

Nutrient utilization of food waste in broiler diets

by

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Abstract

A sequence of experiments were conducted in order to understand the nutrient profile and variability, evaluate the metabolizable energy and amino acid digestibility, and test the efficacy of utilizing food waste in broiler diets. It is estimated that about 30-40% of all food produced in the United States is discarded to a landfill. This contributes to greenhouse gas emissions, water usage, and other environmental impacts. In 2015, the Environmental Protection Agency released a hierarchy of alternative methods for the use of food waste. One of these proposed alternative methods was to use it as livestock feed. In the first experiment, food waste was separated into three streams: vegetable preparation (VP), main stream (MS), and mixed (MX). Vegetable preparation stream consisted of kitchen scraps such as pepper stems, onion peels, and melon rinds. Main stream consisted of any food that had been prepared that could not be reheated, repurposed, or donated to a local food pantry such as pasta, salad bar fixings, and desserts. The mixed stream was calculated based on the total weight of VP and MS. Waste was collected and sampled for 30 consecutive days from Kramer Dining Center at Kansas State University. Each daily sample was analyzed for nutrient contents. Vegetable preparation had a greater moisture and neutral detergent fiber content than MS and MX while ether extract and crude protein was less in VP ($P < 0.05$). Energy and total digestible nutrients were greater in MS than MX while VP was less than MX ($P < 0.05$). To determine nutrient variability, the standard deviation was measured. Dry matter and ether extract were significantly different among all three streams while MS and MX had an increased variability in gross energy, total digestible nutrients, and neutral detergent insoluble crude protein ($P < 0.05$). When food waste streams were mixed the variability and nutrient content were either similar, greater, or less than when the streams were separated depending on the nutrient. Additionally, despite having a high moisture content food waste has nutritive value and therefore the potential to be used in livestock diets.

In experiments 2 and 3, food waste was collected for another 30 consecutive days and split into weekly intervals resulting in four food waste products to determine nutrient variability, nitrogen-corrected apparent metabolizable energy (AMEn), and apparent ileal digestibility (AID). The weekly intervals consisted of product 1 (FW1; days 1-7), product 2 (FW2; days 8-14), product 3 (FW3; days 15-22), and product 4 (FW4; days 23-30). Each product was mixed with soybean meal (SBM) and extruded (InstaPro 2000-10 RTT, Des Moines, IA) to an in-barrel target

temperature of 140°C. Treatments consisted of the four food waste products, conventional SBM, extruded SBM (ESBM), and a common basal corn/SBM treatment was added to the AMEn experiment as a control. 420 and 360 one-day old male broilers (Ross 308, Sallisaw, OK, initial BW 38.5 g) were used in an 18-day study to determine AMEn and AID, respectively. Treatments were randomly assigned to cages and balanced by pen weight resulting in 10 cages per treatment with 6 birds per cage and given *ad libitum* access to feed and water. Fecal samples were collected on days 16-18 and birds were euthanized on day 18 via CO₂ for ileal collection. Metabolizable energy content of FW3 was greater ($P < 0.05$) than SBM, ESBM, FW1 and FW2 while FW4 was an intermediate product. Broilers fed FW1 and FW3 had an increase ($P < 0.05$) in AID of indispensable amino acids (AA), except Leu, when compared to FW2 while FW4 was intermediate. In conclusion, extruded food waste successfully served as a nutrient source for broilers. Food waste products AMEn content were either similar or greater than SBM and the AID of AA's differed depending on the product and the AA to be either similar or less than SBM.

In experiments 4 and 5, the same food waste from experiments 2 and 3 were composited across the 30 days and extruded. Additionally, to create a value-added food waste product the food waste was fermented for 14 days. Treatments consisted of SBM, ESBM, composite food waste (CFW), and SBM + fermented food waste (SFFW). A common basal corn/SBM treatment was added to the AMEn trial as a control. 300 and 240 one-day old male broilers (Ross 308, Sallisaw, OK, initial BW 39.4 g) were used in a 21-day study to determine AMEn and AID, respectively. Treatments were randomly assigned to cages and balanced by pen weight resulting in 10 cages per treatment with 6 birds per cage and given *ad libitum* access to feed and water. Fecal samples were collected on days 18-20 and birds were euthanized on day 21 via CO₂ for ileal collection. Composite food waste and SFFW AMEn content was similar to SBM ($P > 0.05$). Broilers fed CFW and SBM had a greater ($P < 0.05$) AID of indispensable AA's compared to SFFW, except Met. In conclusion, food waste, either extruded or fermented, successfully served as a nutrient source for broilers. Both forms of food waste AMEn were similar to SBM and AID of AA's were either similar or less than that of SBM depending on the form of food waste.

Experiment 6 measured body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR) of CFW (10 and 30%), fermented food waste (FFW; 1.5 and 5.5%), a common basal corn/SBM diet, and a basal diet with a commercial additive (astaxanthin or antibiotic). 420 one-

day-old male broilers (Ross 308, Sallisaw, OK, initial BW 37.7 g) were fed treatments for 21 days and given *ad libitum* access to feed and water. Treatments were randomly assigned to cages balanced by pen weight resulting in 10 cages per treatment with 6 birds per cage. Pen and feeder weights were recorded on days 0, 7, 18, and 21. All inclusion levels of CFW and FFW had similar ($P > 0.05$) BWG to the basal diet while birds fed 5.5% FFW increased FI compared to basal, CFW inclusions, and 1.5% FFW ($P < 0.05$). Birds fed either 10% CFW or 5.5% FFW improved ($P < 0.05$) the FCR compared to birds fed 30% CFW with 1.5% being an intermediate additive. Overall, growth performance varied depending on the form of food waste fed (extruded or fermented) and the inclusion level in the diet.

Keywords: food waste, broilers, amino acid digestibility, nutrient variability, apparent metabolizable energy, feedstuffs

Table of Contents

List of Tables	vii
Acknowledgements.....	ix
Chapter 1 - Nutrient evaluation of dining center food waste and comparison to monogastric and ruminant feedstuffs	1
Chapter 2 - Nitrogen corrected apparent metabolizable energy and apparent ileal digestibility of amino acids of thermally processed food waste for broilers	19
Chapter 3 - Nitrogen corrected apparent metabolizable energy, apparent ileal digestibility of amino acids, and growth performance of thermally processed and fermented food waste for broilers	37
References	62

List of Tables

Table 1.1 Descriptive statistics of nutrients measured in each of the three food waste streams. .	14
Table 1.2 Effect of food waste collection stream on nutrient content of food waste	16
Table 1.3 Effect of stream on the variation (standard deviation) in nutrient concentration of food waste	17
Table 1.4 Comparison of food waste streams to common cattle and swine feedstuffs aggregating all nutrients in an absolute relative difference metric ^{1,2,3,4,5}	18
Table 2.1 Chemical analysis of soybean meal (SBM), extruded soybean meal (ESBM) ¹ , and extruded food waste products ² (FW1, FW2, FW3, FW4; as-is basis) ³	29
Table 2.2 Diet composition formulated to determine apparent ileal digestibility (AID) of food waste products ¹ (FW1, FW2, FW3, and FW4), extruded soybean meal ² (ESBM), and soybean meal (SBM), balanced at 20% crude protein.	30
Table 2.3 Chemical analysis of experimental diets to determine apparent ileal digestibility (AID) of food waste products ¹ (FW1, FW2, FW3, and FW4), extruded soybean meal ² (ESBM), and soybean meal (SBM; as-is basis) ^{3,4}	31
Table 2.4 Diet composition formulated to determine apparent metabolizable energy (AME) of food waste products ¹ (FW1, FW2, FW3, and FW4), extruded soybean meal ² (ESBM), and soybean meal (SBM) ³	32
Table 2.5 Nutrient content of raw food waste products before extrusion, as-is ^{1,2}	33
Table 2.6 Apparent ileal digestibility coefficients of amino acids from food waste ¹ (FW1, FW2, FW3, and FW4), extruded soybean meal ² (ESBM), and soybean meal (SBM) in 18-d old broilers. ^{3,4,5}	34
Table 2.7 Apparent ileal digestibility content of amino acids in food waste products ¹ (FW1, FW2, FW3, and FW4), extruded soybean meal ² (ESBM), and soybean meal (SBM) when fed to 18-d old broilers. ^{3,4,5}	35
Table 2.8 Effect of food waste products ¹ (FW1, FW2, FW3, and FW4), extruded soybean meal ² (ESBM), and soybean meal (SBM) on apparent metabolizable energy (AME) in 18-d old broilers. ³	36
Table 3.1 Chemical analysis of soybean meal, extruded soybean meal, extruded food waste, and fermented food waste product used (as-is basis; experiments 1 and 2) ¹	52

Table 3.2 Diet composition formulated to determine apparent metabolizable energy (AME) of composite food waste and soybean meal (experiment 1) ¹	53
Table 3.3 Diet composition formulated to determine apparent ileal digestibility (AID) of soybean meal, extruded soybean meal, extruded food waste, and fermented food waste product balanced at 20% crude protein (experiment 2) ¹	54
Table 3.4 Chemical analysis of experimental diets to determine apparent ileal digestibility (AID) of soybean meal, extruded soybean meal, extruded food waste, and fermented food waste product (as-is basis; experiment 2) ^{1,2,3}	55
Table 3.5 Diet composition formulated to determine growth performance of male broilers fed composite food waste and fermented food waste (experiment 3) ¹	56
Table 3.6 Effect of composite food waste and soybean meal on apparent metabolizable energy (AME) in 21-d old broilers. ^{1,2,3}	58
Table 3.7 Effect of composite food waste and soybean meal on apparent ileal digestibility coefficients of amino acids in 21-d old broilers. ^{1,2,3,4}	59
Table 3.8 Apparent ileal content of amino acids in food waste products and soybean meal when fed to 21-d old broilers. ^{1,2,3,4}	60
Table 3.9 Effect of composite food waste and fermented food waste on growth performance in 21-d old broilers. ^{1,2,3}	61

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professional, and for all the inside jokes and memories. You all truly made coming into work everyday something to look forward to.

Chapter 1 - Nutrient evaluation of dining center food waste and comparison to monogastric and ruminant feedstuffs

Abstract

Approximately 30-40% of all food produced in the United States is not used and eventually thrown away. One way to redirect food waste away from landfills is to use it for animal feed. Therefore, the objective of this study was to identify and analyze nutrient composition and variability of university dining hall food waste streams as well as compare with common feedstuffs used in ruminant and monogastric diets. Food waste was categorized into two initial streams; mainstream (MS) from the serving line and vegetable preparation (VP) from the kitchen. Food waste was collected from the Kramer Dining Center, Kansas State University for 6 consecutive weeks resulting in 30 daily samples. Waste was weighed and ground to a homogenous particle size using a meat grinder for MS or a food processor for VP. Daily samples of MS and VP were analyzed for nutrient values. The MS and VP results were combined to calculate the nutrient profile of a hypothetical mixed food waste stream (MX) composited by total weight. Data were analyzed using R statistical software (v 4.2.2). Moisture and neutral detergent fiber were greater in VP ($P < 0.05$) while ether extract was less when compared to MS and MX. However, crude protein was greater ($P < 0.05$) in MS and MX streams compared to VP. The total digestible nutrients, gross energy, digestible energy, and metabolizable energy were greater in MS food waste than MX which was also greater than VP ($P < 0.05$). For variability of nutrient content as measured by standard deviation, neutral detergent fiber, nitrogen corrected neutral detergent fiber, acid detergent insoluble crude protein, crude protein, ash, lignin, and digestible and metabolizable energy had similar variabilities among streams ($P > 0.05$). However, dry matter and ether extract had contrasting ($P < 0.05$) variation across streams with

MS having a greater standard deviation than MX, and MX being greater than VP. Standard deviation increased ($P < 0.05$) in MS and MX streams for neutral detergent insoluble crude protein, total digestible nutrients, and gross energy when compared to VP. In conclusion, when food waste streams were mixed, the nutrient content and variability either remained similar, greater, or less than the separate streams depending on the nutrient. Despite having 70-80% moisture, dining hall food waste does have nutritive value and the potential to be included in ruminant and monogastric diets. Further research needs to be done to understand the value of including it in animal diets.

Keywords: food waste, feedstuffs, monogastric, ruminant, nutrient variability

Introduction

Food waste is commonly thought of to be edible food that was intended for human consumption and for various reasons was not utilized and discarded (Giroto et al., 2015). Approximately 30 to 40% of all food in the United States is not used and eventually ending up in a landfill, estimated to be about 133 billion pounds (USDA). This contributes to the unnecessary use of fresh water and fuel as well as emitting greenhouse gases like methane and carbon dioxide from decomposing food without any human benefit (Hall et al., 2009a). The Environmental Protection Agency created a Food Recovery Hierarchy to help mitigate food waste and illustrate how to redirect food waste for greater utilization (US EPA, 2015). Part of this hierarchy is the option to use food scraps and waste to feed animals. Currently, it is being reported that only about 12% of retail waste and 1% of restaurant waste is being recovered for animal feed while 45% and 97% of food waste from retailers and restaurants, respectively, is being disposed of in landfills (Dou et al., 2016a; FWRA_BSR_Tier3_FINAL.pdf). In one study where different sources along the food supply chain were analyzed for nutritional value waste had greater

nutritional value than corn or soybean meal but was also more variable (Fung, Urriola, Baker, et al., 2019a). The vast percentage of waste being generated daily that goes directly to the landfill and the high variability led us to focus on food waste from a cafeteria dining hall.

Cattle are already great recyclers because of the large range of feedstuffs that they can process and use with the help of rumen microbial fermentation. Because of this, based on location and availability, they can utilize nutrients from vegetable and fruit scraps and even rejected candy (Sukri et al., 1999; Besharati and Taghizadeh, 2009; Nelson, 2010). When looking at the potential use in swine diets, a study was conducted at the University of Minnesota by Fung et al. (2019b) to test several different sources of food waste in a digestible and metabolizable energy study (DE and ME). They found that one source, what they characterized as “supermarket waste” had greater energy concentration than corn when fed to swine (5,071 and 3,928 kcal/kg DE and 4,922 and 3,875 kcal/kg ME, waste and corn respectively). Another source they used, “fruit and vegetable waste”, had lower energy concentration than corn (2,570 and 3,928 kcal/kg DE and 2,460 and 3,875 kcal/kg ME, waste and corn respectively) suggesting that some waste sources could be beneficial energy sources for use in swine diets (Fung, Urriola, & Shurson, 2019b). However, there has been little research on exactly what nutrients are available to the animal and how, if at all, food waste compares to feedstuffs that are already commonly used. In addition, there are challenges with transportation, processing, and nutrient variability. For food waste to be included in animal diets, the unpredictability and variation of types of food can be an issue for feed mills from a processing and quality assurance standpoint, but also an issue for nutritionists formulating diets. Therefore, the objective of this study was to determine nutritional composition and variability of different cafeteria food waste streams and compare nutritional value to common monogastric and ruminant feedstuffs. We hypothesized that there

would be a large range of nutritional variability day to day between streams and that separating the MS and VP streams would help reduce the amount of nutritional variability. Additionally, waste such as vegetables and fruits would be more characteristic of high-fiber feedstuffs while waste such as prepared, cooked meals would relate more to high protein and high starch feedstuffs.

