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Nutritional depletion of total mixed rations by European starlings: Projected effects on dairy cow performance and potential intervention strategies to mitigate damage

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ABSTRACT

European starlings are an invasive bird species in North America that are known to cause damage to commercial dairies through the consumption of total mixed rations (TMR) destined for dairy cows. We hypothesized that large foraging flocks of starlings alter the physical composition of TMR, and that this change may be significant enough to affect milk production. To better determine if production losses could potentially occur in commercial dairies as a consequence of feed consumption by foraging flocks of starlings, we conducted controlled feeding experiments using a TMR sourced from a commercial dairy that is chronically plagued with seasonal starling damage. European starlings selected the high-energy fraction of the TMR and reduced starch and crude fat availability. Using the dairy National Research Council production model equations, the nutritional changes measured in the controlled feeding experiments could potentially reduce the productivity of dairies. Model output suggests that for Holsteins producing 32 kg of milk/d, total required net energy intake (NE_I) was 31.5 Mcal/d. Within the reference TMR, NE_I supplied was 29.3 Mcal/d, whereas within the starling-consumed TMR NE_I supplied was 27.7 Mcal/d. Following our nutrition experiments, we assessed the efficacy of pelleted feed as a deterrent strategy for bird damage management in commercial dairies. Six different pelleted feed treatments of differing diameter were offered to starlings. All pellets of 0.95 cm diameter or larger inhibited starling consumption by ≥79%.
Key words: dairy production, bird damage management, nutrition

INTRODUCTION

European starlings (*Sturnus vulgaris*) are native to Eurasia and North Africa and have successfully established populations on each continent except Antarctica (Feare, 1984; Linz et al., 2007; Rollins et al., 2009). Starlings seasonally congregate in large roosting groups and exploit the abundant and nutritious food sources found on concentrated animal feeding operations (Besser et al., 1968; Dolbeer et al., 1978; LeJeune et al., 2008). Starlings have been documented consuming livestock feed in animal agricultural operations in the United States, Europe, and Australia (Feare et al., 1992; Bentz et al., 2007; Carlson et al., 2011).

Livestock feed consumption by starlings appears to cause economically significant damage to feedlots and dairies in the United States (Glahn and Otis, 1981; Twedt and Glahn, 1982). Estimates of bird damage in commercial dairies within Wisconsin, New York, and Pennsylvania suggest that starling damage resulted in $64,000 of feed loss annually within dairies experiencing 10,000 or more birds per day, and feed costs per cwt increased 42% in dairies with 10,000 or more birds (Shwiff et al., 2012).

Feed consumption by starlings may negatively affect animal performance. Wright (1973) and Feare and Swannack (1978) found increased weight gain in cattle when fed in bird-excluded areas. Feare (1984) suggested that if feed consumption by birds occurs at the bunk, then removal of high-energy feed ingredients by starlings may reduce animal performance, and these losses may be economically significant to producers. Depenbusch et al. (2011) provided nutritional comparisons of cattle rations before and after starling damage and concluded these changes could potentially decrease growth rates and feed conversion efficiency of feeder cattle. The producer survey conducted by Shwiff et al. (2012) did not reveal differences in milk production between dairies experiencing and not experiencing bird damage.

To better determine if production losses could potentially occur in commercial dairies as a consequence of feed consumption by foraging flocks of starlings, we conducted controlled feeding experiments using a TMR sourced from a commercial dairy that is chronically plagued with seasonal starling damage. The objectives of these experiments were to (1) estimate the nutritional offsets caused by starling consumption of a TMR; (2) predict the effect on dairy cow performance caused by starling consumption of TMR using the dairy NRC (2001) production model equations; and (3) identify if particle size influences starling consumption of dairy TMR.

MATERIALS AND METHODS

We partnered with a commercial dairy in northern Colorado to conduct these experiments. During the winter of 2011 to 2012, we observed that this commercial dairy experienced approximately 5,000 to 15,000 starlings per day between November 15 and March 31. The dairy had a herd size of 2,767 cows, and 1,403 of these cows were in production. The herd consisted of 80% Holstein and 20% Holstein × Jersey cross. Milk cows on average were 43 mo old, weighed 589 kg, and were approximately 200 DIM. Bulk tank milk contained 3.48% milk fat and 3.02% milk protein. Feed intake and milk production data for late-lactation cattle (DIM ≥160) were used in these analyses. Feed intake for late-lactation cattle was approximately 25.5 kg (dry weight)/head per day. Milk production per head per day for late-lactation cattle was approximately 31.75 kg.

