reproductive status was a significant determinant of NWD, with neutered dogs tending to have higher weight deviation than intact dogs, especially in the upper quantile. The 75th percentile regression showed a clear increase in NWD for neutered dogs, suggesting that neuter status is more strongly associated with weight deviation among dogs at the heavier end of the distribution. At the median, neuter status still had a positive coefficient, though the magnitude was smaller. This pattern is consistent with veterinary evidence identifying neutering as a common predisposing factor for canine obesity, partly through reduced maintenance energy requirements and increased food intake (Loftus and Wakshlag, 2015). The association may also be sex-specific. Bjørnvad et al. (2019) found that neutering increased obesity risk in male dogs but not in females, whereas females were at elevated risk regardless of neuter status. Here in combined-gender analysis, the overall trend indicates that neutered dogs have higher NWD.

2.4.1.7 Robustness to Alternative NWD Definitions

To assess the robustness of the quantile regression results, the models were re-estimated using NWD measures based on the lower and upper bounds of the sex-specific breed reference weight range, in addition to the midpoint-based main specification. The sensitivity analysis generally supports the main quantile-regression findings. Dog age remains positively associated with NWD and reproductive status remains negatively associated with NWD across all three quantiles and all three NWD definitions. Total daily caloric intake remains positive across the specifications and is statistically significant at the 25th and 50th quantiles, although its statistical significance at the 75th quantile is sensitive to the reference definition. Feeding frequency remains generally negatively associated with NWD, while the negative association between veterinary-based feeding guidance and NWD at the 75th quantile is also robust. In contrast, some breed-size coefficients, breed-by-calorie interactions, and selected feeding variables vary in magnitude or statistical significance across the alternative NWD definitions. Overall, the sensitivity analysis supports the main conclusions while indicating that some secondary and breed-related relationships are sensitive to the choice of reference weight.

Supplementary machine-learning results, including SHAP and Partial Dependence analyses, are presented in Appendix G. These results are provided as complementary predictive evidence and are not part of the primary econometric analysis.

2.5 Conclusion

This chapter examined how reported feeding practices, pet food product characteristics, physical activity, and dog characteristics are associated with Normalized Weight Deviation (NWD), a breed-adjusted proxy for relative canine weight status. The study links a nationwide survey of U.S. dog owners with detailed product information collected from an online retailer. Quantile regression is used to identify whether these relationships differ across the conditional NWD distribution.

2.5.1 Main Findings

The most consistent finding is the positive association between total daily caloric intake and NWD. Total calories are positively associated with weight deviation at the 25^{th}, 50^{th}, and 75^{th} percentiles, indicating that caloric intake is relevant throughout the distribution rather than only among dogs with relatively high weight deviation. This result emphasizes the importance of considering the dog's entire daily intake, including primary food, treats, dental chews, table scraps, and other sources of calories.

Food frequency is negatively associated with NWD after total calories are held constant. This finding does not establish that feeding more frequently causes lower weight deviation. Instead, feeding the same total amount across multiple occasions may be associated with more structured portion control or other unobserved owner practices. Treat frequency is positively associated with NWD at the lower and middle quantiles.

Dog age is also positively associated with NWD across the estimated quantiles. As dogs age, changes in metabolism, physical activity, health, and daily routines may reduce their energy requirements. Owners may not adjust portions immediately when these changes occur. The results therefore support periodic reassessment of feeding amounts throughout the dog's life rather than reliance on a fixed feeding routine.

Food form, reproductive status, and breed size are associated with NWD in selected portions of the distribution. Wet and fresh foods are associated with lower NWD. Intact dogs have lower NWD than spayed or neutered dogs after controlling for the other included characteristics.

Extra-small breeds display relatively high proportional weight deviation, particularly toward the upper part of the distribution. Because a small absolute weight increase represents a larger share of expected body weight for a small dog, modest overfeeding may have more substantial proportional consequences for these breeds. However, the breed-by-calorie relationships vary across quantiles, indicating that the association among breed size, calorie intake, and NWD is not uniform across the conditional distribution.

Reported exercise relationships are mixed rather than consistently protective. This does not imply that exercise is unimportant. Rather, owner-reported frequency and duration may not adequately represent actual energy expenditure. Exercise intensity, pace, distance, terrain, the dog's health, and the accuracy of owner reporting may all affect the observed results.

For pet food manufacturers, the recommendations follow directly from the empirical results. Total daily caloric intake was positively associated with NWD across the estimated quantiles, supporting clearer calorie-per-serving information and practical portion guidance. Feeding frequency was negatively associated with NWD after controlling for total calories, while treat frequency was positively associated with NWD at the lower and middle quantiles; therefore, manufacturers could provide clearer instructions on dividing the daily food allowance across meals and accounting for treats within the total daily calorie budget. Dog age was positively associated with NWD, and breed size and reproductive status were also associated with NWD in several specifications, supporting feeding recommendations that are more clearly tailored to dog size, life stage, and reproductive status. In addition, feeding based on veterinary advice was associated with lower NWD at the upper quantile, suggesting value in package instructions or digital feeding tools that complement individualized veterinary guidance.

For veterinarians and consumer educators, the results reinforce the importance of routine weight assessment and individualized feeding discussions. Guidance should consider the dog's complete daily intake, including primary food, treats, table scraps, dental chews, and food provided by other household members. Feeding recommendations should also be reassessed following changes in age, activity, health, or reproductive status.

2.5.2 Limitations

This chapter has several limitations that should be considered when interpreting its findings. First, the data are cross-sectional and cannot establish causality. Feeding practices, food choices, exercise, and weight are observed at the same point in time. Consequently, an association may reflect the effect of a behavior on weight, but it may also reflect a change in behavior made after the owner recognized a weight problem. For example, an owner may switch to fresh food or increase exercise because the dog has already gained weight. The results should therefore be interpreted as conditional associations rather than causal effects.

Second, many variables are self-reported. Owners may not know their dog's current weight, exact food portions, treat calories, or true exercise intensity. The survey also permitted approximate responses for weight and feeding amounts. Reporting errors may reduce the precision of the estimates and may cause calculated daily calorie intake to differ from actual intake. Calories from supplements or food provided by other household members may also be incompletely captured.

A further limitation concerns the construction of NWD from breed-specific reference weights. The reference weights used in this study represent adult breed standards and do not vary across stages of growth. Consequently, applying the same adult reference to puppies and adolescent dogs may produce lower NWD values simply because younger dogs have not yet reached adult size. This issue is particularly relevant when interpreting the positive association between age and NWD. Dogs younger than one year account for approximately 4.17% of the analytical sample. In addition, NWD may be measured less precisely for mixed-breed dogs because a single breed-specific reference may not accurately represent their expected adult body size. Breed was also self-reported and required manual cleaning, so breed-reporting errors may affect both the breed-size classification and the reference weight used to calculate NWD.

Product identification presents a similar limitation. Respondents manually entered brand names, product names, and formulations for foods and treats. A fuzzy-matching similarity-score threshold of 50 was used to preserve a sufficiently large sample, but this increased the possibility of matching a reported product to a similar but incorrect formulation.

The survey also did not identify whether each product was purchased online or in a physical store. Product availability may differ across channels. The absence of shopping-channel information therefore creates uncertainty about whether the matched online listing accurately represents the product available to the respondent. It also prevents analysis of whether online and in-store buyers face different product assortments, information, prices, or convenience constraints.

2.5.3 Future Research

Future research should collect longitudinal information on the same dogs over time. Repeated veterinarian-measured weights, feeding records, activity measures, and health information would help determine whether changes in feeding and exercise precede changes in weight. Longitudinal data would also make it possible to examine weight changes following aging, illness, spaying or neutering, or a change in food products.

Breed identification should be collected through a searchable dropdown menu containing standardized breed names. Owners could select one breed, while mixed-breed owners could select up to three known or suspected breeds and indicate whether the information comes from a veterinarian, shelter, or personal judgment. These changes would reduce manual cleaning and improve both breed-size classification and the calculation of breed-adjusted weight deviation.

Future research should use age-specific growth references when constructing relative weight measures. When reliable growth curves are unavailable, researchers could restrict the primary analytical sample to dogs at least one year old and analyze younger dogs separately. This approach would reduce the likelihood that normal growth is incorrectly classified as underweight status. Future surveys should identify the purchasing channel for each reported product. Respondents should indicate whether they purchased the product online, through a subscription, by curbside pickup, or inside a physical store. They should also identify the retailer, package size, purchase date, regular price, actual price paid, promotion or coupon use, and whether the product was their preferred choice or a substitute caused by unavailability. This information would allow each purchase to be matched with the correct retailer-specific listing and would support analysis of differences between online and in-store purchasing.

Finally, Physical activity could be measured using wearable activity monitors or more detailed questions about pace, distance, and working or sporting activities.

Chapter 3 - Understanding the Gap Between Expressed Attribute Preferences and Actual Purchased Products by Pet Food Buyers

3.1 Introduction

Pet food purchases provide a useful setting for studying the difference between expressed preferences and realized choice. Picture a pet owner standing in a long supermarket aisle, scrolling through social media posts about some specific attributes like: “human-grade”, “grain-free”, and “eco-friendly” dog food. She tells herself that this time she will buy a food that matches all the things she says matter most for her dog’s health and for the planet. Yet a few minutes later, she walks out with a large bag of conventional dry kibble on promotion, because it is familiar, her dog likes it, and the price feels safer for her monthly budget. This everyday disconnect captures the central theme of this chapter: the gap between what pet owners say they value in pet food and the product attributes actually reflected in their purchases.

The economic importance of this question has increased as the pet food market has expanded and as pet humanization has intensified. Owners increasingly treat pets as family members and view food choices as expressions of care, responsibility, and identity (Hobbs & Anderson, 2025). Globally, pet food sales more than doubled between 2010 and 2024, reaching $151.8 billion, with the U.S. market alone accounting for $59.74 billion (Statista, 2025). Within this booming market, surveys show strong stated preferences for natural ingredients, grain-free formulations, high-protein content, and sustainably sourced components (DKSH Discover, 2022).

This distinction is consistent with revealed-preference reasoning, which emphasizes observed choices over hypothetical statements (Samuelson, 1948), and with the broader intention-behavior literature, which shows that stated ethical, health, and sustainability preferences may not fully translate into purchases when consumers face constraints such as budget, product availability, convenience, habit, and other competing considerations (Carrington et al., 2010; Niessen and Hamm, 2008; Liu et al., 2024). In pet food, the gap may be especially important because owners make decisions on behalf of an animal whose health needs, taste responses, and feeding routines constrain the feasible set of products.

This discrepancy is not unique to pet food. In human food markets, consumers routinely claim a preference for organic, sustainable, or ethical products but end up buying conventional alternatives when faced with real-world constraints such as price, convenience, and habit (Carrington et al., 2010; Niessen & Hamm, 2008; Marian et al., 2014). Niessen and Hamm (2008) showed that self-reported organic purchasing frequencies were massively overstated relative to panel purchase data. Carrington et al. (2010) similarly observed that ethically minded shoppers often “don’t walk their talk”, purchasing ethical products much less frequently than they claim they intend to. Auger and Devinney (2007) highlight that even consumers who express strong ethical concerns do not consistently choose ethical products if other considerations intervene. These studies collectively point to a systematic and persistent gap between stated preferences and revealed behavior.

The pet food market offers a particularly vivid illustration of this gap. On the one hand, owners insist they want filler-free, sustainably produced diets and claim to prioritize high-quality ingredients and health attributes. On the other hand, sales data show continued reliance on conventional, economical products (Rombach & Dean, 2021). Ingredients such as corn and wheat, often criticized in popular discourse, remain common because they reduce costs and support convenience in storage and feeding. Price is a central constraint, in which premium or specialized products are frequently priced beyond what owners can sustain as a routine purchase

(Hsu et al., 2020; Marian et al., 2014). Prior work consistently finds high price to be a major barrier to organic or specialty purchases (Marian et al., 2014). Even when budgets tighten, many owners prefer to economize at the margin rather than fully abandon premium brands. Industry evidence suggests that 83% of U.S. pet owners report having a single preferred brand, with roughly half (51%) unwilling to switch even under financial pressure, and only about 15% actually switching to cheaper alternatives during inflationary episodes (Pet Food Industry, 2024). At the same time, palatability and pet preference can override owner ideals. Erzurum and Kayar (2025) show that pet preference/palatability ranks above price and organic claims in many owners' reported priorities.

Existing pet food research identifies health, nutrition, ingredient quality, price, palatability, and brand as important purchase considerations (Schleicher et al., 2019; Rombach and Dean, 2021). Although prior research has documented differences between what consumers say they value and what they ultimately purchase, relatively little research has examined this relationship at the individual owner-product level in the pet food market. Existing pet food studies largely examine stated attribute importance, willingness to pay, purchase considerations, or broad product choices. This study extends that literature by linking each dog owner's stated attribute priorities with detailed attribute information for the specific food and treat products that the owner reports purchasing. This linkage makes it possible to evaluate preference-purchase alignment attribute by attribute within the same owner-product observation rather than comparing aggregate preference and market patterns.

To operationalize this comparison, the chapter introduces the Match Index Score (MIS), which measures the share of an owner's prioritized health, ingredient, processing, and supply-chain attributes that are identified in the reported purchased product. MIS is constructed separately for food and treats and using both the single highest-priority attribute and the top three priorities within each attribute category. This provides an individual-level measure of the extent to which an owner's stated "wishlist" is reflected in the reported "shopping cart".

The chapter asks two questions. First, how closely do the attributes of reported food and treat purchases align with owners' expressed priorities? Second, which owner, dog, feeding, and product characteristics are associated with the degree or incidence of alignment? The explanatory variables include owner age, gender, income, and education; dog weight, breed size, allergy status, age, sex, and reproductive status; feeding and activity measures; veterinary recommendation; and product price. The explanatory variables are used to examine which factors are associated with higher or lower preference-purchase alignment, measured by the MIS and by the probability of having at least one preferred attribute matched in the reported product. By achieving these objectives, the chapter fills a critical gap in the literature by moving from aggregate impressions of "say-do gaps" to a more precise, attribute-level measure of behavioral consistency in pet food purchases.

The empirical strategy uses a binomial generalized linear model with a logit link for the number of matched attributes out of four or twelve. A complementary binary logit model estimates whether at least one prioritized attribute is matched. The analysis is based on survey-reported products matched to product-page information, not on retailer transaction records. The results therefore capture alignment between stated priorities and reported purchases rather than a fully observed scanner-data measure of revealed preference. The dataset, described in detail in Chapter 2, provides both "wishlist" data (stated preferences) and "shopping cart" data (observed purchases) at the product level, enabling construction of MIS for each owner-product pair.

This chapter’s contribution is primarily empirical. Using a novel Match Index Score (MIS), it measures how closely dog owners’ stated priorities over ingredients, health, processing, and supply-chain claims are reflected in the actual products they purchase. The linked survey-product dataset allows us to document where this alignment is strong, where it breaks down, and how the gap varies across income, education, demographics, and pet characteristics. These empirical patterns are then interpreted from a business perspective, yielding concrete guidance for product formulation, pricing, and communication strategies aimed at converting owners’ stated preferences into realized demand.

This approach has limitations: the cross-sectional nature of the data limits dynamic inference; attributes are based on label and formulation information rather than sensory experiences; and the analysis focuses on a single major retailer, which may underrepresent some niche brands or channels.

The chapter proceeds as follows. Section 3.2 reviews the literature on stated versus revealed preferences, intention-behavior gaps, and pet food purchasing behavior. Section 3.3 presents the conceptual framework, defines the Match Index Score, and describes the dataset linking owners’ wishlists to their actual shopping carts, and econometric methodology, including the binomial GLM and binary logit specifications. Section 3.4 reports and discusses the empirical results on the determinants of MIS and the structure of the preference-purchase gap across attribute categories. Finally, Section 3.5 concludes with key implications for industry, policy, and future research.

3.2 Literature Review

3.2.1 Stated Preferences, Revealed Preferences, and Willingness to Pay

Consumer choice research distinguishes between preferences elicited under hypothetical conditions and those revealed in actual markets. Revealed preference theory, formalized by Samuelson (1948), provides a foundation for using actual choices to infer priorities. In this chapter, the observed product purchased by the owner provides the revealed behavior against which expressed attribute priorities are compared.

Stated-preference methods measure choices, rankings, or willingness to pay in hypothetical settings and are useful when attributes are new, uncommon, or not directly observed in market data, such as ethical sourcing or sustainability (Hanley & Czajkowski, 2019). However, because stated-preference methods are hypothetical, they are vulnerable to hypothetical bias, meaning stated willingness to pay can differ systematically from actual willingness to pay (Hanley & Czajkowski, 2019). This limitation is particularly relevant in pet food because the social desirability of caring for pets may encourage owners to overstate preferences for health or sustainability attributes. Revealed-preference data, by contrast, reflect choices made under real-world constraints, but they are not free from bias. Actual purchases may be shaped by habit, marketing, availability, or defaults rather than by normative preferences alone (Beshears et al., 2008), and when purchase information is collected through surveys, responses may also be affected by recall error, misreporting, or other forms of self-report bias.

Willingness to pay connects preference statements to economic value. Consumers pay a premium for an attribute only when the perceived utility gain offsets the price premium (Ali et al., 2021). Prior studies show that willingness to pay is associated with income, education, gender, and other demographic characteristics (Ghali-Zinoubi, 2021; Hu et al., 2024; Smoluk-

Sikorska et al., 2023). Studies that compare stated and purchase-based measures generally find incomplete consistency. Niessen and Hamm (2008) report that self-reported organic purchasing exceeded panel-based purchasing, while Gschwandtner et al. (2021) show that combining stated and revealed information can improve valuation. These findings motivate a direct comparison between the attributes owners prioritize and the attributes identified in the products they report buying.

3.2.2 Intention-Behavior Gaps and Constraints

Beyond economic capacity, psychological factors help explain why intentions often fail to become actions. The Theory of Planned Behavior emphasizes that attitudes, social norms, and perceived behavioral control shape intentions (Müller-Pérez et al., 2025). Yet the connection between intention and behavior is often incomplete. In ethical and health-related consumption, consumers frequently express support for desirable attributes but purchase products that do not reflect those priorities (Jakubowska et al., 2024; Liu et al., 2024). Empirical research in grocery and organic food markets finds only weak or moderate correspondence between what consumers say they will buy and what they actually purchase (Niessen & Hamm, 2008; Wee et al., 2014). Improved knowledge and stronger social support can reduce this gap (Liu et al., 2024), but environmental constraints such as availability or time often undermine even strong intentions (Hatab et al., 2022).

Social desirability bias further widens the gap between stated and revealed behavior. Survey respondents tend to overreport socially approved behaviors and underreport behaviors perceived as undesirable (Untarini, 2020). This potential bias cannot be fully eliminated in the present study because both stated preferences and purchased products are self-reported. Although the online survey format may reduce interviewer-related pressure, no specific procedure was used to directly measure or correct for social desirability bias. Therefore, respondents may overstate the importance of socially desirable attributes, such as health or sustainability, or report purchases that appear more consistent with responsible pet ownership. In pet food markets, this can generate overstated claims about prioritizing health, premium ingredients, or sustainability, particularly when such claims signal responsible pet ownership (Untarini, 2020; Rankin et al., 2018). Price remains one of the most consistent barriers to realizing stated ideals. Even when willingness to pay is positive, budget limits can cause consumers to purchase more affordable conventional alternatives (Ni Mhurchu et al., 2013; Liu et al., 2024).

The food literature provides several examples of this pattern. Hughner et al. (2007), Marian et al. (2014), and Aschemann-Witzel and Zielke (2017) show that high prices and limited availability constrain organic and specialty purchases. Aschemann-Witzel and Zielke (2017) reviewed consumer perceptions of organic pricing and observed that high price is one of the major barriers hampering demand for organic products. Hsu et al. (2020) similarly emphasize the role of price and practical constraints. In their analysis, many consumers like the idea of organic food but will revert to conventional options when organic is too expensive or hard to find, a clear case of behavior diverging from stated preference due to economic factors. These findings suggest that a preference-purchase gap should be expected when owners face trade-offs among health claims, ingredient claims, convenience, and affordability.

3.2.3 Pet Food Purchasing Behavior

Pet food choices extend these general consumer-choice dynamics into a market where the purchaser and consumer are different. Owners may value high-quality ingredients, health benefits, transparency, or sustainability, but the dog's acceptance of the product can override the owner's stated preferences. In pet food, palatability is central because a product that the dog refuses to eat cannot remain in the household's regular feeding routine (Erzurum & Kayar, 2025). Erzurum and Kayar (2025) show that pet preference and palatability can rank above price, protein content, or ingredient quality in reported pet food decisions.

Convenience and trust also affect actual purchases. Packaging, accessibility, brand reputation, and familiarity can outweigh more complex nutritional or ethical claims (Lee, 2025). Veterinary advice remains an important source of nutrition information, with veterinarians cited as a trusted source by many owners (Schleicher et al., 2019). At the same time, online information, marketing claims, and nutrition misinformation can influence perceptions of raw, grain-free, or other specialized diets (Food Industry Executive, 2020; Schleicher et al., 2019). Label interpretation is another challenge, because some owners report difficulty understanding pet food labels despite strong demand for transparency (Global Pets, 2025).

Within the pet food sector, prior studies show that owners value high-quality ingredients and health attributes (Michel et al., 2008), while actual sales remain heavily concentrated in conventional and value-oriented products (Rombach & Dean, 2021). Price sensitivity, brand loyalty, and routine purchasing can therefore lead owners to compromise. Industry evidence suggests that some owners consider switching to lower-priced products during inflationary periods, even though many maintain strong brand loyalty (Pet Food Industry, 2024).

Research in food economics shows that consumers often down-trade from their stated ideals to lower-priced substitutes when budget constraints tighten (Pet Food Industry, 2024). Nielsen survey data indicated that 62% of global consumers were willing to try a new brand if it offered a lower price (Pet Food Industry, 2024), reflecting how price sensitivity can shake even strong preferences. Schleicher et al. (2019) reported over 95% of surveyed pet owners said they prioritize their pet's food as much as or more than their own food in terms of healthiness. Even so, when money is tight, pet owners will look for ways to economize, trading down to smaller bag sizes, buying in bulk, seeking promotions, or switching to a cheaper brand if necessary. A 2024 pet owner survey by Cleveland Research Co. (CRC) found that about one-third had considered switching to a cheaper pet food for cost reasons, though only 15% actually did (Pet Food Industry, 2024).

Research on pet owner involvement also suggests that knowledge, education, income, gender, and caregiving roles may influence the degree of attention owners give to diet decisions (Rombach & Dean, 2021). Dotson and Hyatt (2008) emphasize the symbolic role of pets in owners' lives, while Rombach and Dean (2021) note that routine, low-risk purchases may encourage reliance on habit and brand familiarity. Studies indicate that female pet owners, primary caregivers of pets, and those with higher education or income tend to be more involved in pet food decisions and possibly more likely to seek premium attributes (Rombach & Dean, 2021). The interaction of demographics with factors like knowledge, attitudes, and involvement is complex. What is clear is that consumer knowledge and involvement levels matter. Those who are highly involved and knowledgeable about pet nutrition are more likely to stick to their preferences and carefully evaluate products (Rombach & Dean, 2021). Surie (2014) observed that owners with high subjective knowledge tended to favor raw or natural diets, whereas those with only moderate knowledge were comfortable feeding dry food and might not act on more advanced preferences. Taken together, this literature indicates that preference-purchase alignment is unlikely to be uniform across owners. Some owners may align closely with stated priorities because they have the knowledge, income, and product access to do so. Others may compromise because of price, availability, brand loyalty, label complexity, feeding routines, or the pet's own preferences.

3.2.4 Research Gap

An important reason for the limited evidence on preference-purchase alignment is the difficulty of collecting stated-preference and purchase information for the same consumers at a meaningful scale. Consumer surveys can identify the attributes buyers say they value, together with their demographic and household characteristics, but they often do not provide sufficiently detailed information about the attributes contained in the specific products those consumers purchase. In contrast, retailer transaction or scanner data provide large-scale information on actual purchases but generally do not reveal which product attributes individual consumers intended to prioritize. Experimental studies can collect both stated preferences and actual purchase decisions, but they are costly. A small number of studies have directly compared stated and purchase-based behavior. For example, Niessen and Hamm (2008) compared consumers' self-reported organic purchasing with panel-based purchase information and found substantial differences between the two measures. Gschwandtner et al. (2021) combined stated- and revealed-preference information to improve consumer valuation, while Wee et al. (2014) examined the correspondence between stated preferences and purchasing behavior in food markets. These studies provide important evidence of preference-purchase inconsistency, but they primarily focus on human food markets, aggregate purchasing behavior, or broader product choices. They do not provide an attribute-by-attribute comparison between an individual pet owner's stated priorities and the characteristics of that same owner's reported food or treat product. Consequently, relatively little is known about preference-purchase alignment at the individual owner-product level in the pet food market. This chapter addresses that gap by linking a nationwide dog-owner survey with product-level information collected from an online retailer. The survey identifies owners' preferred attributes and the food and treat products they report purchasing, while the product data provide detailed information about the attributes associated with those products. The Match Index Score uses these linked data to measure alignment through both a four-attribute version based on the single highest-priority attribute in each category and a twelve-attribute version based on the top three attributes in each category.

3.3 Data & Methodology

3.3.1 Conceptual Framework

The conceptual framework follows from the chapter's objective of measuring and explaining the preference-purchase gap. Pet owners enter the purchase decision with expressed attribute preferences over four categories. These preferences form a wish list, but the observed purchase is filtered through constraints and decision contexts, including price, product availability, convenience, brand familiarity, information sources, pet health needs, and palatability. The outcome of interest is alignment between prioritized attributes and the attributes identified in the reported purchased product. The four attribute categories are health, ingredients, processing, and supply-chain (as defined in detail in Table 3.2). Health attributes include benefits such as digestive tract health, joint health /mobility, and weight control. Ingredient attributes include natural, grain-free, non-GMO, and no corn/soy/ or wheat. Processing attributes include fresh, minimally processed, wet, and freeze-dried. Supply-chain attributes include Made in USA, locally made, sustainable, and not made in China. The conceptual framework assumes that owners identify priorities within each category, but the purchased product may contain all, some, or none of those preferred attributes.

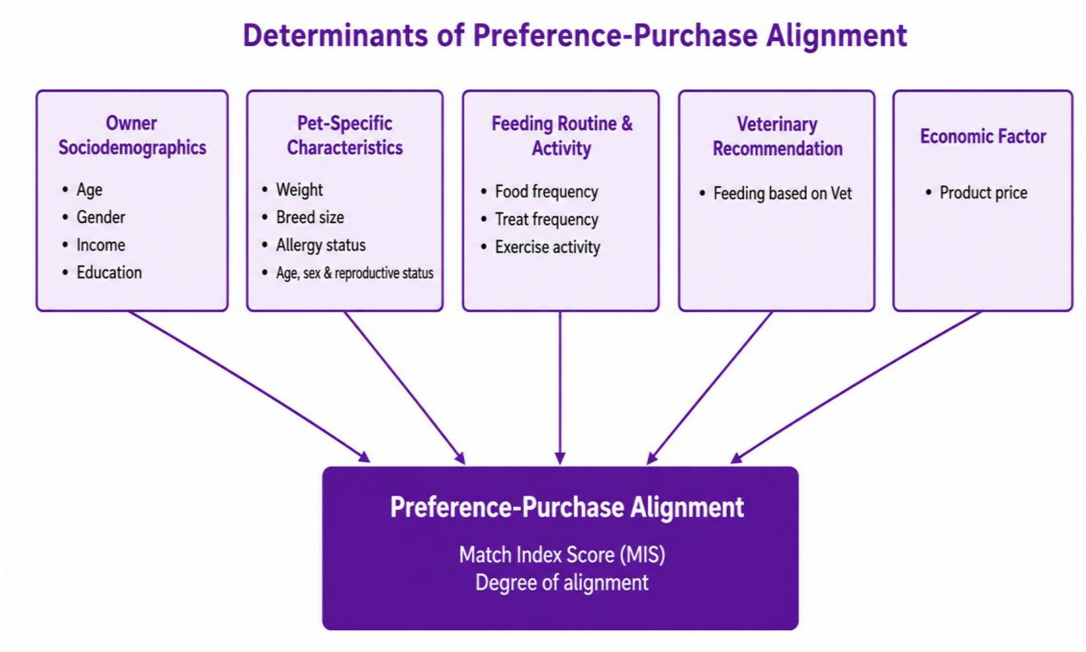
For each respondent, MIS equals the number of preferred attributes that are present in the purchased product divided by the number of preferred attributes specified as most important in respondents pet food/treat purchasing decision. As described in the introduction, this index is quantified as a ratio, $x/4n$, where x is the total number of matched attributes out of attributes specified as number one (n=1) most important attribute in four attribute categories, and top three (n=3) most important attributes in each of four categories . A high MIS (closer to 1) signifies strong behavioral consistency, meaning the consumer "walks the talk" by purchasing a product highly aligned with their stated preferences. A low MIS (closer to 0) indicates a large preference-purchase gap, suggesting a significant compromise was made at the point of purchase. For example, consider an owner whose highest-priority attributes are *digestive tract health* in the health category, *natural* in the ingredient category, *fresh* in the processing category, and *Made in USA* in the supply-chain category. Suppose the owner's reported purchased product is identified as *natural* and *Made in USA* but does not contain *digestive health* or *fresh* claims. In the four-attribute specification, two of the four highest-priority attributes are matched ($MIS_i = {}^2/_4 = 0.5$). This score indicates that the purchased product contains half of the owner's top most important attributes in each of the four categories. For the broader twelve-attribute specification, suppose the same owner selects the following top three priorities in each category:

- Health: *digestive tract health*, *joint health/mobility*, and *weight control*;
- Ingredients: *natural*, *grain-free*, and *no corn/soy/ or wheat*;
- Processing: *fresh*, *minimally processed*, and *wet*;
- Supply-chain: *Made in USA*, *locally made*, and *sustainable*.