Materials and methods

Food Waste Collection

Food waste was collected from the Kramer Dining Center, Kansas State University for 6 consecutive weeks resulting in 30 daily samples. Food waste was initially identified and split into two categories or streams; vegetable preparation (VP) from the kitchen and main (MS) from the serving line. The VP consisted of any food scraps leftover from preparing meals or fruit and vegetables that may have gone bad such as onion peels, pepper stems, whole apples, grapes, or celery stalks. This also consisted of seasonal foods such as melon rinds and pineapple tops. The MS consisted of finished foods that had been out on the buffet line for students and either could not be reheated, repurposed, or donated to a local food pantry. This also consisted of food that could have been burned during the cooking process or the recipe was not followed correctly. Some examples of MS food are combinations of pizza, pasta, rice, scrambled eggs, salad bar fixings, and various desserts. During the collection period, waste was kept separate at the dining center according to streams VP and MS. Each day, food waste was brought back to the lab where it was weighed and ground to a homogenous particle size using either a food processor for VP or a meat grinder (LEM #8, 0.5 HP) for MS. The VP was immediately dried in a 13°C oven to a constant weight and ground (Bliss hammermill, Ponca City, OK, 6 mm screen) for a more uniform particle size. Subsamples were taken from MS, dried in a 13°C oven, and ground

(Hamilton Beach Coffee Grinder). Daily VP and MS samples were analyzed for dry matter (DM, AOAC 930.15), acid detergent insoluble crude protein (ADICP, ANKOM Technology Method 14 and Leco TruMac N Macro), neutral detergent insoluble crude protein (NDICP, ANKOM Technology Method 15 and Leco TruMac N Macro), neutral detergent fiber (NDF, ANKOM Technology Method 15), lignin (ANKOM Technology Method 9), and crude fat (EE, AOCS AM 5-04) at Dairy One Forage Testing Laboratoryl (Ithaca, NY). Ash (AOAC 942.05), crude protein (CP, AOAC 990.03) using a nitrogen analyzer (FP928, LECO Corporation, St. Joseph, MI), and gross energy (GE, Parr 6200 Calorimeter, Parr Instrument Company, Moline, IL) were analyzed at Kansas State University. Nutrient concentrations from VP and MS were used to calculate a weighted value for a hypothetical mixed food waste stream (MX) as follows:

$$MX (Z \text{ nutrient}) = \left(\frac{\text{Weight of MS}}{\text{Total daily weight}} \right) * \% \text{ of MS } Z \text{ nutrient} + \left(\frac{\text{Weight of VP}}{\text{Total daily weight}} \right) * \% \text{ of VP } Z \text{ nutrient}$$

Nitrogen corrected neutral detergent fiber (NDFn), total digestible nutrients (TDN), digestible energy (DE), and metabolizable energy (ME) were calculated using the following equations:

$$NDFn = NDF - NDICP \text{ (Weiss et al., 1992)}$$

$$TDN = 0.98 * (100 - NDFn - CP - Ash - EE) + e^{(-0.012 * ADICP)} * CP + 2.25 * (EE - 1) + 0.75 *$$

$$(NDFn - Lignin) * \left(1 - \left(\frac{Lignin}{NDF} \right)^{0.667} \right) - 7 \text{ (Weiss et al., 1992)}$$

$$DE = 4168 - 9.1 * Ash + 1.9 * CP + 3.9 * EE - 3.6 * NDF \text{ (National Research Council, 2012)}$$

$$ME = 4194 - (9.2 * Ash) + (1.0 * CP) + (4.1 * EE) - (3.5 * NDF) \text{ (National Research Council, 2012)}$$

Comparing Common Ruminant and Monogastric Feedstuffs

In order to compare food waste streams to common ruminant and monogastric feedstuffs, nutrient composition of 29 commonly used feedstuffs (Table 4) were sourced from the Nutrient Requirements of Beef Cattle: Eighth Revised Edition (The National Academies of Science,

Engineering, and Medicine, 2016) and the Nutrient Requirements of Swine: Eleventh Revised Edition (National Research Council, 2012). Nutrient concentrations (CP, ash, EE, lignin, NDF, TDN (cattle), and ME (swine)) for each feedstuff were weighted to each food waste stream's respective nutrient resulting in the absolute relative difference between each nutrient in the feedstuff and food waste stream then summed to give an aggregated relative difference for each food waste stream by feedstuff. The feedstuff with the aggregated absolute relative difference closest to zero was considered the most comparable to the food waste stream. The following equation was used to determine the absolute relative difference of each nutrient then summed together to create an aggregate relative difference for each feedstuff.

$$Relative\ difference\ (z) = \frac{Food\ waste\ (z) - Feedstuff\ (z)}{Food\ waste\ (z)}$$

Statistical Analysis

All data were analyzed using R statistical software (version 4.2.2). Descriptive statistics were computed using the *describe* function of the *psych* package. The *leveneTest* function of the *car* package was used to test for homogeneity of variance and a pairwise comparison of variances was performed using the *pairwise.var.test* in the *RVAidMemoire* package. The *gls* function of the *nlme* package was used to compare nutrient concentrations of food waste streams. Due to unequal variances, the *varIdent* function was used to generate variance coefficients which were used to describe the within-group heteroscedasticity structure in the *gls* model. The *joint_tests* and *emmeans* function of the *emmeans* package were used to generate an ANOVA table from the *gls* model object and calculate the least square means using a Tukey adjustment and the Kenward-Roger approximation. Means and variances were considered significant at $P \leq 0.05$.

Results and Discussion

Analysis of Food Waste Streams

Food waste was separated into three streams for two initial reasons. First, the Food and Drug Administration passed the Modernization Act of 1997 which prohibits the use of mammalian protein products being fed back to ruminant animals to reduce the risk of Bovine Spongiform Encephalopathy (BSE) infection of additional animals (*PLAW-105publ115.Pdf*, 1997). There are exemptions, however, which include meat products that have been cooked for the use of human consumption (*NGFA-BSE-Prevention-Feed-Guidance.pdf*). This is because the meat products that were intended for human consumption have been inspected, cooked, and further processed and are considered to pose little risk. So, while food waste is considered exempt from this law, there is no way to guarantee that the food did not come into contact with other meat products or trimmings that were not cooked. Additionally, producers understandably might not want to take that risk for fear of infection and public opinion even if it could be guaranteed that it was all cooked thoroughly. And secondly, separating the streams improves processing efficiency. For example, the VP stream was greater in NDF content than the MS source ($P < 0.05$) and therefore waste could not be ground in a meat grinder as was done with MS. The two streams required different equipment that could handle the two extremes of fiber content.

Table 1 illustrates each of the three waste streams broken down by their average nutrient content, standard deviation, and minimum and maximum value on a dry matter basis. Nutrient values reported for this study were slightly increased from previously conducted research (Fung, Urriola, Baker, et al., 2019a). However, a similar study collecting cafeteria food waste at the State University of New Jersey found very similar nutrient composition to the reported values in

Table 1 showing that location or palate variability could be a potential factor when considering its usefulness in a livestock diet (Westendorf et al., 1998). Moisture content and EE had wide ranges of reported concentrations that could cause concern. All three waste streams contained high moisture that ranged considerably between the minimum and maximum. For example, main stream fluctuated from 44.4 to 93.9 % moisture while VP only spanned from 81.0 to 96.0 % moisture. Salmonella and other bacteria rapidly multiply in feed that has a water activity level of 40% or greater (Carlson and Snoeyenbos, 1969). This immediately causes concern for rapid spoilage and the need for prompt processing methods. Another nutrient worth noting is the amount of EE in the streams, specifically the MS, which ranged 5.9 -68.8%. While EE is a valuable and expensive component to formulating diets, if it is consistently high it may limit the potential use of food waste. Increasing supplemental fat in feedlot finishing diets to 8% has been shown to decrease ruminal and total tract digestion of organic matter, ADF, and fat which in turn can reduce feed intake due to increased amounts of ruminal solid retention (Zinn, 1989). Thus, finishing diets are commonly formulated at or below 6% total fat. Another factor to consider when potentially feeding high levels of fat is the type of fat. Pigs fed beef tallow have firmer bellies than pigs fed soybean oil, unsaturated fats, which also in turn impacts the marketability of the product (Apple et al., 2007). Most dishes are prepared with vegetable oils that have relatively high concentrations of polyunsaturated fat, and thus, is a concern when using food waste in swine diets. There are certain fat capturing processing methods that are used by biodiesel industries which mainly source soybeans for their oil. These methods could potentially be implemented with food waste to capture value for other markets, however, an economic analysis would be needed to determine if a fat expelling step would be beneficial or detrimental to the overall value of the food waste as an energy source. Another limitation of the ability to feed food

waste is the high fiber content VP, specifically NDF and NDFn. Lignin, however, was not different ($P > 0.05$) among the three waste streams. High fiber feedstuffs and diets for swine are known to lower energy density and digestibility, decrease protein digestibility, and increase the passage rate resulting in less time for digestion and absorption of nutrients (Giusi-Perier et al., 1989; Potkins et al., 1991; Jørgensen et al., 1996; Kerr and Shurson, 2013).

Table 2 compares the nutrient concentrations of the food waste streams. Mainstream and MX had greater ($P < 0.05$) concentrations of DM, EE, NDICP, and CP than VP. Meanwhile, VP had a greater ($P < 0.05$) concentration of ash than MS and MX, and greater ($P < 0.05$) amounts of NDF and NDFn than MX which also had a greater ($P < 0.05$) amount than MS. In both equations by Noblet & Perez (1993) that were used to determine digestible and metabolizable energy, ash and NDF, which were greater ($P < 0.05$) in VP, were subtracted from the total energy value while CP and EE, which were greater in MS and MX, were added to the total energy value. Not surprisingly, MS had greater ($P < 0.05$) energy (GE, DE, and ME) and TDN concentrations than MX, and MX had greater ($P < 0.05$) energy and TDN than VP. There was no difference between the three streams for ADICP ($P = 0.641$), but MS had less ($P < 0.05$) lignin than VP while MX was intermediate.

Table 3 compares the variability in nutrient content of food waste streams. The MS had greater ($P < 0.05$) standard deviation compared to VP, and MX and MX being increased compared to VP for both DM and EE. The VP had the lowest standard deviation compared to MS and MX for NDICP, TDN, and GE ($P < 0.05$). However, the standard deviation for NDF, NDFn, CP, ash, lignin, ADICP, DE, and ME were not different ($P > 0.05$).

Common Feedstuffs Comparison

To further test compatibility of feedstuffs that are commonly used to the food waste streams, 29 feedstuffs were identified and their aggregated absolute relative difference was calculated and ranked (Table 4). It is important to note that each feedstuff evaluation had a different amount of submitted samples thus creating slight variability between sources. This led to the decision to keep feedstuffs and sources separate by species to keep relevancy. The lowest aggregated absolute relative difference was considered the most similar to the respective food waste stream while the highest difference was considered the least similar to the respective food waste stream. Vegetable preparation stream was most similar to citrus pulp for both cattle and swine (aggregated relative difference of 1.40 and 2.04, respectively). More specifically, citrus pulp was most common to VP because of its ash (0.21 [cattle] and 0.10 [swine] relative difference), NDF (0.14 [cattle] and 0.11 [swine] relative difference), lignin (0.09 relative difference for cattle), TDN (0.07 relative difference for cattle), and ME (0.04 relative difference for swine) concentrations. CP (0.55 and 0.52 relative difference for cattle and swine, respectively) and EE (0.35 and 0.27 relative difference for cattle and swine, respectively) were the least compatible nutrients.

The most compatible cattle feedstuff for MS and MX was bakery by-product (aggregated relative differences of 2.54 and 1.84, respectively). Of the nutrients, lignin (0.03 [MS] and 0.07 [MX] relative difference) and TDN (0.18 [MS] and 0.11 [MX] relative difference) were the two most compatible nutrients followed by ash (0.38 [MS] and 0.46 [MX] relative difference) and CP (0.39 [MS] and 0.36 [MX] relative difference). Ether extract of bakery by-product was only 0.60 relative difference for MS and 0.50 relative difference for MX. However, NDF relative difference was much greater in the bakery by-product than the MS and MX (0.95 and 0.35, respectively). On the other hand, the least compatible cattle feedstuff when compared to MS, VP,

and MX waste streams was cottonseed hulls (aggregated relative difference of 21.39, 10.93, and 17.56, respectively). The two main factors contributing to the difference with cottonseed hulls were the NDF and lignin content. The NDF concentration of cottonseed hulls is 11, 3, and 7 times that of the MS, VP, and MX streams, respectively. Additionally, lignin was 9, 7, and 9 times greater than the MS, VP, and MX streams, respectively. Meanwhile, nutrients such as CP, TDN, EE, and ash were all less than 50% of their respective waste stream nutrient concentration with three exceptions: the ash concentration being 55% of the MS ash content, the TDN concentration being 56% of the VP TDN content, and the EE concentration being 72% of the VP EE content.

Other cattle feedstuffs that came comparatively close (less than +2 points from the lowest value mentioned above) for all three food waste streams were grain sorghum, hominy feed, steam flaked corn, and wheat. Other feedstuffs that were comparable to VP but not MS or MX were corn gluten feed, corn silage, oats, and wheat bran and middlings, again, all less than +2 points from the value of citrus pulp. These feedstuffs had similar relative differences in TDN and EE concentrations to VP, with the exception of EE in oats.

The most compatible swine feedstuff for MS and MX streams was wheat (aggregated relative difference of 3.25 and 2.66, respectively). Of the nutrients, CP (0.25 [MS] and 0.20 [MX] relative difference) and ME (0.28 [MS] and 0.21 [MX] relative difference) were the two most compatible nutrients followed by lignin (0.47 [MS] and 0.49 [MX] relative difference) and NDF (0.68 [MS] and 0.16 [MX] relative difference) which exceeded the MS and MX NDF content. The two least compatible nutrients of wheat were ash (0.66 [MS] and 0.70 [MX] relative difference) and EE (0.92 [MS] and 0.90 [MX] relative difference). On the other hand, the least compatible swine feedstuff was whole cottonseed for all three waste streams (aggregated relative

difference of 12.50, 10.02, and 9.82 for MS, VP, and MX, respectively). The NDF content of whole cottonseed is 7, 2, and 5 times that of the NDF content of MS, VP, and MX waste streams, respectively. Additionally, lignin content of wheat is 5, 4, and 5 times that of lignin in the MS, VP, and MX waste streams, respectively. Crude protein of wheat exceeded all three waste streams (0.19 [MS], 0.69 [VP], and 0.25 [MX] relative difference). Ash (0.34 [MS], 0.54 [VP], and 0.42 [MX] relative difference), EE (0.30 [MS], 3.73 [VP], and 0.12 [MX] relative difference), and ME (0.30 [MS], 0.11 [VP], and 0.23 [MX] relative difference) content were all less than their respective food waste streams nutrient content with the exception of EE which was 4 times that of VP EE content and ME of VP (3207 vs. 2895 kcal/kg).