Starlings were live trapped from the commercial dairy using mist nets and modified Australian crow traps. All starlings were transported to the United States Department of Agriculture, National Wildlife Research Center (**NWRC**) in Fort Collins, Colorado, for feeding experiments. Nutrition experiments were conducted in 2012 and particle size testing was conducted in 2016. All starlings were quarantined for 2 wk with ad libitum access to feed (Layena poultry pellets, Purina Animal Nutrition LLC, St. Louis, MO) and water. Starlings were maintained in their quarantine cages until the pretest period of the experiment (4.9 × 2.4 × 2.4 m, length × width × height, respectively).

European Starling Feeding Experiments: Estimating Nutritional Offsets Caused by European Starlings

On February 29, 2012, starlings (n = 55) were moved from quarantine and housed 5 birds per 3.05 × 3.05 × 2.4 m (length × width × height, respectively) cages

for the pretest and test. Birds used on test were selected arbitrarily from quarantined starlings. If a bird was injured or appeared sick it was excluded from the nutrition experiment. The pretest lasted 5 d. During pretest, birds within each cage were fed 1 kg (as fed) of the TMR test diet daily. The TMR offered was a late-lactation ration fed to milk producing cows (DIM ≥160). The TMR offered during pretest was also used for the nutrition experiment.

The nutrition experiment was conducted from March 5 to 8, 2012. Starting March 5, a total of 15 kg of premixed, late-lactation TMR (as fed) was collected directly from feed trucks at 0600 h and brought to NWRC-Fort Collins for nutritional testing. Fresh TMR was offered daily within each of 10 cages (n = 10; 5 starlings per cage). For 4 consecutive days, 1.1 kg of feed, as fed, was weighed out for each cage. A total of 1 kg was offered to starlings within an aluminum tray (0.9 × 0.6 × 2.54 cm, length × width × diameter, respectively) and the remaining 100 g were used as a reference sample. This process of subsampling was used to ensure that the reference ration was representative of the feed offered to starlings in each respective cage. The reference sample was placed outside each respective cage in a paper bag. Both reference and starling-consumed rations were identified by cage number and day. An additional 1-kg TMR sample, as fed, was placed in a cage absent of starlings to estimate daily feed desiccation (e.g., evaporative water loss). Following 24 h of starling foraging, the starling-consumed and desiccation samples were weighed. The starling-consumed and reference samples were then placed in a drying oven at 75°C for 24 h. After drying was complete, all samples were ground using a Model 4, Thomas Wiley mill (Thomas Scientific, Swedesboro, NJ). The Wiley mill was opened and brushed clean after processing each individual sample to eliminate cross contamination. Ground samples were stored in a walk-in cooler, set to 4°C, until all samples were processed and ready to ship to a laboratory for nutritional analysis.

For the purpose of assessing component selection, 1 additional cage of group-housed starlings (5 starlings) was provided TMR separated into the 7 ration components (i.e., 7 bowls, each containing 100 g of individual ration components). This assessment was not replicated; it was conducted to better identify what feed components were likely being consumed to cause the measured changes between rations exposed to starlings and reference TMR formulations. The feed offered consisted of the high-energy components within the TMR: steamed-flaked corn (**SFC**), Propel energy nugget (**EN**; Nestle Purina, St. Louis, MO), corn gluten (**CG**), dry distillers grains (**DDG**), canola meal (**CM**), corn

silage (**CS**), and mineral supplement. The component assessment was conducted for 4 d. An additional cage absent of starlings contained 100 g of each component for estimates of daily feed desiccation. On each of test d 1 and 2, we offered the 5 group-housed starlings all 7 components. On each of test d 3 and 4, we offered the same starlings TMR separated into 6 ration components (i.e., 6 bowls, each containing 100 g of individual ration components). This second assessment deliberately excluded the most favored feed item observed during test d 1 and 2 (i.e., EN). Percent consumed was measured for each component using the equation consumption = $[1 - (\text{treatment/desiccation})] \times 100$. Treatment refers to the grams of feed remaining after exposure to birds and desiccation refers to the grams of feed remaining after exposure to air. Estimates of feed consumption were averaged between days for each of the 2 selection tests and reported as percent consumed.