If the reported product contains *digestive tract health*, *joint health/mobility*, *natural*, *grain-free*, *minimally processed*, *Made in USA*, and *sustainable*, then seven of the twelve prioritized attributes are matched ($MIS_i = {}^{7}/_{12} = 0.583$).

MIS serves as the dependent variable in the conceptual framework, representing the outcome of interest. Figure 3.1 summarizes the main categories of factors associated with preference-purchase alignment, as measured by MIS and the incidence of any match. As shown in Figure 3.1, preference-purchase alignment is modeled as a function of owner sociodemographic characteristics, dog characteristics, feeding and activity measures, veterinary recommendation, and product-related economic factors. These categories reflect the literature reviewed earlier, which emphasized that the translation of stated preferences into purchases may depend on both household characteristics and purchase constraints. The framework is consistent with intention-behavior research because expressed priorities are not assumed to translate automatically into purchase. Alignment is modeled as an outcome associated with economic capacity, owner characteristics, dog-specific needs, feeding routines, and product price (Samuelson, 1948; Carrington et al., 2010; Liu et al., 2024).

Figure 3.1. Determinants of Preference-Purchase Alignment (MIS)



3.3.2 Analytical Framework

The analytical framework translates the conceptual model into estimable relationships. The four-attribute MIS uses the single highest-priority attribute in each category. The twelve-attribute MIS uses the three highest-priority attributes in each category. Each score is calculated separately for food and treats. Thus, the analysis produces four outcomes: food MIS based on four attributes, treat MIS based on four attributes, food MIS based on twelve attributes, and treat MIS based on twelve attributes. Let k_i denote the number of preferred attributes matched in the purchased product for owner-product observation i. Let n_i denote the number of preferred attributes considered, where n_i = 1 for the single most important attribute in each of the four categories, and n_i = 3 for the top three most important attributes in each of the four attribute categories. The score is defined as:

(3.1)

$$MIS_i = {}^{k_i}/_{4n_i}, where\ 0 \leq MIS_i \leq 1, n_i \in \{1,3\}$$

Because MIS is constrained [0 to 1] and derived from a count of matched attributes, a combination of Generalized Linear Model (GLM) and binary outcome models has been used. In this study, MIS will be defined in two distinct ways.

1. Four-Attribute MIS (n_i = 1): For each respondent, select the single most important attribute from each of the four categories (ingredients, health, processing, and supply chain), resulting in a total of four prioritized attributes, then examine the details of the respondent's purchased product to determine whether these preferred attributes are present.
   - If none of the four attributes appear in the product, the score is 0/4.
   - If one attribute matches, the score is 1/4, and so on.
   - A perfect alignment, where all four attributes are found, yields a score of 4/4 = 1.
2. Twelve-Attribute MIS (n_i = 3): In this version, consider the top three most important attributes selected by each respondent within each category, resulting in twelve prioritized attributes across the four categories. As before, compare these preferences with the details of the purchased product.
   - If no preferred attributes appear, the score is 0/12.
   - If one matches, the score is 1/12, continuing up to 12/12 = 1 for complete alignment.

Several dog and feeding characteristics are included as contextual controls rather than as direct determinants of preference-purchase alignment. Dog weight may influence the set of products that is practical or affordable for an owner because feeding requirements, package-size needs, and product formulations vary with dog size. Food and treat frequency capture household feeding routines and the intensity with which these products are used. These routines may affect familiarity with products, purchasing habits, and the attention owners give to product attributes, which in turn may be associated with whether stated preferences are reflected in the reported product. Therefore, these variables are included to account for differences in pet-specific needs and feeding context when estimating preference-purchase alignment, not to imply that they directly cause a higher or lower MIS. The final empirical model can be expressed as:

(3.2)

$$
\begin{aligned}
MIS_i = \ & \beta_0 + \beta_1 owner\_gender + \beta_2 owner\_age + \beta_3 owner\_income + \beta_4 owner\_education \\
& + \beta_5 dog's\ weight + \beta_6 dog's\ allergy + \beta_7\ food\ frequeny \\
& + \beta_8\ treat\ frequency + \beta_9 dog's\ sex + \beta_{10} dog's\ reprostatus \\
& + \beta_{11} dog's\ age\ (in\ months) \\
& + \beta_{12} feeding\ based\ on\ vet + \beta_{13} low\ exercise\ per\ week \\
& + \beta_{14} medium\ exercise\ per\ week + \beta_{15} high\ exercise\ per\ week \\
& + \beta_{16} product\ price + \beta_{17} dog's\ breed\ type + \varepsilon_i
\end{aligned}
$$

Table 3.1 presents the definitions and descriptive statistics for the variables used in both the binomial GLM logit model and the binary logit model of matching versus nonmatching outcomes. Categorical variables were coded according to their measurement structure. Owner gender was entered as a binary indicator, with male as the reference category. Dog breed size was entered as a set of indicator variables, with medium-sized breeds as the omitted reference category. Owner age, income, and education were entered as ordered categorical scores rather than as sets of dummy variables. Therefore, these variables do not have omitted reference categories; their coefficients represent the association with a one-category increase in the corresponding ordered scale.

Table 3.1. Variable Descriptions

Variable	Description	Min.	Max.	Mean	Std. Dev.	Obs. (n)
Owner_Gender	0= male, 1=female	0	1	0.52	0.50	5,211
Owner_Age	1= Under 20 years 2= 21-24 years 3= 25-32 years 4= 33-40 years 5= 41-48 years 6= 49-56 years 7= 57-64 years 8= Above 64 years	1	8	4.05	2.01	5,211
Owner_Income	1= Less than $20,000 2= $20,000 - $40,999 3= $41,000 - $59,999 4= $60,000 - $85,999 5= $86,000 - $99,999 6= $100,000 - $119,999 7= $120,000 - $139,999 8= $140,000 - $164,999 9= $165,000 or more	1	9	4.01	2.35	5,211
Owner_Education	1= Some high school 2= High school diploma 3= Some college or trade 4= College degree 5= Some graduate education 6= Graduate degree or equivalent	1	6	3.49	1.32	5,211
Dog's weight	Dog's weight in lbs	1	220	41.61	33.32	5,211
Dog's allergy	When a dog has any food allergies (1= yes, 2= no)	1	2	1.92	0.27	5,211
Food frequency	Number of times per day dog is fed primary food	1	5	2.29	1.07	5,211

	(1=once, 2= twice, 3=three times, 4=four times, 5=free feed or constant access to food)					
Treat frequency	Number of times per day dog is fed treats (31=more than 30)	0	31	2.15	1.77	5,146
Dog's sex	0= male, 1=female	0	1	0.43	0.50	5,211
Dog's reproductive status	0=spayed/neutered, 1=intact	0	1	0.35	0.48	5,211
Dog's age	Dog's age (in month)	1	210	72.72	49.07	5,159
Feeding based on vet recommendation	Identifier if pet owner determines feeding amount based on vet recommendation (0= does not determine feeding amount based on vet recommendation, 1= determines feeding amount based on vet recommendation)	0	1	.27	.44	5,211
Low intensity activity	Number of times that dog participates in a **low intensity** activity per week (181=more than 180)	0	35	6.91	6.31	5,116

Low intensity duration	Duration of time that dog participates in a **low intensity** activity per occasion (181=more than 180minutes)	0	125	20.11	18.67	5,116
Medium intensity activity	Number of times that dog participates in a **medium intensity** activity per week (181=more than 180)	0	30	4.69	4.68	5,116
Medium activity duration	Duration of time that dog participates in a **medium intensity** activity per occasion (181=more than 180minutes)	0	120	14.29	16.53	5,116
High intensity activity	Number of times that dog participates in a **high intensity** activity per week (181=more than 180)	0	35	3.23	4.58	5,116
High activity duration	Duration of time that dog participates in a **high intensity** activity per occasion (181=more than 180minutes)	0	110	11.19	16.36	5,116
Product price	Identifier if you say the price of products/ brands is most preferred to you (price is important=1, price is not important=0)	0	1	0.28	0.45	5,211
Dog's breed type	1=extra small, 2= small, 3=medium, 4=large, 5=extra large	1	5	2.56	1.17	5,188
MIS (4-attribute Food) GLM	MIS for the most important attribute for **Food** ($n = 1$)	0	4	0.61	0.73	5,211
MIS (4-attribute Treat) GLM	MIS for the most important attribute for **Treat** ($n = 1$)	0	4	0.39	0.68	5,211

MIS (12-attribute Food) GLM	MIS for the top three most important attributes for **Food** ($n = 3$)	0	7	1.47	1.19	5,211
MIS (12-attribute Treat) GLM	MIS for the top three most important attributes for **Treat** ($n = 3$)	0	5	0.89	1.16	5,211
Any match (4-attribute Food) Binary	Is there any match when considering 4 attributes for **Food**	0	1	0.47	0.50	5,211
Any match (4-attribute Treat) Binary	Is there any match when considering 4 attributes for **Treat**	0	1	0.29	0.45	5,211
Any match (12-attribute Food) Binary	Is there any match when considering 12 attributes for **Food**	0	1	0.75	0.43	5,211
Any match (12-attribute Treat) Binary	Is there any match when considering 12 attributes for **Treat**	0	1	0.45	0.50	5,211

Note: Reference categories are male for owner gender and medium-sized breeds for dog breed size. Owner age, income, and education are entered as ordered categorical scores and therefore do not have reference categories.

For the categorical variables, frequency distributions provide additional information beyond the summary statistics reported in Table 3.1. The owner sample is nearly evenly divided by gender, with approximately 52% female and 48% male respondents. The largest age categories are 33-40 years (16.25%) and 49-56 years (15.34%). Household income is concentrated in the $20,000-$40,999 category (22.63%), followed by $41,000-$59,999 (17.23%) and $60,000-$85,999 (16.02%). College graduates represent 29.78% of respondents, while 28.04% report some college or trade education and 22.51% hold a high-school diploma.

Pet and feeding characteristics also show clear patterns. Approximately 8% of dogs are reported to have food allergies, while 43% are female and about 65% are spayed or neutered. Most owners feed their dogs twice per day (59.91%), compared with 16.20% feeding once daily, 12.95% feeding three times daily, and 9.98% allowing free feeding. Treats are also commonly provided once (32.74%) or twice (33.39%) per day. Approximately 27% of owners report using veterinary recommendations to determine feeding amounts, while 28% identify product price as an important purchasing consideration.

Breed sizes are relatively evenly distributed across the main categories: 23.76% of dogs are extra-small, 24.68% are small, 25.06% are medium, and 23.66% are large, while only 2.84% are extra-large. Medium-sized dogs constitute the omitted reference category in the regression models.

3.3.3 Dataset

The data combine the U.S. dog-owner survey described in Chapter 2 with product information scraped from Chewy.com. The survey identifies each respondent's prioritized attributes and the food and treat products the respondent reports purchasing. The product database identifies health, ingredient, processing, and supply-chain claims, together with price and other product characteristics. Product names are standardized and matched. For this chapter, the analysis uses observations for which preference information, a matched product, and the required covariates are available. Table 3.2 lists the attributes included in the four categories.

Table 3.2. Attribute Categories Used to Construct the Match Index Score

Health	Ingredient	Processing	Supply-Chain
Brain aging	Grain-free	Fresh	Eco-friendly
Calming support	Holistic	Raw	Sustainability
Dental care	Organic	Canned	Locally made
Digestive tract health	Natural	Wet	Made in USA
Hypoallergenic	Non-GMO	Freeze-dried	Not made in China
Joint health/Mobility	Sustainable	Minimally processed	
Skin and coat care	Limited-ingredient	Frozen	

Weight control	Human-grade		
	No corn, soy, wheat		
	No byproduct		

3.3.3.1 Descriptive Comparison of Wishlist and Purchased Product Attributes

The descriptive analysis provides the first evidence of the preference-purchase gap examined in this chapter. The survey data capture pet owners' expressed preferences, or the attributes they report as most important when choosing pet food, while the matched shopping cart data capture revealed behavior, or the attributes actually present in the food and treat products they purchased. To avoid repetition, the detailed distributions of single-priority wishlist attributes, top-three wishlist attributes, and purchased product attributes are reported in Appendix Figures D1-D16. The main text focuses on the comparison between stated preferences and actual purchases across four attribute categories: health, ingredients, processing, and supply chain.

Figure 3.2 compares health-related wishlist attributes with health choices observed in purchased food and treat products. The results show a noticeable mismatch between what pet owners say they prioritize and what appears in their shopping carts. Digestive tract health was the leading stated health preference, selected by 28% of respondents as the most important health attribute. However, digestive health appeared in only 15.2% of purchased food products. Instead, purchased foods more commonly emphasized skin and coat care and joint health/mobility. For treats, dental care was the dominant health-related attribute, appearing in 35.7% of purchased treat products. This suggests that pet owners may view treats less as general nutrition products and more as functional products for oral hygiene.

Figure 3.2. Health Attribute

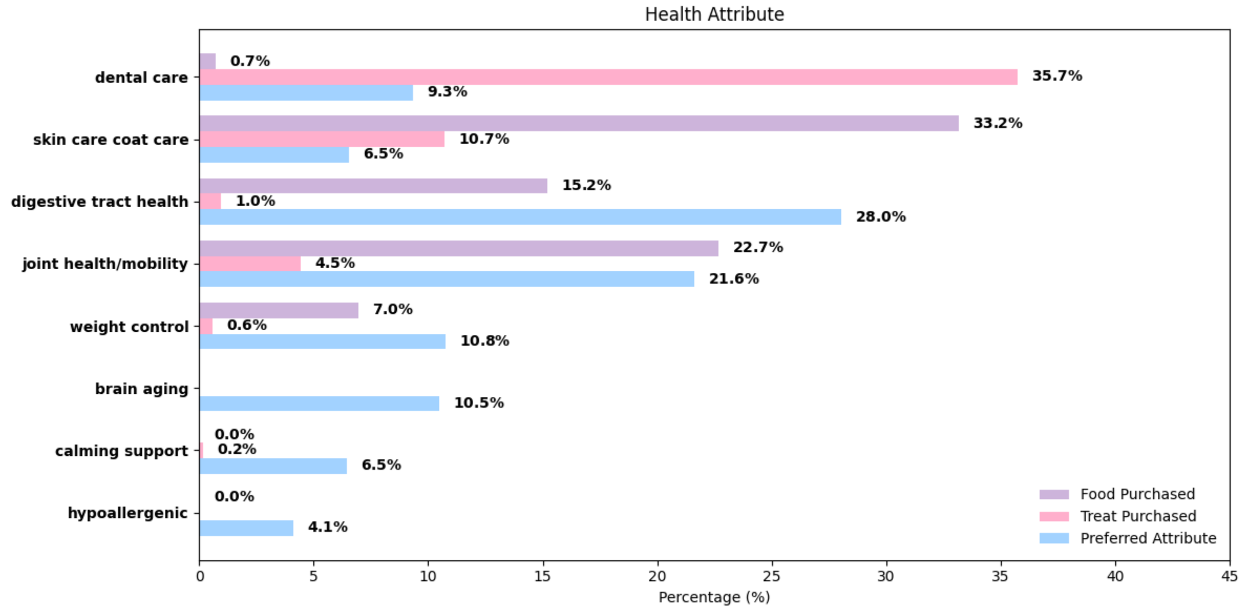


Figure 3.3 presents the comparison for ingredient-related attributes. Ingredient preferences show stronger alignment than health attributes, especially for natural claims. Natural was the leading stated ingredient preference and was also highly represented in purchased products, appearing in 49.2% of purchased foods and 60.6% of purchased treats. This indicates that naturalness has strong market visibility and broad consumer appeal. However, other ingredient-related preferences, such as no by-products, organic, non-GMO, and limited ingredient, were less frequently reflected in actual purchases. This suggests that although consumers express interest in multiple quality-related ingredient claims, only some of these preferences translate into realized shopping behavior.

Figure 3.3. Ingredient Attribute

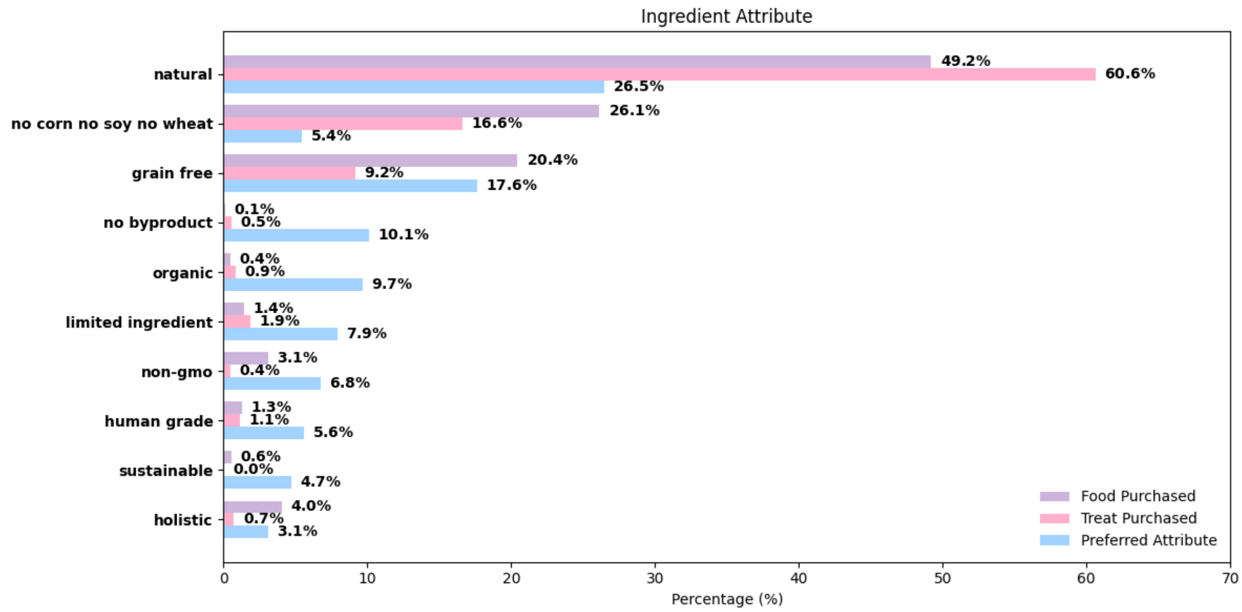


Figure 3.4 shows the comparison for processing-related attributes and reveals one of the clearest gaps between stated preferences and purchases. In the wishlist responses, pet owners strongly favored fresh and minimally processed products, with fresh selected by 45% of respondents and minimally processed selected by 35.2%. However, actual food purchases were more concentrated in shelf-stable and convenient formats, including wet and canned products. This pattern suggests that freshness may operate as an aspirational preference, while convenience, affordability, storage, and availability may play a larger role at the point of purchase. Treat purchases showed somewhat stronger alignment with fresh attributes, but the overall pattern still indicates that stated processing preferences do not fully translate into actual product choices.

Figure 3.4. Processing Attribute

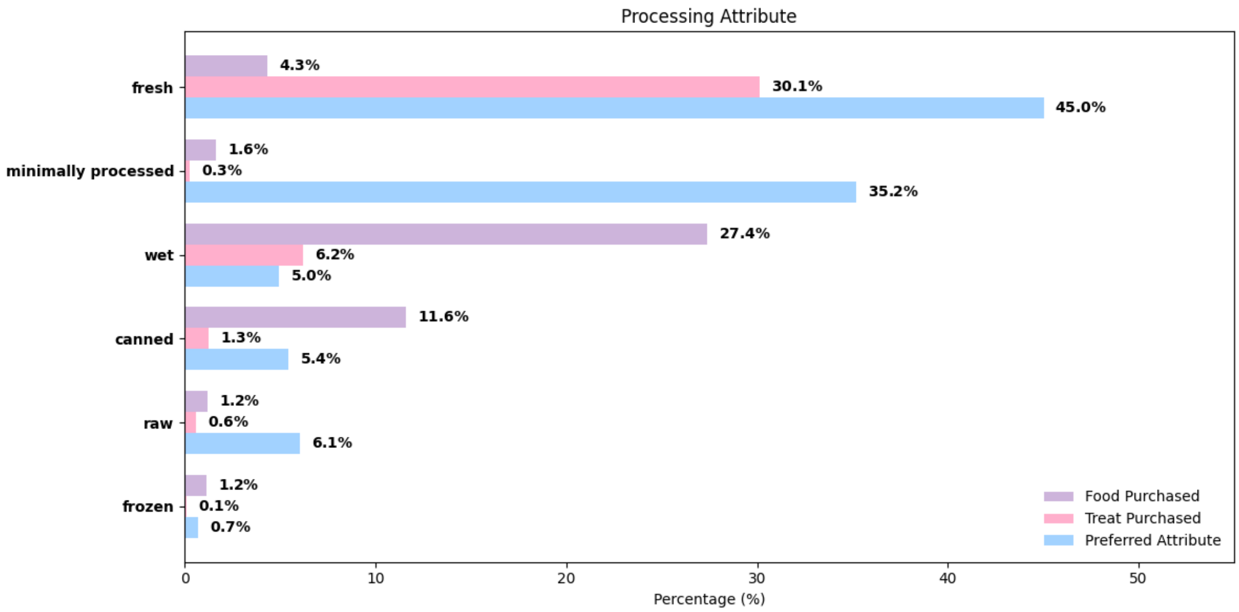
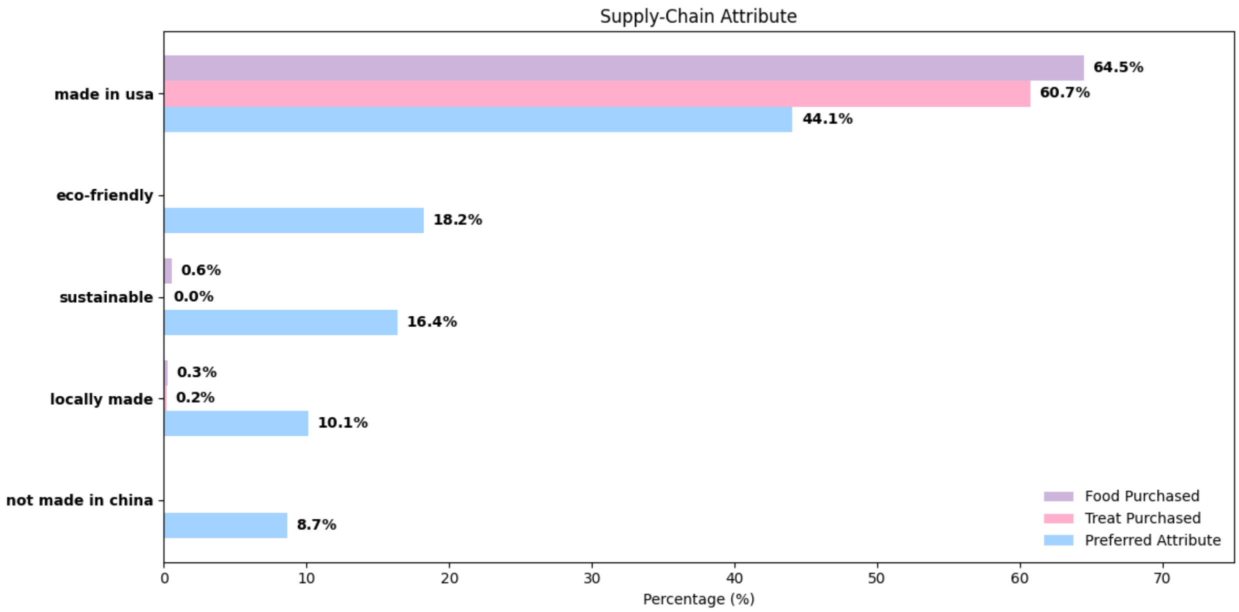


Figure 3.5 compares supply-chain-related attributes across wishlist responses and purchased products. This category shows the strongest alignment between stated preferences and actual purchases. Made in USA was the dominant supply-chain preference, selected by 44.1% of respondents as the most important attribute, and it also appeared frequently in purchased products, including 64.5% of food purchases and 60.7% of treat purchases. In contrast, sustainability, eco-friendliness, and locally made claims appeared much less frequently in shopping carts.

Figure 3.5. Supply-Chain Attribute



3.3.4 Empirical Strategy and Estimation Approach

3.3.4.1 Binomial GLM Logit Model

Because MIS is directly constructed as the ratio ${}^{k_i}/_{4n_i}$ from an underlying count k_i out of $4n_i$ possible attributes, the model would be a binomial outcome using a Binomial GLM with logit link. This treats each observation as a count of "successes" (matched attributes) with total trials $4n_i$. Formally:

(3.3)

$$k_i \sim Binomial\ (n_i, p_i), \quad logit(p_i) = X_i\beta$$

$$E\left(\frac{k_i}{4n_i}|X_i\right) = p_i = \frac{\exp(X_i\beta)}{1 + \exp(X_i\beta)}$$

where p_i is the probability that a preferred attribute is matched in the purchased product, k_i is the number of attributes considered, and X_i includes owner, pet, feeding, and price. Positive coefficients indicate greater alignment and negative coefficients indicate weaker alignment.

The main advantage of the binomial GLM is that it respects the bounded nature of MIS. Because MIS is constructed as the proportion of matched attributes out of a fixed set of possible attributes, the binomial specification models the number of successful matches directly rather than treating the score as an unbounded continuous outcome. It also accommodates observations at the boundaries of zero and one, which are meaningful in this application. A limitation is that the model treats matched attributes as binomial outcomes and may not fully capture correlation or dependence across attributes within the same product. If such dependence is present, standard binomial assumptions may understate uncertainty. In addition, cross-sectional design supports associations but not causal claims. Unobserved factors such as product availability, brand loyalty, store promotions, household routines, and the dog's taste may also influence matching.

3.3.4.2 Binary Logit (Matching vs. Not Matching)

To complement the degree-of-alignment analysis, this study estimates binary logit models to examine whether there is any match at all between the owner's prioritized attributes and the purchased product. The binary outcome is defined as:

(3.4)

$$Y_i^{binary} = \begin{cases} 1 \; if\ at\ least\ one\ attribute\ matches \\ 0 \qquad\qquad\qquad\qquad\qquad otherwise \end{cases}$$

These binary variable captures whether a pet owner had any match between their preferences and purchased attributes or not. Its advantage is ease of interpretation, especially when communicating whether owners obtain at least one preferred attribute.

3.4 Result and Discussion

This section reports the empirical results for the MIS and examines how owner, pet, and product characteristics shape the preference-purchase gap. It first presents estimates from the binomial GLM logit models. The model therefore estimates the expected proportion of preferred attributes that are matched in the reported purchased product. Although the underlying MIS is constructed from a count of matched attributes out of four or twelve opportunities, the empirical specification uses the normalized proportion as the dependent variable rather than estimating the individual attribute matches as separate binary outcomes. Throughout, this section relates the findings back to the research questions and conceptual framework outlined in sections 3.1 and 3.3.

3.4.1 Binomial GLM Logit Model

This study estimates a binomial logistic model for the MIS, defined as the proportion of an owner's prioritized attributes that were present in the purchased product (food or treat). A higher MIS indicates a smaller gap between what the owner values and what is reflected in the purchased product. The estimation results are presented in Table 3.3.