Additional swine feedstuffs worth noting that are similar, but not the closest, to all three waste streams are grain sorghum, ground corn, and oat groats, all less than +1.5 from citrus pulp and wheat as mentioned earlier. Soybean meal was a close comparison to the MS and MX streams, but not VP. Meanwhile, wheat, while not the most comparable to VP, was less than +0.5 from citrus pulp. Other feedstuffs that came very close in comparison to VP were wheat bran, wheat middlings, oats, and corn gluten feed notably for the similarities in CP, EE, and ME.

Conclusion

In conclusion, this study evaluated food waste streams collected by like foods in order to determine the effect of collecting diverse food types separately or together on the nutrient profile. Day to day there is a large range of nutrient concentrations that are possible, but when focusing on the amount of variation it becomes more manageable. However, it seems that by keeping the streams separated by MS and VP it either had no difference or decreased the standard deviation depending on the nutrient. Mainstream food waste was characteristic of high CP and energy while VP was most characteristic of high fiber, specifically NDF and NDFn. This

indicates that food waste could be potentially used as a viable feed alternative. More research needs to be done in terms of digestibility, palatability, and ingredient processing (moisture removal) to determine optimal use of food waste.

Table 1.1 Descriptive statistics of nutrients measured in each of the three food waste streams.

Nutrient	Main Stream				Vegetable Prep Stream				Mixed Stream			
	Average	Std	Min	Max	Average	Std	Min	Max	Average	Std	Min	Max
		Dev.				Dev.				Dev.		
Moisture, %AF	72.23	10.72	44.42	93.92	88.25	3.49	81.01	96.02	76.74	7.09	52.50	90.99
Dry Matter, %AF	27.77	10.72	6.08	55.58	11.75	3.49	3.98	18.99	23.26	7.09	9.01	47.50
Ether Extract,												
%DM	25.38	10.38	5.90	68.80	3.77	1.36	1.53	6.38	20.18	6.84	4.24	38.11
NDICP ¹ , %DM	3.72	1.55	1.20	6.60	1.82	0.74	0.60	3.50	3.32	1.23	1.11	5.74
NDF ² , %DM	7.13	5.40	2.40	30.50	21.11	3.93	10.30	27.90	10.27	4.38	4.59	24.34
NDFn ³ , %DM	3.41	5.50	0.10	26.70	19.29	3.76	8.70	26.20	6.95	4.83	2.07	21.65
Crude Protein,												
%DM	21.66	5.72	4.08	32.43	15.19	4.06	5.13	23.25	20.47	3.81	9.51	28.61
Ash, %DM	6.56	2.80	3.06	17.18	9.42	2.83	4.78	17.24	7.50	2.44	5.12	15.33
Lignin, %DM	2.06	1.01	0.70	6.00	2.68	0.98	1.40	5.80	2.14	0.73	1.04	4.93
ADICP ⁴ , %DM	1.07	0.27	0.50	1.70	0.99	0.44	0.40	2.50	1.07	0.21	0.72	1.60
TDN ⁵ , %DM	112.10	13.53	74.58	161.71	74.91	3.10	69.66	82.07	103.09	10.32	74.83	119.90
GE ⁶ , kcal/kg DM	5464.27	388.51	4370.05	6519.11	4268.63	136.34	3951.11	4627.67	5175.63	344.86	4057.58	5618.90
DE ⁷ , kcal/kg DM	4715.80	538.58	2765.95	6027.64	2986.70	258.06	2495.03	3568.27	4291.54	485.87	2877.37	4821.76
ME ⁸ , kcal/kg DM	4598.24	559.60	2708.31	6168.79	2895.25	281.88	2369.79	3559.19	4176.47	489.76	2767.16	4713.40

¹Neutral Detergent Insoluble Crude Protein (NDICP)

²Neutral Detergent Fiber (NDF)

³nitrogen free Neutral Detergent Fiber (NDFn)

⁴Acid Detergent Insoluble Crude Protein (ADICP)

⁵Total Digestible Nutrients (TDN)

⁶Gross Energy (GE)

⁷Digestible Energy (DE)

⁸Metabolizable Energy (ME)

Table 1.2 Effect of food waste collection stream on nutrient content of food waste

Item	MS	SEM	VP	SEM	MX	SEM	<i>P-value</i>
Dry Matter, %AF	27.77 ^a	2.063	11.75 ^b	0.637	23.26 ^a	1.364	<0.05
Ether Extract, %DM	25.38 ^a	1.997	3.77 ^b	0.249	20.18 ^a	1.316	<0.05
NDICP ¹ , %DM	3.72 ^a	0.299	1.82 ^b	0.136	3.32 ^a	0.237	<0.05
NDF ² , %DM	7.13 ^c	0.883	21.11 ^a	0.838	10.27 ^b	0.883	<0.05
NDFn ³ , %DM	3.41 ^c	0.908	19.29 ^a	0.861	6.95 ^b	0.908	<0.05
Crude Protein, %DM	21.70 ^a	0.883	15.20 ^b	0.837	20.50 ^a	0.883	<0.05
Ash, %DM	6.56 ^b	0.52	9.42 ^a	0.493	7.50 ^b	0.52	<0.05
Lignin, %DM	2.06 ^b	0.177	2.68 ^a	0.168	2.14 ^{ab}	0.177	<0.05
ADICP ⁴ , %DM	1.067 ^a	0.052	0.987 ^a	0.081	1.07 ^a	0.0397	0.641
TDN ⁵ , %DM	112.10 ^a	2.605	74.90 ^c	0.566	103.10 ^b	1.986	<0.05
GE ⁶ , kcal/kg DM	5464 ^a	74.8	4269 ^c	24.9	5176 ^b	66.4	<0.05
DE ⁷ , kcal/kg DM	4716 ^a	103.60	42987 ^c	47.10	4292 ^b	93.50	<0.05
ME ⁸ , kcal/kg DM	4598 ^a	107.70	2895 ^c	51.50	4176 ^b	94.30	<0.05

^{abc}Means without a common superscript within a row differ at *P-value* < 0.05

¹Neutral Detergent Insoluble Crude Protein (NDICP)

²Neutral Detergent Fiber (NDF)

³nitrogen free Neutral Detergent Fiber (NDFn)

⁴Acid Detergent Insoluble Crude Protein (ADICP)

⁵Total Digestible Nutrients (TDN)

⁶Gross Energy (GE)

⁷Digestible Energy (DE)

⁸Metabolizable Energy (ME)

Table 1.3 Effect of stream on the variation (standard deviation) in nutrient concentration of food waste

Item	MS ¹	VP ²	MX ³	<i>P-value</i>
Dry Matter, %AF	10.72 ^a	3.49 ^c	7.09 ^b	<0.05
Ether Extract, %DM	10.38 ^a	1.36 ^c	6.84 ^b	<0.05
NDICP ⁴ , %DM	1.55 ^a	0.74 ^b	1.23 ^a	<0.05
NDF ⁵ , %DM	5.40	3.93	4.38	0.841
NDFn ⁶ , %DM	5.50	3.76	4.83	0.883
Crude Protein, %DM	5.72	4.06	3.81	0.457
Ash, %DM	2.80	2.83	2.44	0.532
Lignin, %DM	1.01	0.98	0.73	0.344
ADICP ⁷ , %DM	0.27	0.44	0.21	0.069
TDN ⁸ , %DM	13.53 ^a	3.10 ^b	10.32 ^a	<0.05
GE ⁹ , kcal/kg DM	388.51 ^a	136.34 ^b	344.86 ^a	<0.05
DE ¹⁰ , kcal/kg DM	538.58	258.06	485.87	0.335
ME ¹¹ , kcal/kg DM	559.60	281.88	489.76	0.381

^{abc}Standard deviations without a common superscript within a row differ at *P-value* < 0.05

¹Main food waste stream

²Vegetable preparation food waste stream

³Mixed food waste stream

⁴Neutral Detergent Insoluble Crude Protein (NDICP)

⁵Neutral Detergent Fiber (NDF)

⁶nitrogen free Neutral Detergent Fiber (NDFn)

⁷Acid Detergent Insoluble Crude Protein (ADICP)

⁸Total Digestible Nutrients (TDN)

⁹Gross Energy (GE)

¹⁰.Digestible Energy (DE)

¹¹.Metabolizable Energy (ME)

Table 1.4 Comparison of food waste streams to common cattle and swine feedstuffs aggregating all nutrients in an absolute relative difference metric^{1,2,3,4,5}

Feedstuff	Cattle			Swine		
	MS	VP	MX	MS	VP	MX
Alfalfa	9.48	3.92	7.23	10.09	4.08	7.53
Bakery Byproduct	2.54	3.19	1.84	4.72	4.72	3.74
Beet Pulp	7.69	2.91	5.81	9.83	3.65	6.76
Blood Plasma				6.27	7.57	6.37
Brome Hay	13.34	5.32	10.13			
Cane Molasses	4.75	3.28	4.42	5.18	4.70	5.11
Citrus Pulp	4.65	1.40	3.36	5.52	2.04	4.25
Corn Gluten Feed	5.46	1.77	3.80	5.77	2.50	4.36
Corn Silage	7.81	2.46	5.88			
Corn Stalks	13.88	5.40	10.45			
Cottonseed Hulls	21.39	10.93	17.56			
Cottonseed Meal	9.29	5.04	7.58	6.09	4.03	4.88
DDGS	6.52	4.94	4.99	5.99	4.69	4.34
Fish Meal	6.82	8.09	5.85	6.46	8.38	6.12
Grain Sorghum	2.69	2.46	2.91	3.73	2.63	3.12
Ground Corn	4.31	1.86	3.42	3.71	2.84	3.16
Hominy Feed	3.70	2.76	2.89	4.34	3.66	3.50
Oat Groats				3.34	3.30	2.72
Oats	5.17	1.97	3.86	6.12	2.90	4.81
Rice Bran	6.06	5.37	4.31	6.46	5.22	4.65
SBM, Dehull, Sol						
Ext	4.03	4.23	3.35	3.34	4.67	3.25
Soybean Hulls	10.30	3.36	7.47	11.43	4.77	8.62
Steam flaked Corn	3.09	2.84	2.88			
Wheat	3.16	2.36	2.58	3.25	2.46	2.66
Wheat Bran	7.18	2.20	5.35	6.92	2.98	5.27
Wheat Midds	6.66	1.96	4.91	7.53	2.90	5.74
Wheat Silage	10.57	3.02	7.74			
Wheat Straw	14.34	6.08	10.84			
Whole Cottonseed	9.02	8.41	6.71	12.50	10.02	9.82

¹Common feedstuffs values for cattle were sourced from the Nutrient Requirements of Beef Cattle: Eighth Revised Edition (National Academies of Science, Engineering, and Medicine, 2016).

²Common feedstuffs values for swine were sourced from the Nutrient Requirements of Swine: Eleventh Revised Edition (NRC, 2012).

³The absolute relative difference between CP, ash, EE, NDF, lignin, TDN (cattle), and ME (swine) of the feedstuff and food waste stream were summed to give an aggregated relative difference for each food waste stream.

⁴Feedstuffs that are most similar to the respective food waste stream has the lowest value, feedstuffs that are the least similar have the highest value.

⁵Highest and lowest values per stream are in bold

Chapter 2 - Nitrogen corrected apparent metabolizable energy and apparent ileal digestibility of amino acids of thermally processed food waste for broilers

Abstract

To determine the economic viability of utilizing food waste in animal feed, knowledge of the nutrient availability and variability is needed. The objective of this study was to determine the nutrient variability, AMEn and AID, of food waste when fed to broilers. Dining hall food waste (FW) products were created by dividing 30-day collections into weekly intervals resulting in product 1 (FW1; days 1-7), 2 (FW2; days 8-14), 3 (FW3; days 15-22), and 4 (FW4; days 23-30). Each product was mixed with soybean meal (SBM) and extruded to a target barrel temperature of 140°C. At hatch, 420 and 360 one-day old male broilers (Ross 308 byproduct broiler) were used in an 18-day study to determine AMEn and AID AA, respectively. Treatments were randomly assigned to cages, resulting in 10 cages per treatment with 6 broilers per cage. Treatments for both studies consisted of conventional SBM, extruded SBM (ESBM), FW1, FW2, FW3, and FW4. Data were analyzed using PROC GLIMMIX in SAS v. 9.4 (Cary, NC). Broilers fed ESBM had increased ($P < 0.01$) AID of indispensable AA, except Met, when compared to SBM. Of the FW products, broilers fed FW1 and FW3 had increased ($P < 0.01$) AID of indispensable AA, except Leu, when compared to FW2 with FW4 AID AA being intermediate. The FW3 had increased ($P < 0.01$) AMEn when compared to SBM, ESBM, FW1, and FW2, with FW4 being intermediate to all other treatments. In conclusion, extruding food waste blended with SBM successfully served as a nutrient source for broilers.

Keywords: amino acid digestibility, food waste, soybean meal, apparent metabolizable energy, extrusion

Introduction

Food waste is generated at every step along the food chain from farm production to the consumer (Jaglo et al., 2021). While there are varying reports and estimates on the amount of waste produced each year as outlined by Jaglo et al. 2021 and Thyberg et al. 2015, the USDA estimates about 30-40% of all food produced in the US is discarded into a landfill annually equating to 133 billion pounds of food loss (Thyberg et al., 2015; Jaglo et al., 2021; USDA). The amount of food waste has increased by about 50% since 1974 and contributes to greenhouse gas emissions and a large portion of freshwater and fossil fuel usage (Hall et al., 2009b). More specifically, the largest contributors, by proportion of total waste, are the retail and restaurant sectors where 45 and 97% of their unused food is sent to a landfill, respectively (Analysis of the U.S. Food Waste Among Food Manufacturers, Retailers, and Restaurants, 2014; Dou et al., 2016a). In 2015, the Environmental Protection Agency and United States Department of Agriculture partnered to target food waste and reduce the quantity 50% by 2030. To better outline this goal, they created a Food Recovery Hierarchy that depicts preferred alternative uses of unwanted food (US EPA, 2015). One of the top preferred uses of food waste is conversion to animal feed. The retail and restaurant sectors contribute the least percentage of their waste to animal feed with 12% from retail and 1% from restaurants (Dou et al., 2016a). Preliminary work done at Kansas State University reported that dining hall food waste was 21.66, 25.38, and 72.23% crude protein, ether extract, and moisture respectively on a dry matter basis (Beckman et al., unpublished). Similarly, a study done at the University of Minnesota analyzing the efficacy of using supermarket food waste in swine diets reported 24.39% crude protein, 29.05% ether extract, and 17.11% moisture on an as-fed basis (Fung et al., 2019b).