Testing Pellet Size as a Deterrent to Livestock Feed Depredation by European Starlings

On April 6, 2016, starlings (n = 132) were removed from quarantine and housed 2 birds per $1.83 \times 0.914 \times 0.914$ m (length × width × height, respectively) cage for pretest and particle size testing. Pretest lasted 5 d. During the pretest, all cages were offered 150 g of a nutritionally complete poultry layer pellet of 0.396 cm in diameter (Ranch-Way Feeds, Fort Collins, CO). Starting April 11, 2016, the layer pellet offered to starlings was collected and weighed. Weighback occurred for 3 d. We ranked birds based upon their 3-d average consumption of pretest pellets and then cages were assigned to 1 of 6 test pellets (2.22, 1.91, 1.27, 0.953, 0.553, or 0.396 cm in diameter). Treatment assignments were stratified based upon ranked consumption data such that treatment groups were similarly populated with high and low consumers. The pellets were all produced by Ranch-Way Feeds using the same nutritionally complete poultry layer feed offered to birds during pretreatment. Starting April 14, we offered starlings 150 g of the test diet consisting of 1 of the 6 different pellet diameters (n = 11 cages per treatment). An additional cage housed desiccation samples of feed for each of the 6 treatments. The following day the remaining feed was collected and weighed. The response variable is pellet consumption per cage and it was measured in grams of feed consumed using the equation consumption per cage = (desiccation – treatment).

At the completion of all European starling feeding experiments, captured starlings were euthanized following methods conforming to agency policy as stated in USDA/APHIS/WS Directive 2.505 (USDA APHIS, 2011) and approved by the NWRC Internal Animal Care and Use Committee (QA-1742, J. C. Carlson, study director).

Data Analysis

Nutritional Analysis. Nutritional testing of dairy TMR samples were conducted at Cumberland Valley Analytical Services (Hagerstown, MD) using near-infrared reflectance spectroscopy and wet-chemistry analyses. Near-infrared reflectance spectroscopy was used to estimate DM, moisture as a percentage of as-fed CP, calcium, phosphorus, magnesium, ADF, NDF, starch, crude fat (**CF**), ash, sodium, TDN, NE_L (mcal/kg), NE_M (mcal/kg), NE_G (mcal/kg), and NFC on a DM basis. Wet chemistry was used to determine calcium, phosphorus, magnesium, potassium, iron (mg/kg), zinc (mg/kg), and copper (mg/kg) content.

Statistical Analysis. All nutritional and particle size data were analyzed using ANOVA within mixed linear models (Proc Mixed, SAS 9.2, SAS Institute Inc., Cary, NC). For the nutrition data, fixed effects included treatment status (starling consumed and reference rations) and cage was included as a random effect. For the particle size data, fixed effects included treatment group (the 6 particle sizes) and cage was included as a random effect. For both analyses, denominator degrees of freedom were calculated using the Satterthwaite approximation.

Nutrition data were compared for starling consumed and reference rations. A total of 22 univariable models ($m = 22$) were created, 1 model for each of the nutritional variables reported by Cumberland Valley Analytical Services. Because multiple hypotheses were tested, we controlled for false discoveries using the Benjamini-Hochberg procedure (Benjamini and Hochberg 1995). For all analyses, the false discovery rate was set at $\alpha = 0.05$. Univariable analyses were ranked by P-value from smallest (1) to largest (m). Cutoff values for the rejection of null hypotheses were calculated as $(\text{rank}/m) \times \alpha$ (Table 1).

Starling consumption of the 7 TMR components is reported as percent consumed with standard deviations. To estimate grams of TMR consumed by cage and by bird, we assumed the difference in grams of TMR recovered within the rations exposed to starlings and the desiccation rations reflect TMR consumed by starlings. This difference was then divided by the number of birds within each cage (5) for the estimation of per-bird consumption, calculated as TMR consumption = (desiccation − treatment)/5.

NRC Dairy Production Modeling. Parameterization of the NRC (2001) dairy production model was

Table 1. Analysis of TMR nutrition data for reference and rations exposed to starlings

Variable	Metric	Reference mean	Starling mean	P-value	Rank[1]	Cutoff value[2]
NE_L	Mcal/kg	1.72	1.61	<0.0001	5.5	0.0125
NE_M	Mcal/kg	1.77	1.64	<0.0001	5.5	0.0125
NE_G	Mcal/kg	1.15	1.03	<0.0001	5.5	0.0125
ADF	% DM	18.99	22.11	<0.0001	5.5	0.0125
NDF	% DM	30.03	35.01	<0.0001	5.5	0.0125
Starch	% DM	28.69	24.55	<0.0001	5.5	0.0125
Crude fiber	% DM	4.36	3.30	<0.0001	5.5	0.0125
Potassium	% DM	1.09	1.28	<0.0001	5.5	0.0125
Iron	mg/kg	224.93	268.83	<0.0001	5.5	0.0125
TDN	% DM	74.56	70.14	<0.0001	5.5	0.0125
Calcium	% DM	0.69	0.84	0.0001	11.5	0.0261
Magnesium	% DM	0.34	0.38	0.0001	11.5	0.0261
DM	% DM	95.27	95.74	0.0003	14	0.0318
Moisture	% DM	4.74	4.26	0.0003	14	0.0318
Ash	% DM	6.86	7.49	0.0003	14	0.0318
NFC	% DM	43.37	39.48	0.0004	16	0.0364
Zinc	mg/kg	182.20	207.83	0.0027	17	0.0386
Sodium	% DM	0.44	0.49	0.0087	18	0.0409
Manganese	mg/kg	102.43	114.10	0.0097	19	0.0432
CP	% DM	16.36	15.79	0.0375	20	0.0455
Phosphorus	% DM	0.38	0.39	0.1376	21	0.0477
Copper	mg/kg	21.93	22.70	0.2473	22	0.05

