Note

True Metabolizable Energy of American Black Duck Foods

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ABSTRACT Understanding the true metabolizable energy (TME) of foods is critical to estimating the energetic carrying capacity of landscapes for migrating and wintering waterfowl. We estimated gross energy, nutrient composition, and TME_N (TME corrected for zero nitrogen balance) for 7 foods that are commonly found in the diet of American black duck (*Anas rubripes*) and other waterfowl wintering along the Atlantic Coast. TME_N values ($\bar{x} \pm SE$) were 3.66 ± 0.12 kcal/g for mummichog (*Fundulus heteroclitus*), 2.02 ± 0.12 kcal/g for grass shrimp (*Palaemonetes intermedius, P. pugio,* and *P. vulgaris*), 1.57 ± 0.11 kcal/g for fiddler crabs (*Uca minax, U. pugilator,* and *U. pugnax*), 1.42 ± 0.13 kcal/g for sea lettuce (*Ulva lactuca*), 1.39 ± 0.12 kcal/g for saltmarsh cordgrass seeds (S*partina alterniflora*), 1.10 ± 0.14 kcal/g for widgeon grass vegetation (*Ruppia maritima*), and 0.77 ± 0.16 kcal/g for saltmarsh snails (*Melampus bidentatus*). TME_N estimated for foods in this study will assist conservation planners in carrying out bioenergetics modeling along the Atlantic Coast. © 2014 The Wildlife Society.

KEY WORDS American black duck, *Anas rubripes*, bioenergetics modeling, carrying capacity, food, true metabolizable energy.

Quantifying regional carrying capacity throughout the American black duck (*Anas rubripes*) wintering range is a priority research need identified by the Black Duck Joint Venture (Black Duck Joint Venture Management Board 2008). Determining the carrying capacity of any landscape requires knowledge of both the types and amounts of different foods available and their energetic value (Miller and Newton 1999, Ballard et al. 2004, Williams et al. 2014). Recent studies have quantified food availability for wintering black ducks along the Atlantic Coast (Plattner et al. 2010, Cramer et al. 2012); however, limited information exists regarding the energetic value of common black duck foods.

  Estimates of true metabolizable energy (TME) are currently available for only 6 species of animals and the seeds of 5 plants found in the black duck diet (Hoffman and Bookhout 1985, Jorde and Owen 1988, Petrie et al. 1998, Sherfy 1999, Checkett et al. 2002, Kaminski et al. 2003,

Ballard et al. 2004, Dugger et al. 2007). This represents a small fraction of the foods consumed by black ducks. Given the range of values for the few species reported to date, additional work is required to improve our understanding of the foraging landscape for migrating and wintering black ducks. We report the TME_N (TME corrected to zero nitrogen balance) value for an additional 3 plant and 4 animal foods commonly occurring in wetlands along the Atlantic Coast and in the black duck diet.

METHODS

We conducted feeding trials at the Winous Point Marsh Conservancy located near Port Clinton, Ohio, USA using captive-reared black ducks >5 months of age provided by a local breeder. Between feeding trials, all birds were confined in an unheated pen, subject to natural temperature and photoperiod, and provided with unlimited access to a commercial game bird ration (crude protein ≥20%, crude fat ≥3.0%, crude fiber ≤5.0%), grit, and fresh water (Petrie et al. 1997). We conducted feeding trials between September and March following the general procedures outlined in Checkett et al. (2002) and Dugger et al. (2007). We determined TME_N for saltmarsh cordgrass seeds (S*partina alterniflora*), widgeon grass vegetation (*Ruppia maritima*), sea lettuce (*Ulva lactuca*), saltmarsh snails (*Melampus bidentatus*), mummichog (*Fundulus heteroclitus*), fiddler crabs (*Uca minax,*

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U. pugilator, and *U. pugnax*), and grass shrimp (*Palaemonetes intermedius, P. pugio*, and *P. vulgaris*). We selected test species based on their common occurrence in wetlands and presence in the diet of black ducks (Costanzo and Malecki 1989, Cramer 2009, Plattner et al. 2010, Cramer et al. 2012, B. Lewis, Jr., Southern Illinois University, unpublished report).

We obtained saltmarsh cordgrass seeds from a commercial seed supplier and widgeon grass vegetation, sea lettuce, and animal foods during September–March from natural wetlands located near Forsythe National Wildlife Refuge in southern New Jersey, USA. We collected widgeon grass vegetation and sea lettuce during low tide using a rake and removed adhering seeds or animals by rinsing and handpicking samples. We handpicked fiddler crabs and saltmarsh snails during low tide along exposed mud banks and from *Spartina* vegetation, respectively. We seined and hand netted grass shrimp and mummichog along tidal creek edges and ditches.