Spoilage and microorganisms are the top two concerns regarding food waste and the high moisture content. Salmonella and mold multiply and grow at a rapid rate in feedstuffs that are 30-40% water (Carlson and Snoeyenbos, 1969). Additionally, there are pathogenic concerns when using food waste such as bacteria, viruses, parasites, and prions which require a thermal processing step (Shurson, 2020). Raw materials can be extruded at 15-40% moisture and reach high temperatures that can achieve a biological kill-step (Berk, 2009; Tsagareishvili et al., 2019). This makes dry extrusion an ideal thermal processing step to ensure feed safety of the food waste.

Previous research has demonstrated that food waste can successfully be used as a nutrient source in livestock diets. However, there has been little information on the nutrient variation of food waste and nutrient digestibility. Therefore, the objective of this study was to test the effect of variation of food waste nutrient content over time on the nitrogen corrected apparent metabolizable energy (AMEn) and amino acid apparent ileal digestibility (AID) in broilers. An additional objective was to compare digestibility of food waste to soybean meal.

Materials and Methods

Food waste collection

Food waste was initially identified and characterized as any food thrown away that has been cooked and/or set out for consumption that was either improperly cooked or could not be reheated, repurposed, or donated to a local food pantry. Some examples of this are salad bar fixings, pasta, pizza, breakfast foods, and desserts. Waste was collected for 6 consecutive weeks resulting in 30 days of collection (Kramer Dining Center, Kansas State University) and ground down to a uniform particle size using a meat grinder (LEM #8, 0.5 HP). Samples were taken daily to be used for nutrient analysis (0.5 kg) and to be used in treatment diets (4.54 kg). To test

nutrient variability of food waste, collection days were split into 4 products: Product 1 (FW1, days 1-7), Product 2 (FW2, days 8-14), Product 3 (FW3, days 15-22), and Product 4 (FW4, days 23-30). Daily samples were analyzed for dry matter (DM, AOAC 930.15), ether extract (EE, AOAC 2003.05), ash (AOAC 942.05), crude protein (CP, AOAC 990.03), acid detergent fiber (ADF, AOAC 973.18), neutral detergent fiber (aNDF, (Van Soest et al., 1991); ashed in 535°C furnace for 2 hours), and starch (Hall, M.B., 2009) at Cumberland Valley Analytical Services (Waynesboro, PA). Gross energy (GE, Parr 6200 Calorimeter, Parr Instrument Company, Moline, IL) was analyzed at Kansas State University.

Extrusion of ingredients

Prior to extrusion, food waste products were initially mixed with soybean meal until the mixture reached a combined moisture and fat content of 40%. This resulted in products 1, 2, 3, and 4 constituting 39.9, 38.6, 38.9, and 39.0% food waste, respectively. The high moisture and fat content allowed the mash mixture to flow consistently through the extrusion process while maintaining a high in-barrel temperature to achieve a kill-step. Water and oil were also added to conventional soybean meal (CSBM) to reach the same fat and moisture target percentage. Food waste products and CSBM were then dry extruded (InstaPro 2000-10 RTT, Des Moines, IA) with a single screw at a minimum of 140°C. Two extruder set ups were used for this experiment. The food waste mixture was extruded with the following (entrance to exit): single flight screw, 4 spacers, #11 steam lock, double flight screw, #6 steam lock, S spacer, double flight screw, Super 6 steam lock, and a 24 mm diameter end cap. The SBM mixture was extruded with the same setup with the exception of the Super 6 steam lock which was exchanged for a #6 steam lock to maintain consistent temperature parameters. Extruded products and extruded soybean meal (ESBM) were allowed to cool in a heated, forced air environment until dry.

Soybean meal (SBM), extruded SBM, and the four extruded food waste products were analyzed for DM (AOAC 934.01), CP (AOAC 990.03), EE (AOAC 920.39), crude fiber (AOAC 978.10), ash (AOAC 942.05), and amino acid profiles (AOAC 982.30 E [a,b,c]) at the University of Missouri Analytical Lab (Table 1).

Dietary treatments and bird management

This study was approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #4344). These two studies used 420 and 360 one-day (d) old male broilers (Ross 308, Sallisaw, OK, BW 38.5 g) in an 18-day study housed in 7 Petersime batteries for AME and AID determination, respectively. Birds were randomly assigned to 60 and 70 cages balanced by body weight (BW) for AID and AMEn determination, respectively. There were 10 replicates per treatment and 6 birds per cage. All birds had *ad libitum* access to feed and water. For the first 48 hours birds were on a 24:0 L:D lighting program followed by 18:6 L:D until the end of the study. Temperature of the room was adjusted based on bird comfortability. The average temperature of the room was 25.4°C and 48.2 relative humidity (RH, %).

Apparent ileal digestibility dietary treatments were formulated to 20% crude protein and analyzed for amino acids (Table 2, 3) and AME dietary treatments were formulated according to (Perryman and Dozier, 2012) to be 70% corn/soybean meal basal diet + 30% test ingredient (Table 4). Titanium dioxide was included in all test diets as an indigestible marker. Vitamins and minerals were included to meet nutritional requirements. Dietary test ingredients for both studies consisted of 1) CSBM, 2) ESBM, 3) FW1, 4) FW2, 5) FW3, and 6) FW4. Additionally, a common corn/soybean meal basal diet was included to act as a reference control in the AMEn study.

AMEn and AID determination

To determine AMEn, birds were fed a crumbled starter diet from d 0-8 and treatment diets from d 9-18. Fecal samples were collected on d 16-18 twice daily every 12 hours. Fecal samples were dried for 24 hours in a 55°C forced air oven before being ground (Wiley Mill Model 3, Swedesboro, NJ, screen 6/64”) for analysis. To determine AID, birds were fed a crumbled starter diet from d 0-10, and treatment diets from d 11-18. On d 18 all birds were euthanized via carbon dioxide (CO₂) and ileal samples collected for amino acid (AA) content and digestibility. Ileal samples were freeze dried before analysis. Metabolizable energy, amino acid digestibility, and ileal content were calculated using the following equations:

$$\text{Coefficient, AME} = \frac{TiO_2 \text{ Diet}}{TiO_2 \text{ Fecal}} \text{ (Roza et al., 2018)}$$

$$\begin{aligned} \text{AMEn, DM} = & GE_{\text{Diet}} - (GE_{\text{Fecal}} * \text{Coefficient}) + (8.22 \\ & * (N_{\text{Diet}} - (N_{\text{Fecal}} * \text{Coefficient}))) \text{ (Roza et al., 2018)} \end{aligned}$$

$$\text{Digestibility Coefficient, AA} = 1 - \left(\frac{TiO_2 \text{ Diet}}{TiO_2 \text{ Ileal}} * \frac{AA_{\text{Ileal}}}{AA_{\text{Diet}}} \right) \text{ (Bedford et al., 2016)}$$

$$\text{Ileal Content, AA} = \text{Dig. Coeff, AA} * \text{Test Ing. AA}$$

Statistical analysis

All data were analyzed using the GLIMMIX procedure in SAS version 9.4 (Cary, NC). Cage was considered the experimental unit for both AMEn and AID determination. The statistical model included treatment as fixed effect. Pairwise comparison of least square means were performed using Tukey’s HSD test and were considered significantly different at $P \leq 0.05$.

Results and Discussion

Nutrient and amino acid content were determined for each of the four food waste products as they were collected before being mixed with SBM and extruded (Table 5). Proximate values of moisture, CP, EE, and crude fiber were all similar to the preliminary work mentioned

previously at Kansas State University. The nutrient content of the products looks relatively low compared to other common feedstuffs such as corn and SBM on an as-is basis. However, when changed to a DM basis the CP and EE content increases making it a promising potential feedstuff. Food waste products' CP content ranged from 21.29-24.69% on a DM basis depending on the collection period indicating that it has a greater CP than corn but less than that of SBM. Meanwhile the EE content ranged from 24.98-32.54% on a DM basis depending on collection which is greater than both corn and SBM.

Apparent ileal digestibility coefficients and ileal content

Digestibility coefficients of CSBM for this trial were all less than values reported by the Brazilian Tables for Poultry and Swine (Rostagno et al., 2017). Extruded SBM had greater ($P < 0.01$) digestibility for all indispensable amino acids compared to CSBM with the exception of methionine which were similar to each other ($P > 0.05$). Previous research determined that extruding under processed SBM at a temperature of 150°C resulted in greater CP and AA digestibility compared to conventional SBM (Jahanian and Rasouli, 2016). While this current study did not measure trypsin inhibitors or urease, Jananian and Rsaouli, 2016 concluded that further processing SBM at high temperatures help eliminate those factors making extruded SBM more digestible than conventional SBM. This agrees with the response observed in the data reported herein.

There were varied digestibility results between the four food waste products (Table 6). The FW1 had a greater ($P < 0.01$) arginine digestibility than FW2 (84.57 and 80.24%, respectively) while FW3 and FW4 were intermediate ($P > 0.05$) to FW1 and FW2. Lysine and methionine digestibility were greater ($P < 0.01$) in FW1 (77.08 and 76.48%, respectively) and FW3 (76.32 and 75.73%, respectively) compared to FW2 (70.68 and 67.42%, respectively).

Food waste product 4 (75.29 and 71.80%, respectively) was an intermediate ($P > 0.05$) product to the other three food waste products. Digestibility of threonine, however, was similar for all four food waste products ($P < 0.05$). Food waste products 1 (78.79%) and 3 (77.38%) had greater ($P < 0.01$) tryptophan digestibility than FW2 and FW4 (72.95 and 72.72%, respectively).

Overall, there is some variation found among the four food waste products, however, three of the four products were similar to each other whereas only one product's AA digestibility was consistently less than the other products. There are a lot of unknown variables that could potentially explain the inconsistencies between the four food waste products. These being how the food was stored, handled, and processed before it was thrown away. While freezing food for long periods of time does not reduce the protein or fat levels, it can affect the vitamin vitality with losses anywhere from 10-30% (Evans, 2009). However, another study found that meat stored during the freezing process above -20°C still has a certain amount of water activity that can incur protein and lipid oxidation (Akhtar et al., 2013). A second variable is the types of food waste that the products were made up of such as vegetables, fruits, grains, or meat. Previous research demonstrated that animal by-products processed at 129°C had greater AA digestibility than by-products processed at a higher temperature such as 143°C (Johnson et al., 1998). Additionally, animal by-products have lower AA digestibility's than plant based feedstuffs such as soybean meal and corn (Lemme et al., 2004; Rostagno et al., 2017).

Food waste products 1, 3, and 4 were similar ($P > 0.05$) to CSBM AA digestibility with the exception of isoleucine, methionine, and tryptophan. Phenylalanine digestibility, however, was similar ($P > 0.05$) among all four food waste products and CSBM. Extruded soybean meal digestibility of all AAs were greater ($P < 0.05$) than the four food waste products. In the study previously mentioned by Fung et al. (2019) varying AA digestibility's were reported depending

on the AA to be either less than, similar, or greater than soybean meal. Digested ileal content followed similar patterns as the digestibility results (Table 6 & 7) where the ESBM had a greater amount of AA's digested than CSBM, CSBM was similar to the food waste products, and among the four products three were consistently similar to each other while the fourth product's AA content was either similar or slightly less than the other three products .

Nitrogen Corrected Apparent Metabolizable Energy

Nitrogen corrected apparent metabolizable energy values were similar ($P > 0.01$) for ESBM and CSBM (2,349 and 2,388 kcal/kg DM; Table 8). However, research in pigs has demonstrated that dry extruded SBM either with or without hulls had a greater metabolizable energy content than solvent-extracted SBM (Woodworth et al., 2001). Additionally, the ESBM contained a higher fat content than the CSBM because of the 4% addition before the extrusion process. Thus, we expected to see a difference between the CSBM and ESBM. Between the four food waste products, FW3 (3,295 kcal/kg DM) had a greater ($P < 0.01$) energy content than FW1 and FW2 (2,259 and 2,401 kcal/kg DM). Product 4 was an intermediate product that was similar ($P > 0.05$) to FW1, FW2, FW3, CSBM, and ESBM. The AMEn value of CSBM for this study was slightly greater than reported metabolizable energy values of SBM according to the Brazilian Tables for Poultry and Swine (Rostagno et al., 2017). However, the determined AMEn values for CSBM, ESBM, FW1, and FW2 were less than AMEn values calculated using equations from Alvarenga et al. (2015) suggesting that the AMEn content reported are conservative values. While fiber can affect energy metabolism the fiber content of all treatment ingredients in this study were alike to each other leaving little reason to suspect that fiber played a role in the differences reported in the AMEn content between the food waste products and the soybean meals. (Hervik and Svihus, 2019). Dietary fiber begins to inhibit energy metabolism

above 7% thus previous research has found that complete diets should limit crude fiber around 3-4% (Varastegani, 2018). The low fiber content and the unknown processing and handling variables before the food waste was acquired could potentially explain why we see no differences between CSBM, ESBM, and certain food waste products while others have a greater energy content despite having a similar fat and fiber content.

This study determined that food waste can be utilized as a nutrient source for broilers. More specifically, that the metabolizable energy content is similar or greater than SBM and that the AA AID value is either similar or less than that of SBM. This shows that food waste has the potential to be a feedstuff. However, further research needs to be done to determine growth performance, additional processing parameters such as possibly pelleting or spray drying, and feed mill application. Additionally, an economic cost analysis needs to be completed to estimate the efficacy of including it in least-cost formulated broiler diets.

Conclusions and Applications

1. Extruding food waste successfully served as a nutrient source for broilers
2. Extruding soybean meal improved the amino acid digestibility compared to conventional soybean meal
3. Food waste products' AMEn content was similar or improved, depending on the collection period, when compared to soybean meal
4. Food waste products' AID amino acid value, depending on the collection period, to be either similar or less than soybean meal
5. Further research is needed to determine growth performance, feed mill application, and an economic analysis of utilizing food waste

Table 2.1 Chemical analysis of soybean meal (SBM), extruded soybean meal (ESBM)¹, and extruded food waste products² (FW1, FW2, FW3, FW4; as-is basis)³.