[1]Rank order of P-values from nutrient analyses of cattle feed samples.

[2]Benjamini-Hochberg cutoff values for rejection of null hypotheses.

based upon animal condition and feed formulation data provided by the commercial dairy and the nutrition experimental data. We rebalanced the ration based upon the fractional difference in CF concentrations between the rations exposed to starlings and the reference ration. To rebalance the rations exposed to starlings, we assumed the nutritional changes were influenced by starlings selectively consuming the 2 most preferred components (EN and EFC).

Using the known change in CF between reference and rations exposed to starlings, we estimated the amount of SFC and EN remaining following starling consumption using the linear equation

$$\%CF_{TMR} = X \times (\%CF_{SFC} + \%CF_{EN})$$
$$+ \Sigma\%CF \text{ for all other TMR components,}$$

where X = change in percent of CF attributed to starling consumption of EN and SFC; $\%CF_{SFC}$ is percent of CF within the SFC component; and $\%CF_{EN}$ is the percent of CF within the EN component. All other components were assumed to be unaffected by bird feeding and set to the relative mass distribution of the remaining feed components. To estimate the effect of starling foraging on feed formulation, the mass percent of the remaining components was increased by a constant scalar so that the resulting feed composition summed to 100%. The dry mass and wet mass for each feed component were calculated from these consumption-corrected distribu-

tions. These corrected feed component values were then used to parameterize the NRC dairy production model for rations exposed to starlings (Table 2).

RESULTS

Component Selection by European Starlings

Within the starling cage used to assess TMR component selection, the birds primarily selected EN among the 7 components offered (Figure 1). Within the percent consumed graph, the 5 group-housed starlings consumed, on average, 21.5 ± 3.79 g ($\pm$SD) of TMR/bird per day, and 49.2% of their total diet consisted of EN. In the second assessment of TMR component selection, excluding EN, component selection and percent consumed by starlings changed considerably, where the 5 group-housed birds primarily selected SFC and consumed 31.1 ± 1.41 g of TMR/bird per day (Figure 2).

Nutritional Analysis

The nutritional data in Table 1 suggests starling consumption of TMR altered the nutritional characteristics within the ration. Rations exposed to starlings had lower DM concentrations of NE_L ($P < 0.001$), NE_M ($P < 0.001$), and NE_G ($P < 0.001$). Rations exposed to starlings also had lower DM concentrations of starch ($P < 0.001$), CF ($P < 0.001$), TDN ($P < 0.001$), and CP ($P = 0.038$). Rations exposed to starlings had higher

Table 2. Dairy TMR formulations for reference and rations exposed to starlings

High-energy TMR components	Reference wet weight (kg/cow)	% DM	Reference DM (kg/cow)	Starling DM[1] (kg/cow)	Percent reduction[2]
Corn silage	5.26	34	1.79	1.79	0
Alfalfa haylage	2.31	30	0.69	0.69	0
Wet brewer's grain	1.41	21	0.30	0.30	0
Alfalfa hay	4.38	90	3.94	3.93	0
Hominy	3.40	90	3.06	3.06	0
Dry distillers grain	1.34	90	1.21	1.21	0
Late mineral	0.84	98	0.82	0.82	0
Straw	0.48	90	0.43	0.43	0
Energy nugget	0.45	97	0.44	0.30	47.19
Canola meal	2.81	90	2.53	2.53	0
Steam-flaked corn	2.72	90	2.45	1.70	44.50

[1]Starling DM (kg/cow) refers to the amount of DM of feed, measured in kilograms, offered to a single cow per day. Energy nugget (Nestle Purina, St. Louis, MO).

[2]Percent reduction is a measurement of the reduction projected to occur in starling consumed feed relative to the reference rations for each specific component.