Table 3.3. Binomial GLM Logit Estimates

Variable	Food (4-attrs)	Treat (4-attrs)	Food (12-attrs)	Treat (12-attrs)
Intercept	**-1.9803***** (0.179)	**-2.7076***** (0.256)	**-2.0201***** (0.120)	**-2.5763***** (0.178)
Owner_gender	0.0145 (0.040)	0.0623 (0.056)	-0.0015 (0.026)	**0.0928**** (0.040)
Owner_age	**0.0997***** (0.010)	**-0.0328**** (0.015)	**0.0390***** (0.007)	**-0.0655***** (0.011)
Owner_income	**0.0158*** (0.009)	**0.0237*** (0.013)	**0.0121**** (0.006)	**0.0268***** (0.009)

Owner_eduction	**-0.0506***** (0.017)	0.0023 (0.023)	**-0.0183*** (0.011)	0.0146 (0.017)
Dog_weight	**0.0023***** (0.001)	-0.0000 (0.001)	**0.0015***** (0.001)	-0.0005 (0.001)
Dog_allergy	-0.0649 (0.069)	**0.2836***** (0.102)	-0.0539 (0.048)	0.0831 (0.072)
Food_frequency	-0.0093 (0.019)	0.0217 (0.025)	-0.0107 (0.012)	**0.0347*** (0.018)
Treat_frequency	0.0010 (0.011)	-0.0212 (0.018)	-0.0036 (0.007)	-0.0055 (0.012)
Dog_sex	-0.0275 (0.040)	-0.0025 (0.056)	-0.0064 (0.026)	-0.0483 (0.040)
Dog_reprostatus	-0.0335 (0.045)	-0.0612 (0.063)	0.0112 (0.029)	**-0.0907**** (0.046)
Do_age (month)	0.0004 (0.001)	-0.0006 (0.001)	-0.0002 (0.000)	-0.0003 (0.000)
feeding_vet_recommendation_binary	0.0237 (0.044)	0.0344 (0.061)	0.0262 (0.029)	0.0637 (0.044)
low exercise per week	-0.0000 (0.000)	-0.0000 (0.000)	-0.0000 (0.000)	0.0000 (0.000)
medium exercise per week	0.0000 (0.000)	**-0.0001*** (2.89e-05)	0.0000 (0.000)	**-0.0001***** (3.45e-05)
high exercise per week	-0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	**0.0001**** (1.23e-05)
Product_price	**-0.0987**** (0.045)	**-0.1597**** (0.063)	-0.0432 (0.029)	**-0.1102**** (0.045)
Dog_breed_extrasmall	0.0382 (0.063)	-0.0229 (0.085)	0.0556 (0.041)	-0.0233 (0.063)
Dog_breed_small	0.0463 (0.060)	**0.1756**** (0.079)	0.0584 (0.039)	0.0732 (0.059)
Dog_breed_large	**0.1105**** (0.056)	0.0082 (0.079)	0.0101 (0.037)	-0.0569 (0.057)
Dog_breed_extralarge	-0.1068 (0.119)	0.1262 (0.171)	-0.1289 (0.084)	0.1262 (0.126)
Observations	5,068	5,068	5,068	5,068
Pseudo R^2	0.0077	0.0026	0.0011	0.0023

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$ (Standard error in parentheses)

3.4.1.1 Socio-Demographic

Owner age emerged as one of the strongest predictors. For dog foods, owner age had a positive effect on MIS ($\beta = 0.0997$, $p < 0.001$ (4-attrs); $\beta = 0.0390$, $p < 0.001$ (12-attrs). This indicates that older owners tend to have a higher proportion of their preferred food attributes present in the product they purchased. This finding is consistent with evidence from the Dog Aging Project showing that owner age is associated with dog diet choices and that younger owners were more likely to feed kibble than older owners, while income and education were less strongly related to diet choice (O'Brien et al., 2024).

Interestingly, the owner age effect reverses for dog treats. In the MIS model, owner age showed a significant negative coefficient ($\beta = -0.0328$, $p < 0.01$ (4-attrs); $\beta = -0.0655$, $p < 0.001$ (4-attrs). In practical terms, older owners were less likely to have their preferred treat attributes match the product, indicating a wider gap for treats as owner age increases. This contrast with the food results suggests that senior owners may be quite vigilant about the main diet's attributes but more lenient when it comes to treats.

Owner income had a modest but consistent positive impact on MIS for both food and treats. Higher-income owners experienced slightly better alignment between desired and actual product attributes. For instance, in the food model (4-attrs), each unit increase in income corresponded to a coefficient of 0.0158 ($p < 0.05$), and in treats 0.0237 ($p < 0.05$). One explanation is that higher-income owners can afford premium pet foods that check off more of their desired attributes. Industry analyses have noted that pet "premiumization" is driven in part by owners' willingness and ability to pay for foods with specific health or quality claims (Hobbs & Anderson, 2025). These findings reveal that the ability to spend more may enable owners to purchase products that align more closely with their wish list.

Owner education level also showed a significant effect, particularly for dog food. The coefficient on owner education was negative for food MIS ($\beta = -0.0506$, $p < 0.001$ for the 4-attribute model; $\beta = -0.0183$, $p < 0.05$ for the 12-attribute model), indicating that more highly educated owners had slightly larger preference-purchase gaps in the food category. Prior evidence from the Dog Aging Project also suggests that owner education was less strongly associated with dog diet choices than other demographic factors, while owner age showed a clearer relationship with diet selection (O'Brien et al., 2024). Therefore, the negative association observed here may reflect differences in expectations or preference specificity rather than broad differences in diet type alone.

3.4.1.2 Pet Characteristic

Several dog-related factors significantly affected the matching score as well. Dog weight is one: in the food models, dog weight had a small positive coefficient ($\beta = 0.0023$, $p < 0.001$ (4-attrs), and similarly for the 12-attribute model (0.0015, $p < 0.001$). This implies that owners of larger/heavier dogs achieved a slightly higher MIS for dog food. In practical terms, big dogs' owners face a marginally smaller gap. This trend is echoed by the categorical breed size variables. Having a large-breed dog was associated with higher food matching ($\beta = 0.1105$, $p < 0.01$ relative to medium breeds), and extra-large breeds showed a positive (though non-significant) coefficient as well. One explanation is that pet food products are often tailored by size, and owners of large breeds may specifically seek out large breed formulas that cater to joint health, calorie density, kibble size, etc. Interestingly, for treats, the results indicate the opposite direction. Owning a small breed dog corresponded to a better match in treat attributes ($\beta = 0.1756$, $p < 0.01$ for small breed (4-attrs)). This suggests owners of small dogs are more likely to get treats that match their important criteria.

For the four-attribute treat model, having an allergic dog was associated with higher preference-purchase alignment (β=0.2836). The corresponding odds ratio is approximately 1.33, indicating about 33% higher odds of alignment compared with owners of dogs without allergies, holding other variables constant. In other words, owners of dogs with allergies tend to achieve much higher alignment on treat attributes. This makes intuitive sense that if a dog has allergies or sensitivities, the owner is likely to be very careful in selecting food/treats that meet specific criteria.

Dog reproductive status (spayed/neutered vs intact) showed significance in the treat model. In the 12-attribute treat, the coefficient for intact was about -0.0907 ($p < 0.01$), indicating that owners of intact dogs had a lower matching score for treats compared to owners of spayed/neutered dogs.

The dog exercise level had very small but statistically significant associations with treat MIS. Medium exercise was associated with a slight decrease in treat matching in the 4-attribute model ($\beta = -0.0001$, $p < 0.05$), while high exercise was associated with a slight increase in treat matching in the 12-attribute model ($\beta = 0.0001$, $p < 0.01$). However, the coefficients are extremely close to zero, indicating that the practical magnitude of these effects is minimal despite statistical significance. Broadly, this is consistent with evidence from the Dog Aging Project showing that dog-level characteristics, including activity level, are associated with diet choices (O'Brien et al., 2024).

3.4.1.3 Product and Cost Trade-Offs

In this model, the price of the product itself was a significant negative predictor of matching. For both foods and treats, higher product price was associated with a lower MIS (e.g., $\beta = -0.0987$, $p < 0.01$ for food; $\beta = -0.1597$, $p < 0.01$ for treats (4-attrs)). It likely reflects the role of cost trade-offs in widening the gap. Owners seeking affordable options, may not buy high-priced specialty products, so when we do see a high price in the data, it could indicate an owner who didn't consider price as important but instead paid more for some other attribute. In those cases, that owner may have sacrificed other preferred attributes for a premium feature, resulting in a lower overall match score.

3.4.2 Binary Logit (Matching vs. Not Matching)

In addition to the MIS proportion, a binary logistic model was estimated for a simpler outcome: whether there was any match between the owner's prioritized attributes and the product's attributes (coded as a binary outcome: match vs. no match). This analysis complements the MIS by focusing on the likelihood of at least one alignment. The results, presented in Table 3.4, were broadly consistent with the MIS findings, reinforcing which factors help reduce the preference-purchase gap, even if only a single attribute is matched, and which factors hinder alignment.

Table 3.4. Binary Logit Estimates

Variable	Food (4-attrs)	Treat (4-attrs)	Food (12-attrs)	Treat (12-attrs)
Intercept	-0.2939 (0.260)	**-1.2719***** (0.293)	**0.8707***** (0.306)	-0.4085 (0.260)
Owner_gender	-0.0119 (0.058)	0.0850 (0.064)	-0.1033 (0.068)	**0.1718***** (0.059)
Owner_age	**0.1363***** (0.016)	**-0.0369**** (0.017)	**0.0630***** (0.018)	**-0.0983***** (0.015)
Owner_income	**0.0286**** (0.014)	**0.0281*** (0.015)	0.0249 (0.017)	**0.0408***** (0.014)
Owner_education	**-0.0736***** (0.024)	-0.0058 (0.026)	-0.0432 (0.029)	0.0008 (0.024)
Dog_weight	**0.0024**** (0.00100)	0.0005 (0.00100)	0.0009 (0.00100)	-0.0003 (0.00100)
Dog_allergy	-0.1494 (0.104)	**0.2318**** (0.117)	-0.0060 (0.121)	0.1298 (0.103)
Food_frequency	-0.0079 (0.027)	0.0360 (0.030)	0.0218 (0.032)	**0.0805***** (0.027)

Treat_frequency	-0.0042 (0.017)	-0.0088 (0.019)	-0.0120 (0.018)	0.0225 (0.018)
Dog_sex	-0.0170 (0.059)	-0.0439 (0.064)	0.0609 (0.068)	-0.0698 (0.059)
Dog_reprostatus	-0.0222 (0.065)	-0.1072 (0.072)	**0.1290*** (0.077)	**-0.1501**** (0.066)
Dog_age_month	0.0001 (0.00100)	-0.0006 (0.00100)	-0.0010 (0.00100)	0.0000 (0.00100)
feeding_vet_recommendation_binary	0.0104 (0.066)	0.0211 (0.071)	0.1400* (0.078)	0.0656 (0.066)
low exercise per week	0.0000 (0.000035)	-0.0000 (0.000028)	0.0000 (0.000053)	0.0000 (0.000039)
medium exercise per week	0.0000 (0.000037)	**-0.0001*** (0.000050)	0.0000 (0.000050)	**-0.0002**** (0.000094)
high exercise per week	-0.0000 (0.000029)	0.0000 (0.000030)	-0.0000 (0.000034)	**0.0001*** (0.000032)
Product_price	-0.0916 (0.065)	**-0.1590**** (0.072)	0.0392 (0.076)	**-0.1423**** (0.065)
Dog_breed_extrasmall	0.0151 (0.090)	-0.0162 (0.099)	0.0869 (0.106)	0.0050 (0.091)
Dog_breed_small	0.1005 (0.087)	0.1477 (0.094)	0.1344 (0.103)	0.1291 (0.087)
Dog_breed_large	0.1580* (0.083)	-0.0283 (0.091)	0.0525 (0.096)	0.0224 (0.083)
Dog_breed_extralarge	-0.0015 (0.183)	0.1087 (0.196)	-0.2760 (0.203)	0.0811 (0.184)
Observations	5,068	5,068	5,068	5,068
Pseudo R^2	0.02390	0.00640	0.00572	0.01825

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$ (Standard error in parentheses)

Owner age remained a strong positive predictor of food matching. Combined with the MIS result, this underscores that older owners not only achieve higher overall matching proportions but also are less likely to have a complete miss on all desired attributes for dog food. For dog treats, the baseline scenario was different: the intercept for the 4-attribute match model was strongly negative (-1.2719***), indicating the average owner had a relatively low probability of even one match in treats.

Owner gender showed a significant effect in the treat any-match model (when 12 attributes were considered). Being female was associated with higher odds of a match (β =

0.1718, $p < 0.001$). In other words, female owners were more likely than male owners to buy a treat that hit at least one of their priority attributes. One might speculate that female pet owners could be more attentive to ingredient lists or nutritional claims on treats. On the other hand, prior studies on alternative diet adoption found no major gender differences (Vékony et al., 2024).

Owner income continued to play a positive role in the binary outcome. In the treat model using 12 attributes, higher income had a positive and statistically significant coefficient (β = 0.0408, $p < 0.001$), indicating that higher-income owners were more likely to have at least one preferred attribute present in the purchased treat. Income was also significant in the 4-attribute treat model ($p < 0.05$). Thus, similar to the MIS results, higher income is associated with a greater likelihood of achieving at least some preference-purchase alignment, suggesting that higher-income owners may have greater ability to access products that satisfy at least one desired criterion. This finding is consistent with broader pet market trends showing that higher-income households have contributed to increased pet spending and premiumization in pet food and treats (Pet Food Processing, 2021).

The dog-specific factors similarly mirror their MIS influences in the binary context. In the food model, the coefficient for large breed was positive (β = 0.1580, $p < 0.05$ (4-attrs)). So, owners of large breed dogs had higher odds of achieving some match on food attributes compared to medium-breed owners, consistent with the idea that large-breed diets often overlap with owner priorities.

Dog allergy once again stood out as a significant positive factor in the treat models. In the 4 attributes model, having an allergic dog raised the log-odds of any match by 0.232 ($p < 0.01$). In contrast, without an allergy, an owner might end up with a treat that hits none of their ideal.

Feeding frequency and exercise effects also appeared in the binary treat model with 12 attributes. Food feeding frequency was positively associated with at least one treat match ($\beta = 0.0805$, $p < 0.001$). This suggests that owners who feed their dogs more frequently are also more likely to be structured in treat selection.

Finally, the product price effect persisted in the binary models as well. For treats, a higher price significantly lowered the probability of any attribute match ($\beta = -0.1590$, $p < 0.01$ (4-attrs); -0.1423, $p < 0.01$ (12-attrs)).

Across both the MIS proportion models and the binary match models, the results tell a consistent story. Older and higher-income owners, and those with heavier or allergic dogs, tend to achieve higher alignment between their stated priorities and the attributes of the products they buy, especially for staple dog foods, while more educated owners, owners of small dogs, and those facing higher product prices exhibit larger gaps. These patterns reinforce the conceptual framework in which economic constraints, pet needs, and sociodemographics jointly determine whether owners "walk their talk" or compromise on desired attributes. The next section summarizes these findings, discusses their implications for marketing strategy, limitations, and outlines directions for future research.

3.5 Conclusion

This chapter developed the Match Index Score to measure the extent to which the attributes of pet food products reported by owners align with their expressed priorities. The four-attribute MIS uses the single highest-priority attribute in each of four categories: health, ingredients, processing, and supply chain, while the twelve-attribute MIS uses the three highest-priority attributes in each category. The scores are calculated separately for food and treats. A binomial GLM estimates the proportion of preferred attributes matched, while a complementary binary logit model estimates whether at least one preferred attribute is present in the reported product.

3.5.1 Main Findings

The descriptive results show that preference-purchase alignment differs substantially across attribute categories. Natural and Made in USA attributes have relatively strong visibility in both owners' expressed priorities and the claims associated with their reported products. Larger differences appear for several health and processing attributes, particularly digestive health, fresh, and minimally processed products. These patterns indicate that frequently stated priorities are not always reflected in reported purchases.

The regression results further show that alignment varies across owner characteristics, dog characteristics, and product categories. Older age categories are associated with stronger food alignment but weaker treat alignment. Higher income is positively associated with alignment in several treat models, whereas education is negatively associated with food alignment in selected specifications. Greater dog weight and the large-breed indicator are associated with stronger food alignment, while small-breed and allergy status are associated with stronger alignment in selected treat models.

The product price is negatively associated with alignment in several food and treat models. This result is consistent with the possibility that cost constraints or trade-offs among product attributes prevent owners from obtaining products that satisfy all of their priorities. However, the analysis does not observe the actual price paid, discounts, or product availability.

The findings have two principal implications for pet food firms. First, stated attribute importance should not automatically be treated as realized demand, but it should not be discounted. Expressed preferences provide evidence of underlying consumer interest, even when those preferences are not fully reflected in current purchases. The gap may arise because preferred products are unavailable, difficult to identify, or priced above what consumers are willing or able to pay. Therefore, firms should view stated preferences as potential demand that may be converted into actual purchases when desired attributes are offered in accessible, clearly communicated, and affordable products. Product development decisions should consider whether desired attributes are understandable, visible, available, and affordable in actual shopping environments. Marketing communication may be more effective when it clearly connects product claims with benefits that owners recognize rather than presenting a large number of claims without explaining their practical relevance.

Second, food and treats should be treated as distinct purchasing categories because the study shows that preference-purchase alignment differs between them. The descriptive results indicate that some attributes appear differently across food and treat purchases; for example, dental-care claims are much more prominent among treats, while food purchases show stronger representation of other health and ingredient attributes. The regression results also reveal different relationships across the two product types. Owner age is positively associated with food alignment but negatively associated with treat alignment in several specifications, while dog allergy status is more strongly associated with treat alignment. Price also shows a negative association with alignment in several food and treat models, although the magnitude differs across specifications. However, the analysis does not observe the actual price paid, discounts, local product availability, or stock-outs. These differences suggest that consumers do not necessarily apply the same priorities or constraints when selecting staple food and treats. Pet food firms should therefore consider separate product-development, pricing, segmentation, and communication strategies for these two categories.

The chapter contributes to the literature by moving beyond aggregate measures of stated importance and examining preference-purchase alignment at the individual owner-product level. The MIS provides a practical method for comparing expressed priorities with the attributes of reported purchased products. It also demonstrates how linked survey and product data can bridge part of the information gap between stated-preference studies, which rarely observe detailed purchases, and transaction datasets.

3.5.2 Limitations

The first limitation is that purchased products are self-reported rather than directly observed in retailer transaction records. Respondents may have forgotten the exact product name, confused similar formulations, or reported the brand they usually purchase rather than the product purchased most recently. Recall error may therefore cause the reported product to differ from the product actually purchased. In addition, respondents who wish to appear health conscious may report products that seem more consistent with their stated preferences. These errors can either increase or decrease the calculated MIS and limit the interpretation of the score as a complete measure of revealed preference.

Another limitation concerns the matching of survey responses to online product pages. Brand names, product names, and flavors/formulations were entered manually and required standardization and fuzzy matching. Incomplete or misspelled entries may have been linked to a similar but incorrect formulation. Because products within the same brand may differ in product names, claims, and ingredients, an incorrect match can produce measurement error in both the MIS and the explanatory variables. This error is likely to weaken some estimated relationships.

The product information was obtained from one major online retailer, although respondents may have purchased products from supermarkets, pet stores, or other online retailers. The survey does not identify whether each purchase occurred online or in a physical store. Product availability, package size, labeling, promotions, and formulation may differ across retail channels. Consequently, the online listing used in the analysis may not perfectly represent the product information, or choice environment faced by the respondent.

Another limitation is that the analysis does not directly observe all of the constraints that may prevent owners from purchasing products that contain their preferred attributes. A low Match Index Score may reflect not only a difference between stated preferences and purchasing behavior, but also limited availability or accessibility of products containing those attributes. For example, a preferred attribute may not be available at the respondent's usual retailer, may be available only in certain product forms or package sizes, or may be offered at a higher price. Consumers may also face trade-offs involving convenience, brand familiarity, product availability, pet health needs, and palatability. Because the survey does not observe the complete choice set available to each respondent at the time of purchase, the analysis cannot determine whether an unmatched preferred attribute reflects a deliberate compromise or whether a product containing that attribute was simply unavailable or difficult to access. Therefore, the preference-purchase gap should not be interpreted solely as inconsistency between what consumers say they prefer and what they purchase.

Another limitation is that the analysis does not account for differences in how prominently individual attributes are marketed or communicated on product packaging and online product pages. Some attributes may receive substantial marketing emphasis, prominent front-of-package claims, or clearer descriptions, while others may receive relatively little attention. As a result, consumers may find it easier to identify and purchase products associated with highly marketed attributes. Consequently, differences in observed preference-purchase alignment across attributes may partly reflect differences in attribute visibility and marketing emphasis rather than differences in consumer commitment to those preferences alone.

The analysis also does not account for differences in the number of products available with each attribute or for breed-specific product positioning. Some preferred attributes may be offered across a large number of products, making them easier for consumers to match, whereas other attributes may be available in relatively few products. Similarly, although dog breed size is included as an explanatory variable, the analysis does not identify whether the purchased product is specifically formulated or marketed for a particular breed or breed-size category. Therefore, observed differences in alignment across attributes and breed sizes may partly reflect differences in product availability and market positioning rather than consumer preferences alone.

The MIS also assigns equal weight to every selected attribute. Under this structure, matching an owner's most important attribute contributes the same amount as matching a lower-ranked attribute. However, consumers may value some attributes much more strongly than others. Equal weighting may therefore understate alignment when a product satisfies the owner's dominant priority but misses less important attributes or overstate alignment when it includes several secondary attributes but omits the most important one.

In addition, attributes within a product are not necessarily independent. Claims such as natural, organic, non-GMO, minimally processed, and sustainable may appear together because of a firm's broader positioning strategy. Treating each match as a separate component of the MIS does not capture these relationships.

Finally, the cross-sectional design provides information at one point in time and therefore cannot establish causal relationships. For example, higher income may provide greater access to products with desired attributes, but owners who prioritize certain attributes may also differ from other owners in unobserved ways. Similarly, allergy status may lead owners to choose products more carefully, but the survey cannot determine how preferences and purchases changed after the allergy was identified.

3.5.3 Future Research

Future research should combine stated-preference information with directly observed purchase records. Respondents could provide electronic receipts, subscription records, or photographs of recent purchases. Linking these records to survey responses would reduce error and provide stronger evidence about the products actually purchased. Repeated purchase data would also show whether alignment is stable over time or varies with price changes, promotions, health events, and product availability.

Product identification should be improved by allowing respondents to select the exact brand, product name, and flavor/formulation from a searchable product database rather than entering this information manually.

Future surveys should also identify whether the product was purchased online or in a physical store and record the specific retailer, purchase date, package size, regular price, actual price paid, or discounts. Respondents should be asked whether the purchased product was their first choice or a substitute selected because another product was unavailable.

Future research should incorporate measures of attribute-level product availability, the prominence of claims on packaging and product pages, and whether products are explicitly marketed for particular breeds or breed-size categories. This would help distinguish preference-purchase inconsistency from differences in market availability and marketing exposure.

The MIS could be extended by assigning weights based on the owner's ranking or stated importance of each attribute. A weighted MIS would give greater importance to matching an owner's highest-ranked priorities. Future research should also examine whether the category in which alignment occurs matters. The current MIS combines matches across health, ingredient, processing, and supply-chain attributes into a single overall score, even though the descriptive results suggest that some categories are matched more frequently than others. For example, a health-match variable equal to one when at least one prioritized health attribute appears in the reported product and zero otherwise, with comparable indicators for ingredient, processing, and supply-chain matches. This extension would show not only whether owners achieve preference-purchase alignment, but also which categories are most likely to align and which factors explain health-related matches compared with ingredient, processing, or supply-chain matches.

Finally, longitudinal research could follow the same owners across multiple purchases. Such data would make it possible to evaluate whether preference-purchase alignment changes after a dog develops an allergy, receives a veterinary diagnosis, enters a new life stage, or experiences a change in household income.

Chapter 4 - How Can Sorghum Win? Consumer Preferences for Sorghum Relative to Competing Grains in Pet Food

4.1 Introduction

Ingredient choice in pet food reflects both technical performance and consumer interpretation. Grains provide energy and functional starch in many extruded products, yet some consumers view conventional grains as low-quality fillers despite evidence that properly processed grains can contribute digestible nutrients (Twomey et al., 2002; Cho et al., 2024; Abood and Wara, 2023). At the same time, ancient-grain, natural, and sustainability claims have become increasingly visible in pet food positioning (Viana et al., 2020; Traughber et al., 2021). In this environment, understanding how pet owners perceive different grain ingredients is no longer a narrow nutrition question, it has become a central economic problem for firms, farmers, and ingredient suppliers who must decide which ingredients to promote, how to position them, and where to invest.

This market environment creates an opportunity for ingredients that can connect pet-health perceptions with upstream sustainability concerns. Sorghum is one of the most promising candidates. Sorghum can provide digestible starch, fiber, minerals, and antioxidant compounds, and research indicates that properly processed sorghum can substitute for corn or rice in pet food formulations (Twomey et al., 2002; Schaumburg et al., 2021; Cho et al., 2024; Maichel, 2021). It is also drought tolerant and can use water efficiently under constrained production conditions (Bhattarai et al., 2020). These attributes create a potential value proposition based on formulation flexibility and sustainability.

Despite these technical benefits, the economic competitiveness of sorghum depends on consumer perception. The market question is whether pet owners recognize that value proposition when sorghum appears beside more familiar grains. Rice, corn, oat, barley, quinoa, and millet carry different associations related to digestibility, naturalness, premium quality, and familiarity. Sorghum may be evaluated as an ancient grain, a neutral ingredient, or an unfamiliar alternative. The resulting perception gap can limit demand even when the ingredient is technically feasible. Industry insights suggest that sorghum could command a premium in some niche segments, but broader consumer awareness remains limited (Texas Farm Bureau, 2021). For sorghum growers, processors, and pet food manufacturers, this uncertainty complicates product design, market positioning, and demand forecasting.

Existing research provides important but incomplete guidance. Pet-food studies emphasize the rise of grain-free and natural formulations and show that concerns about ingredient quality and digestive health shape product choices (Simonsen et al., 2014). Related veterinary nutrition sources note that grains such as corn are often criticized or mislabeled as fillers, despite their nutritional and functional roles in pet food (Abood and Wara, 2023). A related literature on sorghum emphasizes its drought tolerance, water-use efficiency, and potential as a sustainable food and feed ingredient (Bhattarai et al., 2020; Maichel, 2021; Sorghum Checkoff, n.d.). Yet direct evidence remains limited on how pet owners evaluate sorghum against specific competing grains in a realistic choice setting and which owner segments are most receptive to sorghum as a pet-food ingredient.

This chapter asks two questions. First, how likely is sorghum to be selected as the most preferred grain when it competes directly with alternative grains? Second, how are demographic characteristics and stated health, ingredient, and sustainability priorities associated with the probability of choosing sorghum rather than another grain? To address these questions, the analysis compares consumers' grain preferences across three choice sets: sorghum-rice-barley, sorghum-quinoa-corn, and sorghum-oat-millet. These comparisons allow sorghum's relative position to be evaluated against both familiar staple grains and other alternative grains used in pet food.

The main contribution of this chapter is to move beyond technical feasibility and broad grain-inclusive versus grain-free comparisons by directly estimating sorghum's position within the competitive grain landscape. By examining how dog owners choose sorghum relative to rice, corn, barley, quinoa, oat, and millet across the three sorghum-containing choice sets, the analysis identifies where sorghum fits within the competitive grain landscape and which consumers are more likely to select it. A key contribution of this chapter is the integration of consumer and producer perspectives on sorghum. The consumer survey identifies how pet owners position sorghum relative to competing grains and which consumer characteristics and priorities are associated with grain choice. The producer survey provides complementary evidence on industry use of sorghum and perceived advantages and barriers to adoption. Comparing these two perspectives makes it possible to identify where industry perceptions and consumer demand align and where important market gaps remain.

The consumer survey included a seven-task Best-Worst Scaling (BWS) exercise designed to measure preferences among seven plant-based ingredients: barley, corn, millet, oat, quinoa, rice, and sorghum. In each task, respondents were shown three ingredients and asked to identify the ingredient they preferred most and the ingredient they preferred least when purchasing pet food. Because this essay focuses specifically on the competitive position of sorghum, the analysis uses the three BWS choice tasks in which sorghum appeared: (1) sorghum, rice, and barley; (2) sorghum, quinoa, and corn; and (3) sorghum, oat, and millet. The remaining four BWS tasks did not contain sorghum and therefore are not included in the Chapter 4 econometric analysis. Although both most- and least-preferred choices were collected, the multinomial logit analysis uses the most-preferred choice from each of the three sorghum-containing sets as the dependent choice outcome.

Three multinomial logit models are estimated, one for each choice set, with sorghum as the reference alternative. Relative risk ratios show how covariates shift the relative likelihood of choosing each competing grain rather than sorghum, and average marginal effects show changes in predicted choice probabilities. The analysis contributes direct evidence on sorghum's position relative to named competitors rather than treating grain-inclusive pet food as a single category.

The remainder of the chapter is organized as follows. Section 4.2 reviews the relevant literature, and section 4.3 describes the survey design, grain-choice experiment, and econometric methods, including the MNL specification and the variables of interest. Section 4.4 presents and discusses the empirical results. Finally, Section 4.5 summarizes the main findings, draws implications for sorghum promotion and pet food marketing strategies, and outlines directions for future research.

4.2 Literature Review

4.2.1 Grains in Pet Nutrition

Carbohydrate sources derived from grains, legumes, and starches provide energy and help support the structural integrity of extruded pet-food products (Cho et al., 2024). Traditional grains such as corn and rice have historically been used because, when properly processed, they provide digestible starch and energy in canine diets (Twomey et al., 2002; Cho et al., 2024). However, the rise of grain-free marketing has reshaped consumer attitudes toward traditional cereal ingredients, even though veterinary nutrition sources note that grain allergies are uncommon and that grains can provide valuable nutrients when included in balanced pet foods (Abood and Wara, 2023).