Procedures for TME bioassays followed Sibbald (1986). We randomly selected 12 treatment birds (6 male and 6 female) to be fed 7 test foods. We randomly selected 6 (3 of each sex) additional birds to serve as controls (not fed test foods) to provide a measure of endogenous contributions to excreta energy (Sibbald 1976). We used the same 6 control birds for all trials and fed treatment birds the same food during each trial. We separated feeding trials by a 10-day period to allow birds to recover any lost body mass during the previous trial.

Prior to each feeding trial, we placed control and treatment birds in individual metabolism cages ($20 \times 20 \times 30$ cm), provided ad libitum water, and fasted them for 48 hours. Following fasting, we weighed each bird (± 10 g) and immediately returned control birds to metabolic chambers. We then attempted to feed each treatment bird a quantity of food equal to 1% of its body weight (Sibbald 1986). We fed treatment birds by inserting clear plastic tubes (1.2×40 cm) that were pre-loaded with the test food into the esophagus and pushing the food down the tube using a wooden dowel. We collected, weighed, and subtracted food items failing to enter a treatment bird's esophagus (e.g., foods clinging to the tube wall or wooden dowel) from each treatment bird's original dose. We eliminated treatment birds that regurgitated any portion of a test food following feeding from the feeding experiment. Therefore, for some test foods, more than 1 trial was required to achieve desired sample sizes. We fed treatment birds only once during a trial, and we returned birds to their metabolic chambers immediately following handling.

We placed plastic tubs under each metabolic chamber to capture fecal and urinary material. We collected excreta from control and treatment cages for 48 hours following feeding (Petrie et al. 1998, Checkett et al. 2002, Kaminski et al. 2003, Dugger et al. 2007). Following collection of excreta, we processed samples for laboratory analysis. We removed feathers and grit from each sample; the remaining excreta was oven-dried at 60° C, weighed to the nearest 0.0001 g, and ground with a mortar and pestle. We estimated gross energy (GE_F; kcal/g) of test foods and excreta from fed and fasted birds on duplicate subsamples using a Parr adiabatic oxygen bomb calorimeter (30 atmospheres O_2). We calculated TME (kcal/g) as:

$$TME = ((GE_F \times W_F) - (EE_F - EE_C))/W_F$$

where GE_F was the gross energy of the food item (kcal/g), W_F was the dry mass fed (g), EE_F was the energy voided as excreta by the experimental bird (kcal), and EE_C was the energy voided as excreta by the control bird (kcal). We used the average energy excreted by control birds to estimate EE_C. To account for potentially greater catabolism of body tissue by control birds and avoid overestimating energy derived from non-food origin, we corrected TME to zero nitrogen balance (TME_N; Parsons et al. 1982, Sibbald and Morse 1983).

We determined the following nutrient components for all foods using standard methods (Servello et al. 2005): energy density (described above), percent water, crude protein, fat, ash, fiber, and nitrogen-free extract. We determined percent water by drying samples in a forced air oven at 100° C and percent nitrogen using a Carla Erba NA 1500 Elemental Analyzer. We multiplied percent nitrogen by 6.25 to estimate crude protein (Servello et al. 2005). We estimated crude fat using petroleum ether extraction for 6 hours (Dobush et al. 1985), and ash content by heating in a 550° C muffle furnace for 12–15 hours (Association of Official Analytical Chemists 2000). We used the detergent analysis system to measure fiber content (Goering and Van 1970). Specifically, we used the amylase-treated Neutral Detergent Fiber (aNDF) method (Mertens 2002) to measure total fiber (combined hemicellulose, cellulose, lignin, cutin) followed sequentially by measurement of Acid Detergent Fiber (ADF; cellulose and lignin; Mould and Robbins 1981) as recommended for wildlife studies (Servello et al. 2005). We calculated nitrogen free extract as (100% − %water − % crude fiber − %ash − %fat − %crude protein) where crude fiber was ADF $\times$ 0.80. We expressed TME_N values as a percentage of gross energy [(TME_N /GE_F) $\times$ 100%] to estimate digestive efficiency (Petrie et al. 1998).

We used a linear mixed effects model to determine whether TME_N differed among test foods (Littell et al. 1996, PROC MIXED, SAS Institute 2002). The fixed effects of test food, sex, quantitative covariate body mass, and their interactions were specified in the full model. Because body mass may influence TME_N results (Sherfy 1999), we included this variable as a covariate. We employed a backwards elimination procedure (preserving model hierarchy) for model simplification purposes and selected a best approximating model using corrected Akaike's Information Criterion (AIC_c). We considered models with $\Delta AIC_c < 2$ and which did not contain uninformative parameters (Arnold 2010) as competing models. We included random effects corresponding to individual birds and date-specific trials in all models to account for the multiple test foods and trials across birds. Using the best model, we constructed pairwise contrasts among test food least-square means. We used Tukey multiplicity-adjusted *P*-values (<0.05) for identifying differences among test foods.