Item, %	SBM	ESBM	FW 1	FW 2	FW 3	FW 4
Dry matter	88.54	94.08	92.67	94.22	94.47	94.23
Crude protein	45.29	47.20	44.08	44.86	45.41	45.26
Crude fat	0.79	4.69	4.72	5.23	5.02	4.60
Crude fiber	3.32	3.62	3.05	4.50	3.61	3.25
Ash	7.06	7.12	6.54	7.00	6.91	7.37
KOH protein solubility	87.95	72.11	60.84	70.32	74.47	76.08
Indispensable AA						
Arginine	3.23	3.34	3.01	3.09	3.17	3.11
Histidine	1.17	1.23	1.14	1.20	1.21	1.20
Isoleucine	2.12	2.21	2.08	2.14	2.15	2.15
Leucine	3.50	3.61	3.37	3.45	3.48	3.47
Lysine	2.93	3.02	2.69	2.82	2.94	2.91
Methionine	0.62	0.67	0.62	0.64	0.67	0.65
Phenylalanine	2.31	2.40	2.21	2.27	2.29	2.28
Threonine	1.78	1.88	1.74	1.78	1.81	1.80
Tryptophan	0.57	0.55	0.50	0.52	0.53	0.53
Valine	2.17	2.24	2.14	2.19	2.21	2.19
Total AA	44.51	46.40	43.42	44.22	44.79	44.43

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

Table 2.2 Diet composition formulated to determine apparent ileal digestibility (AID) of food waste products¹ (FW1, FW2, FW3, and FW4), extruded soybean meal² (ESBM), and soybean meal (SBM), balanced at 20% crude protein.

Ingredient, % as fed	SBM	ESBM	FW 1	FW 2	FW 3	FW 4
Test Ingredient	43.96	42.64	45.68	44.90	44.09	44.45
Dextrose	51.92	53.24	50.20	50.98	51.79	51.43
Soybean oil	2.00	2.00	2.00	2.00	2.00	2.00
Dicalcium phosphate	1.90	1.90	1.90	1.90	1.90	1.90
Limestone	1.00	1.00	1.00	1.00	1.00	1.00
Sodium bicarbonate	0.20	0.20	0.20	0.20	0.20	0.20
Sodium chloride	0.20	0.20	0.20	0.20	0.20	0.20
Titanium dioxide	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin trace mineral premix ³	0.32	0.32	0.32	0.32	0.32	0.32

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³Provided per kg of diet: 40 g Zn, 20 g Fe, 40 g Mn, 4500 ppm Cu, 600 ppm I, 60 ppm Se, 635,029 IU vitamin A, 226,796 IU vitamin D₃, 1360 IU vitamin E, 0.91 mg vitamin B₁₂, 68 mg menadione, 544 mg riboflavin, 90 mg thiamine, 544 mg pantothenic acid, 2268 mg niacin, 113 mg vitamin B₆, 57 mg folic acid, 31,751 mg choline, and 2.7 mg biotin.

Table 2.3 Chemical analysis of experimental diets to determine apparent ileal digestibility (AID) of food waste products¹ (FW1, FW2, FW3, and FW4), extruded soybean meal² (ESBM), and soybean meal (SBM; as-is basis)^{3,4}.

Item, %	SBM	ESBM	FW 1	FW 2	FW 3	FW 4
Dry matter	88.95	89.42	90.25	90.68	90.68	90.54
Crude protein	21.98	20.50	20.71	20.30	20.13	19.96
Total AA	18.74	19.33	20.38	19.08	18.52	19.33
Indispensable AA						
Arginine	1.30	1.35	1.38	1.30	1.26	1.33
Histidine	0.48	0.49	0.53	0.50	0.48	0.51
Isoleucine	0.85	0.88	0.94	0.88	0.85	0.89
Leucine	1.44	1.49	1.61	1.47	1.42	1.49
Lysine	1.23	1.25	1.30	1.21	1.21	1.27
Methionine	0.25	0.26	0.28	0.26	0.27	0.27
Phenylalanine	0.95	0.99	1.06	0.97	0.93	0.98
Threonine	0.74	0.77	0.79	0.76	0.73	0.76
Tryptophan	0.24	0.22	0.25	0.23	0.23	0.21
Valine	0.87	0.90	0.97	0.91	0.88	0.91
Dispensable AA						
Alanine	0.81	0.84	0.90	0.84	0.82	0.85
Aspartic acid	2.16	2.24	2.31	2.19	2.11	2.19
Cystine	0.27	0.27	0.28	0.27	0.27	0.27
Glutamic acid	3.54	3.65	3.89	3.60	3.47	3.66
Glycine	0.79	0.81	0.86	0.82	0.79	0.81
Proline	0.91	0.94	1.00	0.94	0.91	0.96
Serine	0.88	0.91	0.92	0.87	0.84	0.89
Tyrosine	0.68	0.71	0.78	0.70	0.68	0.71

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³Dietary treatments consisted of 1 of 4 food waste products, conventional soybean meal, or extruded soybean meal. Food waste was collected for 30 consecutive days and split into 4 products based on collection day. All food waste products were mixed with soybean meal and extruded at 140°C. Soybean meal was also extruded at 140°C. Therefore, dietary treatments consisted of Product 1 (days 1-7), Product 2 (days 8-14), Product 3 (days 15-22), Product 4 (days 23-30), conventional soybean meal, and extruded soybean meal.

⁴Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

Table 2.4 Diet composition formulated to determine apparent metabolizable energy (AME) of food waste products¹ (FW1, FW2, FW3, and FW4), extruded soybean meal² (ESBM), and soybean meal (SBM)³.

Ingredient, %	Basal	SBM	ESBM	FW 1	FW 2	FW 3	FW 4
Ground Corn	57.90	40.38	40.38	40.38	40.38	40.38	40.38
Soybean Meal	35.95	25.16	25.16	25.16	25.16	25.16	25.16
Test Ingredient	0.00	30.00	30.00	30.00	30.00	30.00	30.00
Soy Oil	1.81	1.26	1.26	1.26	1.26	1.26	1.26
Limestone	0.99	0.69	0.69	0.69	0.69	0.69	0.69
Dicalcium Phosphate	1.42	1.00	1.00	1.00	1.00	1.00	1.00
Salt	0.46	0.33	0.33	0.33	0.33	0.33	0.33
L-Lysine	0.21	0.14	0.14	0.14	0.14	0.14	0.14
DL-Methionine	0.33	0.23	0.23	0.23	0.23	0.23	0.23
L-Threonine	0.13	0.09	0.09	0.09	0.09	0.09	0.09
Phytase ⁴	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Choline Chloride	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Vitamin Trace Mineral Premix ⁵	0.25	0.18	0.18	0.18	0.18	0.18	0.18
Titanium Dioxide	0.50	0.50	0.50	0.50	0.50	0.50	0.50

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³Dietary treatments consisted of 1 of 4 food waste products, conventional soybean meal, or extruded soybean meal. Food waste was collected for 30 consecutive days and split into 4 products based on collection day. All food waste products were mixed with soybean meal and extruded at 140°C. Soybean meal was also extruded at 140°C. Therefore, dietary treatments consisted of Product 1 (days 1-7), Product 2 (days 8-14), Product 3 (days 15-22), Product 4 (days 23-30), conventional soybean meal, and extruded soybean meal.

⁴ Quantum Blue, AB Vista. Phytase, 10,000 FTU/g.

⁵ Provided per kg of diet: 40 g Zn, 20 g Fe, 40 g Mn, 4500 ppm Cu, 600 ppm I, 60 ppm Se, 635,029 IU vitamin A, 226,796 IU vitamin D₃, 1360 IU vitamin E, 0.91 mg vitamin B₁₂, 68 mg menadione, 544 mg riboflavin, 90 mg thiamine, 544 mg pantothenic acid, 2268 mg niacin, 113 mg vitamin B₆, 57 mg folic acid, 31,751 mg choline, and 2.7 mg biotin.

Table 2.5 Nutrient content of raw food waste products before extrusion, as-is^{1,2}.

Item, %	Product 1	Product 2	Product 3	Product 4
Moisture	76.98	76.21	77.72	74.86
Crude Protein	4.90	5.36	5.50	6.07
Crude Fat	5.75	7.25	6.69	8.18
Crude Fiber	0.36	0.38	0.47	0.66
Ash	1.10	1.56	1.39	2.31
Indispensable AA				
Arginine	0.24	0.25	0.26	0.3
Histidine	0.13	0.17	0.16	0.18
Isoleucine	0.22	0.23	0.25	0.29
Leucine	0.38	0.39	0.41	0.48
Lysine	0.28	0.32	0.33	0.39
Methionine	0.11	0.11	0.12	0.14
Phenylalanine	0.22	0.22	0.23	0.27
Threonine	0.19	0.20	0.21	0.25
Tryptophan	0.05	0.05	0.05	0.06
Valine	0.25	0.26	0.28	0.32
Total AA	4.78	5.04	5.14	5.87

¹ Food waste was collected for 6 consecutive weeks resulting in 30 collection days from a campus dining center at Kansas State University. The 30 collection days were split into four separate products: product 1 (days 1-7), product 2 (days 8-14), product 3 (days 15-22), and product 4 (days 23-30).

² Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

Table 2.6 Apparent ileal digestibility coefficients of amino acids from food waste¹ (FW1, FW2, FW3, and FW4), extruded soybean meal² (ESBM), and soybean meal (SBM) in 18-d old broilers.^{3,4,5}

Item, %	SBM	ESBM	FW 1	FW 2	FW 3	FW 4	SEM	Probability, <i>P</i> <
Indispensable AA								
Arginine	84.06 ^b	90.24 ^a	84.57 ^b	80.24 ^c	83.63 ^{bc}	82.73 ^{bc}	0.791	0.001
Histidine	78.45 ^b	85.21 ^a	77.12 ^b	71.59 ^c	75.51 ^{bc}	74.97 ^{bc}	1.062	0.001
Isoleucine	75.21 ^b	83.75 ^a	74.30 ^b	69.24 ^{bc}	73.40 ^{bc}	72.21 ^c	1.114	0.001
Leucine	75.51 ^b	84.34 ^a	76.59 ^b	70.65 ^c	74.10 ^{bc}	73.02 ^{bc}	1.036	0.001
Lysine	79.18 ^b	85.99 ^a	77.08 ^b	70.68 ^c	76.32 ^b	75.29 ^{bc}	1.187	0.001
Methionine	78.61 ^{ab}	83.62 ^a	76.48 ^{bc}	67.42 ^d	75.73 ^{bc}	71.80 ^{dc}	1.462	0.001
Phenylalanine	77.40 ^{bc}	86.36 ^a	79.56 ^b	74.15 ^c	77.21 ^{bc}	76.45 ^{bc}	0.920	0.001
Threonine	65.69 ^b	77.25 ^a	63.56 ^{bc}	58.00 ^c	62.25 ^{bc}	59.77 ^{bc}	1.430	0.001
Tryptophan	80.35 ^b	85.20 ^a	78.79 ^b	72.95 ^c	77.38 ^b	72.72 ^c	0.975	0.001
Valine	72.57 ^b	81.90 ^a	71.43 ^b	65.98 ^c	70.04 ^{bc}	68.10 ^{bc}	1.229	0.001
Total AA	75.00 ^b	83.47 ^a	74.22 ^b	68.95 ^c	73.37 ^{bc}	71.66 ^{bc}	0.791	0.001

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³At hatch, 360 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment. Dietary treatments consisted of 1 of 4 food waste products, conventional soybean meal, or extruded soybean meal. Food waste was collected for 30 consecutive days and split into 4 products based on collection day. All food waste products were mixed with soybean meal and extruded at 140°C. Soybean meal was also extruded at 140°C. Therefore, dietary treatments consisted of Product 1 (days 1-7), Product 2 (days 8-14), Product 3 (days 15-22), Product 4 (days 23-30), conventional soybean meal, and extruded soybean meal.

⁴Means within a row followed by a different letter (^{a-d}) are significantly different ($P \leq 0.01$).

⁵AA = amino acids.

Table 2.7 Apparent ileal digestibility content of amino acids in food waste products¹ (FW1, FW2, FW3, and FW4), extruded soybean meal² (ESBM), and soybean meal (SBM) when fed to 18-d old broilers.^{3,4,5}

Item, %	SBM	ESBM	FW 1	FW 2	FW 3	FW 4	SEM	Probability, <i>P</i> <
Indispensable AA								
Arginine	2.72 ^b	3.01 ^a	2.55 ^d	2.48 ^d	2.65 ^{bc}	2.57 ^{cd}	0.025	0.001
Histidine	0.92 ^b	1.05 ^a	0.88 ^{bc}	0.86 ^c	0.91 ^b	0.90 ^{bc}	0.013	0.001
Isoleucine	1.59 ^b	1.85 ^a	1.55 ^{bc}	1.48 ^c	1.58 ^{bc}	1.55 ^{bc}	0.024	0.001
Leucine	2.64 ^b	3.04 ^a	2.58 ^{bc}	2.44 ^c	2.58 ^{bc}	2.53 ^{bc}	0.036	0.001
Lysine	2.32 ^b	2.60 ^a	2.07 ^{cd}	1.99 ^d	2.24 ^b	2.19 ^{bc}	0.034	0.001
Methionine	0.49 ^b	0.56 ^a	0.47 ^{bc}	0.43 ^d	0.51 ^b	0.47 ^{cd}	0.009	0.001
Phenylalanine	1.79 ^b	2.07 ^a	1.76 ^{bc}	1.68 ^c	1.77 ^{bc}	1.74 ^{bc}	0.021	0.001
Threonine	1.17 ^b	1.45 ^a	1.11 ^{bc}	1.03 ^c	1.13 ^{bc}	1.08 ^{bc}	0.026	0.001
Tryptophan	0.46 ^a	0.47 ^a	0.39 ^{bc}	0.38 ^c	0.41 ^b	0.39 ^c	0.005	0.001
Valine	1.57 ^b	1.83 ^a	1.53 ^{bc}	1.44 ^c	1.55 ^{bc}	1.49 ^{bc}	0.027	0.001
Total AA	33.38 ^b	38.73 ^a	32.72 ^b	30.49 ^c	32.86 ^b	31.84 ^{bc}	31.84	0.001

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³At hatch, 360 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment. Dietary treatments consisted of 1 of 4 food waste products, conventional soybean meal, or extruded soybean meal. Food waste was collected for 30 consecutive days and split into 4 products based on collection day. All food waste products were mixed with soybean meal and extruded at 140°C. Soybean meal was also extruded at 140°C. Therefore, dietary treatments consisted of Product 1 (days 1-7), Product 2 (days 8-14), Product 3 (days 15-22), Product 4 (days 23-30), conventional soybean meal, and extruded soybean meal.

⁴ Means within a row followed by a different letter (^{a-d}) are significantly different ($P \leq 0.01$).

⁵ AA = amino acids.