This shift has created market space for ingredients that combine nutritional value with positive consumer associations. Ancient grains are often positioned to fill this space. Sorghum offers a broad nutritional profile: varieties can contain higher crude protein than corn and higher levels of minerals such as iron and zinc (Cho et al., 2024). Its starch composition can produce a lower glycemic index than common ingredients such as rice, which is relevant to concerns about pet obesity and diabetes (Schaumburg et al., 2021). Although earlier work raised concerns about the digestibility of raw sorghum, modern extrusion techniques can improve starch gelatinization and support digestibility similar to corn and rice (Sorghum Checkoff, n.d.).

4.2.2 Sorghum's Competitive Advantages

From a producer and manufacturer perspective, sorghum offers competitive advantages relative to several commonly used grains, particularly in water-constrained production regions. Sorghum is frequently recognized for resilience, drought tolerance, and relatively low input requirements. Compared with corn, sorghum can achieve higher water-use efficiency under limited irrigation, which may reduce production risk in water-scarce regions (Bhattarai et al., 2020). In the context of climate-smart agriculture, these environmental attributes position sorghum as a sustainable alternative grain (Majzoobi et al., 2023).

Sorghum may also offer cost advantages in certain formulation contexts. Schaumburg et al. (2021) report that sorghum can be less expensive to source than rice, while Maichel (2021) describes it as a sustainable and cost-effective alternative to conventional grains such as corn and rice. Because carbohydrate ingredients constitute a substantial share of many dry pet-food formulations, differences in ingredient price, availability, and processing functionality can be economically meaningful to manufacturers (Schaumburg et al., 2021). Nutritionally, sorghum has a lower glycemic index and high fiber/antioxidant content, which can support digestive health and weight management in pets (Maichel, 2021). Importantly, studies show sorghum can replace rice or corn in pet diets without sacrificing palatability or nutrition (Maichel, 2021), making it a feasible substitute from a product development standpoint. The challenge for the sorghum industry, as noted by industry leaders, is transitioning sorghum from a commodity primarily used for ethanol and animal feed into a high-value specialty ingredient for the premium pet food sector.

4.2.3 Consumer Valuation of Ancient Grains

Consumers often use labels and ingredient names as signals of quality when technical characteristics are difficult to evaluate directly. In human food markets, ancient grains can be associated with health, authenticity, and sustainability, and some consumers are willing to pay premiums for those attributes (Nazzaro et al., 2025). Similar signaling may occur in pet food because owners frequently project their own food values onto products purchased for pets.

The strength of the ancient-grain signal is likely to vary by ingredient. Quinoa and oat may be more familiar or have stronger existing health associations than sorghum. Sorghum's success may therefore depend not only on belonging to the ancient-grain category but also on whether consumers understand its specific relevance to the benefits they value (Traughber et al., 2021).

4.2.4 Empirical Gap and Contribution

Prior research establishes the technical feasibility and agronomic advantages of sorghum but provides limited evidence on how pet owners choose it relative to specific competing grains. It is unclear whether sorghum can compete with familiar staples such as rice and corn or with grains that already carry premium or natural associations, such as quinoa and oat. To address this, the current research employs a Discrete Choice Model (DCM) framework to see consumer preferences for a range of grains (sorghum, rice, corn, barley, quinoa, oats, and millet) captured in the survey.

4.3 Data & Methodology

4.3.1 Conceptual Framework

The conceptual framework assumes that pet owners choose the grain ingredient that provides the highest perceived utility when selecting food for their dog. In this context, utility represents the overall value the owner associates with the ingredient, including perceived health and nutritional benefits, familiarity, ingredient quality, and other personal priorities. Utility depends on the identity of the grain and on the owner's characteristics, beliefs, and priorities. Sorghum's agronomic or nutritional attributes can influence choice only to the extent that owners recognize and value them. Consumer knowledge and familiarity with sorghum may also influence perceived utility and grain choice. Although the survey does not directly measure respondents' existing knowledge of sorghum, it does measure their interest in learning more about sorghum as an ingredient in pet food or treats. The empirical model therefore tests whether age, education, income, gender, region, and priorities related to digestive health, weight control, non-GMO ingredients, avoidance of corn/soy/wheat, local production, and sustainability are associated with relative grain choice. Table 4.1 summarizes the observed owner characteristics and attitudes included in the empirical analysis and their expected theoretical links to sorghum preference.

Table 4.1. Conceptual Link Between Owner Characteristics, Attitudes, and Sorghum Preference

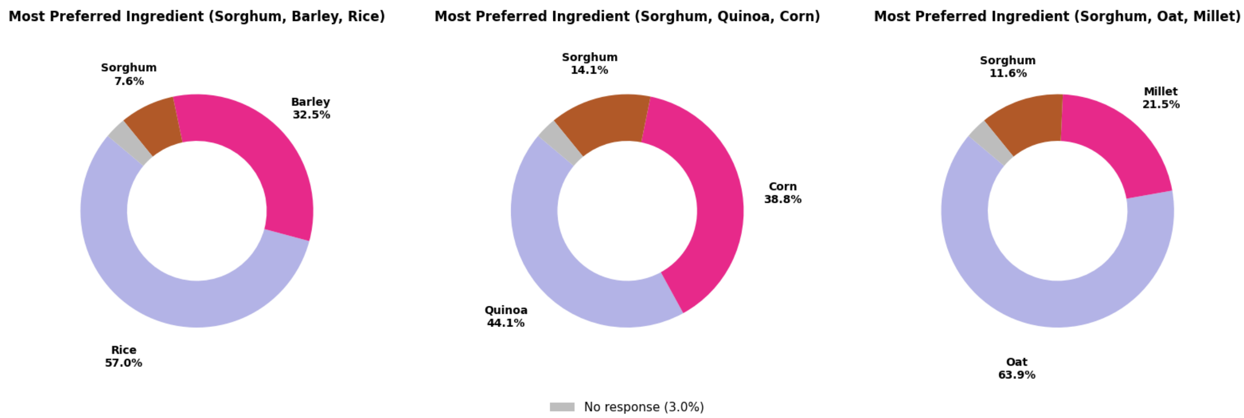
Variable Group	Variables	Theoretical link to sorghum preference
Demographics	Age, Education, Income, Gender, Region	Education and income may be associated with health and environmental consciousness and with willingness to consider premium or less familiar ingredients such as ancient grains and sustainability-oriented products (Nazzaro et al., 2025; Kohansal & Firoozzare, 2013). Age, gender, and region may capture differences in familiarity, shopping routines, and exposure to specialty pet-food claims.
Health attitudes	Digestive tract health, Weight control	If owners understand sorghum's functional fiber, antioxidant content, and lower-glycemic-index profile, these attitudes should increase sorghum preference. If awareness is low, these same owners may instead choose more familiar grains that they perceive as safer or easier to digest.
Ingredient and supply-chain attitudes	Non-GMO, Sustainable, No-soy/corn/wheat, Locally made	These attitudes align with sorghum's promoted attributes, including drought tolerance, U.S. production, and suitability as an alternative in grain-inclusive but corn/soy/wheat-free formulations.

4.3.2 Dataset

This chapter focuses on respondents' preferences for sorghum relative to six other plant-based ingredients commonly found in pet foods: barley, rice, corn, millet, oat, and quinoa. The consumer survey included a seven-task Best-Worst Scaling (BWS) exercise covering seven plant-based ingredients used or potentially used in pet food: barley, corn, millet, oat, quinoa, rice, and sorghum. In each choice task, respondents were presented with three ingredients and asked, “When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least?” Respondents selected one ingredient as most preferred and one as least preferred. The composition of the three-ingredient sets varied across the seven tasks. Because the objective of this chapter is specifically to evaluate sorghum relative to competing grains, the empirical analysis focuses on the three BWS tasks that contained sorghum. These choice sets were: (1) sorghum, rice, and barley; (2) sorghum, quinoa, and corn; and (3) sorghum, oat, and millet. The other four BWS tasks were excluded from the Chapter 4 analysis because sorghum was not included as an alternative. For each of the three retained choice sets, the most-preferred response is used as the dependent choice outcome in a separate multinomial logit model. Although the BWS exercise also collected respondents’ least-preferred choices, those responses are not used in the multinomial logit estimation.

This analytical design allows sorghum to be evaluated against familiar staple grains and other grains commonly marketed within the ancient-grain space. Figure 4.1 presents the percentage of respondents selecting each ingredient as the most preferred option in the three comparison sets. Across all three sets, sorghum is selected less often than the leading alternatives. In the first set, rice receives the largest share of top choices, followed by barley and sorghum. In the second set, quinoa and corn both exceed sorghum. In the third set, oat is the dominant preferred ingredient, followed by millet and sorghum. These descriptive patterns indicate that sorghum enters the consumer choice environment with a demand-side disadvantage relative to the leading competing grains. The choice exercise alone does not identify the reason for this disadvantage; however, the follow-up perception questions show that relatively few respondents currently consider sorghum an important pet food ingredient, while a substantially larger share express at least some interest in learning more about it.

Figure 4.1. Most Preferred Pet Food Grain Ingredient Across the Three Comparison Sets



Several demographic variables were collapsed from the original survey response categories into broader groups before estimation. The purpose of this grouping was to obtain a more parsimonious multinomial logit specification, maintain meaningful numbers of observations within each category, and facilitate interpretation of the estimated relationships. The cutoffs follow boundaries already present in the original survey response categories and were not selected based on the regression results.

- Owner age was grouped into young adults (under 33 years), middle-aged adults (33-56 years), and older adults (57 years and above). In the sample, these groups represent 42.98%, 42.22%, and 14.80% of respondents, respectively. The grouping therefore preserves a distinction between broad stages of adulthood while retaining a substantial number of observations even in the oldest category.
- Household income was grouped into lower-income (less than $60,000), middle-income ($60,000-$119,999), and higher-income ($120,000 or more) categories. These groups account for 50.16%, 32.35%, and 17.49% of the estimation sample, respectively. The thresholds correspond to boundaries in the original survey income categories and provide

interpretable comparisons across broad income levels. These labels describe relative income groups used in this analysis and are not intended as official definitions of low-, middle-, or high-income households.

- Education was consolidated into three broad attainment groups. The lowest education group represents 25.03% of the sample, the college-level group 57.97%, and the graduate-level group 17.00%. Collapsing the original education responses reduces the number of model parameters while retaining meaningful differences in educational attainment.
- Geographic location was treated differently because it follows an established geographic classification rather than a study-specific cutoff. Respondents' states of residence were classified into the four U.S. Census regions: South (39.71%), West (22.66%), Midwest (21.33%), and Northeast (16.30%). Owner gender was nearly evenly distributed, with 51.74% female and 48.26% male respondents.

The attribute-priority variables were also grouped to provide interpretable comparisons related to sorghum positioning. Rather than treating the original responses as an ordered numerical scale, the analysis identifies specific priorities of theoretical interest and groups the remaining responses into an "other" category. For health-related priorities, 28.75% of respondents prioritized digestive tract health, 11.04% prioritized weight control, and 60.21% were classified in the other category. For ingredient-related priorities, 6.89% prioritized non-GMO products, 5.60% prioritized avoidance of corn, soy, and wheat, and 87.51% were classified as other. For supply-chain priorities, 55.60% prioritized locally made products, 35.52% prioritized sustainability, and 8.88% were classified as other. These groupings isolate the consumer priorities most directly related to the hypothesized value propositions for sorghum while retaining the remaining preferences as a comparison group.

In addition to the consumer preference data, this study incorporates findings from a targeted survey of pet food producers. The objective of this survey was to assess industry professionals' awareness, perceptions, and use of sorghum as a plant-based ingredient in pet food formulations, with particular attention to its viability as a resource-efficient and sustainable input. The sampling frame consisted of pet food manufacturers operating within the United States. A target sample size of 100 was determined to be sufficient for statistical inference. The final response count exceeded expectations, yielding 167 usable surveys collected from two prominent industry events: KibbleCon2022 (50 responses) and the Petfood Forum2022 (117 responses). The survey was implemented by graduate and undergraduate students from Kansas State University's Pet Food Program and Department of Agricultural Economics. It was distributed both in hard-copy form and electronically through Qualtrics. The producer survey provides the industry-side component of the analysis and is used together with the consumer-choice results to evaluate alignment and disconnects between producer perceptions and consumer demand for sorghum (survey questionnaire is available in Appendix E).

4.3.3 Analytical Framework

The analytical framework operationalizes the conceptual framework using random utility theory (McFadden, 1972; Ben-Akiva & Lerman, 1985), which holds that consumers choose the alternative yielding the highest utility among a set of discrete options (Simonsen et al., 2014). Each respondent i faces a choice set C_t containing three grain alternatives in scenario t. The utility that respondent i receives from choosing grain j in choice set t is written as:

(4.1)

$$U_{ijt} = V_{ijt} + \varepsilon_{ijt}$$

where U_{ijt} is the latent utility from grain j, V_{ijt} is the observed component of utility (based on attributes and consumer characteristics), and ε_{ijt} is an unobserved random component. The observed component of utility is represented by an alternative-specific constant and the interaction of respondent characteristics and attitudes with each grain alternative. It can be written as:

(4.2)

$$\boldsymbol{V_{ijt} = \alpha_j + \beta_j Z_i + \varepsilon_{ijt}}$$

Where α_j is alternative-specific constant for grain j, β_j is a vector of alternative-specific coefficients, and Z_i is a vector of respondent characteristics and attitudes. Here, Z_i is a vector of respondent characteristics and attitudes, including owner age, education, income, gender, region, and priorities related to digestive health, weight control, non-GMO ingredients, sustainability, avoidance of corn, soy, and wheat, and local production. The coefficients β_j capture how these respondent characteristics and attitudes are associated with the relative utility of grain alternative j. The variable of primary interest is the relative probability of choosing sorghum compared with competing grains. Sorghum is used as the reference alternative in each model so that coefficients for the other grains can be interpreted as shifts in the log-odds of choosing those grains relative to sorghum.

For example, the log-odds of choosing rice over sorghum can be written as:

(4.3)

$$\ln \frac{P_{i,rice}}{P_{i,sorghum}} = \beta_{rice} + \sum_{m=1}^{6} \gamma_{rice,m} Z_{im}$$

Where:

$\frac{P_{i,rice}}{P_{i,sorghum}}$ is the odds ratio of choosing rice over the reference sorghum.

β_{rice} is the alternative-specific constant for rice.

Z_{im} are the independent variables.

$\gamma_{rice,m}$ are the estimated coefficients, which will indicate how the individual characteristics and attitudes affect the probability of choosing the non-reference grain.

Coefficients are estimated by maximum likelihood and capture how owner demographics and attitudes shift the relative probability of choosing each grain compared with the reference category, sorghum. Relative risk ratios, calculated as exp(β), provide a multiplicative interpretation of these effects on the odds of choosing a given grain relative to sorghum. Average marginal effects translate the estimates into marginal changes in the predicted probability of choosing each grain. Table 4.2 summarizes the descriptive statistics for the demographic variables and the three categorical attitude measures.

Table 4.2. Variable Descriptions

Variable	Description	Min.	Max.	Mean	Std. Dev.	Obs. (n)
US_Region	Northeast=1, Midwest=2, South=3, West=4	1	4	2.69	0.99	5,211
Owner_Age	Young adults (Under 33)=1, Middle-aged adults (33 to 56)=2, Older adults (57 and above)=3	1	3	1.72	0.71	5,211
Owner_Income	Low income (Less than $60,000)=1, Middle income ($60,000 to$119,999)=2, High income ($120,000 or more)=3	1	3	1.67	0.75	5,211

Owner_Education	High school diploma or some=1, College degree or some=2, Graduate degree or some=3	1	3	1.92	0.64	5,211
Health attitudes	Respondent's ranked health-related pet food attribute (digestive tract health=1, weight control=2, other=3)	1	3	2.31	0.89	5,074
Ingredient attitude	Respondent's ranked ingredient-related pet food attribute (non-GMO=1, no corn no soy no wheat=2, other=3)	1	3	2.81	0.54	5,074
Supply-chain attitude	Respondent's ranked supply-chain-related pet food attribute (locally made=1, sustainable=2, other=3)	1	3	1.53	0.65	5,074

Because the explanatory variables used in the multinomial logit models are categorical, Table 4.3 provides their category-level distributions and identifies the reference categories used for estimation.

Table 4.3. Distribution and Reference Categories for Estimation

Variable	Category	Frequency	Percent	Reference
Geographic region	Northeast	824	16.30	
	Midwest	1,078	21.33	Reference
	South	2,007	39.71	
	West	1,145	22.66	
Owner age	Young adults (under 33)	2,172	42.98	Reference
	Middle-aged adults (33-56)	2,134	42.22	
	Older adults (57 and above)	748	14.80	
Household income	Lower income (less than $60,000)	2,535	50.16	Reference

Variable	Category	Frequency	Percent	Reference
	Middle income ($60,000-$119,999)	1,635	32.35	
	Higher income ($120,000 or more)	884	17.49	
Education	High school diploma or some college	1,265	25.03	Reference
	College degree or some college	2,930	57.97	
	Graduate degree or some graduate education	859	17.00	
Owner gender	Male	2,439	48.26	Reference
	Female	2,615	51.74	
Health attitude	Other	3,043	60.21	Reference
	Digestive tract health	1,453	28.75	
	Weight control	558	11.04	
Ingredient attitude	Other	4,423	87.51	Reference
	Non-GMO	348	6.89	
	No corn, soy, or wheat	283	5.60	
Supply-chain attitude	Other	449	8.88	Reference
	Locally made	2,810	55.60	
	Sustainable	1,795	35.52	

4.3.4 Estimation Approach

The original BWS exercise generated both most- and least-preferred responses across seven choice tasks. However, this chapter does not estimate an aggregate BWS score using all best and worst responses. Instead, because the research question focuses specifically on sorghum's competitive position, the empirical analysis uses the most-preferred response from each of the three sorghum-containing choice tasks. Each retained task therefore produces a three-category discrete choice outcome.

The empirical analysis estimates three separate multinomial logit models, one for each grain-choice set. In each choice set, respondents selected one most-preferred and one least-preferred grain from three alternatives. The multinomial logit model uses only the most-preferred choice as the dependent variable. Therefore, for estimation, each respondent contributes one mutually exclusive most-preferred alternative within each choice set. Under the multinomial logit framework, the probability that respondent i chooses grain j from choice set C_t is:

(4.4)

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_{k \in C_t} e^{V_{ik}}} = \frac{e^{\beta_j X_i}}{\sum_{k \in C_t} e^{\beta_k X_i}}$$

The model is estimated by maximum likelihood. Sorghum is the reference alternative in all three models, so the coefficients for barley, rice, quinoa, corn, oat, and millet are interpreted relative to sorghum. For the explanatory variables, the omitted reference categories are Midwest for geographic region, young adults (under 33 years) for age, the lower-income group (less than $60,000) for household income, the lowest education group, and male for gender. The “other” category serves as the reference group for each of the health, ingredient, and supply-chain priority variables. Using “other” as the reference for the attribute-priority variables allows the estimated coefficients to show how respondents prioritizing digestive health, weight control, non-GMO products, corn/soy/wheat avoidance, local production, or sustainability differ from respondents prioritizing other attributes.

Sorghum is used as the outcome reference alternative because the primary research objective is to evaluate how competing grains perform relative to sorghum. The selection of reference categories determines the comparison used to interpret individual coefficients but does not change the model’s fitted choice probabilities or overall fit.

The estimated models are: MNL1, sorghum versus barley versus rice; MNL2, sorghum versus quinoa versus corn; and MNL3, sorghum versus oat versus millet. The multinomial logit model has several advantages for this application. First, it is grounded in random utility theory and is widely used to analyze discrete choices among multiple products or attributes (McFadden, 1972; Ben-Akiva & Lerman, 1985). Second, it produces coefficients, relative risk ratios, and marginal effects that are interpretable for marketing and product-positioning decisions. Third, it is consistent with previous applications in food and agricultural product choice, including studies of meat and other agricultural products (Mennecke et al., 2007; Nilsson et al., 2006), pet-food preferences (Simonsen et al., 2014), and sorghum-related decisions (Musara et al., 2018). Pina and Díaz Delfa (2005) used a multinomial logit model to examine how tourist characteristics were associated with the choice among different types of rural accommodation. Similarly, Kohansal and Firoozzare (2013) used a multinomial logit model to examine how socioeconomic characteristics influenced consumers' primary food-purchasing priorities, such as healthiness, price, and taste. These applications are comparable to the present study because the MNL framework is used here to relate respondent characteristics and attitudes to choice among alternative grains. The model also has limitations. The multinomial logit assumes independently and identically distributed error terms, which implies the independence of irrelevant alternatives property. This assumption may be restrictive if respondents view some grains as closer substitutes than others, such as quinoa and millet within an ancient-grain category. The analysis also relies on stated preferences rather than observed market purchases.

Despite these limitations, the estimation approach is well suited to the chapter's research questions. It directly measures sorghum's relative position within each competitive set and identifies owner segments for which sorghum is more or less attractive. Reporting both relative risk ratios and average marginal effects allows the discussion to connect statistical results to practical product and marketing implications.

4.4 Result & Discussion

This section presents evidence from both the consumer grain-choice analysis and the producer survey. The discussion proceeds in four steps. First, the descriptive consumer-choice patterns establish sorghum's competitive position relative to alternative grains. Second, the relative risk ratios and average marginal effects identify the owner characteristics and attitudes associated with choosing sorghum rather than its competitors. Third, descriptive results from the producer survey summarize current industry use of sorghum, perceptions of its advantages and limitations, expectations about future demand, and interest in learning more about the ingredient. Finally, the consumer and producer findings are compared to identify areas of agreement and disconnect between industry perceptions and consumer demand.

The descriptive results in Figure 4.1 show that sorghum is not the leading ingredient in any comparison set. Rice dominates the sorghum-rice-barley set, quinoa and corn both exceed sorghum in the sorghum-quinoa-corn set, and oat dominates the sorghum-oat-millet set. This answers the first research question by showing that sorghum is currently a niche ingredient from the perspective of most dog owners. The gap is especially important because sorghum is technically suitable for pet-food formulations, but the descriptive results indicate that technical suitability alone does not generate consumer preference.

4.4.1 Consumer Grain-Choice Results

Tables 4.4-4.6 report the relative risk ratios from the three multinomial logit models. A relative risk ratio greater than one indicates that the variable increases the likelihood of choosing the listed alternative rather than sorghum. The intercept RRRs represent the baseline relative likelihood of choosing each competing grain rather than sorghum for respondents in all reference categories. For example, in MNL1, the intercept RRR of 4.324 for barley indicates that the baseline relative likelihood of choosing barley rather than sorghum is 4.324 times as large, while the intercept RRR of 9.455 for rice indicates that the baseline relative likelihood of choosing rice rather than sorghum is 9.455 times as large. Full marginal effects are reported in Appendix Tables F.1-F.3. The discussion below reports selected AMEs.

Table 4.4. Multinomial Logit Estimation/ Relative Risk Ratios, MNL1

Variable	Barley coef. (SE)	Barley RRR	Rice coef. (SE)	Rice RRR
Intercept	**1.4643***** (0.289)	4.324	**2.2466***** (0.278)	9.455
Northeast (vs Midwest)	0.0146 (0.190)	1.015	-0.0342 (0.182)	0.966
South (vs Midwest)	-0.1400 (0.155)	0.869	-0.0964 (0.148)	0.908
West (vs Midwest)	0.0095 (0.171)	1.010	-0.1846 (0.165)	0.831
College degree or some (vs HS/some)	-0.0988 (0.141)	0.906	-0.1739 (0.134)	0.840
Graduate degree or some (vs HS/some)	-0.1382 (0.186)	0.871	**-0.4193**** (0.178)	0.657
High income ≥$120k (vs < $60k)	-0.1912 (0.162)	0.826	-0.1295 (0.154)	0.879
Middle income $60-119k (vs < $60k)	-0.0300 (0.133)	0.970	-0.0431 (0.127)	0.958
Age 33–56 (vs <33)	**0.5577***** (0.126)	1.747	**0.3473***** (0.121)	1.415
Age ≥57 (vs <33)	**0.7360***** (0.200)	2.088	**0.5359***** (0.194)	1.709

Digestive tract health (vs other)	0.1638 (0.132)	1.178	**0.2282*** (0.127)	1.256
Weight control (vs other)	**0.4092**** (0.205)	1.506	**0.3769*** (0.200)	1.458
No corn/soy/wheat (vs other)	-0.3393 (0.229)	0.712	**-0.4117*** (0.220)	0.663
Non-GMO (vs other)	-0.1243 (0.206)	0.883	-0.2826 (0.198)	0.754
Locally made (vs other)	-0.2247 (0.231)	0.799	-0.2676 (0.223)	0.765
Sustainable (vs other)	-0.3374 (0.239)	0.714	**-0.4970**** (0.230)	0.608
Gender (female=1)	0.1163 (0.114)	1.123	**0.3165***** (0.109)	1.372
No. Observations	5,054			
Pseudo R-squared	0.01128			
Log-Likelihood	-4386.0			

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10 (Standard error in parentheses)*

Table 4.5. Multinomial Logit Estimation/ Relative Risk Ratios, MNL2

Variable	Quinoa coef. (SE)	Quinoa RRR	Corn coef. (SE)	Corn RRR
Intercept	0.2942 (0.204)	1.342	**0.9645***** (0.208)	2.623
Northeast (vs Midwest)	**0.2352*** (0.141)	1.265	0.0867 (0.142)	1.091
South (vs Midwest)	0.1463 (0.114)	1.158	0.0912 (0.114)	1.096
West (vs Midwest)	**0.3055**** (0.128)	1.357	0.0071 (0.131)	1.007
College degree or some (vs HS/some)	**0.2629**** (0.108)	1.301	-0.1212 (0.105)	0.886
Graduate degree or some (vs HS/some)	0.2072 (0.146)	1.230	**-0.3477**** (0.147)	0.706
High income ≥$120k (vs < $60k)	0.1623 (0.130)	1.176	-0.0326 (0.133)	0.968
Middle income $60-119k (vs < $60k)	0.0318 (0.101)	1.032	-0.0597 (0.101)	0.942
Age 33-56 (vs <33)	**0.3338***** (0.097)	1.396	**0.2158**** (0.098)	1.241
Age ≥57 (vs <33)	**0.3573**** (0.139)	1.429	0.1670 (0.143)	1.182
Digestive tract health (vs other)	0.1438 (0.100)	1.155	**0.1710*** (0.101)	1.187

Weight control (vs other)	0.1386 (0.149)	1.149	**0.3282**** (0.148)	1.388
No corn/soy/wheat (vs other)	**-0.3524**** (0.162)	0.703	**-0.9861***** (0.184)	0.373
Non-GMO (vs other)	-0.0243 (0.171)	0.976	-0.0278 (0.170)	0.972
Locally made (vs other)	0.0121 (0.159)	1.012	0.0213 (0.165)	1.022
Sustainable (vs other)	-0.2296 (0.167)	0.795	0.0169 (0.172)	1.017
Gender (female=1)	**0.5850***** (0.087)	1.795	-0.0126 (0.088)	0.987
No. Observations	5,054			
Pseudo R-squared	0.02578			
Log-Likelihood	-4950.0			

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10 (Standard error in parentheses)*

Table 4.6. Multinomial Logit Estimation/ Relative Risk Ratios, MNL3

Variable	Oat coef. (SE)	Oat RRR	Millet coef. (SE)	Millet RRR
Intercept	**1.5399***** (0.211)	4.664	**0.4588*** (0.242)	1.582
Northeast (vs Midwest)	-0.0143 (0.146)	0.986	**0.3848**** (0.168)	1.469
South (vs Midwest)	0.0179 (0.120)	1.018	**0.2742*** (0.140)	1.316
West (vs Midwest)	-0.0636 (0.133)	0.938	**0.2956*** (0.154)	1.344
College degree or some (vs HS/some)	-0.1535 (0.114)	0.858	-0.1956 (0.129)	0.822
Graduate degree or some (vs HS/some)	**-0.3898**** (0.152)	0.677	**-0.4738***** (0.171)	0.623
High income ≥$120k (vs < $60k)	**-0.3162**** (0.130)	0.729	-0.1500 (0.147)	0.861
Middle income $60-119k (vs < $60k)	-0.0197 (0.106)	0.980	-0.0452 (0.121)	0.956
Age 33-56 (vs <33)	**0.3205***** (0.100)	1.378	0.1289 (0.115)	1.138
Age ≥57 (vs <33)	**0.3788**** (0.147)	1.461	0.2081 (0.167)	1.231
Digestive tract health (vs other)	**0.2466**** (0.104)	1.280	0.1094 (0.118)	1.116
Weight control (vs other)	**0.3328**** (0.156)	1.395	0.0908 (0.179)	1.095

No corn/soy/wheat (vs other)	-0.2399 (0.191)	0.787	-0.0288 (0.216)	0.972
Non-GMO (vs other)	-0.1572 (0.169)	0.855	-0.1110 (0.192)	0.895
Locally made (vs other)	0.1421 (0.161)	1.153	0.0407 (0.185)	1.042
Sustainable (vs other)	-0.0690 (0.168)	0.933	0.2471 (0.191)	1.280
Gender (female=1)	**0.1755*** (0.090)	1.192	-0.1338 (0.103)	0.875
No. Observations	5,054			
Pseudo R-squared	0.01680			
Log-Likelihood	-4286.2			

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10 (Standard error in parentheses)*

Age is one of the most consistent correlates. Relative to respondents younger than 33, those aged 33-56 have a lower predicted probability of choosing sorghum in all three models. Respondents aged 57 or older show the same pattern. The largest offsetting increases occur for barley in the first model, quinoa in the second, and oat in the third. The results indicate that younger respondents are relatively more receptive to sorghum within these choice sets. In parallel, AMEs show that being 33-56 reduces the probability of choosing sorghum by about 3% and raises the probability of choosing barley by 5.6% (MNL1). In MNL2, AMEs show that being 33-56 reduces the probability of choosing sorghum by about 3% and raises the probability of choosing quinoa by 4.2%.