RESULTS

Residual plots from the full model revealed that they were reasonably approximated by a normal distribution, homoge-

nous variability, and with little evidence of non-linearity of association between TME_N and body mass. The best candidate model, as indexed by AIC_c, included test food (Table 1). There was one additional model (test food, sex) with $\Delta AIC_c < 2$, but it was not a competitor because there was little change in model deviance from the simpler, best model and only a small penalty for including the uninformative effect of sex. Values of TME_N differed among test foods ($F_{6,47} = 65.09$, $P < 0.001$; Table 2). Pairwise comparisons indicated mean TME_N was highest for mummichog, which provided 4.8 times more energy than saltmarsh snails, 3.3 times more energy than widgeon grass vegetation, 2.6 times more energy than saltmarsh cordgrass seed and sea lettuce, 2.3 times more energy than fiddler crabs, and 1.8 times more energy than grass shrimp (Table 2). Values of TME_N were also significantly higher for grass shrimp than sea lettuce, saltmarsh cordgrass seed, widgeon grass vegetation, and saltmarsh snails. Saltmarsh snails yielded lower TME_N than all test foods except widgeon grass vegetation. Digestibility was highest for saltmarsh snails (82.8%) and mummichog (76.1%) followed by grass shrimp (60.8%), fiddler crabs (59.5%), sea lettuce (47.7%), saltmarsh cordgrass seed (36.8%), and widgeon grass vegetation (35.6%). Mummichog, grass shrimp, and fiddler crabs were high in protein content and with the exception of mummichog, fat content of foods were relatively low (Table 2). Saltmarsh cordgrass seeds were highest in carbohydrates (nitrogen free extract) and fiber but were low in metabolizable energy.

DISCUSSION

Black ducks received the most energy per gram eaten from mummichog whose TME_N value (3.66 kcal/g) was the highest reported for animal foods fed to waterfowl (Jorde and Owen 1988, Sherfy 1999, Ballard et al. 2004). During winter, ice and tide conditions often trap and concentrate mummichog in high densities in small tidal creeks (Costanzo and Malecki 1989). When the surrounding salt marsh freezes, black ducks congregate in these areas and exploit this highly digestible and energy-rich food resource (Costanzo and Malecki 1989).

Our TME_N value for grass shrimp (2.02 kcal/g) was similar to published estimates for the Class Malacostraca (Jorde and Owen 1988, Ballard et al. 2004). The TME_N value (1.57 kcal/g) for fiddler crabs was similar to the estimate (1.90 kcal/g) reported from diets of whimbrel (*Numenius phaeopus*; Zwarts and Blomert 1990). Soft-bodied animals such as grass shrimp provide an important source of energy for black ducks because they can be consumed in large quantities and are highly digestible (Jorde and Owen 1988, Ballard et al. 2004).

The TME_N value for saltmarsh snails (0.77 kcal/g) was the lowest of foods fed to black ducks but slightly higher than estimates (0.27–0.60 kcal/g) previously reported for gastropods consumed by black ducks (Jorde and Owen 1988) and northern pintails (*Anas acuta*; Ballard et al. 2004). Despite their low energy value, saltmarsh snails are commonly found in the black duck diet (Costanzo and Malecki 1989, Cramer 2009, B. Lewis, Jr., Southern Illinois University, unpublished thesis). The occurrence of this low-energy food in the diet may be related to abundance and handling time. For example, saltmarsh snail densities can range from 0.4–7.1 million per ha on *Spartina* marshes (Alpaugh and Ferrigno 1973, Peck et al. 1994) and can be consumed efficiently (Costanzo and Malecki, 1989). In addition, the shells of saltmarsh snails are very thin (Hausman 1948) leading to high digestibility (83%).

Our TME_N estimate for saltmarsh cordgrass seed (1.39 kcal/g) was substantially higher than the value reported by Sherfy (1999) for saltmeadow cordgrass seed (0.05 kcal/g; *Spartina patens*) fed to blue-winged teal (*Anas discors*). However, saltmarsh cordgrass seed provides significantly less energy when compared to other seeds from the Family Poaceae (Hoffman and Bookhout 1985, Petrie et al. 1998, Sherfy 1999, Checkett et al. 2002). Our TME_N values for sea lettuce (1.42 kcal/g) and widgeon grass vegetation (1.10 kcal/g) were higher than that reported for shoalgrass foliage (*Halodule wrightii*) by Ballard et al. (2004). Although saltmarsh cordgrass seeds, sea lettuce, and widgeon grass provided less energy than other test foods, at times they provide an important source of energy for black ducks. For example, when *Spartina* marshes ice over making other foods unavailable, black ducks rely on sea lettuce found in

Table 1. Candidate models, number of parameters (K), Akaike's Information Criterion corrected for small sample size (AIC_c), increase over the lowest AIC_c (ΔAIC_c), and Akaike model weight (w_i) for models used to examine factors influencing nitrogen-corrected true metabolizable energy (TME_N) for plant and animal foods fed to adult male and female captive American black ducks at Winous Point Marsh Conservancy, Port Clinton, Ohio, USA, September 2009–March 2010.