Table 2.8 Effect of food waste products¹ (FW1, FW2, FW3, and FW4), extruded soybean meal² (ESBM), and soybean meal (SBM) on apparent metabolizable energy (AME) in 18-d old broilers.³

Item	SBM	ESBM	FW 1	FW 2	FW 3	FW 4	SEM	Probability, <i>P</i>
AMEn, kcal/kg DM	2,388 ^b	2,349 ^b	2,259 ^b	2,401 ^b	3,295 ^a	2,761 ^{ab}	181.9	0.001

¹SBM was mixed with oil and water until the mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

²Food waste products were mixed with SBM until mixture was 40% moisture + fat and extruded (InstaPro 2000-10 RTT, Des Moines, IA) at a minimum of 140°C

³At hatch, 420 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment. Dietary treatments consisted of 1 of 4 food waste products, conventional soybean meal, or extruded soybean meal. Food waste was collected for 30 consecutive days and split into 4 products based on collection day. All food waste products were mixed with soybean meal and extruded at 140°C. Soybean meal was also extruded at 140°C. Therefore, dietary treatments consisted of Product 1 (days 1-7), Product 2 (days 8-14), Product 3 (days 15-22), Product 4 (days 23-30), conventional soybean meal, and extruded soybean meal.

² Means within a row followed by a different letter (^{a-b}) are significantly different ($P \leq 0.01$).

Chapter 3 - Nitrogen corrected apparent metabolizable energy, apparent ileal digestibility of amino acids, and growth performance of thermally processed and fermented food waste for broilers

Abstract

Three experiments were conducted to determine the nutrient availability of extruded and fermented food waste and subsequent effects on growth performance of broilers. Dining hall food waste was either mixed with soybean meal (SBM) and extruded or was fermented for 14 days to create a value-added product (FFW). One-day old male broilers (Ross 308, Sallisaw, OK) were used in 21-day studies to determine nitrogen-corrected apparent metabolizable energy (AMEn, Exp. 1, n = 300), apparent ileal digestibility (AID, Exp. 2, n = 240), and growth performance (Exp. 3, n = 420). Treatments for Exp. 1 and 2 consisted of 1) composite food waste (CFW), 2) conventional SBM (CSBM), 3) extruded SBM (ESBM), 4) SBM + FFW (SFFW). A basal treatment was added to Exp. 1 as a control. Treatments for Exp. 3 consisted of 1) corn/SBM basal, 2) 10% CFW, 3) 30% CFW, 4) 1.5% FFW, 5) 5.5% FFW, 6) basal + commercial astaxanthin, and 7) basal + commercial antibiotic. There were 10 cages per treatment with 6 broilers per cage and balanced by body weight. Data were analyzed using the GLIMMIX procedure of SAS v. 9.4 (Cary, NC). The ESBM had a greater ($P < 0.01$) AMEn content than CSBM and SFFW whereas CFW was intermediate. Broilers fed CFW and CSBM had increased ($P < 0.05$) AID of indispensable amino acids compared to SFFW, except Met whereas ESBM was increased ($P < 0.05$) compared to SFFW with the exception of His, Met, and Try. Broilers fed 1.5% FFW had increased ($P < 0.01$) FI and BWG compared to those fed the control basal diet. Broilers fed the commercial astaxanthin or 30% CFW had poorer ($P < 0.01$) FCR compared to

those fed the basal control. In conclusion, two different forms of food waste successfully served as a nutrient source for broilers. Composite food waste and SFFW had similar AMEn to CSBM while CFW had a similar AID of amino acids to CSBM. Including 30% of CFW reduced FCR of broilers; however, including 5.5% of SFFW increased FI and BWG of broilers.

Keywords: food waste, broiler, fermentation, apparent metabolizable energy, amino acid digestibility

Introduction

Food waste can often be defined as any food that was intended for human consumption and for various reasons was discarded (Giroto et al., 2015). Food waste is generated at every step along the food supply chain from production to the final consumer (Jaglo et al., 2021). Extensive reviews by Jaglo et al. 2021 and Thyberg et al. 2015 illustrate the discrepancies and varying estimates in the reported amount of food waste that is accumulated (Thyberg et al., 2015; Jaglo et al., 2021). However, in 2010 the United States Department of Agriculture estimated the amount to be anywhere from 30-40% of all food produced in the United States (USDA). This equates to a loss of about 133 billion pounds and \$161 billion annually. Consequently, this waste, if sent to a landfill, contributes to greenhouse gas emissions and the use of inputs and resources such as oil, freshwater, and labor that could have been used elsewhere (Hall et al., 2009a). Of retailers and consumers unused food, 45 and 97%, respectively, is landfilled (Analysis of the U.S. Food Waste Among Food Manufacturers, Retailers, and Restaurants, 2014; Dou et al., 2016b). In an effort to reduce the amount of food waste that is generated the Environmental Protection Agency created a hierarchy of alternative methods for the end result of food waste (US EPA, 2015). One of these proposed alternative methods is livestock feed. The

livestock production and feed industries already utilize multiple sources of by-products or food waste such as bakery meal, brewers' grains, and unwanted fruit/vegetable waste (Sukri et al., 1999; Westendorf and Wohlt, 2002; Nelson, 2010; Liu et al., 2018). These feed ingredients are often sourced from the production side of the human food or commodity supply chain, not necessarily waste from retailers or final consumers despite these two being the largest contributors to landfill food waste. There has been little previous research specifically evaluating cafeteria food waste and its nutrient availability as a feed ingredient. One study evaluated energy and amino acid (AA) digestibility in pigs found that supermarket food waste (4,922 kcal/kg DM) had a greater ($P < 0.01$) metabolizable energy (ME) content than corn (3,875 kcal/kg DM). Additionally, the waste also had greater apparent ileal digestibility (AID) of methionine and tryptophan than reported values for soybean meal (SBM) in the Nutrient Requirements of Swine (2012) with the exception of lysine (Fung et al., 2019b). However, food waste and soybean meal were not compared directly within the study. A similar study by the same group calculated energy values of food waste from a university dining hall and found that the ME (4,188 kcal/kg DM) was greater than both corn (3,395 kcal/kg DM) and SBM (3,660 kcal/kg DM) (Fung et al., 2019a). More specifically, they analyzed the nutrient profile on a DM basis and found that crude protein (CP) of dining hall food waste was greater than corn and less than SBM while ether extract (EE) content was greater than both corn and SBM. Similarly, in a preliminary study done at Kansas State University analyzing the nutrient profile of dining hall food waste and its potential use as a feedstuff, the nutrient values were slightly higher than reported values by Fung et al. 2019a. Moisture (72.23%), CP (21.66%), EE (25.38%), ME (4598 kcal/kg) and neutral detergent fiber (7.13%) on a DM basis were all elevated but still follow the same trends when compared to corn and SBM (Beckman et al., unpublished). Fat and CP are two of the most

expensive nutrients when formulating diets (Abudabos, 2014; Kerr et al., 2015; Jabbar et al., 2021). Therefore, the high fat and CP content of food waste makes it a promising feed ingredient. However, the high moisture content causes concerns from a logistics and manufacturing perspective.

Bacteria, such as salmonella, and mold rapidly reproduce in feedstuffs with a water activity level greater than 40% (Carlson and Snoeyenbos, 1969). Furthermore, flowability through a feed mill would be poor. A thermal processing step, such as dry extrusion, can be used to reduce moisture and reach high temperatures to act as a kill step to reduce biological concerns such as bacteria, viruses, and parasites (Berk, 2009; Shurson, 2020). Another advantage of extrusion is that it can handle raw ingredients that have moisture contents from 15-40%, allowing the maximum amount of food waste to be included (Tsagareishvili et al., 2019). One disadvantage, however, is that the food waste needs to be mixed with a dry carrier such as SBM to achieve this moisture range. The low fat and low starch characteristics of soybean meal make it a more favorable dry carrier feedstuff than ingredients that are high starch such as corn. High starch materials, depending on other processing parameters, tend to have a greater expansion ratio and gelatinization making it more difficult to extrude (Berk, 2009; Ye et al., 2018).

Food waste can also be used to produce a keto-carotenoid, called astaxanthin, through the process of fermentation when mixed with yeast creating a cost effective medium for a highly valuable product (Basiony et al., 2022; Lai et al., 2022). In 2020, the global market for astaxanthin totaled \$1.37 billion and is expected to continue to grow (Basiony et al., 2022). Originally used in aquaculture, it has been studied for its multiple health benefits including antioxidant and anti-inflammatory effects (Yuan et al., 2011). By using food waste, an abundant

and rather inexpensive source, to create astaxanthin it could help boost the intrinsic value of the waste as well as help supply the feed additive market.

The abundance of waste generated and minimal previous research in broilers led us to focus on the final consumers' food waste for this experiment. Therefore, the objective of this study was to determine AMEn and AID of extruded and fermented food waste, and growth performance of broilers when fed extruded or fermented food waste. We hypothesized that the extruded food waste would have greater AMEn than SBM, AID of indispensable AA's would either be similar or less than that of SBM, and growth performance would either be similar or less than a common basal diet. Meanwhile, the fermented food waste nutrient digestibility would be similar to SBM and improve growth performance compared to the common basal diet.

Materials and Methods

Collection

Food waste was initially identified and characterized as any food thrown away that has been cooked and/or set out for consumption that was either improperly cooked or could not be reheated, repurposed, or donated to a local food pantry. Some examples of this are salad bar fixings, pasta, pizza, breakfast foods, and desserts. Waste was collected for 6 consecutive weeks resulting in 30 days (Kramer Dining Center, Kansas State University) and ground to a uniform particle size using a meat grinder (LEM #8, 0.5 HP). Daily samples were collected to be fermented (1.4 kg) or to be extruded (2.3 kg). Samples intended for fermentation and extrusion were composited over the 30 days.

Extrusion and Fermentation

Prior to extrusion, the composite food waste sample was mixed with soybean meal (SBM) until the mixture contained 40% moisture + fat content, resulting in the mixture being

39.1% food waste and 60.9% SBM. This target percentage allowed the mash to flow evenly through the extruder while simultaneously maintaining a high in-barrel temperature to act as a kill-step and include as much food waste as possible. The food waste/SBM mash was extruded (InstaPro 2000-10 RTT, Des Moines, IA) with a single screw at an in-barrel minimum temperature of 140°C. The extruder screw setup was the following (entrance to exit): single flight screw, 4 spacers, #11 steam lock, double flight screw, #6 steam lock, S spacer, double flight screw, Super 6 steam lock, and a 15/16" diameter end cap. Additionally, water and oil were added to a separate batch of soybean meal until 40% moisture + fat content was reached to act as a positive control. The SBM mix was extruded under the same conditions as the food waste mixture apart from the Super 6 steam lock changed to a #6 steam lock to maintain a consistent processing temperature. All extruded products were cooled in a heated, forced air environment at 38°C until dry.

To create a fermented, value-added food waste product (FFW), the composite food waste sample was hydrolyzed for 2 days using glucoamylase, α -amylase, and Viscozyme L enzymes. On day 2, the pH was adjusted to 7 using HCl and/or NaOH. The neutral, hydrolyzed food waste was then autoclaved at 120°C for 15 minutes and cooled down to 55°C where sterile enzymes were added to begin enzymatic hydrolysis. The mixture underwent enzymatic hydrolysis for 2 days at 150 rpm stirring speed at 55°C. On day 4, the mixture was set in a heated water bath at 85°C for 30 minutes to end hydrolysis. 2% of a pre-made culture of *X. dendrorhous* was added to the hydrolyzed food waste mixture to commence fermentation for 10 days stirred at 150 rpm in a 4330 refrigerated incubator shaker at a constant 25°C. The fermented food waste slurry was then added to SBM to create the FFW. During the fermentation process, samples were collected on

day14 then air dried in a fume hood where astaxanthin was extracted and analyzed by HPLC (Wang et al., unpublished).

The extruded composite food waste, SBM + fermented product, SBM, and extruded SBM were analyzed for amino acids (AOAC 982.30 E [a,b,c]), CP (AOAC 990.03), moisture (AOAC 934.01), EE (AOAC 920.39), crude fiber (AOAC 978.10), ash (AOAC 942.05), NDF (JAOAC 56, 1352-1356), ADF (AOAC 973.18 [A-D]), starch (AACC 76-13 with Megazyme assay kit K-AMYL), and protein solubility (KOH, J. Anim Sci, 69:2918-2921, 1991) at the University of Missouri Analytical Lab (Table 1).

Dietary Treatments and Bird Management

These studies were approved by the Institutional Animal Care and Use Committee at Kansas State University (IACUC #4344). A total of 300, 240, and 420 one-day old male broilers (Ross 708, Sallisaw, OK) were brought to the Kansas State University Poultry Unit for determination of nitrogen corrected apparent metabolizable energy (AMEn, Exp. 1, BW 39.4 g), apparent ileal digestibility (AID, Exp. 2, BW 39.4 g), and effects on growth performance (Exp. 3, BW 37.7 g), respectively. Birds were housed in Petersime batteries with *ad libitum* access to feed and water throughout the duration of the experiments. Each pen consisted of 6 birds balanced by body weight with ten replicates per treatment for all experiments. For the first 48 hours the room lighting was 24:0 L:D. Following the 48-hour period, the lighting was kept at 18:6 L:D. Temperature was adjusted daily based on birds' comfortability. Average room temperature was 28.3°C and 65.4% relative humidity for Exp. 1 and 2. Average room temperature of Exp. 3 was 28.1°C and 46.3% relative humidity.

Dietary treatments for Exp. 1 were formulated according to (Perryman and Dozier, 2012) to be 70% basal corn/SBM + 30% test ingredient (Table 2). Dietary treatments for Exp. 2 were

formulated to be 20% total crude protein supplemented with dextrose (Table 3) and analyzed for amino acid content (Table 4). All treatment diets for Exp. 1 and 2 included 0.5% titanium dioxide as an indigestible marker. Treatments for Exp 1 and 2 are as follows: 1) composite food waste (CFW), 2) SBM + fermented food waste (SFFW), 3) conventional soybean meal (CSBM), and 4) extruded soybean meal (ESBM). Additionally, a control treatment consisting of a common basal corn/SBM diet was added to Exp 1 to calculate AMEn. Treatments for Exp. 3 were formulated to meet the recommended nutritional requirements and balanced for AME and SID of AA (Table 5). Apparent metabolizable energy and AID AA values of CFW and SFFW determined in experiments 1 and 2 were used to formulate diets in experiment 3. Treatments were balanced by metabolizable energy and SID of AAs. Treatments were the following: 1) basal corn/SBM, 2) 10% CFW, 3) 30% CFW, 4) 1.5% FFW, 5) 5.5% FFW, 6) basal + commercial astaxanthin (Pink Carophyll 10%, DSM, Parsippany, NJ, 5 mg/kg), and 7) basal + antibiotic (BMD 50, Zoetis, Parsippany-Troy Hills, NJ, 55 mg/kg). All dietary treatments for experiments 1, 2, and 3 were fed as mash to avoid denaturing nutrient content in the CFW and FFW through the pelleting process.