Gender effects are concentrated in particular alternatives. Female respondents have a lower probability of choosing sorghum in the first two models and higher probabilities of choosing rice and quinoa. In marginal terms, females are about 5.3% more likely to choose rice and 14.1% more likely to choose quinoa, and 3.6% less likely to choose sorghum (MNL2). In contrast, males have relatively higher sorghum preference. These gender effects align with prior observations that grain-free pet-food consumers tend to be female and diet-conscious (Banton, 2021).

Education effects vary by set. Graduate education is associated with a higher probability of choosing sorghum in the first and third models and with lower relative risks for rice, corn, oat, and millet. At the same time, college and graduate education increase the probability of choosing quinoa in the second model. Higher education therefore appears to shift respondents away from some conventional grains, but the destination is not always sorghum.

Regional differences are specific. Relative to the Midwest (reference), respondents in the Northeast and West show higher odds of choosing quinoa or millet over sorghum, while Southerners favor millet most. For instance, Northeastern owners have an RRR=1.27 for quinoa and 1.47 for millet; Western owners likewise have RRR=1.36 (quinoa) and 1.34 (millet). South vs. Midwest yields only RRR=1.32 for millet. The AMEs mirror these trends: Northeast and West each show significant positive marginal effects for quinoa and millet (and negative for oat). Overall, residents outside the Midwest show a mild tendency to prefer novelty grains (quinoa, millet) to sorghum.

In terms of attitudinal variables, health and ingredient attitudes strongly influence grain choice. Owners citing digestive health as their primary concern are significantly more inclined toward rice, corn, and oat over sorghum. The MNL results give RRRs =1.256 for rice, 1.187 for corn, and 1.280 for oat. Corresponding AMEs show that these owners have about 2.2% lower probability of choosing sorghum (MNL3) and 3.85% higher for oat. In brief, owners focused on digestive health tend to avoid sorghum and prefer grains they view as easier to digest. The reason could be that they have no information about the digestibility of sorghum in pet food. Similarly, concern with weight control predicts avoidance of sorghum. Owners who feed for weight control have RRRs =1.506 for barley, 1.458 for rice, 1.388 for corn, and 1.395 for oat. That is, they are 39-51% more likely to choose those grains instead of sorghum. The marginal effects again show a significant drop in sorghum probability (about 3% in all 3 models) and strong increases for corn (5.23%) and oat (6.01%). These results indicate that respondents who prioritize digestive health or weight control do not currently associate sorghum strongly enough with those benefits to choose it over the listed alternatives.

An especially influential attitude is avoiding corn/soy/wheat. In the sorghum-quinoa-corn set, this priority reduces the probability of choosing corn by 16.8 percentage points and increases the probabilities of choosing sorghum and quinoa by approximately 8.1 and 8.8 percentage points, respectively. The effect on sorghum is smaller and only marginally significant in the first model and is not significant in the third. Thus, corn/soy/wheat avoidance creates an opportunity for sorghum primarily when the competing set contains corn, but sorghum shares that opportunity with quinoa.

Sustainability attitudes provide only conditional support for sorghum positioning. In the barley-rice-sorghum choice set, sustainability concern increases the predicted probability of choosing sorghum and reduces the relative likelihood of choosing rice. However, this pattern does not hold consistently in the quinoa-corn or oat-millet choice sets. This suggests that sustainability may help sorghum compete against some traditional grains, but less so against grains such as quinoa, oat, or millet that may already carry natural or premium associations.

Overall, the results suggest that sorghum's weak position is partly a problem of consumer association. This is an inference from the pattern of choices, not a direct measure of familiarity or knowledge. Sorghum appears most promising among younger respondents, some graduate-educated and high-income segments, respondents prioritizing sustainability in the rice-barley comparison, and respondents avoiding corn/soy/wheat when corn is present. Marketing claims related to digestive health or weight control would require evidence and communication strong enough to overcome existing associations with more familiar grains.

4.4.2 Consumer Perceptions and Information Interest Regarding Sorghum

Following the grain-choice exercise, respondents were asked additional questions about their perceptions of sorghum and their interest in learning more about the ingredient. These questions provide additional context for understanding sorghum's relatively weak performance in the grain-choice sets.

Current perceptions of sorghum were relatively modest. Among the 5,054 respondents who answered the question, 40.96% considered sorghum not important as a pet food or treat ingredient and 41.21% considered it somewhat important. Only 13.47% considered it important and 4.35% considered it extremely important. Thus, only about 17.8% of respondents currently viewed sorghum as an important or extremely important pet food ingredient.

Respondents were somewhat more positive about sorghum's future role. Among 5,032 respondents, 22.12% expected the importance of sorghum in pet food or treats to increase, while 68.04% expected it to remain the same and 9.84% expected it to decrease. This suggests that although sorghum does not currently have a strong perceived position among most consumers, expectations of future growth are more positive than negative.

The survey also provides evidence of consumer receptivity to additional information about sorghum. Approximately 25.40% of respondents were not interested in learning more, while 43.92% were somewhat interested, 21.28% were interested, and 9.40% were extremely interested. Therefore, nearly three-quarters of respondents (74.60%) expressed at least some interest in learning more about sorghum, including 30.68% who were interested or extremely interested. This distinction is important because sorghum's low current preference does not necessarily indicate complete consumer rejection. Rather, the results suggest an opportunity for consumer education and communication about the ingredient.

4.4.3 Producer Survey Descriptive Results

The producer survey provides complementary evidence on how pet food industry professionals view sorghum from a formulation and market perspective. The survey included 167 respondents representing different parts of the pet food industry. Approximately 46.49% represented businesses involved in pet food or treat manufacturing, marketing, research and development, or formulation; 37.30% represented ingredient suppliers and nutrition or formulation consultants; and 8.11% represented equipment, processing service, or food engineering businesses. Research and development, formulation, and consulting positions accounted for 40.54% of respondents, followed by marketing and sales at 24.32% and corporate or general management at 15.14%.

The results show that sorghum has a more limited current industry presence than several competing plant-based ingredients. Corn or corn protein was used by 39.77% of respondents, followed by rice at 39.18%, soy or soy protein at 37.43%, oats at 35.67%, potato at 35.09%, wheat at 33.33%, sweet potato at 30.99%, barley at 29.82%, chickpea at 29.24%, and tapioca at 23.98%. Sorghum was identified as a currently used pet food or treat ingredient by 20.47% of respondents, placing it thirteenth among the plant-based ingredients included in the survey. Because respondents could select multiple ingredients, these percentages represent the proportion using each ingredient and do not sum to 100%.

Despite its relatively limited current use, producer perceptions of sorghum were moderately favorable. Approximately 34% of respondents considered sorghum an important pet food ingredient, and an additional 8% considered it extremely important. Another 36% viewed it as somewhat important, while 22% considered it unimportant.

The most frequently identified advantages of sorghum were availability or consistent supply, selected by 38.60% of respondents; relatively low price or cost, selected by 36.84%; and U.S. production, selected by 29.24%. Respondents also recognized technical food properties, low water use, potential wellness benefits, and ease of handling. These findings indicate that industry professionals primarily recognize sorghum through supply, cost, sourcing, and formulation characteristics rather than through a single dominant consumer-facing health benefit.

At the same time, the leading perceived limitations were directly related to market acceptance. Low customer demand was selected by 38.01% of respondents, negative customer perception by 25.15%, and taste or flavor by 18.13%. Respondents who considered sorghum important were more likely to identify availability, U.S. production, ease of handling, and positive customer perception as advantages. In contrast, respondents who considered it unimportant most frequently identified low customer demand, negative customer perception, and taste or flavor as constraints.

4.4.4 Integrating Consumer and Producer Evidence: Market Alignment and Gaps

Integrating the consumer and producer evidence provides the central market insight of this chapter. The two surveys examine sorghum from different sides of the pet food market: producers evaluate the ingredient from formulation, sourcing, cost, and market perspectives, while consumers reveal how sorghum performs relative to competing grains. Examining these perspectives together helps distinguish technical and supply-side advantages from the characteristics that currently generate consumer demand. The consumer and producer results provide a consistent explanation for sorghum's current market position. On the supply side, sorghum is recognized by industry professionals for availability, cost, U.S. production, and other technical or sustainability-related characteristics. However, only 20.47% of producer-survey respondents reported currently using it, and low customer demand and negative customer perception were identified as its two leading constraints. On the demand side, sorghum was not the leading consumer choice in any of the three grain comparison sets.

The producer finding that low customer demand is the leading constraint is supported by the consumer-choice results. Consumers generally preferred rice, quinoa, corn, or oat to sorghum, depending on the comparison set. This provides direct demand-side evidence for the concern expressed by industry respondents. The producer perception that negative customer attitudes constrain sorghum also corresponds with the finding that respondents prioritizing digestive health or weight control were less likely to choose sorghum. Consumers may not currently connect sorghum with these health outcomes, even though producers and previous technical research identify potential nutritional or functional benefits.

The results also reveal a disconnect between the advantages emphasized by producers and the attributes that influence consumer choice. Producers most frequently identified availability, low price, and U.S. production as sorghum's advantages. Availability and ingredient cost are important to manufacturers, but they are not necessarily benefits that consumers observe directly when selecting pet food.

The consumer analysis helps identify where targeted market development may be most promising. Younger respondents were more receptive to sorghum than older respondents. Some graduate-educated and high-income groups also showed greater openness in particular comparison sets. Avoidance of corn, soy, or wheat created a clear opportunity when corn was present, although quinoa benefited similarly.

The combined findings also indicate that digestive health and weight control positioning requires caution. Producer respondents acknowledged potential health and wellness benefits, but consumers who prioritized digestive health or weight control were generally less likely to select sorghum. This mismatch suggests that technical evidence alone has not created a recognized consumer benefit. Health-related claims should therefore be supported by appropriate nutritional evidence and communicated in language that clearly explains sorghum's function in the product. Firms should not assume that consumers will infer digestive health or weight management benefits simply from seeing sorghum in an ingredient list.

4.5 Conclusion

This chapter examined consumer preferences for sorghum relative to rice, barley, quinoa, corn, oat, and millet and complemented the consumer-choice analysis with descriptive evidence from a survey of pet food industry professionals. Three multinomial logit models were estimated with sorghum as the reference alternative, and the results were interpreted using relative risk ratios and average marginal effects.

4.5.1 Main Findings

The primary finding of this chapter comes from considering the consumer and producer evidence together. Producers recognize several technical and supply-side advantages of sorghum, including availability, cost, and U.S. production, but they also identify weak customer demand

and negative consumer perception as major barriers. The consumer-choice results provide direct demand-side evidence consistent with these concerns: sorghum is not the leading choice in any of the three competitive grain sets. Together, the findings show that expanding sorghum use in pet food requires not only technical feasibility and producer adoption but also stronger consumer recognition and demand.

Age is the most consistent demographic correlate of sorghum choice. Respondents aged 33-56 and those aged 57 or older are generally less likely than respondents younger than 33 to choose sorghum. Younger consumers therefore appear relatively more receptive to sorghum within the choice sets examined. Gender, education, income, and region also matter, but their effects depend on the competing grains. Female respondents show stronger preferences for rice and quinoa relative to sorghum and a more limited preference for oat in the third model. Graduate education increases openness to sorghum in some comparisons, particularly against rice, oat, and millet, but higher education also increases preference for quinoa in the second choice set. High income similarly increases relative openness to sorghum in selected comparisons.

The attitudinal results reveal an important consumer-perception barrier. Respondents who prioritize digestive health or weight control are generally less likely to choose sorghum and more likely to favor rice, corn, barley, or oat. These findings do not directly establish why health-focused consumers avoid sorghum, because the survey does not measure their knowledge of sorghum's nutritional properties. However, the pattern suggests that sorghum is not currently associated strongly enough with digestive health or weight control benefits to compete with more familiar grains.

Avoidance of corn, soy, or wheat creates a more specific opportunity. In the sorghum-quinoa-corn set, this priority substantially reduces the probability of selecting corn and increases the probabilities of selecting both sorghum and quinoa. Sorghum therefore benefits when corn is the direct competitor, but it does not capture the entire market opportunity because quinoa gains by a similar amount. Sustainability also supports sorghum only conditionally. It increases sorghum preference in the rice-barley comparison but does not provide a consistent advantage against quinoa, corn, oat, or millet. Sorghum's value proposition therefore depends on both the competing ingredient and the consumer benefit being emphasized.

The producer survey provides complementary evidence on sorghum's current industry position. Only 20.47% of respondents reported currently using sorghum, placing it thirteenth among the listed plant-based ingredients. Its most frequently identified advantages were availability or consistent supply, relatively low price, and U.S. production. In contrast, the leading constraints were low customer demand, negative customer perception, and taste or flavor.

The consumer and producer findings are therefore broadly consistent. Producers recognize sorghum's supply, cost, sourcing, and technical advantages but identify weak customer demand and negative consumer perception as major barriers. Consumer results support this concern because sorghum is not the leading choice in any comparison set and is particularly weak among respondents prioritizing digestive health or weight control. Together, the findings indicate that sorghum's limited market position is not solely a technical formulation problem. It is also a demand-creation and communication problem.

The comparison also reveals a disconnect between producer-oriented and consumer-oriented value propositions. Availability and ingredient cost are economically important to manufacturers, but consumers may not directly observe these advantages. U.S. production and sustainability may be more suitable for consumer communication, although the consumer models show that sustainability is effective only in selected competitive contexts.

Health-related positioning requires particular caution. Digestive health and weight control claims should be supported by appropriate nutritional, feeding, and palatability evidence and should clearly explain the role sorghum performs in the product. The results do not support relying on the ingredient name alone to communicate these benefits. Pet food manufacturers, ingredient suppliers, and sorghum organizations may need to coordinate product development, technical testing, and consumer education to translate sorghum's production advantages into benefits that consumers understand.

This chapter contributes to the literature by evaluating sorghum relative to specific competing grains rather than treating all grain-inclusive foods as a single category. It also combines consumer and producer perspectives, showing that market development depends on alignment between technical feasibility, manufacturer willingness to adopt the ingredient, and consumer willingness to select products containing it.

4.5.2 Limitations

The first limitation is that the consumer analysis measures stated grain preferences rather than observed product purchases. Respondents selected ingredients in hypothetical choice situations, but they did not spend their own money or choose among actual pet food products. A respondent may select sorghum in a survey while purchasing a different product when faced with price or the dog's taste of the food.

Second, the grain-choice tasks are intentionally simplified. Respondents choose among ingredient names without information about price, nutritional composition, health claims, or feeding benefits. The analysis also uses only part of the information generated by the original BWS exercise. Although respondents completed seven BWS tasks and identified both their most- and least-preferred ingredients in each task, the Chapter 4 econometric analysis focuses only on the most-preferred responses from the three tasks containing sorghum. This restriction is consistent with the chapter's sorghum-specific research objective, but it does not use the full preference information available from the BWS design. Consequently, the results should be interpreted as sorghum's relative position within these three specific competitive choice sets rather than as a complete ranking of all seven ingredients.

Third, the data are cross-sectional. The estimated relationships cannot establish that age, education, income, sustainability concern, or ingredient avoidance causes consumers to choose or reject sorghum. These variables may be correlated with unobserved factors such as shopping experience, dietary beliefs, or brand loyalty.

The producer survey also has limitations. Respondents were recruited at KibbleCon and Petfood Forum rather than selected through a probability sample of all U.S. pet food companies. Also, the consumer and producer datasets are separate and cannot be linked at the respondent, firm, product, or market level.

4.5.3 Further Research

Future research should incorporate sorghum into a more complete discrete-choice experiment. Product alternatives could vary simultaneously in grain ingredient, price, brand, product form, and nutritional information. This would allow researchers to estimate consumers' willingness to pay for sorghum and determine whether its value changes when it is accompanied by specific product claims.

The experimental design should include broader and more varied choice sets, a no-purchase or no-preference option, and randomized placement of ingredients. Randomizing the competitors, order, and presentation of sorghum would help identify whether the current results are affected by choice-set position.

Future studies should also use observed purchase behavior. Retailer scanner data or online transaction records could determine whether stated openness to sorghum translates into actual demand.

Future surveys should directly measure familiarity, knowledge, and beliefs about sorghum. Respondents could be asked whether they have previously seen or purchased pet food containing sorghum, whether they recognize it as a grain, and what they believe about its digestibility, nutrition, and taste.

Future producer research should use a larger and more systematically selected sample of manufacturers and retailers. Producer surveys should also collect more detailed measures of commercial adoption, including the number of sorghum containing products.

Finally, future research should directly connect consumer demand with producer adoption. One approach would be to conduct coordinated studies in which firms introduce sorghum formulations while researchers measure consumer response.

Chapter 5 - Conclusion

This dissertation set out to generate research-based insight on how pet food products are evaluated, selected, and used in ways that matter for business strategy and, in some cases, for animal health outcomes. Across the three essays, a consistent pattern emerges: success in the pet food market depends not only on technical product quality, but also on whether product attributes are translated into choices and behaviors that survive real-world consumer constraints. Put differently, the dissertation shows that the most important problems in pet food economics and management are often problems of alignment: alignment between feeding behavior and healthy body condition, between stated preferences and purchased products, and between ingredient potential and consumer acceptance.

The first essay shows that canine weight deviation is associated with a combination of owner behavior, pet characteristics, and product-related factors. Caloric intake, age, reproductive status, feeding practices, and other dog and product characteristics are associated with NWD, with several relationships differing across the conditional weight-deviation distribution. These findings demonstrate the value of examining different points of the distribution rather than relying only on average relationships. The second essay shows that even when owners express strong preferences for health, ingredient quality, processing style, or supply-chain attributes, those priorities do not always appear in the products they actually purchase. The third essay reinforces this point from a different angle: sorghum may offer technical and sustainability advantages, but those advantages do not automatically create demand when consumers remain more comfortable with familiar grains or do not associate sorghum with the benefits they value most.

These findings have several implications. For product developers and manufacturers, the dissertation suggests that innovation should be evaluated not only for nutritional or functional merit, but also for fit with buyer interpretation, shopping constraints, and downstream use. For marketers and retailers, the evidence indicates that communication matters most when it reduces decision friction, clarifies relevance, and helps owners act on intentions they already claim to hold. For veterinarians and animal-health professionals, the obesity chapter underscores the continuing importance of feeding guidance, owner education, and targeted intervention for higher-risk dogs. For researchers and policy-oriented stakeholders, the dissertation illustrates the value of integrating economic reasoning with product-level and owner-level data rather than treating pet nutrition, consumer behavior, and market strategy as separate domains.

At the same time, the dissertation has important limitations. Much of the empirical evidence is cross-sectional, which means the results should be interpreted as strong associations and structured patterns rather than definitive causal effects. For instance, chapter 4 is based on stated choice among limited ingredient sets and does not directly incorporate full market signals such as brand, packaging, or price in every choice context. These limitations do not weaken the core contribution of the dissertation, but they do define the boundaries within which the findings should be interpreted.

Future research can build on this dissertation in several directions. Longitudinal and experimental designs would strengthen causal inference on feeding behavior, obesity management, and attribute choice. Broader retail coverage would improve the study of preference-purchase alignment by capturing offline channels, brand portfolios, and stock availability. Ingredient-focused work should combine demand-side experiments with supply-side adoption analysis so that promising inputs such as sorghum can be evaluated as part of a full value-chain problem rather than as isolated technical substitutes. More generally, future studies should continue to examine not only what pet owners say they want, but also when they follow through, why they do not, and how firms can narrow that gap in ways that improve both market performance and pet well-being.

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Appendix A - Pet Food Ingredient Consumer Perception Survey

Thank you for your participation in this survey. The purpose is to gain improved understanding of pet food industry members' perceptions about sorghum as an ingredient in pet food. Participation in the survey is voluntary. You may discontinue at any time without penalty. For questions or concerns, please contact Dr. Greg Aldrich at aldrich4@ksu.edu .

1. Do you have a dog?
    a. Yes
    b. No

<u>Owner Demographics (6 questions)</u>

2. Please specify your gender.
    a. Male
    b. Female
    c. Other

3. Please indicate your age.
    a. Under 20 years
    b. 21 - 24 years
    c. 25 - 32 years
    d. 33 - 40 years
    e. 41 - 48 years
    f. 49 - 56 years
    g. 57 - 64 years
    h. 65 - 75 years
    i. Above 75 years

4. Which category best describes your household annual income level?
    a. Less than $20,000
    b. $20,000 - $40,999
    c. $41,000 - $59,999
    d. $60,000 - $85,999
    e. $86,000 - $99,999
    f. $100,000 - $119,999
    g. $120,000 - $139,999
    h. $140,000 - $164,999
    i. $165,000 or more

5. Please indicate your highest level of education.
    a. Some high school
    b. High school diploma

c. Some college or trade
d. College degree
e. Some graduate education
f. Graduate degree or equivalent

6. In which state do you currently reside? (Use the dropdown below to select your state)
   **this question has a drop down menu*

7. Please enter your current zip code in the space provided below.

   ____

Pet Characteristics (7 questions)

Now, we would love to know more about your pet.

8. How many dogs do you have? ▼ 1 **this question has a drop down menu*

To answer the remaining survey questions, please refer to the dog with the name closest to the beginning of the alphabet to answer the remaining questions in this survey.
(e.g. if your dog's names are Aaron and Donald, please answer the remaining questions in reference to Aaron)

9. What is your dog's name? ________________________________

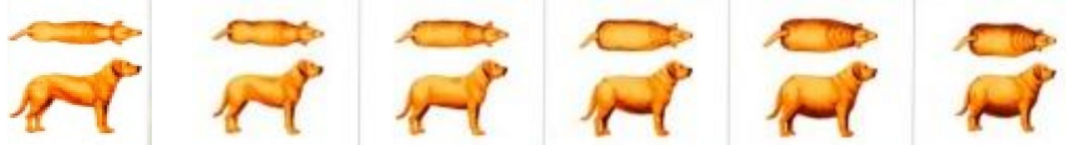
10. What is your dog's breed? ________________________________

11. What is your dog's weight? (Specify in lbs.) If you are uncertain, it is ok to provide a ballpark estimate. ▼ 1 **this question has a drop down menu*

12. What is your dog's sex and reproductive status?
    a. Male - intact
    b. Male - neutered
    c. Female - intact
    d. Female - spayed

13. Please specify your dog's age in the text box below. Specify in years AND months (e.g. 1 year and 5 months).
    Years ▼ 1 **this question has a drop down menu*
    Months ▼ 1 **this question has a drop down menu*

14. Based on the pictures provided below, please select the body condition that best matches the condition of your dog.



1	2	3	4	5	6

Current Pet Food Feeding Habits (7 questions)

15. Does your dog have any food allergies?
    a. Yes
    b. No

    If "Yes", please specify the type of ingredients identified as the allergies:

    1) ______________________________ 4) ______________________________

    2) ______________________________ 5) ______________________________

    3) ______________________________

16. Describe your dog's primary food type.
    a. Dry kibbles (croquettes)
    b. Wet food (canned, pouch, or tray)
    c. Fresh (cooked) food (commercial or home prepared)
    d. Raw food (commercial or home prepared)
    e. Other ____

17. How many times per day do you feed your dog's primary food? (snacks and treats not included)
    a. Once
    b. Twice
    c. Three times
    d. Four times
    e. Free feed (constant access)

18. How do you decide the amount of food given to your dog per feeding?
    a. Feeding guidelines found on the package label
    b. Veterinarian recommendation
    c. Decide based on animal cues (begging, signs of hunger, etc.)
    d. Decide based on animal body condition or weight
    e. Decide on how much feels just about right

19. Please specify the amount of food you give your dog per feeding. Feel free to use EITHER grams or ounces, which ever you feel more comfortable with. If you are uncertain, it is ok to provide a ballpark estimate.

Amount in Grams ▼ 1 *this question has a drop down menu*

OR Amount in Ounces ▼ 1 *this question has a drop down menu*

20. Please specify the brand name, product name, and formulation type of your dog's **primary foods** in the space provided below. (e.g. Blue Buffalo, Life protection, chicken and rice recipe)

Primary Food 1:

Brand Name ______________

Product Name _____________

Flavor/Formulation Type______

Primary Food 2 (if applicable):

Brand Name ______________

Product Name _____________

Flavor/Formulation Type_____

21. What is your average monthly expense for pet **food**? $ __________*this question has a drop down menu*

22. What type of **treats** do you feed your dog? (Select all that apply)
    a. Crunchy baked treats
    b. Soft-moist treats
    c. Jerky
    d. Dental treats
    e. Animal parts (bones, hooves, ears, pizzles, etc.)
    f. Rawhides
    g. Table scraps
    h. Other (Please specify): ___________________________

23. Please specify the brand name, product name, and treat size of your dog's **treats** in the space provided below. (e.g. Purina, Busy Bone, Medium)

Treat 1:

Brand Name ______________

Product Name _____________

Flavor/Formulation Type______

Treat2 (if applicable):

Brand Name ______________

Product Name _____________

Flavor/Formulation Type______

Treat 3 (if applicable):

Brand Name ______________

Product Name _____________

Flavor/Formulation Type______

24. What is your average monthly expense for pet **treats**? $ _________*this question has a drop down menu*

25. How many times per day do you give your dog treats?

▼ 1 **this question has a drop down menu*

26. Please specify the amount of treats (in pieces) you give your dog per occasion. If you are uncertain, it is ok to provide a ball park estimate.

Amount in units (pieces) ▼ 1 **this question has a drop down menu*

Current Exercise Habits (3 questions)

27. First, let's think about your dog's low intensity activities (e.g. walk). Please specify below the number of times per week that your dog participates in a low intensity activity and the duration per occasion.

    # of times per week ▼ 1 *this question has a drop down menu*

    Duration per time/activity (in minutes) ▼ 1 *this question has a drop down menu*

28. Next, let's think about your dog's **medium intensity** activities (e.g. play fetch or other organized activity). Please specify below the number of times per week that your dog participates in a **medium intensity** activity and the duration per occasion.

    # of times per week ▼ 1 *this question has a drop down menu*

    Duration per time/activity (in minutes) ▼ 1 *this question has a drop down menu*

29. Now, let's think about your dog's **high intensity** activities (e.g. run, jog). Please specify below the number of times per week that your dog participates in a **high intensity** activity and the duration per occasion.

    # of times per week ▼ 1 *this question has a drop down menu*

    Duration per time/activity (in minutes) ▼ 1 *this question has a drop down menu*

30. Where does your dog spend majority of its time during the day?
    a. Exclusively indoors
    b. Mostly indoors
    c. Equal amounts indoors and outdoors
    d. Mostly outdoors
    e. Exclusively outdoors

Current Pet Food Buying Habits (3 questions)

31. What statement best describes your role in purchasing food for your dog?
    a. I do all the food purchasing.
    b. I share responsibility with someone else.
    c. I do not participate in any of the food purchasing.

32. If you have to choose between two products/ brands, which criteria are most preferred to you? (Rank them from 1 to 3 based on preference.)

   a. Price ▼---- *this question has a drop down menu*
   b. Ingredients ▼----
   c. Attributes/ Claims ▼----

33. Considering attributes/claims, of the following four categories (Health, Ingredient, Processing, and Supply Chain), please rank the top three important attributes for each category. (1 is the most important and 3 is the least important)

Health		Ingredient		Processing		Supply Chain	
Brain aging care	---	Grain-free	---	Fresh	---	Eco-friendly	---
Calming support	---	Holistic	---	Raw	---	Sustainability	---
Dental care	---	Organic	---	Canned	---	Locally made	---
Digestive tract health	---	Natural	---	Wet	---	Made in USA	---
Hypoallergenic	---	Non-GMO	---	Freeze-dried	---	Not made in China	---
Joint health/Mobility	---	Sustainable	---	Minimally processed	---		
Skin and coat care	---	Limited-ingredient	---				
Weight control	---	Human-grade	---	Frozen	---		
		No corn, soy, wheat	---				
		No byproduct	---				

this question has a drop down menu

<u>Plant-Based Ingredient Perception (17 question)</u>

The next seven questions are designed to gain insights on your preference of plant-based ingredients in pet food. Although the questions may seem to be worded similar to each other, the options vary. We would greatly appreciate your thoughtful response to each question as the insights gained will have important implications for product design and pet nutrition.

34. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)

Most		Least
	Barley	
	Corn	
	Millet	

35. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)		
Most		Least
	Barley	
	Oat	
	Quinoa	

36. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)		
Most		Least
	Barley	
	Rice	
	Sorghum	

37. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)		
Most		Least
	Corn	
	Oat	
	Rice	

38. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)		
Most		Least
	Corn	
	Quinoa	
	Sorghum	

39. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)		
Most		Least
	Millet	
	Oat	
	Sorghum	

40. When purchasing pet food, which of the following ingredients do you prefer most and which do you prefer least? (Choose only one as most preferred and one as least preferred)		
Most		Least
	Millet	
	Quinoa	
	Rice	

41. Rate your **current** perception of the importance of **sorghum** as an ingredient in pet food/treat. (0=not important, 1=somewhat important, 2= important, 3=extremely important)

0 1 2 3

42. In your opinion, the importance of **sorghum** as a pet food/treat ingredient will ________ in the future.
    a. Increase b. Stay the same c. Decrease

The next seven questions are designed to gain insights on your preference of plant-based ingredients in pet food. Although the questions may seem to be worded similar to each other, the options vary. We would greatly appreciate your thoughtful response to each question as the insights gained will have important implications for product design and pet nutrition.

43. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Ancient Grain	
	Antioxidant Rich	
	Eco-Friendly/ Sustainable	

44. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Ancient Grain	
	Functional Fiber	
	Locally Sourced	

45. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Ancient Grain	
	Healthy Weight	
	Taste/ Flavor	

46. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Antioxidant Rich	
	Functional Fiber	
	Healthy Weight	

47. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Antioxidant Rich	
	Locally Sourced	
	Taste/ Flavor	

48. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Eco-Friendly/ Sustainable	
	Functional Fiber	
	Taste/ Flavor	

49. In the set of factors below, please select the factor that you consider to be the MOST important **benefit** of **sorghum** as an ingredient in pet food and the factor that you consider to be the LEAST important **benefit** of **sorghum** as an ingredient in pet food.		
Most		Least
	Eco-Friendly/ Sustainable	
	Locally Sourced	
	Healthy Weight	

50. Rate your interest in learning more about **sorghum** as an ingredient in pet food/treat. (0=not interested, 1=somewhat interested, 2=interested, 3=extremely interested)

0 1 2 3

Appendix B - Product Example (Purina ONE Natural Adult Chicken & Rice Formula Dry Dog Food)

Dog / Food / Dry Food

Purina ONE Natural Adult Chicken & Rice Formula Dry Dog Food, 40-lb bag

By Purina ONE

4.6 ★★★★★ 7691 Ratings 37 Answered Questions

Flavor: **Chicken & Rice**

Adult High-Protein | Chicken & Rice | Lamb & Rice | Large Breed

Size: **40-lb bag**

8-lb bag $2.04/lb | 16.5-lb bag $1.84/lb | 31.1-lb bag $1.58/lb | 40-lb bag $1.48/lb | 40-lb bag, bundle of 2 $1.47/lb

About This Item

Details

- Real chicken is the first ingredient in this food featuring protein-rich, tender, meaty morsels and crunchy kibble for a taste your furbaby will love.
- 4 antioxidant sources provide immune support, while natural sources of glucosamine help support healthy joints.
- This recipe includes omega-6 fatty acids, vitamins, and minerals, to support your best friend's skin and coat health.
- It's free of fillers, so all of the ingredients have a purpose.
- The recipe provides complete and balanced nutrition and is highly digestible, so more nutrition goes to work inside your dog.

Serve your furbaby flavor-filled, complete and balanced nutrition with Purina ONE Chicken and Rice Formula Dry Dog Food. With chicken as the first ingredient, this high-protein recipe helps support healthy muscles, including the heart. Prebiotic fiber nourishes gut health, while vitamins A and E, zinc, and selenium support immune function. To help promote your pup's hip and joint health, this formula also includes glucosamine. Rest assured, you're giving your best friend only what they need to thrive because this food contains no fillers, meaning every ingredient has a purpose. Plus, this recipe is highly digestible, so more nutrition goes to work inside your dog. Give your best friend the boost they need with this tasty recipe.

Specifications

Item Number	143259
Weight	40 pounds
Made In	United States
Sourced From	Various
Lifestage	All Lifestages, Adult
Breed Size	All Breeds
Food Form	Dry Food
Special Diet	High-Protein, Natural, With Grain

Ingredient Information

—

Ingredients

Chicken, Rice Flour, Corn Protein Meal, Whole Grain Corn, Chicken By-Product Meal , Whole Grain Wheat, Soybean Meal, Beef Fat Preserved With Mixed-Tocopherols, Natural Flavor, Glycerin, Calcium Carbonate, Mono And Dicalcium Phosphate, Dried Chicory Root, Salt, Potassium Chloride, Dried Carrots, Dried Peas, Vegetable Juice (Color), VITAMINS [Vitamin E Supplement, Niacin (Vitamin B-3), Vitamin A Supplement, Calcium Pantothenate (Vitamin B-5), Thiamine Mononitrate (Vitamin B-1), Vitamin B-12 Supplement, Riboflavin Supplement (Vitamin B-2), Pyridoxine Hydrochloride (Vitamin B-6), Folic Acid (Vitamin B-9), Vitamin D-3 Supplement, Menadione Sodium Bisulfite Complex (Vitamin K), Biotin (Vitamin B-7)], MINERALS [Zinc Sulfate, Ferrous Sulfate, Manganese Sulfate, Copper Sulfate, Calcium Iodate, Sodium Selenite], Choline Chloride, DL-Methionine, L-Lysine Monohydrochloride. A415423

Caloric Content

4004 kcal/kg, 383 kcal/cup

Guaranteed Analysis

Crude Protein	26.0% min
Crude Fat	16.0% min
Crude Fiber	3.0% max
Moisture	12.0% max
Linoleic Acid	1.4% min
Calcium (Ca)	1.0% min
Phosphorus (P)	0.80% min
Zinc (Zn)	150 mg/kg min
Selenium (Se)	0.35% min
Vitamin A	13000 IU/kg min
Vitamin E	250 IU/kg min

Feeding Instructions

—

Weight	Daily Feeding (Cups)
3 - 12 lbs	1/3 - 1
13 - 20 lbs	1 - 1 1/2
21 - 35 lbs	1 1/2 - 2 1/4
36 - 50 lbs	2 1/4 - 3
51 - 75 lbs	3 - 4
76 - 100 lbs	4 - 5
Over 100 lbs	5 + 1/2 for each 10 lbs over 100 lbs

The recommended feeding amounts indicated are based upon the average nutritional needs of an adult dog with normal activity. Factors, such as a dog's metabolism, breed size, activity level, age and whether the dog is spayed or neutered, will affect the amount of Purina ONE needed to maintain an ideal body condition. If you find that your dog is losing weight or becomes overweight when fed these amounts, please adjust accordingly. To help your dog maintain an ideal body condition, monitor your dog's weight on a regular basis, making sure that his ribs are easily felt and the waist is visible when viewed from above.

Puppies: Start puppies on moistened Purina ONE as early as they will nibble at solid foods, generally 3-4 weeks of age. Feed pups (to six months of age) all of the moistened or dry Purina ONE they will consume at intervals throughout the day. If water is added, use no more than one part warm (not hot) liquid to four parts Purina ONE, changing frequently to ensure freshness. If fed dry, this formula may be kept before pups at all times.

Reproduction: Purina ONE provides the extra nutrition needed by reproducing females in stages of gestation and lactation. Food consumption may vary during gestation, so feed the amount needed to maintain the pregnant female's good body condition. Food intake may double or even quadruple during lactation.

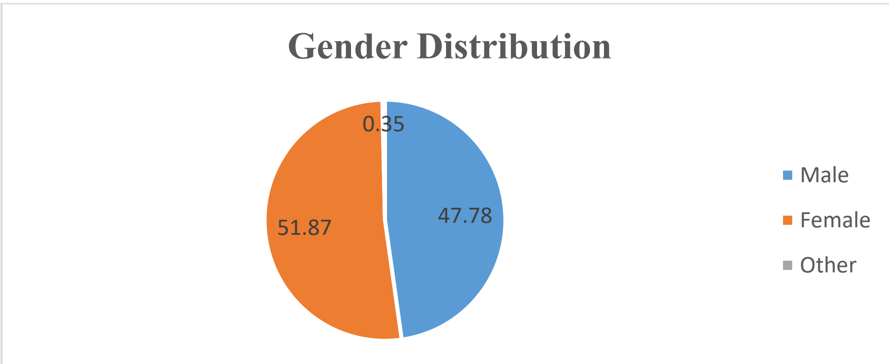
Transition Instructions

Please allow 7 - 10 days to ease the transition from his current food and a little more Purina ONE until you're feeding Purina ONE exclusively. This gradual transition will help avoid dietary upsets.

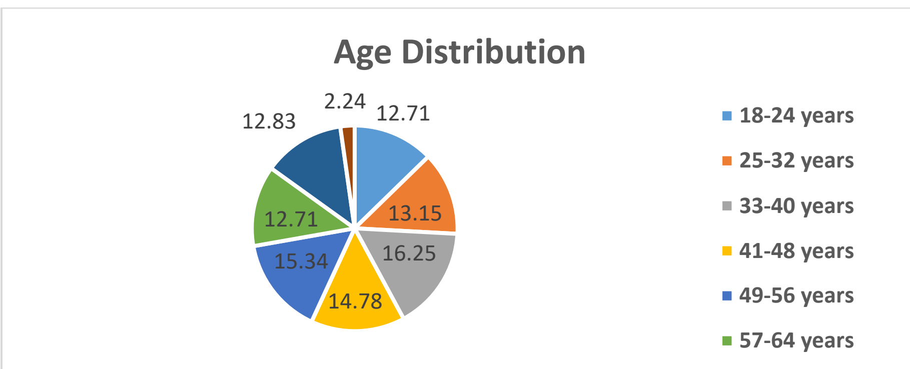
Appendix C - Dog/Owner Characteristics

Owner Characteristics

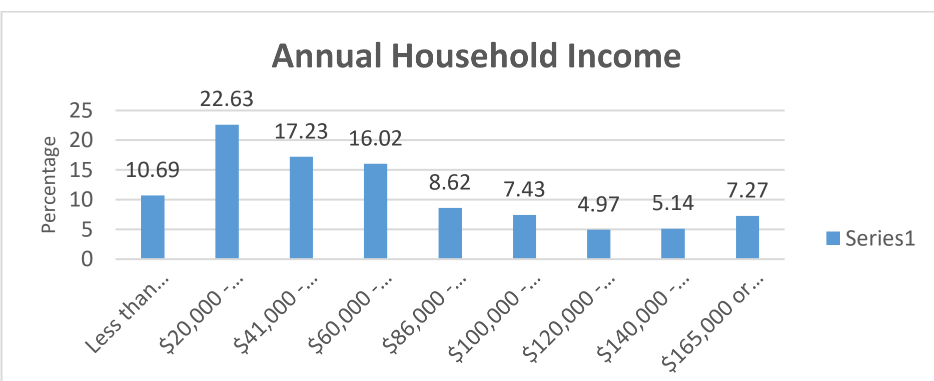
Appendix Figure C.1. Distribution of Survey Respondents by Gender



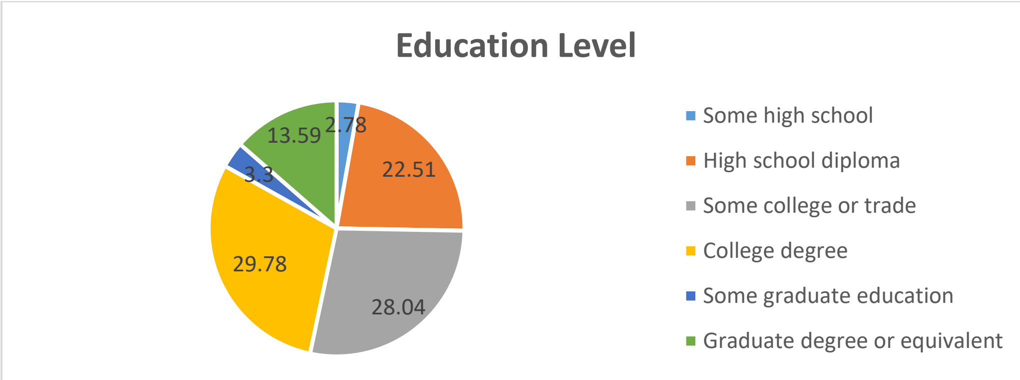
Appendix Figure C.2. Distribution of Survey Respondents by Age Group



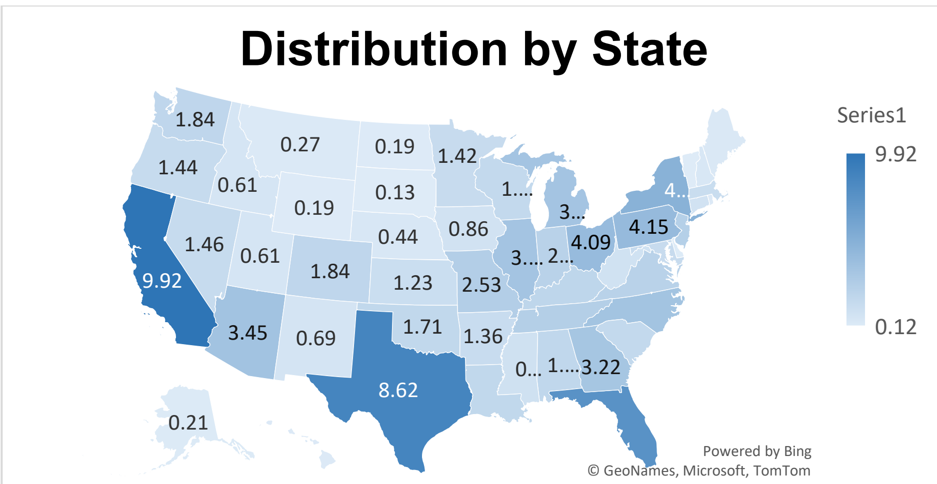
Appendix Figure C.3. Distribution of Survey Respondents by Annual Household Income



Appendix Figure C.4. Distribution of Survey Respondents by Education Level

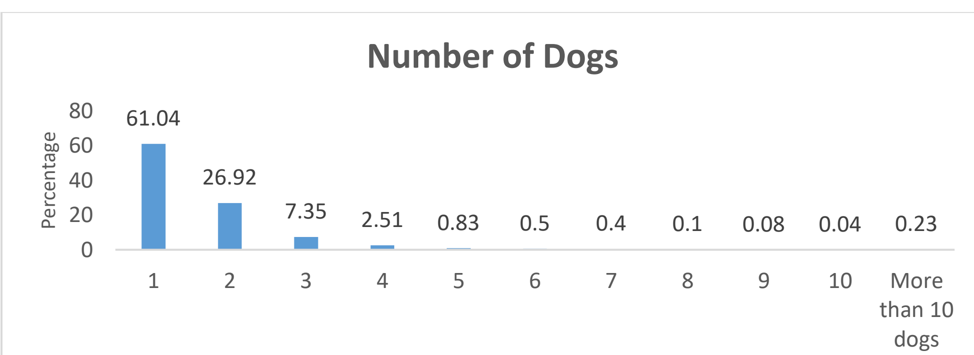


Appendix Figure C.5. Geographic Distribution of Survey Respondents by U.S. State

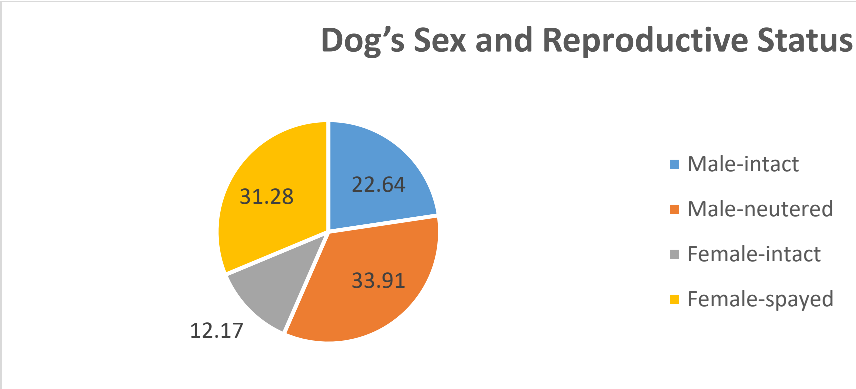


Dog Characteristics

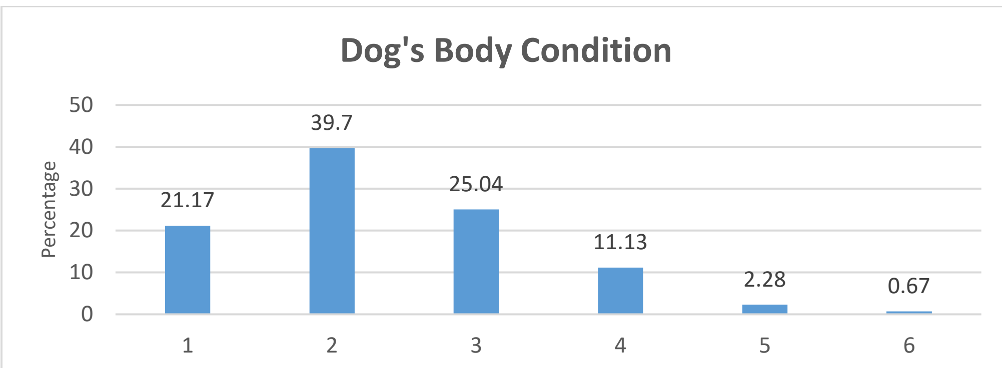
Appendix Figure C.6. Distribution of Number of Dogs Owned by Survey Respondents



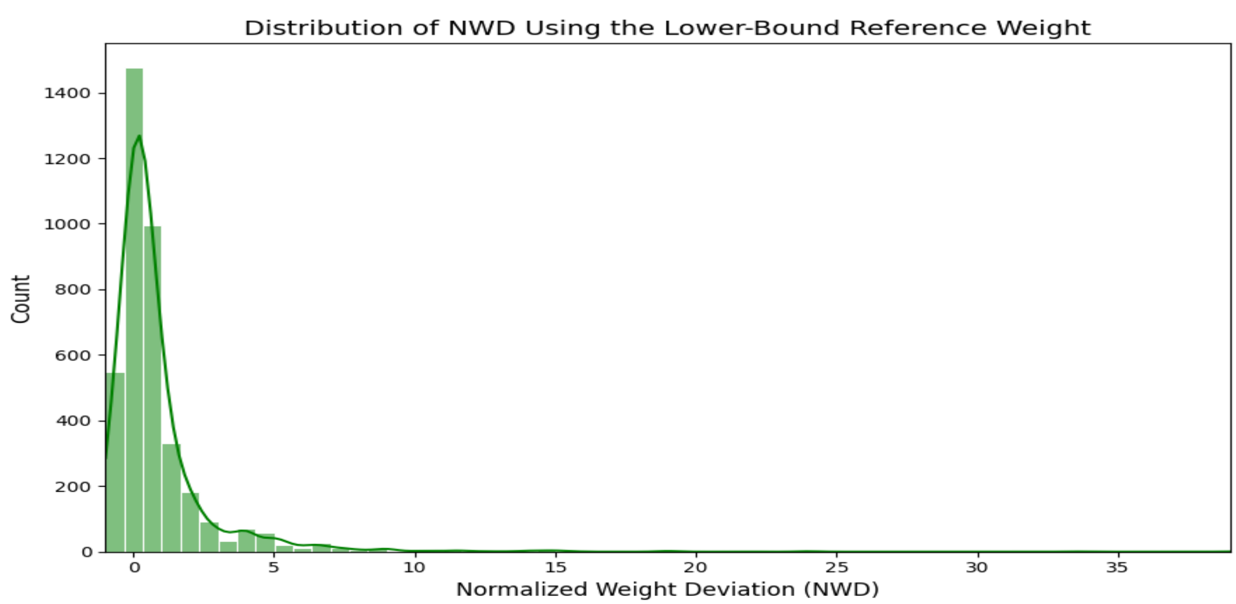
Appendix Figure C.7. Distribution of Dogs by Sex and Reproductive Status



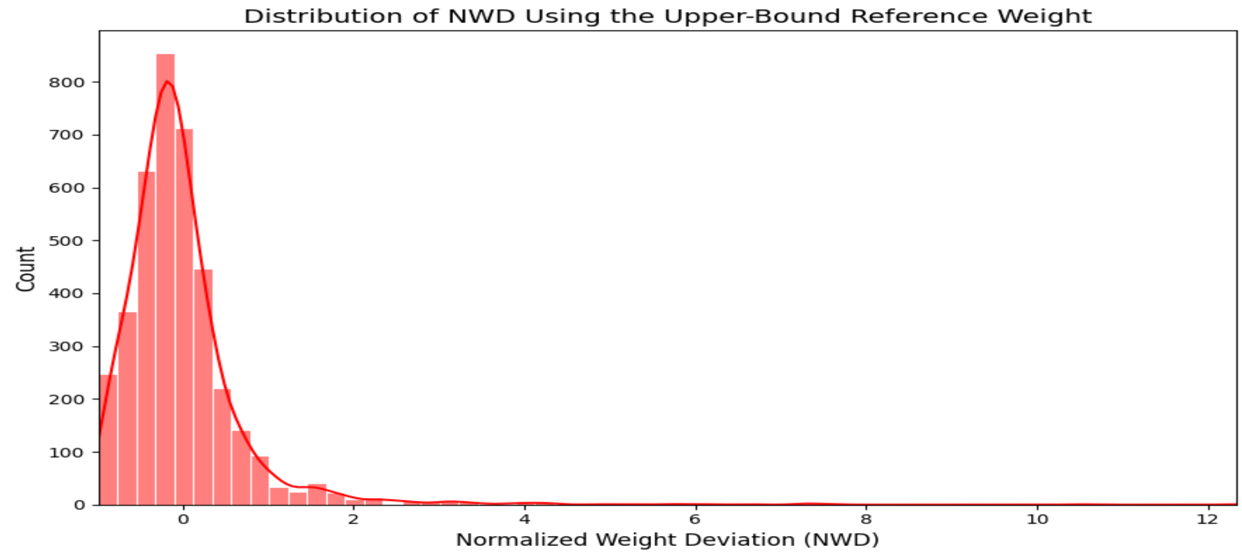
Appendix Figure C.8. Distribution of Owner-Reported Dog Body Condition



Appendix Figure C.9. Distribution of Normalized Weight Deviation (NWD) Using the Lower-Bound Reference Weight



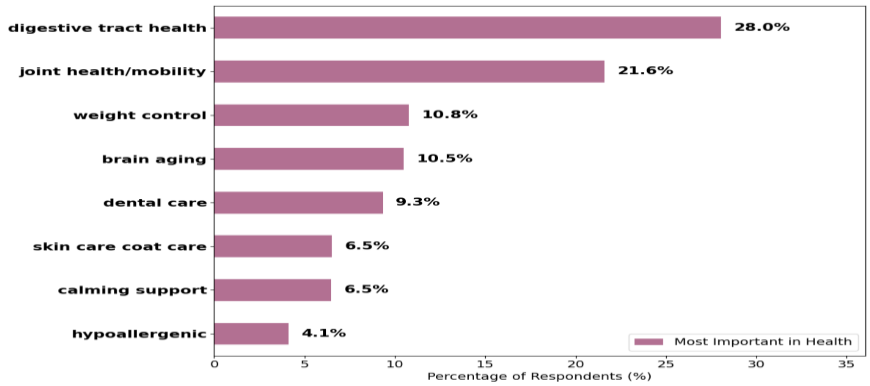
Appendix Figure C.10. Distribution of Normalized Weight Deviation (NWD) Using the Upper-Bound Reference Weight



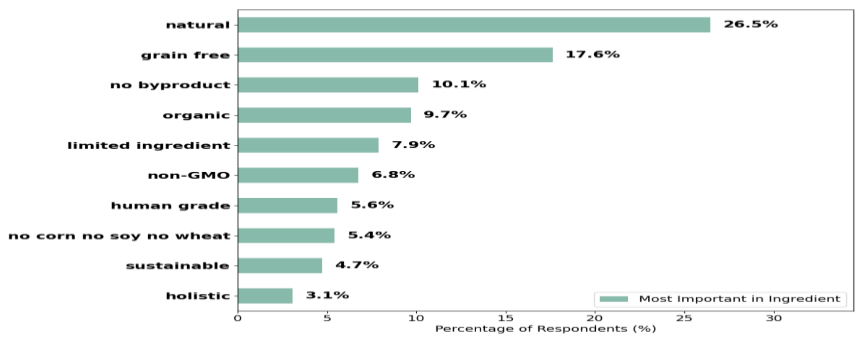
Appendix D - Wishlist/Shopping Cart Attributes

Figures of Single Top-Priority Attributes (Wishlist)

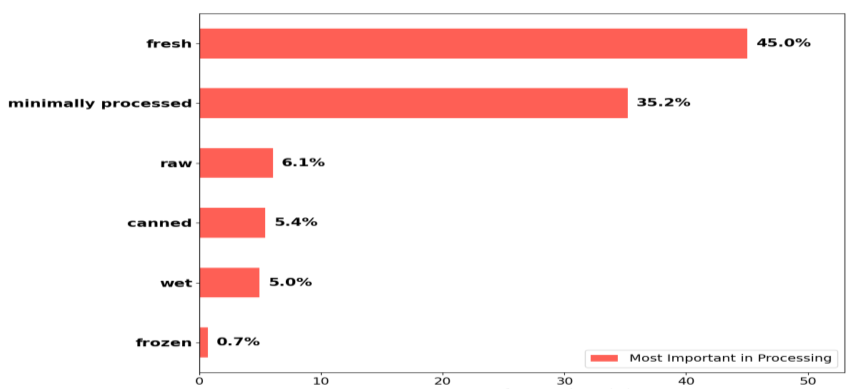
Appendix Figure D.1. Distribution of Pet Owners' Single Top-Priority Health Attributes



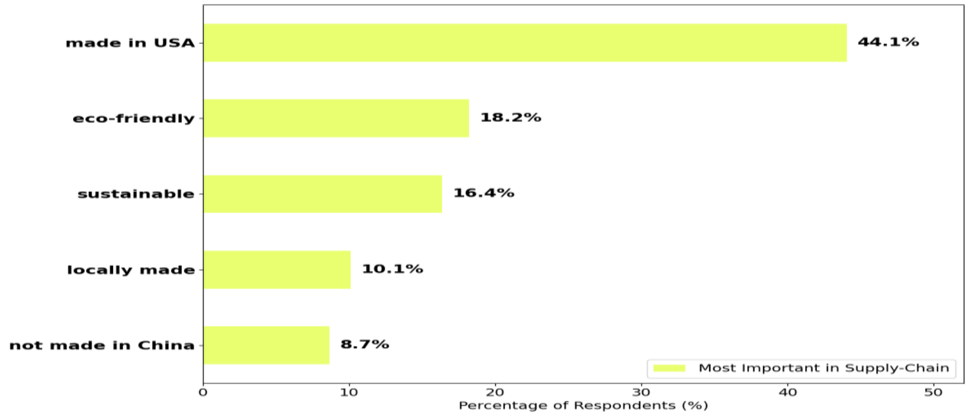
Appendix Figure D.2. Distribution of Pet Owners' Single Top-Priority Ingredient Attributes



Appendix Figure D.3. Distribution of Pet Owners' Single Top-Priority Processing Attributes

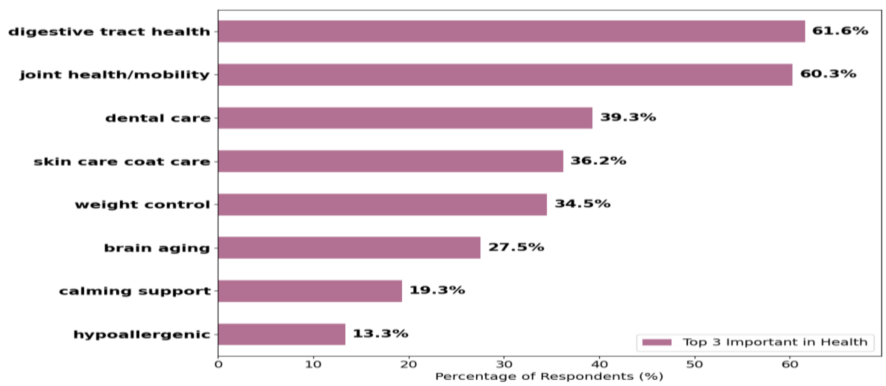


Appendix Figure D.4. Distribution of Pet Owners' Single Top-Priority Supply-Chain Attributes