Parameters[a]	K[b]	AIC_c[c]	ΔAIC_c	w_i
Test food	9	94.8	0	0.50
Test food, sex	10	96.1	1.30	0.26
Test food, sex, body mass, sex × body mass	12	97.2	2.40	0.15
Test food, sex, body mass	11	98.4	3.60	0.08
Test food, sex, body mass, test food×body mass, sex × body mass	18	111.3	16.50	0
Intercept only	3	123.6	28.80	0
Test food, sex, body mass, test food × sex, test food × body mass, sex × body mass	24	132.7	37.9	0
Test food, sex, body mass, test food × sex, test food × body mass, sex × body mass, test food × sex × body mass	30	157.6	62.80	0

[a] All models include random effects of bird and trial.

[b] Includes parameters for intercept, fixed effect parameters, random effect of bird, and random error; no parameter for random effect of trial because variance estimated to be 0.

[c] $n = 74$.

Table 2. Gross energy (GE$_F$, kcal/g), least-square predicted means of nitrogen-corrected true metabolizable energy (TME$_N$, kcal/g), and nutrient composition (% dry mass basis) for plant and animal foods fed to adult male and female captive American black ducks at Winous Point Marsh Conservancy, Port Clinton, Ohio, USA, September 2009–March 2010.

Test food	n[b]	GE$_F$	TME$_N$ $\bar{x}$[c]	TME$_N$ SE	Protein	Fat	Ash	NFE	ADF	NDF
Mummichog	12	4.81	3.66A	0.12	58.1	13.1	18.7	NA	NA	NA
Grass shrimp	12	3.32	2.02B	0.12	46.8	1.2	34.9	11.7	6.7	23.8
Fiddler crab	13	2.64	1.57BC	0.11	38.4	1.2	45.9	8.9	7.0	11.3
Sea lettuce	9	2.98	1.42C	0.13	21.7	0.1	28.2	38.2	14.7	30.1
Saltmarsh cordgrass seed	13	3.78	1.39C	0.12	11.6	1.6	11.4	42.0	41.8	68.5
Widgeon grass	9	3.09	1.10CD	0.14	8.1	0.9	20.5	38.6	39.9	42.8
Saltmarsh snail	6	0.93	0.77D	0.16	12.6	0.2	80.5	6.1	0.7	6.1

[a] ADF, acid detergent fiber; NDF, neutral detergent fiber; NFE, nitrogen free extract = 100% − (protein + fat + fiber + ash).
[b] Reduced sample sizes due to regurgitation of food fed to birds or spurious TME$_N$ estimates.
[c] Least-square means followed by different letters were statistically different ($\alpha = 0.05$).

surrounding bays to meet daily energy demands (Costanzo and Malecki 1989). In addition, saltmarsh cordgrass seeds and widgeon grass often become wind-rowed along shorelines making these foods highly concentrated and readily available to foraging black ducks (Grandy and Hagar 1971).

Finally, our TME$_N$ estimates for mummichog, grass shrimp, fiddler crab, saltmarsh cordgrass seed, and saltmarsh snail differed by 127%, 71%, −19%, 186%, and 57%, respectively, than values used by Cramer et al. (2012; Table S1) to estimate food energy for coastal black duck habitats in New Jersey. Using our estimates of TME$_N$ for these foods, resulted in a 41%, 14%, 7%, and 4% increase in black duck food energy for subtidal, high marsh, low marsh, and mudflat habitats, respectively. Higher energy values associated with these habitats will ultimately affect habitat objectives generated via bioenergetics models to support black duck populations at North American Waterfowl Management Plan goals along the Atlantic Coast. This example clearly demonstrates the importance of precise TME$_N$ values in bioenergetics modeling to predict habitat needs for waterfowl during the non-breeding period.

MANAGEMENT IMPLICATIONS

Managers require reliable TME$_N$ estimates of common waterfowl foods to perform bioenergetics modeling. Our TME$_N$ estimates can be combined with diet information and food biomass estimates to more accurately calculate energetic carrying capacity of various habitats used by wintering black ducks along the Atlantic Coast. Although our TME$_N$ values add considerably to the number of known values, this represents a small fraction of common waterfowl food items. Therefore, we recommend an increase in research effort focused on deriving TME$_N$ values for a wider variety of common waterfowl food items.

ACKNOWLEDGMENTS

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