AMEn, AID, and Growth Determination

For Exp. 1, birds were fed a common starter diet from days 0-8. On day 8, pens were randomly assigned one of 5 dietary treatments to determine AMEn of food waste and a fermented food waste product. Fecal samples were collected twice daily on days 18-20, dried for 24 hours in a 55°C forced air oven, and ground (Wiley Mill, 6 mm screen). Feed and fecal samples were analyzed for CP, GE, and titanium dioxide at Kansas State University. The following equations were used to calculate AMEn:

$$\text{Coefficient, AME} = \frac{TiO_2 \text{ Diet}}{TiO_2 \text{ Fecal}} \text{ (Roza et al., 2018)}$$

$$AMEn, DM = GE_{Diet} - (GE_{Fecal} * Coefficient) + (8.22 \\ * (N_{Diet} - (N_{Fecal} * Coefficient))) (Roza et al., 2018)$$

For Exp. 2, birds were fed a common starter diet from days 0-13. On day 13, pens were randomly assigned to one of 4 dietary treatments to determine AID of food waste and fermented food waste. On day 21 birds were euthanized via CO₂ and ileal samples were collected, freeze dried, and sent to the University of Missouri where ileal and feed samples were analyzed for amino acids (AOAC 982.30). The following equations were used to calculate AID of AA's:

$$Digestibility\ Coefficient, AA = 1 - \left(\frac{TiO_2\ Diet}{TiO_2\ Ileal} * \frac{AA_{Ileal}}{AA_{Diet}} \right) (Bedford et al., 2016)$$

$$Ileal\ Content, AA = Dig. Coeff, AA * Test\ Ing. AA$$

In Exp. 3, pens were balanced by body weight and randomly assigned to one of seven dietary treatments. Feed intake and pen weight were measured and recorded on days 0, 7, 18, and 21 to calculate feed intake (FI), body weight gain (BWG), and feed conversion ratio (FCR).

Statistical analysis

All data were analyzed using the GLIMMIX procedure in SAS version 9.4 (Cary, NC). Cage was considered the experimental unit for AMEn, AID, and growth performance determination. The statistical model included treatment as fixed effect. Pairwise comparison of least square means were performed using Tukey's HSD test and were considered significantly different at $P \leq 0.05$.

Results and Discussion

Nitrogen Corrected Apparent Metabolizable Energy

Nitrogen corrected apparent metabolizable energy content (Table 6) of extruded soybean meal (2,862 kcal/kg DM) had a greater ($P < 0.05$) energy concentration than CSBM and SFFW (2,424 and 2,441 kcal/kg DM, respectively). The composite food waste (2,576 kcal/kg DM) was

intermediate ($P > 0.05$) to the CSBM, ESBM, and the SFFW metabolizable energy content. The reported SBM and CFW AMEn values for this study are similar to values from a previous study (Beckman et al., 2023) and slightly less than SBM ME in the Brazilian Tables for Poultry and Swine by 100 kcal/kg on a DM basis (Rostagno et al., 2017). Additionally, when reported AMEn values were compared to AMEn values calculated using two different equations from Alvarenga et al. (2015) the reported values for SBM, CFW, and SFFW determined in this study were less. More specifically, the calculated SBM values (2,497 and 2,469 kcal/kg DM) were about 45 kcal/kg greater than what was determined in this study while the calculated CFW values (2,741 and 2,718 kcal/kg DM) were about 150 kcal/kg greater and calculated SFFW values (2,544 and 2,514 kcal/kg DM) were about 75 kcal/kg greater than their counterparts determined in this study. Extruded SBM's reported AMEn content, however, was greater than the values using Alvarenga's equations (2,655 and 2,632 kcal/kg DM) by more than 200 kcal/kg. In this experiment, the treatments with the greatest AMEn were also the only two products that were extruded and contained higher levels of fat (ESBM 3.91%, CFW 4.62%) compared to CSBM (1.11%) and SFFW (1.21%). Starch also plays a key role in providing energy in a diet. When exposed to high temperatures with high moisture content, such as in an extrusion process, gelatinization of the starch molecules can occur making starch more digestible (Svihus, 2014). While gelatinization was not measured in this particular study, the extruder did reach a high enough temperature and beginning moisture content to facilitate gelatinization potentially aiding in energy digestibility of the two extruded products, ESBM and CFW.

Apparent Ileal Digestibility of Amino Acids

The AID of indispensable AA's for CFW, SFFW, CSBM, and ESBM are shown in Table 7. Digestibility coefficients for SBM were lower than expected and reported values in the

Brazilian Tables for Poultry and Swine: Feedstuff Composition and Nutritional Requirements tables (Rostagno et al., 2017). Conventional SBM had a greater ($P < 0.05$) digestibility of all indispensable AA's compared to SFFW. Composite food waste and ESBM also had similar ($P > 0.05$) digestibility's to CSBM. More specifically, lysine digestibility of CFW, CSBM, and ESBM (78.65, 79.66, and 78.78%, respectively) were all greater ($P < 0.05$) than SFFW (67.09%) as well as threonine (71.20, 71.92, and 70.52%, respectively, vs. 62.41%) and arginine (86.37, 85.65, and 85.57%, respectively, vs. 79.50%) digestibility. However, CFW methionine digestibility (78.03%) and ESBM histidine (79.98%), methionine (76.67%), and tryptophan (80.79%) digestibility's were intermediate ($P > 0.05$) to CSBM (79.31, 81.99, and 82.07% methionine, histidine, and tryptophan, respectively) and SFFW (69.59, 75.45, and 75.65% methionine, histidine, and tryptophan, respectively). Digested ileal content (Table 8) was as expected and followed a similar pattern to what was seen in the digestibility coefficient differences. Extruded SBM, SBM, and CFW had a greater ($P < 0.05$) digestible AA content than SFFW depending on the AA. Therefore, ESBM, SBM, and CFW are more valuable when formulating diets because they provide more available AAs. Either a greater amount of SFFW or supplementing with synthetic AAs would need to be included in a diet to make up for the lack of digestible AAs that SFFW provides.

Determined amino acid digestibility of SBM in this study was less than reported values in the Brazilian Tables for Poultry and Swine (Rostagno et al., 2017). In a previous study that measured AID in different food waste products that were extruded in the same manner as this experiment ESBM had a greater digestibility than CSBM and the food waste products were all less digestible than ESBM (Beckman et al., 2023). Contradictory to previous studies, this study shows no differences between the CFW, CSBM, or ESBM. Animal by-product proteins are

known to be less digestible than plant proteins such as SBM (Lemme et al., 2004; Rostagno et al., 2017). Additionally, it's been reported that animal by-products thermally processed at lower temperatures such as 129°C had greater AA digestibility's than when processed at 143°C- similar to our extrusion temperature used in this study (Johnson et al., 1998). The CFW, which contains some amount of animal protein, did have a diminished KOH solubility. Meanwhile, the KOH protein solubility for CSBM (83.86%) falls within the acceptable solubility range of 78-84% as did ESBM (82.40%) such that the extrusion process seeming has very little effect on its protein degradation (El-Shemy, 2011). Amino acid digestibility of SFFW was reduced compared to CSBM, ESBM, and CFW depending on the AA. Fermentation has been shown to improve digestibility of plant proteins by reducing enzyme blocks like trypsin and chymotrypsin inhibitors (Shekib, 1994; Çabuk et al., 2018). However, this doesn't agree with the data reported in this study. There is limited data about fermentation of animal proteins or food waste that could be affecting the digestibility as well.

Growth performance

Body weight gain, FI, and FCR were measured and calculated for treatments from days 0-21 (Table 9). Birds fed the basal and commercial antibiotic diets had no differences ($P > 0.05$) in BWG, FI, FCR. Meanwhile, the basal and commercial antibiotic diets resulted in greater ($P < 0.05$) BWG and FI with an improved ($P < 0.05$) FCR compared to the diet containing the commercial astaxanthin. To determine the efficacy of different forms of food waste as a possible feed ingredient it was compared back to a common basal diet. There was no evidence of differences ($P > 0.05$) in BWG and FI between broilers fed the basal, 10% CFW, and 30% CFW. However, broilers fed diets contain 30% CFW had poorer ($P > 0.05$) FCR compared to those fed the basal and 10% CFW. When comparing the basal diet to 1.5% FFW and 5.5% FFW there was

no evidence of differences ($P > 0.05$) in BWG or FCR. However, birds fed diets that contained 5.5% FFW had greater ($P < 0.05$) FI than birds fed the basal and 1.5% FFW. Additionally, diets containing 5.5% FFW had greater ($P < 0.05$) BWG, FI, and FCR than birds fed diets that contained the commercial astaxanthin product. Birds fed the 1.5% FFW had no difference ($P > 0.05$) in BWG compared to the commercial astaxanthin product diet, but did have a greater ($P < 0.05$) FI and FCR.

Feed intake greatly influences BWG and FCR (Ferket and Gernat, 2006). However, there are many extrinsic factors that affect FI such as antinutritional factors, nutritional content of the diet, and health status. Dietary energy content is considered one of the most predictable indicators of FI with the theory that birds eat to their energy requirements (Ferket and Gernat, 2006). Experiment 1 of this study showed that CFW and SFFW had similar energy content to SBM which is reflected in the FI of Exp. 3 for CFW. Diets for experiment 3 were balanced by energy. Composite food waste did not affect FI and therefore we can assume that the AMEn value is correct. However, when birds were fed 5.5% FFW the FI increased suggesting that either there is something in the fermented product that stimulates FI or that the AMEn value is underestimated. Another dietary nutritional factor recognized by Ferket and Gernat is protein content. Experiment 2 showed that CFW had similar amino acid digestibility and digested ileal content to SBM, however, SFFW was less than SBM suggesting that protein content could be a contributing factor but likely not the leading cause of FI. There are many antinutritional factors that affect feedstuffs such as trypsin inhibitors and the maillard reaction of processed grains. One concern we had with the extrusion process was protein degradation and solubility caused by the potential of a maillard reaction. When protein solubility falls below 70% chicks show lower growth performance rates (Araba and Dale, 1990; Thakur and Hurburgh, 2007). Composite food

waste had the lowest KOH solubility (73.96%) but still above the 70% threshold. However, this might explain the increased FCR when composite food waste was included at 30% of the diet.

The fermented food waste in this study produced less astaxanthin than expected. The dietary astaxanthin concentration was 0.0195 and 0.0715 mg of astaxanthin per kg of feed for 1.5 and 5.5% FFW, respectively. When birds were fed the 5.5% FFW they performed better than birds fed the commercial astaxanthin which contained 5 mg of astaxanthin per kg of feed, 70x less than the amount suggested to feed from the commercial product. However, birds fed the commercial astaxanthin also had decreased ($P < 0.05$) BWG and FI and an increased FCR compared to the basal diet. In a previous broiler study, when astaxanthin was added to diets of either 2.3 or 4.6 mg/kg of feed it resulted in a linear increase in BWG and improvement in FCR in the finisher phase with no impact in the starter phase when compared to a common basal diet (Jeong and Kim, 2014). However, other studies report no effect on bird performance when including astaxanthin in increments of 0-179 mg/kg of feed but see a reduction in cecal *Clostridium perfringens* content and reduce oxidative stress altogether helping the bird maintain a healthier condition (Waldenstedt et al., 2003; Pertiwi et al., 2022). As mentioned previously, astaxanthin has antioxidant and anti-inflammatory properties which support a positive health status and in turn prevent FI from decreasing. Despite the miniscule amount of astaxanthin between the two FFW treatments the 5.5% FFW increased BWG and FI compared to birds fed the 1.5% FFW suggesting that there could be another component of the FFW that when fed at higher levels could be contributing to an increase in performance.

Conclusion

In conclusion, multiple forms of food waste were successfully utilized as nutrient sources for broilers. Extruded SBM had a greater AMEn content than fermented food waste mixed with SBM while both the conventional SBM and extruded SBM were similar to extruded food waste. Conventional SBM had a greater AID of indispensable AA's compared to fermented food waste mixed with SBM whereas extruded food waste was similar to SBM. Growth performance depended on the inclusion level of extruded and fermented food waste to be either similar, less, or greater than that of the corn/SBM basal, commercial astaxanthin, or commercial antibiotic diets. Birds fed either 10 or 30% extruded food waste of the total diet had similar BWG and FI as the birds fed the basal diet. However, including 10% extruded food waste improved the FCR compared to including 30% extruded food waste. Fermented food waste at both 1.5 and 5.5% inclusion of the diet resulted in similar BWG and FCR as the basal diet. Meanwhile birds fed 5.5% fermented had a greater FI than birds fed 1.5% fermented food waste. The addition of 5.5% fermented food waste increased BWG compared to the commercial antibiotic whereas the commercial antibiotic was similar to including 10% extruded food waste and 1.5 or 5.5% fermented food waste. Compared to the commercial astaxanthin the 10% extruded food waste and 5.5% fermented food waste increased BWG. Feed intake increased with both inclusions of extruded food waste and 5.5% fermented food waste compared to the commercial antibiotic whereas all inclusions of extruded and fermented food waste increased FI compared to the commercial astaxanthin. Feed conversion ratio improved when birds were fed the 10% extruded food waste, 1.5 or 5.5 % fermented food waste, the basal, or the commercial antibiotic diet compared to the 30% extruded food waste and commercial astaxanthin.

Table 3.1 Chemical analysis of soybean meal, extruded soybean meal, extruded food waste, and fermented food waste product used (as-is basis; experiments 1 and 2)¹

Item, %	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product ²
Dry matter	88.90	93.78	94.08	77.92
Crude protein	46.63	47.50	45.49	40.88
Crude fat	1.11	3.91	4.62	1.21
Crude fiber	3.48	3.51	3.25	2.79
Starch	11.00	11.08	14.12	9.37
Ash	6.46	6.82	6.69	5.60
Neutral detergent fiber	6.68	6.86	6.62	5.72
Acid detergent fiber	6.39	4.85	5.90	3.48
KOH protein solubility	83.86	82.40	73.96	78.58
Indispensable AA				
Arginine	3.40	3.44	3.19	2.83
Histidine	1.31	1.33	1.26	1.10
Isoleucine	2.20	2.31	2.12	1.91
Leucine	3.64	3.70	3.51	3.13
Lysine	3.05	3.09	2.88	2.52
Methionine	0.61	0.65	0.62	0.55
Phenylalanine	2.42	2.47	2.30	2.06
Threonine	1.82	1.87	1.80	1.57
Tryptophan	0.60	0.62	0.56	0.54
Valine	2.28	2.38	2.20	1.98
Total AA	46.34	47.25	44.65	39.81

¹ Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

²The fermentation product was mixed with SBM resulting in the product being 14.5% of the fermented food waste

Table 3.2 Diet composition formulated to determine apparent metabolizable energy (AME) of composite food waste and soybean meal (experiment 1)¹

Ingredient, % as fed	Basal	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product
Ground Corn	57.90	40.38	40.38	40.38	40.38
Soybean Meal	35.95	25.16	25.16	25.16	25.16
Limestone	0.99	0.69	0.69	0.69	0.69
Dicalcium Phosphate	1.42	1.00	1.00	1.00	1.00
Salt	0.46	0.33	0.33	0.33	0.33
L-Lysine	0.21	0.14	0.14	0.14	0.14
DL-Methionine	0.33	0.23	0.23	0.23	0.23
L-Threonine	0.13	0.09	0.09	0.09	0.09
Quantum Blue ²	0.01	0.01	0.01	0.01	0.01
Choline Chloride	0.04	0.03	0.03	0.03	0.03
Vitamin Trace Mineral Premix ³	0.25	0.18	0.18	0.18	0.18
Soy Oil	1.81	1.26	1.26	1.26	1.26
Test Ingredient	0.00	30.00	30.00	30.00	30.00
Titanium Dioxide	0.50	0.50	0.50	0.50	0.50
Total	100	100	100	100	100

¹A total of 300 one-day old male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment. Treatment diets were formulated to be 70% basal+30% test ingredient.