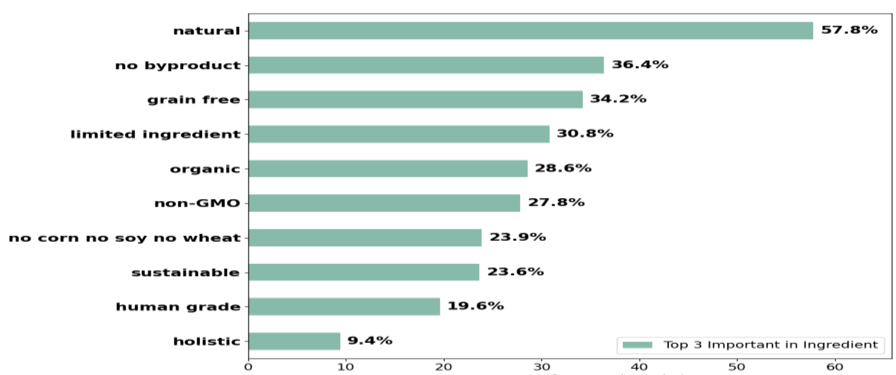


Figures of Top Three Attributes (Wishlist)

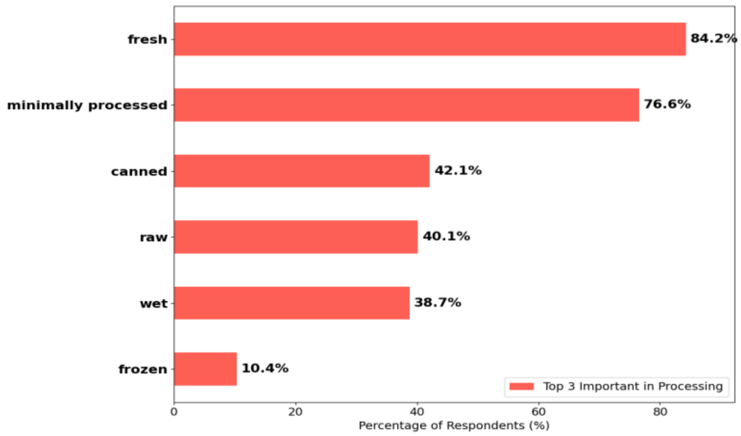
Appendix Figure D.5. Distribution of Pet Owners' Top Three Health Attributes



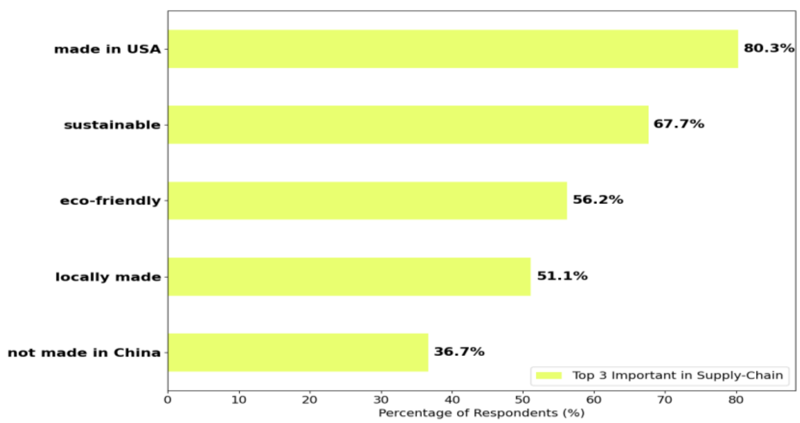
Appendix Figure D.6. Distribution of Pet Owners' Top Three Ingredient Attributes



Appendix Figure D.7. Distribution of Pet Owners' Top Three Processing Attributes

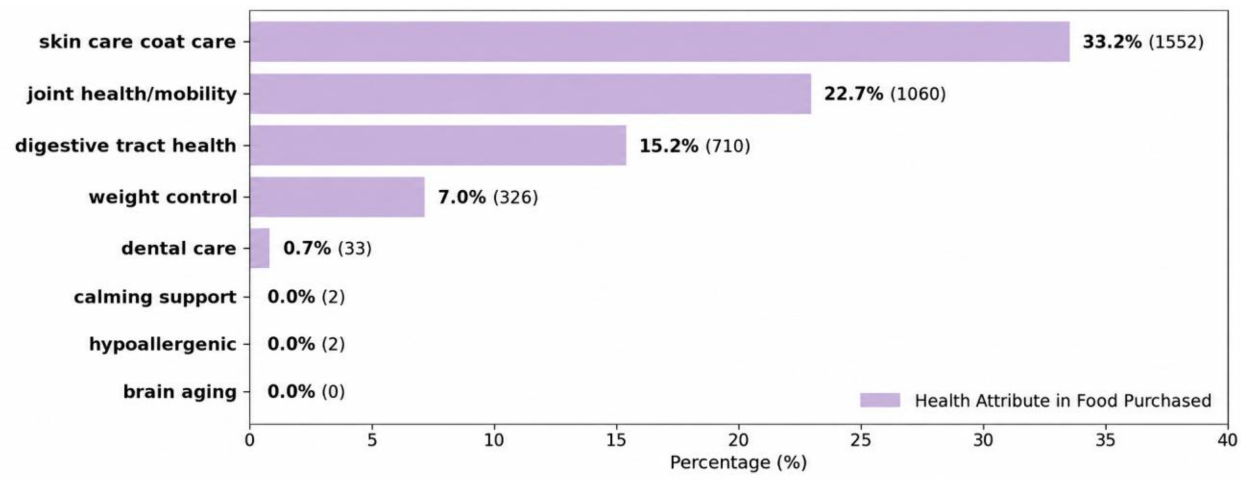


Appendix Figure D.8. Distribution of Pet Owners' Top Three Supply-Chain Attributes

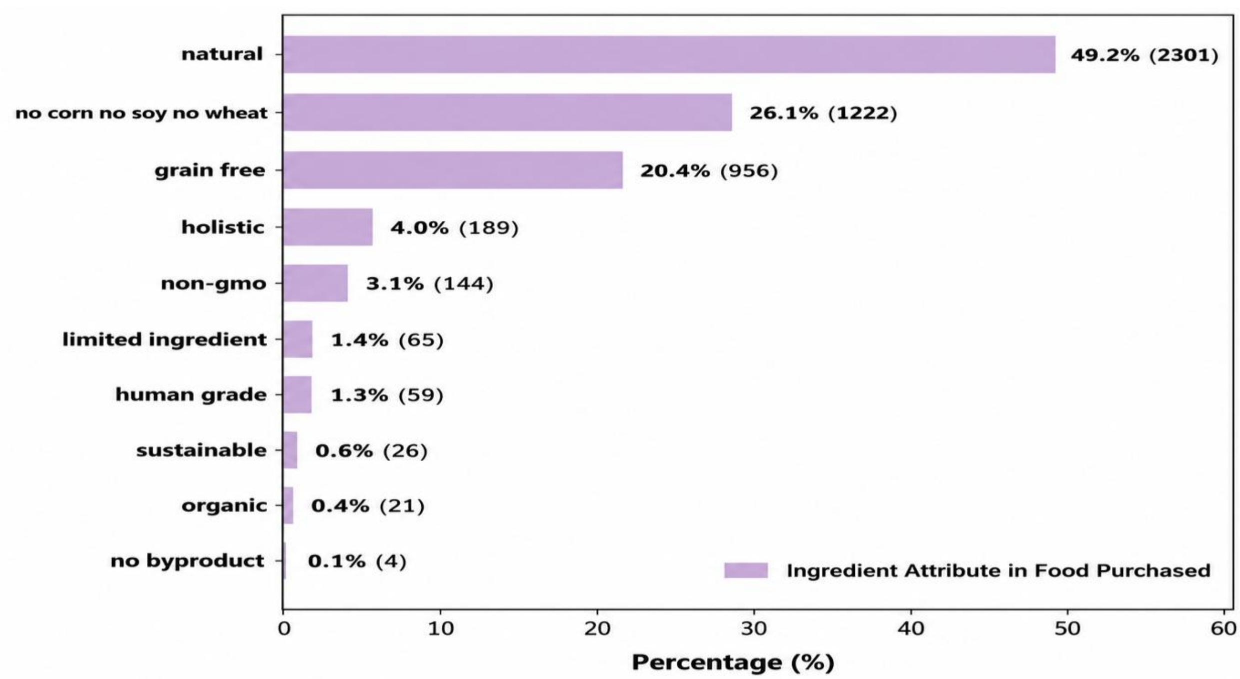


Figures of Single Top-Priority Food Attributes (Shopping Cart)

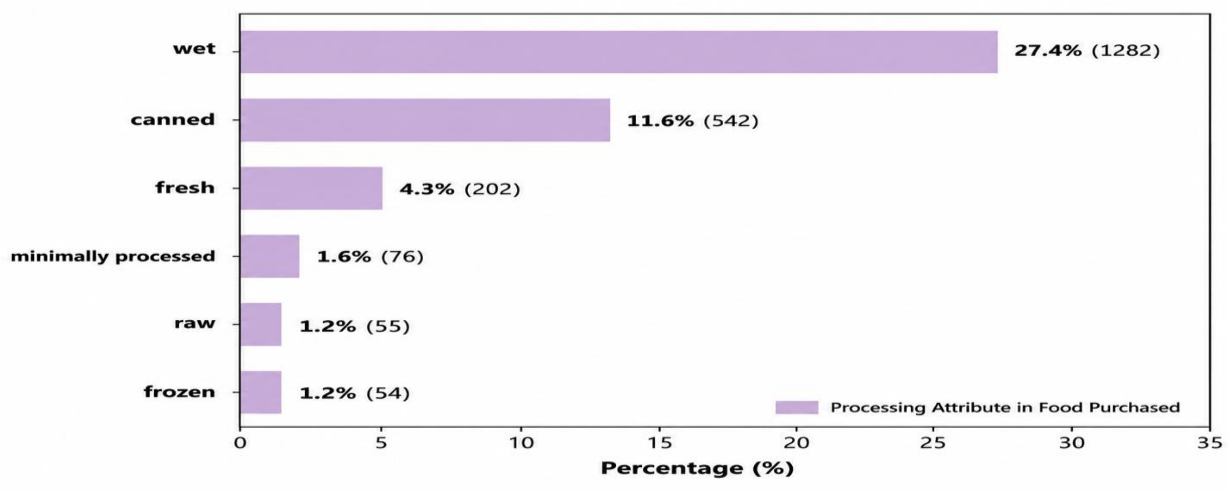
Appendix Figure D.9. Distribution of Health Attributes Identified in Reported Purchased Food Products



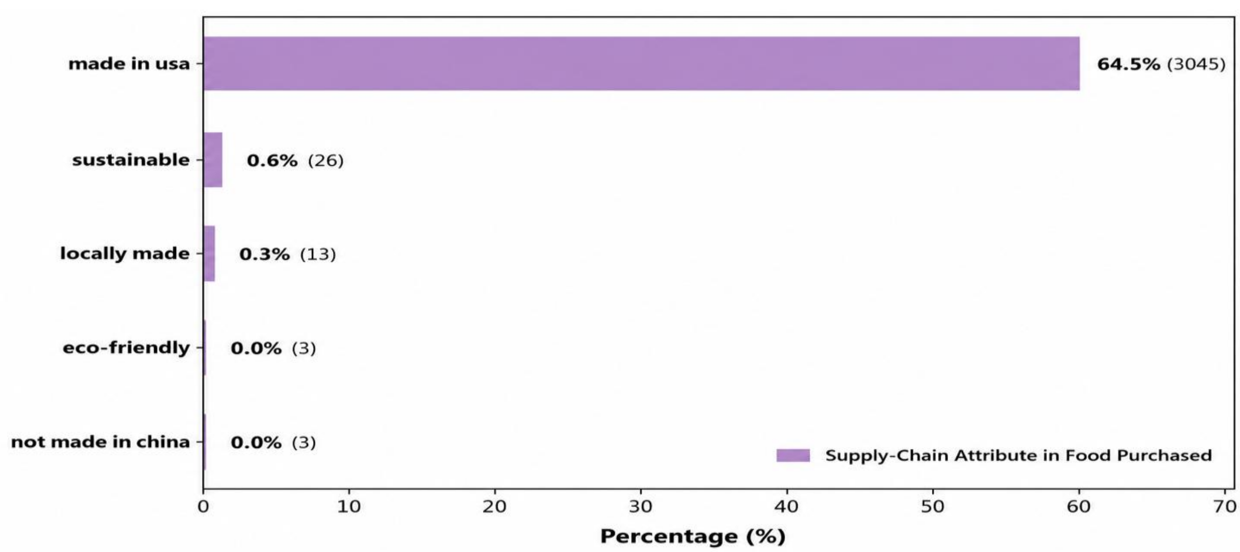
Appendix Figure D.10. Distribution of Ingredient Attributes Identified in Reported Purchased Food Products



Appendix Figure D.11. Distribution of Processing Attributes Identified in Reported Purchased Food Products

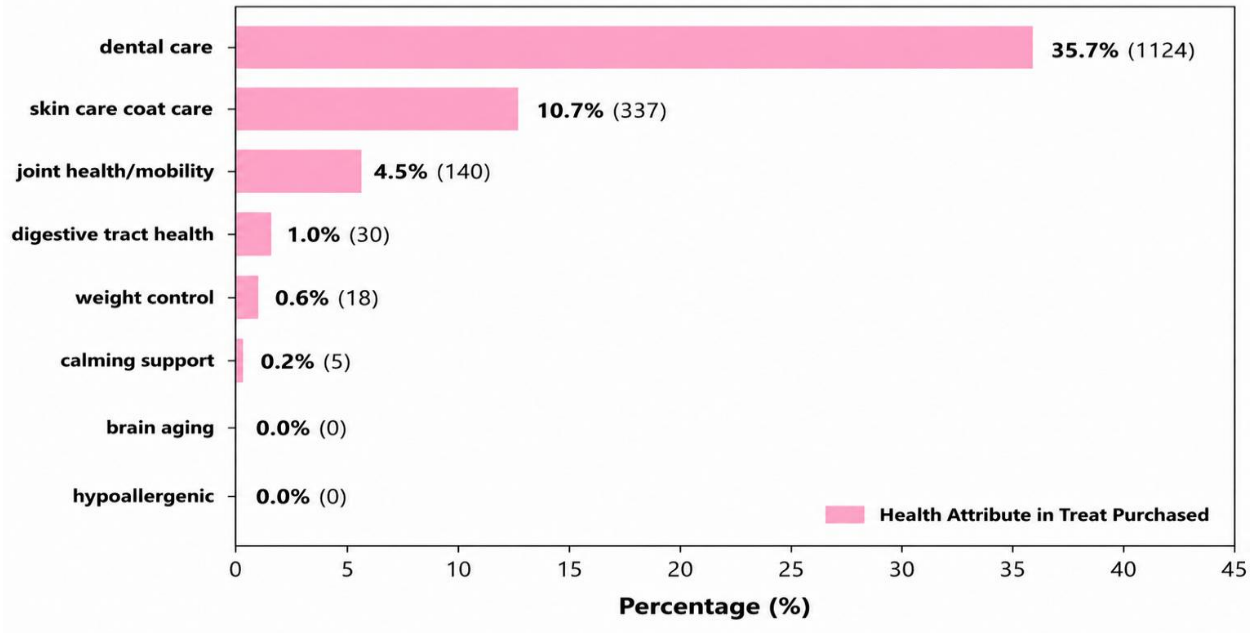


Appendix Figure D.12. Distribution of Supply-Chain Attributes Identified in Reported Purchased Food Products

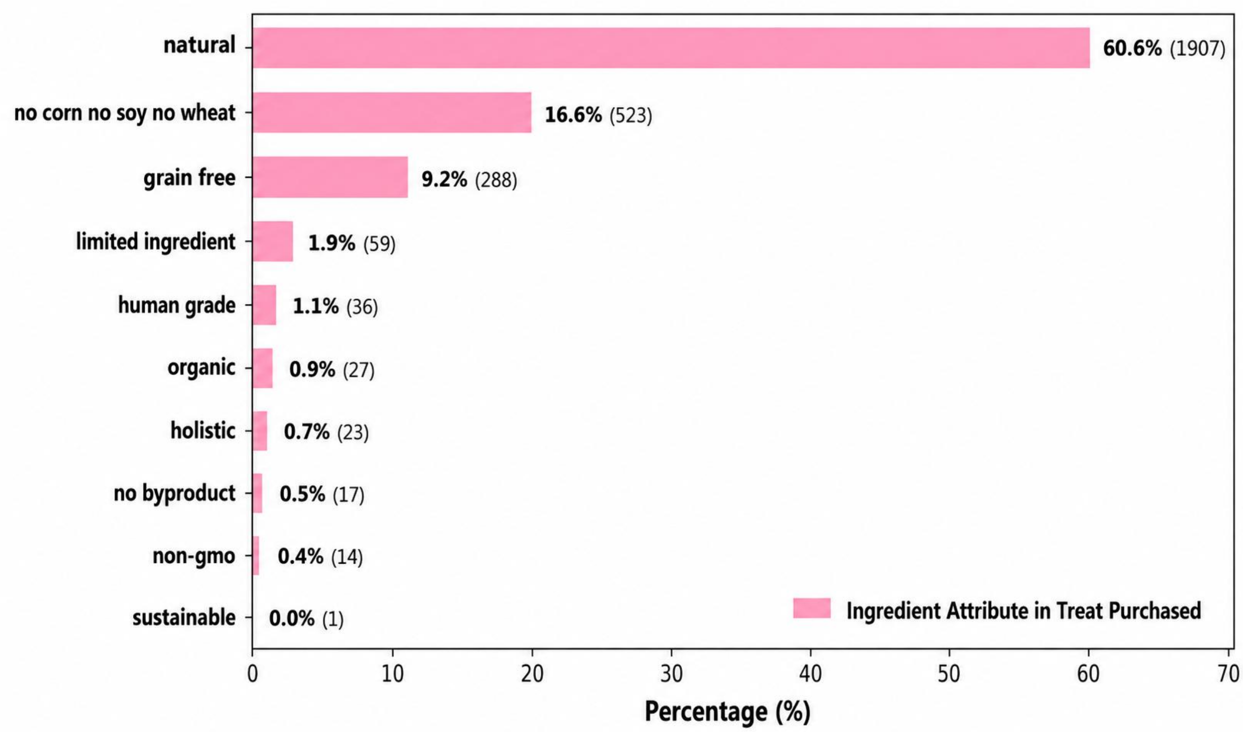


Figures of Single Top-Priority Treat Attributes (Shopping Cart)

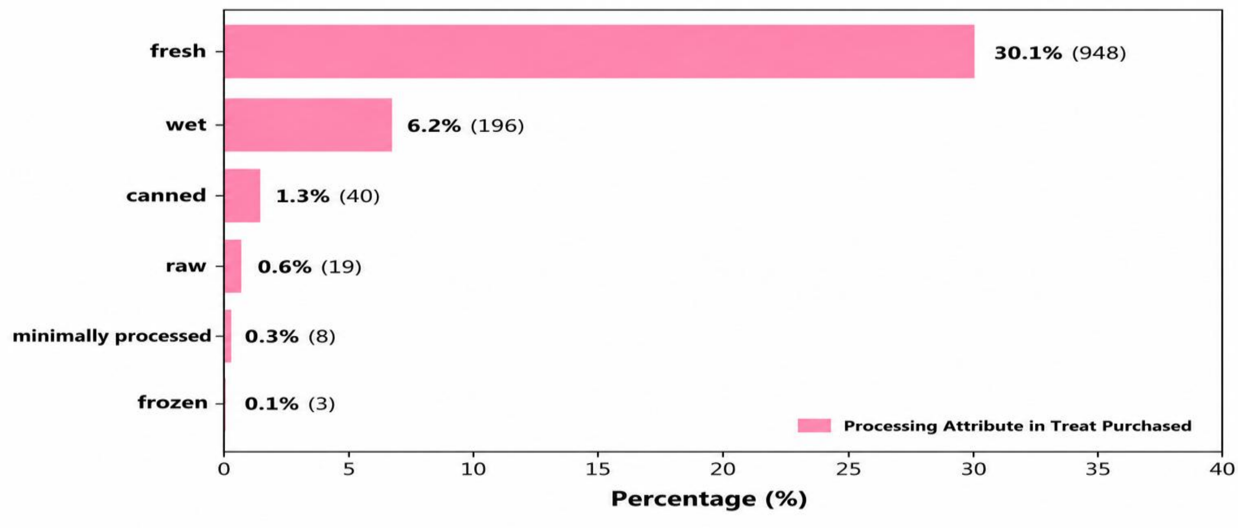
Appendix Figure D.13. Distribution of Health Attributes Identified in Reported Purchased Treat Products



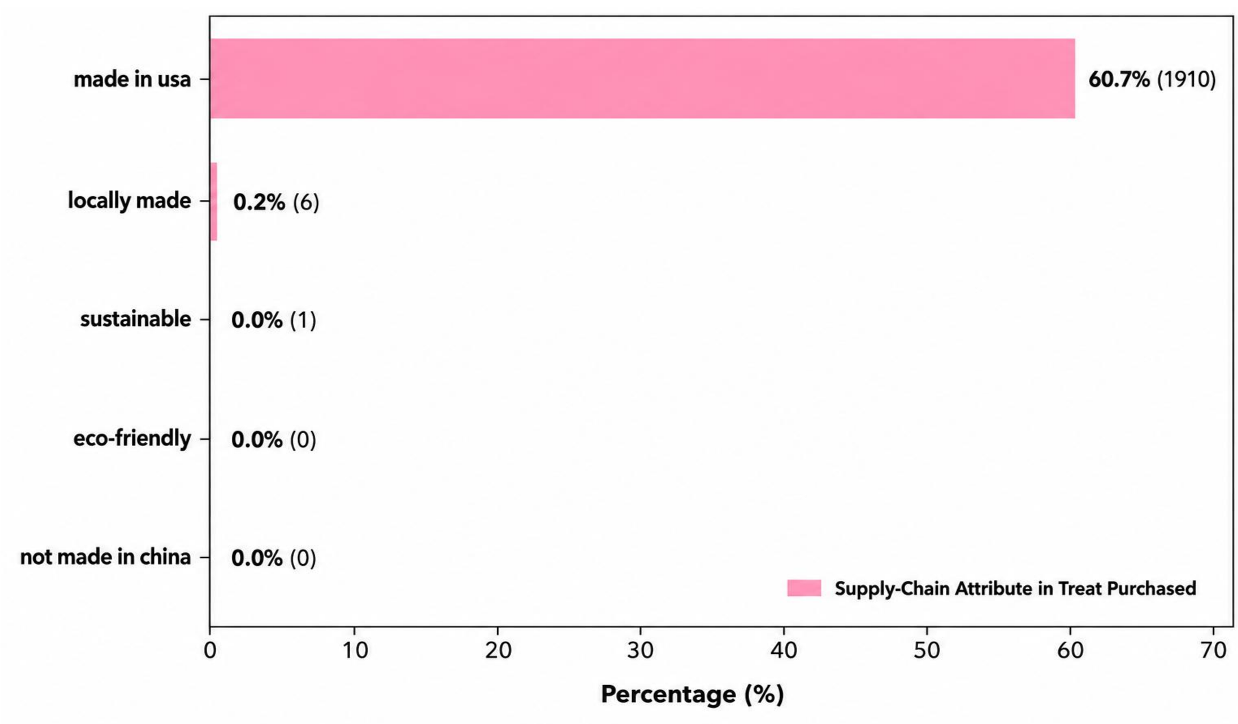
Appendix Figure D.14. Distribution of Ingredient Attributes Identified in Reported Purchased Treat Products



Appendix Figure D.15. Distribution of Processing Attributes Identified in Reported Purchased Treat Product



Appendix Figure D.16. Distribution of Supply-Chain Attributes Identified in Reported Purchased Treat Products



Appendix E - Pet Food Ingredient Perception (Producer Survey)

Thank you for your participation in this survey. The purpose is to gain improved understanding of pet food industry members' perceptions about plant-based ingredients in pet food. Participation in the survey is voluntary. You may discontinue at any time without penalty. For questions or concerns, please contact Dr. Greg Aldrich at aldrich4@ksu.edu .

Demographics (5 questions)

1. Please indicate your business type.
   a. Pet Food Brand Owner / Marketer / R&D/ Formulator
   b. Pet Treat or Supplement Brand Owner / Marketer / R&D / Formulator
   c. Private Label Manufacturer / Co Packer
   d. Ingredient Supplier
   e. Equipment / Processing Service Provider / Food Engineering
   f. Consultant (nutrition solutions, formulation, processing)
   g. Other (please specify): ___________________________________

2. Please estimate your company's number of employees.

   ____

3. Please indicate your job function.
   a. Corporate / General Management
   b. Ingredient Procurement
   c. Marketing / Sales
   d. Production / Operations Management
   e. Quality Control / Quality Assurance / Food Safety
   f. Research & Development / Formulator / Consultant
   g. Other (please specify): ___________________________________

4. Please indicate the number of years you have worked in the pet food industry.

   ____

5. Please estimate number of times you have made or been involved in decisions within your company related to product ingredients/raw materials over the last year.

   ____

Current Plant-based Ingredient Use (supply, interact, or deal with) (2 questions)

6. Please indicate the plant-based ingredients you currently use in your product. (Select all that apply)

a. Amaranth	j. Oats	s. Teff
b. Barley	k. Potato	t. Wheat
c. Bean	l. Quinoa	u. Canola
d. Buckwheat	m. Rice	v. Miscanthus
e. Chickpea	n. Rye	w. Beet Pulp

f. Corn / Corn Protein
g. Kaniwa
h. Lentils
i. Millet
o. Sorghum
p. Soy / Soy Protein
q. Sweet Potato
r. Tapioca
x. Other (Please specify): ---------------

7. Please rank the top five plant-based ingredients you use based on the importance to the success of your company. (1 is the most important and 5 is the least important of the five ingredients)
   1) ________________________________ 4) ________________________________
   2) ________________________________ 5) ________________________________
   3) ________________________________

Perception of sorghum as pet food/treat ingredient (6 questions)

8. Rate your **current** perception of the importance of **sorghum** as an ingredient in pet food/treat.. (0=not important, 1=somewhat important, 2=important, 3=extremely important)
   0 1 2 3

9. In your opinion, the importance of **sorghum** as a pet food/treat ingredient will ________ in the future.
   a. Increase b. Stay the same c. Decrease

10. In your opinion, consumer demand for **sorghum** as a pet food/treat ingredient will ________ in the future.
    a. Increase b. Stay the same c. Decrease

11. Please circle the major **advantage or attractive** features of **sorghum** as an ingredient. (Circle all that apply). Also, please rank the **top three** attractive features using the boxes provided. (Example: [3] a availability; [1] i price; [2] d demand)

- [ ] a. Availability / Consistent Supply
- [ ] b. Ease of Handling / Processing
- [ ] c. Health / Wellness Benefits
- [ ] d. High Customer Demand/ Request
- [ ] e. Locally (U.S.) Produced
- [ ] f. Low Herbicide / Pesticide Use
- [ ] g. Low Water Use
- [ ] h. Positive Customer Perception
- [ ] i. Relatively Low Price / Cost
- [ ] j. Taste / Flavor
- [ ] k. Technical Food Properties
- [ ] l. Other (please specify) ______________

12. Please indicate the major **constraints or limiting factors** of **sorghum** as an ingredient. (Circle all that apply). Also, please indicate the **top three** limiting factors using the boxes provided. (Example: [2] i flavor; [3] f demand; [1] d water use)

- [ ] a. Availability / Consistent Supply
- [ ] b. Difficulty of Handling / Processing
- [ ] c. High Herbicide / Pesticide Use
- [ ] d. High Water Use
- [ ] e. Limited Health / Wellness Benefits
- [ ] f. Low Customer Demand / Request
- [ ] g. Negative Customer Perception
- [ ] h. Relatively High Price / Cost
- [ ] i. Taste / Flavor
- [ ] j. Technical Food Properties
- [ ] k. Other (please specify): ________________________________

13. Rate your interest in learning more about opportunities for using **sorghum** as an ingredient in pet food/treat. (0=not important, 1=somewhat important, 2=important, 3=extremely important)

0 1 2 3

Perception of Soybean as pet food/treat ingredient (8 questions)

14. Rate your **current** perception of the importance of **soybean** as an ingredient in pet food/treat. (0=not important, 1=somewhat important, 2=important, 3=extremely important)

0 1 2 3

15. In your opinion, the importance of **soybean** as a pet food/treat ingredient will ________ in the future.
    a. Increase b. Stay the same c. Decrease

16. In your opinion, consumer demand for **soybean** as a pet food/treat ingredient will ________ in the future.
    a. Increase b. Stay the same c. Decrease

17. Please circle the major **advantage or attractive** features of **soybean** as an ingredient. (Circle all that apply). Also, please rank the **top three** attractive features using the boxes provided. (Example: [3] a. availability; [1] i. price; [2] d demand)

- [ ] a. Availability / Consistent Supply
- [ ] b. Ease of Handling / Processing
- [ ] c. Health / Wellness Benefits
- [ ] d. High Customer Demand / Request
- [ ] e. Plant-based / Sustainable
- [ ] f. Nutritious Ingredient
- [ ] g. Hypoallergenic
- [ ] h. Positive Customer Perception
- [ ] i. Relatively Low Price / Cost
- [ ] j. Taste / Flavor (Palatable by dogs)
- [ ] k. Technical Food Properties
- [ ] l. Other (please specify) ____________

18. Please indicate the major **constraints or limiting factors** of **soybean** as an ingredient. (Circle all that apply). Also, please indicate the **top three** limiting factors using the boxes provided. (Example: [2] i. flavor; [3] d. GMO; [1] k. allergenics)

- [ ] a. Availability / Consistent Supply
- [ ] b. Difficulty of Handling / Processing
- [ ] c. High Herbicide / Pesticide Use
- [ ] d. GMO
- [ ] e. Antinutritional factors
- [ ] f. Low Customer Demand / Request
- [ ] g. Negative Customer Perception
- [ ] h. Relatively High Price / Cost
- [ ] i. Taste / Flavor (Palatable by dogs)
- [ ] j. Technical Food Properties
- [ ] k. Allergenics
- [ ] l. Other (please specify):____________

19. Which of the following best reflects your attitude towards soy (i.e. soy, soy protein, soy hulls) as an ingredient in pet food.
    a. Prefer b. Avoid c. Don't care

20. In your opinion, consumer demand for **vegetarian** of pet food will ________ in the future.
    a. Increase b. Stay the same c. Decrease

21. Please provide any additional thoughts or comments on the use of **sorghum/soybean** as an ingredient in pet food/treat.

Appendix F - Average Marginal Effect Estimation

Appendix Table F.1. Average Marginal Effects, MNL1

Variable	Sorghum	Barley	Rice
Age 33-56 (vs <33)	-0.0301*** (0.008)	0.0555*** (0.015)	-0.0253 (0.016)
Age ≥57 (vs <33)	-0.0433*** (0.014)	0.0581*** (0.021)	-0.0148 (0.022)
College degree or some (vs HS/some)	0.0104 (0.009)	0.0121 (0.017)	-0.0225 (0.017)
Digestive tract health (vs other)	-0.0145 (0.009)	-0.0083 (0.015)	0.0228 (0.016)
Graduate degree or some (vs HS/some)	0.0225* (0.012)	0.0512** (0.022)	-0.0737*** (0.023)
High income ≥$120k (vs < $60k)	0.0108 (0.011)	-0.0170 (0.020)	0.0062 (0.021)
Locally made (vs other)	0.0179 (0.016)	0.0025 (0.024)	-0.0204 (0.025)
Middle income $60-119k (vs < $60k)	0.0027 (0.009)	0.0018 (0.016)	-0.0045 (0.016)
No corn/soy/wheat (vs other)	0.0274* (0.015)	0.0053 (0.029)	-0.0327 (0.030)
Non-GMO (vs other)	0.0160 (0.014)	0.0276 (0.026)	-0.0436 (0.027)
Northeast (vs Midwest)	0.0012 (0.013)	0.0099 (0.022)	-0.0111 (0.023)
Gender (female=1)	-0.0173** (0.008)	-0.0360*** (0.013)	0.0533*** (0.014)
South (vs Midwest)	0.0080 (0.010)	-0.0121 (0.018)	0.0042 (0.019)
Sustainable (vs other)	0.0312* (0.016)	0.0223 (0.026)	-0.0535** (0.027)
Weight control (vs other)	-0.0276** (0.014)	0.0169 (0.022)	0.0107 (0.023)
West (vs Midwest)	0.0081 (0.011)	0.0381* (0.020)	-0.0461** (0.021)

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10 (Standard error in parentheses)*

Appendix Table F.2. Average Marginal Effects, MNL2

Variable	Sorghum	Quinoa	Corn
Age 33-56 (vs <33)	-0.0341*** (0.011)	0.0419*** (0.016)	-0.0078 (0.015)
Age ≥57 (vs <33)	-0.0327** (0.016)	0.0559** (0.022)	-0.0232 (0.022)
College degree or some (vs HS/some)	-0.0097 (0.012)	0.0835*** (0.017)	-0.0738*** (0.016)
Digestive tract health (vs other)	-0.0193* (0.012)	0.0045 (0.016)	0.0148 (0.016)
Graduate degree or some (vs HS/some)	0.0072 (0.017)	0.1096*** (0.023)	-0.1168*** (0.023)
High income ≥$120k (vs < $60k)	-0.0085 (0.015)	0.0442** (0.020)	-0.0358* (0.020)
Locally made (vs other)	-0.0020 (0.019)	-0.0008 (0.025)	0.0029 (0.025)
Middle income $60-119k (vs < $60k)	0.0015 (0.012)	0.0179 (0.016)	-0.0194 (0.016)

No corn/soy/wheat (vs other)	0.0806*** (0.019)	0.0875*** (0.031)	-0.1681*** (0.033)
Non-GMO (vs other)	0.0032 (0.020)	-0.0010 (0.028)	-0.0022 (0.027)
Northeast (vs Midwest)	-0.0202 (0.016)	0.0408* (0.022)	-0.0207 (0.022)
Gender (female=1)	-0.0367*** (0.010)	0.1412*** (0.013)	-0.1045*** (0.013)
South (vs Midwest)	-0.0147 (0.013)	0.0189 (0.018)	-0.0042 (0.018)
Sustainable (vs other)	0.0137 (0.019)	-0.0575** (0.026)	0.0438* (0.026)
Weight control (vs other)	-0.0282* (0.017)	-0.0241 (0.023)	0.0523** (0.022)
West (vs Midwest)	-0.0200 (0.015)	0.0713*** (0.021)	-0.0514** (0.021)

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10 (Standard error in parentheses)*

Appendix Table F.3. Average Marginal Effects, MNL3

Variable	Sorghum	Oat	Millet
Age 33-56 (vs <33)	-0.0282*** (0.010)	0.0519*** (0.015)	-0.0238* (0.013)
Age ≥57 (vs <33)	-0.0348** (0.015)	0.0535** (0.021)	-0.0187 (0.019)
College degree or some (vs HS/some)	0.0171 (0.012)	-0.0058 (0.016)	-0.0113 (0.014)
Digestive tract health (vs other)	-0.0220** (0.011)	0.0385** (0.015)	-0.0166 (0.013)
Graduate degree or some (vs HS/some)	0.0429*** (0.015)	-0.0180 (0.022)	-0.0249 (0.020)
High income ≥$120k (vs < $60k)	0.0284** (0.013)	-0.0480** (0.019)	0.0196 (0.017)
Locally made (vs other)	-0.0120 (0.016)	0.0254 (0.024)	-0.0133 (0.021)
Middle income $60-119k (vs < $60k)	0.0027 (0.011)	0.0021 (0.016)	-0.0048 (0.014)
No corn/soy/wheat (vs other)	0.0192 (0.019)	-0.0485* (0.029)	0.0293 (0.025)
Non-GMO (vs other)	0.0151 (0.017)	-0.0187 (0.026)	0.0036 (0.023)
Northeast (vs Midwest)	-0.0094 (0.015)	-0.0580*** (0.022)	0.0673*** (0.019)
Gender (female=1)	-0.0099 (0.009)	0.0575*** (0.013)	-0.0477*** (0.012)
South (vs Midwest)	-0.0088 (0.012)	-0.0351* (0.018)	0.0440*** (0.016)
Sustainable (vs other)	-0.0014 (0.017)	-0.0503** (0.025)	0.0518** (0.022)
Weight control (vs other)	-0.0281* (0.016)	0.0601*** (0.022)	-0.0320 (0.020)
West (vs Midwest)	-0.0032 (0.014)	-0.0560*** (0.020)	0.0592*** (0.018)

*Note: *** p < 0.01; ** p < 0.05; * p < 0.10 (Standard error in parentheses)*

Appendix G - Supplementary Machine-Learning Analysis for Chapter 2

G.1 Purpose of the Supplementary Analysis

The primary empirical analysis in Chapter 2 uses quantile regression. This appendix presents a supplementary machine-learning analysis conducted to explore nonlinear predictive patterns that may not be imposed directly in the econometric specification. The machine-learning results are intended as complementary predictive evidence rather than as causal estimates.

G.2 Machine-Learning Methods

Random Forest, Extreme Gradient Boosting, and Support Vector Regression are used as complementary predictive models for NWD. Random Forest averages predictions across many bootstrapped decision trees and can capture nonlinearities and interactions without imposing a fixed functional form (Breiman, 2001). XGBoost fits a sequence of boosted trees that iteratively reduce prediction error and can represent complex interactions among mixed predictors (Chen and Guestrin, 2016). Support Vector Regression estimates a prediction function within a specified error margin and can model nonlinear relationships through kernel functions (Smola and Schölkopf, 2004).

The machine-learning models are used to evaluate predictive importance and functional form, not to estimate causal effects. SHAP values summarize how each feature contributes to a model's prediction relative to the model's average prediction (Lundberg and Lee, 2017). Partial Dependence Plots summarize the model-implied relationship between a selected predictor and predicted NWD while averaging over the observed values of other predictors (Friedman, 2001).

These tools can reveal nonlinear patterns, but they may be sensitive to correlated predictors and sparse regions of the data.

G.3 Machine-Learning Results

Figures G.1-G.2 report SHAP summaries for the Random Forest, XGBoost, and Support Vector Regression models. Across the models, age, total daily calories, extra-small breed, and interactions between breed size and calories appear among the most influential predictors. This broad agreement indicates that the flexible predictive models repeatedly use the same set of variables that are important in the quantile regressions.

G.3.1 Random Forest Results

The top three drivers are interaction between extra small breed and daily caloric intake, dog's age, interaction between small breed and daily caloric intake, followed by physical activity. In Figure G.1, each point represents an individual observation, plotted on a horizontal axis of SHAP value (impact on NWD prediction) for a given feature; the color indicates the feature value (red for high value, blue for low). The interaction between extra small breed and daily caloric intake, most red points (high interaction between extra small breed and daily caloric intake) are on the right-hand side with positive SHAP values, confirming that interaction between extra small breed and caloric intake push the RF's predicted NWD upward (i.e., toward higher NWD). Conversely, blue points (low interaction between extra small breed and daily caloric intake) lie to the left (negative or lower SHAP), meaning low-fed dogs are predicted to have lower NWD. Dog age shows a similar trend: the oldest dogs (red) have positive SHAP contributions to NWD, the model anticipates higher weight deviations for older dogs, whereas very young dogs (blue) contribute negatively (predicting lower NWD). Interaction between extra small breed and daily caloric intake followed the same as the extra small breed. Overall, the RF's explainability confirms that it has learned the same primary relationships identified by quantile regression.

Appendix Figure G.1. SHAP Summary Plot for Random Forest Model

G.3.2 XGBoost Results

The XGBoost model likewise placed the interaction between extra small breed and daily caloric intake, age, and caloric intake at the top of the SHAP importance list (Figure G.2). SHAP values associated with this interaction demonstrate that when extra small dogs receive fewer calories (represented by blue data points), the model predicts lower deviations in weight. The dog's age (measured in months) emerged as the second most important predictor.

Total daily caloric intake, as a standalone variable, ranked just below age in importance. Higher caloric intake (red points) generally increased the predicted weight deviation, while lower intake (blue points) exerted a downward pressure on the model output. This is consistent with the biological mechanism of caloric surplus contributing to weight gain.

Appendix Figure G.2. SHAP Summary Plot for XGBoost Model

G.3.3 Support Vector Regression Results

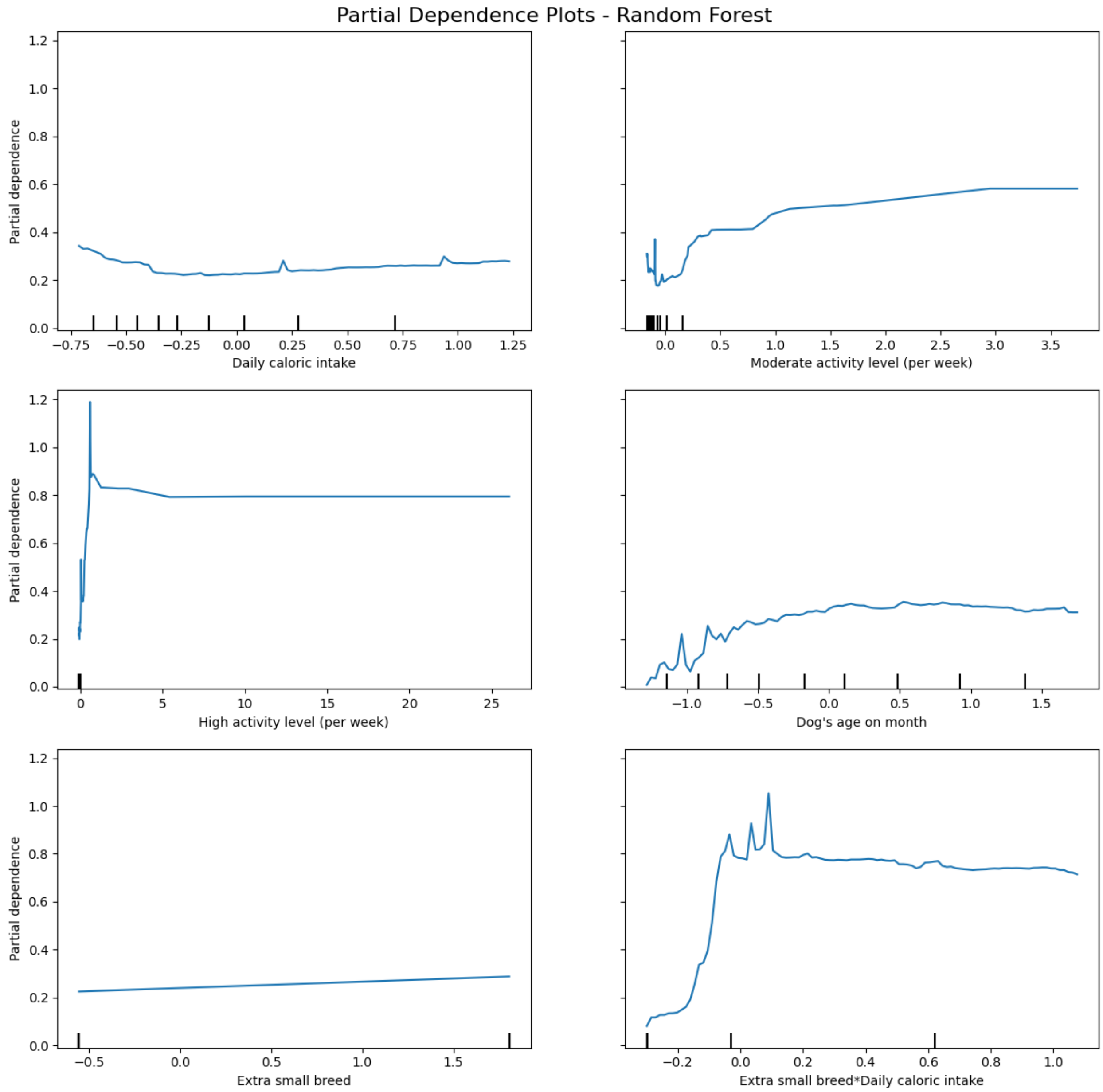
The SVM model was also analyzed with SHAP (Figure G.3). Despite being a very different algorithm, the SVM's top SHAP drivers were virtually the same set of features. Extra small breed, daily calories, and age. High-calorie dogs received consistently large positive SHAP contributions in the SVM, marking them as prone to high NWD predictions. Unlike the XGBoost model, where interaction terms played dominant roles, the SVM model placed individual features at the forefront of predictive influence. The variable extra small breed emerged as the top contributor to weight deviation. SHAP values indicate that being an extra small breed is associated with consistently higher positive contributions to predicted deviation from breed-standard weight. Similarly, dog age showed a positive impact, with older dogs showing substantial variation in predicted NWD.

Appendix Figure G.3. SHAP Summary Plot for SVM Model

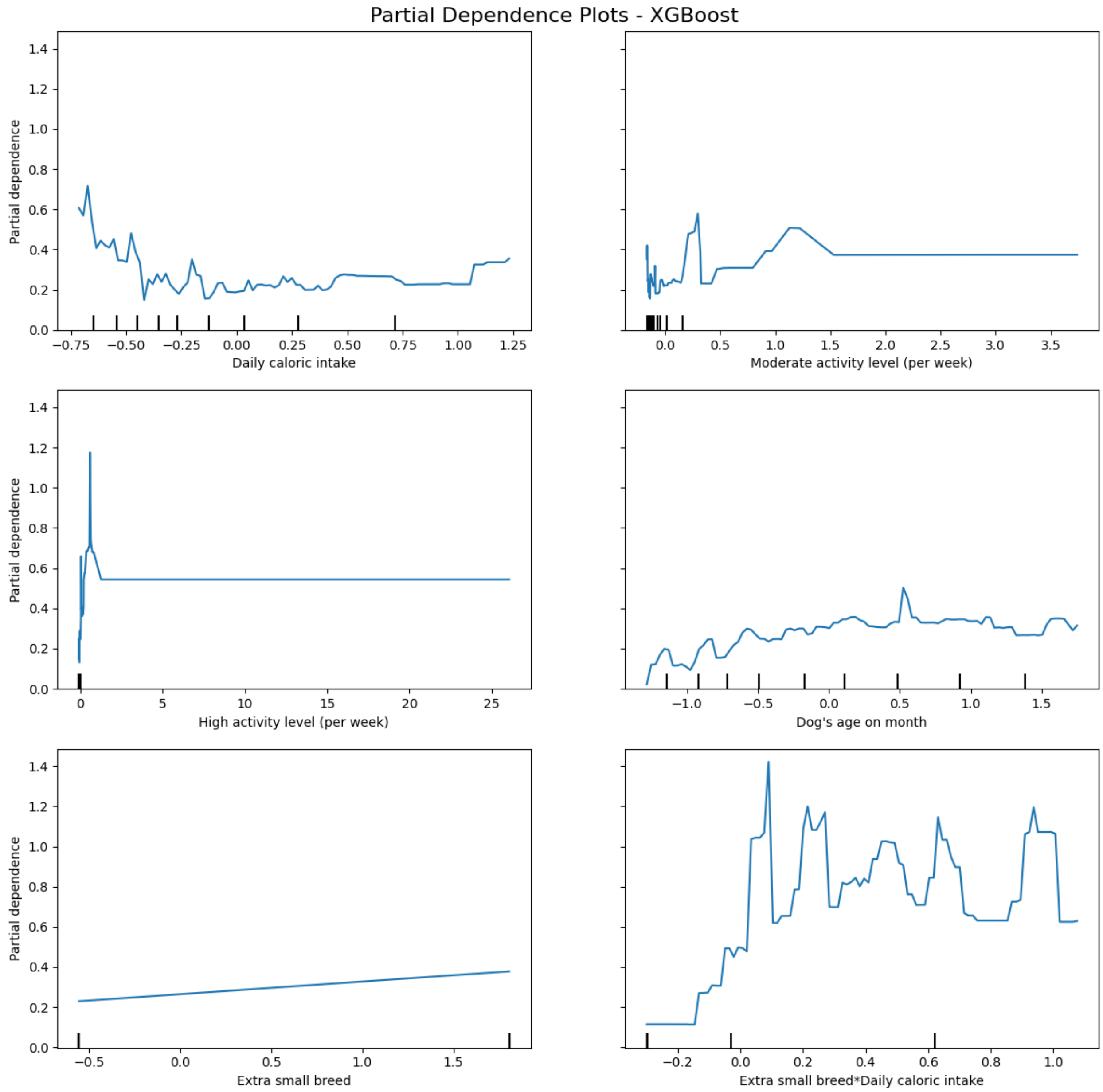
G.3.4 Partial Dependence Plot Results

To enhance the interpretability of the machine learning models and evaluate the consistency of feature effects across algorithms, Partial Dependence Plots (PDPs) for the top six features identified via SHAP analysis were examined. Figures G.4, G.5, and G.6 display PDPs generated from the three models. These plots illustrate the partial dependence of the fitted model on each selected predictor by showing how the model's average prediction changes as that predictor varies, while averaging over the observed values of the other predictors. The selected features, daily caloric intake, moderate and high activity levels, dog's age in months, extra small breed, and its interaction with daily caloric intake, represent the most influential predictors of the model outcomes.

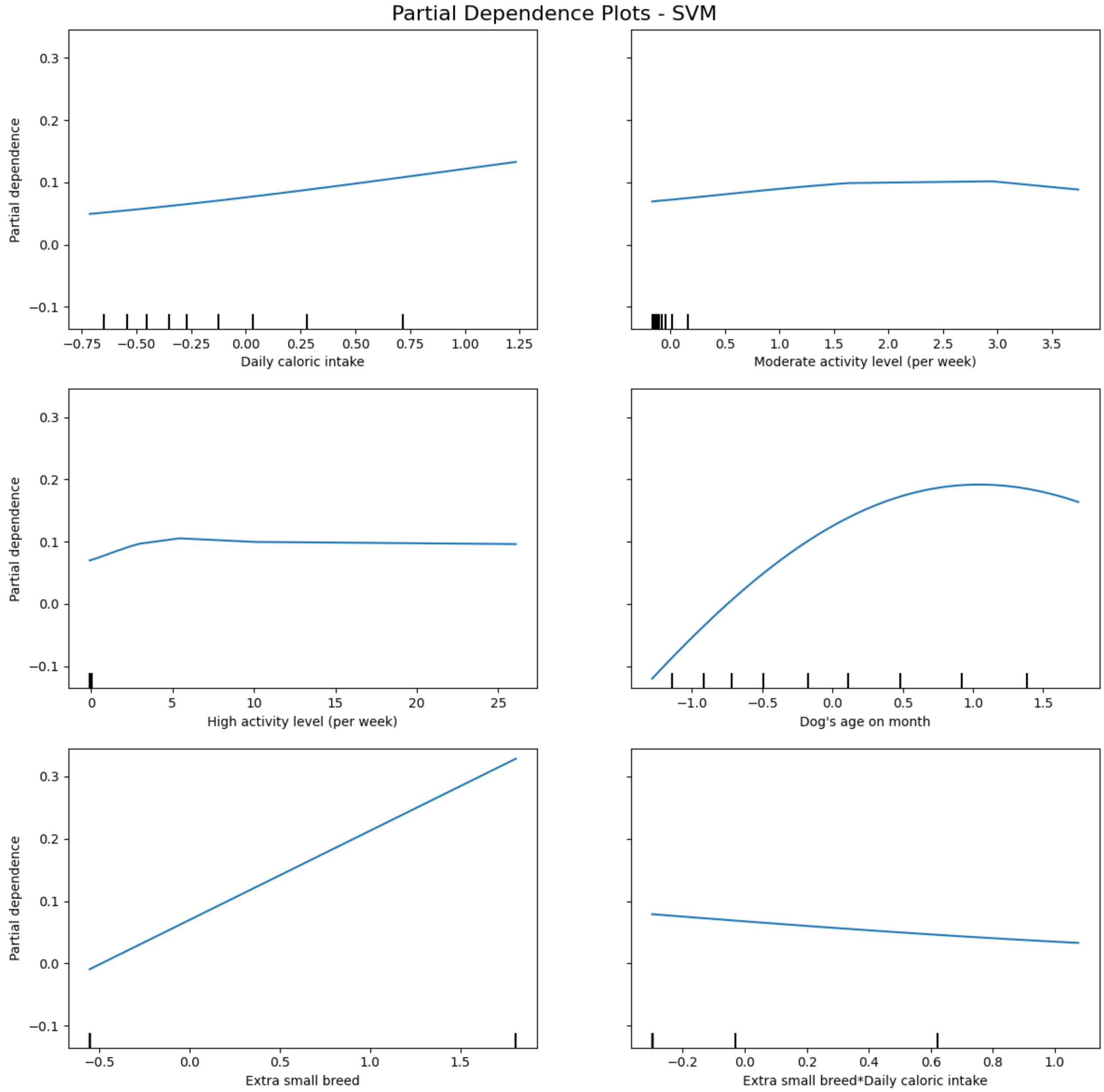
Appendix Figure G.4. PDP Plots - Random Forest



Appendix Figure G.5. PDP Plots - XGBoost



Appendix Figure G.6. PDP Plots - SVM



G.3.4.1 Daily Caloric Intake

In both RF and XGBoost models, the PDPs exhibit a non-linear U-shaped relationship. Initially, as daily caloric intake increases from low to moderate levels, NWD tends to decrease. However, beyond a certain threshold, increased caloric intake correlates with a sharp rise in NWD, indicating that excessive calorie consumption is associated with a higher risk of obesity.

This aligns with previous veterinary research highlighting overfeeding as a significant contributor to canine obesity (German, 2006; Laflamme, 2012).

Specifically, the RF model shows a steep drop in predicted NWD for caloric values moving from -0.75 to around -0.25 (standardized scale), followed by a gradual increase. Contrastingly, the SVM model suggests a more monotonic, linear increase in NWD with increasing daily caloric intake. All three models consistently indicate that caloric overconsumption contributes to elevated NWD, reinforcing the established link between energy intake and weight outcomes in dogs.

G.3.4.2 Moderate Activity Level (per week)

In the Random Forest model, the partial dependence curve for moderate physical activity declines at lower activity levels, particularly between approximately 0 and 1.5 on the plotted activity scale. This pattern indicates that the model predicts lower NWD as moderate activity increases over this range, after averaging over the observed values of the other predictors. Beyond this range, the curve becomes relatively flat, suggesting little additional change in predicted NWD at higher levels of moderate activity.

The XGBoost partial dependence plot shows a broadly similar pattern, although with greater variability. Predicted NWD generally declines over the lower range of moderate activity and then shows localized fluctuations and flatter regions. This suggests a nonlinear predictive relationship between moderate activity and NWD rather than a constant marginal effect.

These findings are strongly supported by existing veterinary research. According to the Association for Pet Obesity Prevention (APOP) and studies by Lund et al. (2006) and Courcier et al. (2010), moderate physical activity performed multiple times per week is one of the most effective strategies for maintaining ideal body condition in dogs.

Moreover, recent work by German (2016) highlights that the first steps in any obesity management plan should include activity tailored to a dog's size, age, and condition. A study by Mao et al. (2013) in the Journal of Animal Physiology and Animal Nutrition also emphasizes that even low-to-moderate intensity exercise significantly improves body composition, especially when paired with dietary management.

G.3.4.3 High Activity Level (per week)

In both the Random Forest and XGBoost models, the partial dependence function increases at very low levels of high-intensity activity and then levels off or declines slightly as activity increases. This pattern indicates a nonlinear relationship in the fitted models between high-intensity activity and the model's partial-dependence value.

In contrast, the SVR model displays a more linear increase in the partial-dependence value as high-intensity activity increases over the lower-to-moderate range, after which the relationship begins to level off.

White et al. (2011) highlighted that while physical activity is essential for managing weight, inappropriate matching of exercise intensity and caloric intake can reduce its effectiveness or even lead to unintended weight gain.

G.3.4.4 Dog's Age in Months

Across the three machine-learning models, the partial dependence plots indicate a nonlinear relationship between dog age and the fitted model predictions. In the Random Forest and XGBoost models, the partial-dependence value increases over the lower range of the age variable and then becomes relatively stable or declines slightly at higher values. The SVM model shows a smoother pattern, with the partial-dependence value initially increasing and then gradually leveling off or declining. These patterns suggest that age contributes nonlinearly to the models' predictions rather than having a constant relationship across its range.

G.3.4.5 Extra Small Breed

The partial dependence plots for the extra-small breed indicator show higher partial-dependence values when a dog is classified as extra-small compared with dogs outside this category. This pattern appears across the Random Forest, XGBoost, and SVM models, although the magnitude differs across models. The XGBoost model shows the largest difference in partial dependence between the extra-small and non-extra-small categories.

G.3.4.6 Interaction Between Extra Small Breed and Daily Caloric Intake

The partial dependence plots for the interaction between extra-small breed and daily caloric intake show a nonlinear pattern in the Random Forest and XGBoost models. In both models, the partial-dependence value increases relatively sharply over the lower-to-moderate range of the interaction variable and then becomes relatively stable at higher values. The SVM model shows a smoother and less pronounced increase in the partial-dependence value.

G.4 Comparison with the Quantile Regression Results

The quantile regressions and machine-learning models converge on the importance of total caloric intake, age, breed size, and breed-by-calorie interactions. The quantile estimates add information about where associations differ across the conditional NWD distribution, while the machine-learning models reveal nonlinear patterns that are not imposed in advance.

The approaches do not agree on every relationship. Exercise effects are mixed in the quantile models and vary across the PDPs. The calorie relationship is positive in the quantile regressions but nonlinear in the tree-based PDPs. Breed-size interactions also change direction across quantiles and algorithms.

Taken together, the evidence indicates that weight deviation is associated with a combination of calorie intake, dog age, reproductive status, food form, feeding decisions, and breed-related scaling.

G.5 Limitations of Machine-Learning Analysis

The machine-learning models are predictive rather than causal. SHAP values and Partial Dependence Plots describe how variables contribute to model predictions, but they do not establish that changing a variable would cause NWD to change.