² Quantum Blue, AB Vista. Phytase, 10,000 FTU/g.

³ Provided per kg of diet: 40 g Zn, 20 g Fe, 40 g Mn, 4500 ppm Cu, 600 ppm I, 60 ppm Se, 635,029 IU vitamin A, 226,796 IU vitamin D₃, 1360 IU vitamin E, 0.91 mg vitamin B₁₂, 68 mg menadione, 544 mg riboflavin, 90 mg thiamine, 544 mg pantothenic acid, 2268 mg niacin, 113 mg vitamin B₆, 57 mg folic acid, 31,751 mg choline, and 2.7 mg biotin.

Table 3.3 Diet composition formulated to determine apparent ileal digestibility (AID) of soybean meal, extruded soybean meal, extruded food waste, and fermented food waste product balanced at 20% crude protein (experiment 2)¹

Ingredient, %	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product
Test Ingredient	43.19	42.27	44.07	49.69
Dextrose	52.69	53.61	51.81	46.19
Soybean oil	2.00	2.00	2.00	2.00
Dicalcium phosphate	1.90	1.90	1.90	1.90
Limestone	1.00	1.00	1.00	1.00
Sodium bicarbonate	0.20	0.20	0.20	0.20
Sodium chloride	0.20	0.20	0.20	0.20
Titanium dioxide	0.50	0.50	0.50	0.50
Vitamin trace mineral premix ²	0.32	0.32	0.32	0.32
Total	100	100	100	100

¹A total of 240 one-day old male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

² Provided per kg of diet: 40 g Zn, 20 g Fe, 40 g Mn, 4500 ppm Cu, 600 ppm I, 60 ppm Se, 1,635,029 IU vitamin A, 226,796 IU vitamin D₃, 1360 IU vitamin E, 0.91 mg vitamin B₁₂, 68 mg menadione, 544 mg riboflavin, 90 mg thiamine, 544 mg pantothenic acid, 2268 mg niacin, 113 mg vitamin B₆, 57 mg folic acid, 31,751 mg choline, and 2.7 mg biotin.

Table 3.4 Chemical analysis of experimental diets to determine apparent ileal digestibility (AID) of soybean meal, extruded soybean meal, extruded food waste, and fermented food waste product (as-is basis; experiment 2)^{1,2,3}

Item, %	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product
Dry matter	86.51	86.04	85.83	82.27
Crude protein	22.45	20.95	21.40	21.14
Total AA	21.66	20.15	20.44	19.23
Indispensable AA				
Arginine	1.53	1.42	1.42	1.37
Histidine	0.61	0.53	0.57	0.54
Isoleucine	1.02	0.95	0.96	0.90
Leucine	1.68	1.56	1.58	1.49
Lysine	1.41	1.29	1.28	1.19
Methionine	0.29	0.27	0.28	0.25
Phenylalanine	1.11	1.03	1.03	0.98
Threonine	0.85	0.80	0.81	0.76
Tryptophan	0.26	0.26	0.26	0.25
Valine	1.05	0.97	1.00	0.92
Dispensable AA				
Alanine	0.94	0.88	0.90	0.84
Aspartic acid	2.51	2.34	2.34	2.22
Cystine	0.31	0.29	0.29	0.27
Glutamic acid	4.07	3.76	3.82	3.60
Glycine	0.92	0.85	0.86	0.82
Proline	1.10	1.01	1.04	0.97
Serine	0.97	0.91	0.91	0.87
Tyrosine	0.74	0.70	0.73	0.67

¹At hatch, 240 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

²Food waste was collected for 30 consecutive days, composited, and either extruded at 140°C or fermented with yeast to make a fermented product. Soybean meal was also extruded at 140°C for one treatment. Therefore, dietary treatments consisted of composite food waste, conventional soybean meal, extruded soybean meal, and fermented food waste product mixed with soybean meal.

³Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

Table 3.5 Diet composition formulated to determine growth performance of male broilers fed composite food waste and fermented food waste (experiment 3)¹

Item	Basal	10% Composite Food Waste	30% Composite Food Waste	1.5% Fermentation Product	5.5% Fermentation Product	Commercial Astaxanthin	Commercial Antibiotic
Ingredient, % as fed							
Ground Corn	56.38	56.15	55.64	53.83	47.02	56.37	56.38
Soybean Meal	38.43	29.04	10.26	38.86	40.03	38.43	38.43
Limestone	0.68	0.67	0.67	0.66	0.63	0.68	0.68
Dicalcium Phosphate	1.92	1.97	2.08	1.93	1.98	1.92	1.92
Salt	0.38	0.38	0.38	0.38	0.38	0.38	0.38
L-Lysine	0.17	0.16	0.14	0.16	0.14	0.17	0.17
DL-Methionine	0.34	0.34	0.34	0.34	0.35	0.34	0.34
L-Threonine	0.16	0.15	0.12	0.16	0.15	0.16	0.16
Quantum Blue ²	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Choline Chloride	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Vitamin Trace	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral Premix ³							
Soy Oil	1.19	0.79	0.00	1.81	3.46	1.19	1.19
Test Ingredient	0.00	10.00	30.00	1.50	5.50	0.01 ⁴	0.0005 ⁵
Analyzed analysis, % as-is ⁶							
Dry matter	89.98	90.13	90.19	89.00	86.19	89.70	89.78
Crude protein	23.67	21.69	22.87	24.74	24.23	23.36	23.26
Crude fat	3.29	2.93	2.97	3.67	4.89	3.17	3.37
Crude fiber	2.58	2.55	2.44	2.40	2.61	2.25	2.33
Ash	5.51	6.23	5.78	5.59	5.57	5.95	5.37
Indispensable AA							

Arginine	1.53	1.43	1.38	1.48	1.65	1.36	1.35
Histidine	0.61	0.58	0.58	0.59	0.64	0.55	0.56
Isoleucine	1.09	1.04	1.02	1.06	1.15	0.97	1.01
Leucine	1.96	1.86	1.87	1.92	2.03	1.80	1.81
Lysine	1.44	1.41	1.27	1.40	1.58	1.33	1.34
Methionine	0.56	0.61	0.57	0.53	0.54	0.67	0.55
Phenylalanine	1.17	1.11	1.09	1.14	1.23	1.05	1.07
Threonine	0.96	0.92	0.91	0.98	1.08	0.93	0.88
Tryptophan	0.32	0.29	0.29	0.32	0.32	0.27	0.29
Valine	1.17	1.11	1.10	1.13	1.23	1.04	1.09
Total AA	23.22	22.23	21.90	22.70	24.52	21.35	21.23

¹A total of 420 one-day old male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

² Quantum Blue, AB Vista. Phytase, 10,000 FTU/g.

³ Provided per kg of diet: 40 g Zn, 20 g Fe, 40 g Mn, 4500 ppm Cu, 600 ppm I, 60 ppm Se, 635,029 IU vitamin A, 226,796 IU vitamin D₃, 1360 IU vitamin E, 0.91 mg vitamin B₁₂, 68 mg menadione, 544 mg riboflavin, 90 mg thiamine, 544 mg pantothenic acid, 2268 mg niacin, 113 mg vitamin B₆, 57 mg folic acid, 31,751 mg choline, and 2.7 mg biotin.

⁴ Pink Carophyll 10%, DSM. Astaxanthin, 5 mg/kg.

⁵ BMD® 50, Zoetis. Antibiotic, 55 mg/kg.

⁶ Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

Table 3.6 Effect of composite food waste and soybean meal on apparent metabolizable energy (AME) in 21-d old broilers.^{1,2,3}

Item	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product	SEM	Probability, <i>P</i>
AME, kcal/kg DM	2,424 ^b	2,862 ^a	2,576 ^{ab}	2,441 ^b	127.6	0.003

¹At hatch, 300 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

²Food waste was collected for 30 consecutive days, composited, and either extruded at 140°C or fermented with yeast to make a fermented product. Soybean meal was also extruded at 140°C for one treatment. Therefore, dietary treatments consisted of composite food waste, conventional soybean meal, extruded soybean meal, and fermented food waste product mixed with soybean meal.

³ Means within a row followed by a different letter (^{a-b}) are significantly different ($P \leq 0.05$).

Table 3.7 Effect of composite food waste and soybean meal on apparent ileal digestibility coefficients of amino acids in 21-d old broilers.^{1,2,3,4}

Item, %	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product	SEM	Probability, <i>P</i>
Indispensable AA						
Arginine	85.65 ^a	85.57 ^a	86.37 ^a	79.50 ^b	1.153	0.001
Histidine	81.99 ^a	79.98 ^{ab}	81.05 ^a	75.45 ^b	1.251	0.006
Isoleucine	77.82 ^a	77.60 ^a	77.78 ^a	70.10 ^b	1.493	0.002
Leucine	77.75 ^a	77.77 ^a	78.49 ^a	70.43 ^b	1.465	0.002
Lysine	79.66 ^a	78.78 ^a	78.65 ^a	67.09 ^b	1.749	0.001
Methionine	79.31 ^a	76.67 ^{ab}	78.03 ^{ab}	69.59 ^b	2.170	0.020
Phenylalanine	79.94 ^a	80.40 ^a	81.12 ^a	72.82 ^b	1.342	0.001
Threonine	71.92 ^a	70.52 ^a	71.20 ^a	62.41 ^b	1.818	0.003
Tryptophan	82.07 ^a	80.79 ^{ab}	81.13 ^a	75.65 ^b	1.339	0.010
Valine	74.06 ^a	72.63 ^a	73.42 ^a	64.68 ^b	1.742	0.002
Total AA	78.74 ^a	77.81 ^a	79.32 ^a	70.52 ^b	1.478	0.001

¹At hatch, 240 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

²Food waste was collected for 30 consecutive days, composited, and either extruded at 140°C or fermented with yeast to make a fermented product. Soybean meal was also extruded at 140°C for one treatment. Therefore, dietary treatments consisted of composite food waste, conventional soybean meal, extruded soybean meal, and fermented food waste product mixed with soybean meal.

³Means within a row followed by a different letter (^{a-b}) are significantly different ($P \leq 0.05$).

⁴AA = amino acids.

Table 3.8 Apparent ileal content of amino acids in food waste products and soybean meal when fed to 21-d old broilers.^{1,2,3,4}

Item, %	SBM	Extruded SBM	Composite Food Waste	SBM + Fermentation Product	SEM	Probability, <i>P</i>
Indispensable						
AA						
Arginine	2.92 ^a	2.95 ^a	2.75 ^b	2.25 ^d	0.038	0.001
Histidine	1.07 ^a	1.07 ^a	1.02 ^a	0.83 ^b	0.016	0.001
Isoleucine	1.72 ^{ab}	1.79 ^a	1.65 ^b	1.34 ^c	0.032	0.001
Leucine	2.83 ^a	2.88 ^a	2.75 ^a	2.21 ^b	0.052	0.001
Lysine	2.43 ^a	2.44 ^a	2.26 ^a	1.69 ^b	0.051	0.001
Methionine	0.49 ^a	0.50 ^a	0.48 ^a	0.38 ^b	0.013	0.001
Phenylalanine	1.93 ^a	1.98 ^a	1.87 ^a	1.50 ^b	0.031	0.001
Threonine	1.31 ^a	1.32 ^a	1.28 ^a	0.98 ^b	0.033	0.001
Tryptophan	0.50 ^a	0.50 ^a	0.46 ^b	0.41 ^c	0.008	0.001
Valine	1.69 ^a	1.73 ^a	1.62 ^a	1.28 ^b	0.039	0.001
Total AA	36.49 ^a	36.76 ^a	35.42 ^a	28.08 ^b	0.702	0.001

¹At hatch, 240 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

²Food waste was collected for 30 consecutive days, composited, and either extruded at 140°C or fermented with yeast to make a fermented product. Soybean meal was also extruded at 140°C for one treatment. Therefore, dietary treatments consisted of composite food waste, conventional soybean meal, extruded soybean meal, and fermented food waste product mixed with soybean meal.

³Means within a row followed by a different letter (^{a-d}) are significantly different ($P \leq 0.05$).

⁴AA = amino acids.

Table 3.9 Effect of composite food waste and fermented food waste on growth performance in 21-d old broilers.^{1,2,3}

Item	Basal	10% Composite Food Waste	30% Composite Food Waste	1.5% Fermentation Product	5.5% Fermentation Product	Commercial Astaxanthin ⁴	Commercial Antibiotic ⁵	SEM	Probability, <i>P</i>
BWG, g	659 ^{ab}	677 ^{ab}	629 ^{bc}	625 ^{bc}	705 ^a	563 ^c	636 ^b	24.72	0.002
FI, g	737 ^{bc}	795 ^{ab}	770 ^b	705 ^c	839 ^a	631 ^d	696 ^c	23.66	0.0001
FCR, g/g	1.26 ^a	1.25 ^a	1.31 ^{bc}	1.28 ^{ab}	1.26 ^a	1.32 ^c	1.27 ^a	0.012	0.0001

¹At hatch, 420 male broilers (Ross 308, Aviagen, Sallisaw, OK) were placed in battery cages with 6 broilers per cage and 10 replicates per treatment.

²Food waste was collected for 30 consecutive days, composited, and either extruded at 140°C or fermented to make a fermented product. Therefore, dietary treatments consisted of composite food waste (10% and 30%), fermented food waste (1.5% and 5.5%), a commercial astaxanthin, and a commercial antibiotic.

³Means within a row followed by a different letter (^{a-d}) are significantly different ($P \leq 0.05$).

⁴Pink Carophyll 10%, DSM. Astaxanthin, 5 mg/kg.

⁵BMD® 50, Zoetis. Antibiotic, 55 mg/kg.

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