DM concentrations of ADF ($P < 0.001$), NDF ($P < 0.001$), potassium ($P < 0.001$), and calcium ($P < 0.001$). On average, individual starlings ate 44.43 ± 2.88 g of TMR/bird per day. The rations exposed to starlings contain 1.06% less CF than the reference rations. Using the equation above, we were able to estimate a decrease of 0.14 kg/cow of EN and a 0.75 kg/cow of SFC in the TMR. This reduction accounts for a 47.2 and 44.5% dry mass reduction in the component fraction of the TMR for EN and SFC, respectively (Table 2).

NRC Dairy Production Modeling

Based upon our NRC (2001) dairy production model estimates, dairy cow performance can be affected as a consequence of starling consumption of the late-lactation TMR (Table 3). For Holsteins producing 32 kg of milk/d, total required net energy intake ($\mathbf{NE_I}$) was 31.5 Mcal/d. Within the reference TMR the NE_I supplied was 29.3 Mcal/d, and within the starling consumed TMR the NE_I supplied was 27.7 Mcal/d. The resulting energy balance for reference and starling controlled rations was −2.2 and −3.9 Mcal/d, respectively. Consequently, Holsteins fed the reference TMR were estimated to lose 1 BCS in 161 d and experience daily weight change due to reserves of −0.4 kg/d. Holsteins fed starling consumed TMR could potentially lose 1 condition score in 91 d and experience daily weight change due to reserves of −0.8 kg/d.

Pellet Size Analysis

Pelleted feed was effective at deterring starlings from consuming food ($F_{5,66} = 316.88$, $P < 0.001$, Table 4).
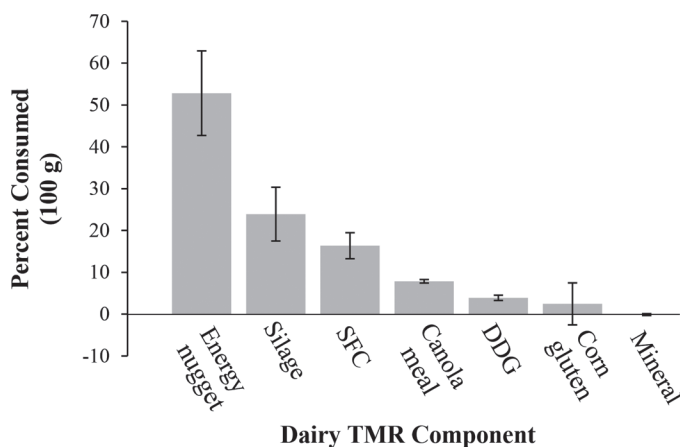

Figure 1. Component selection by 5 group-housed European starlings for dairy TMR with energy nugget (Nestle Purina, St. Louis, MO). SFC = steam-flaked corn; DDG = dried distillers grain. Error bars denote SE.
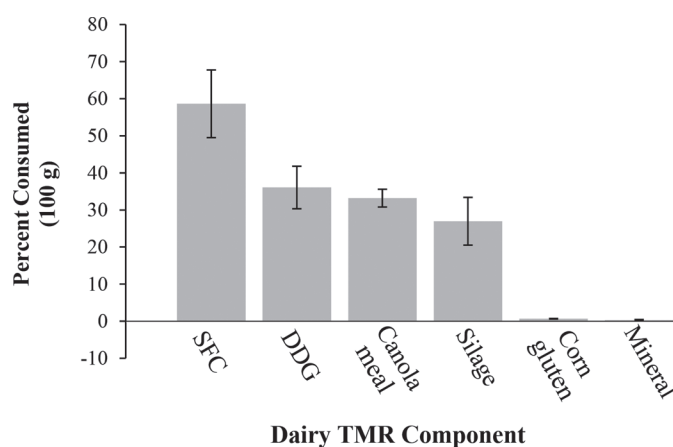

Figure 2. Component selection by 5 group-housed European starlings for dairy TMR excluding energy nugget (Nestle Purina, St. Louis, MO). SFC = steam-flaked corn; DDG = dried distillers grain. Error bars denote SE.

Table 3. Output of NRC (2001), dairy production model for reference and rations exposed to starlings

NRC model output	Reference TMR	Starling TMR[1]
NE_I[2] required (Mcal/d)	31.5	31.5
NE_I supplied (Mcal/d)	29.3	27.7
NE_I balance (Mcal/d)	−2.2	−3.9
Days to lose 1 BCS	161	91
Weight change (kg/d)	−0.4	−0.8
RDP required (g/d)	1,778	1,674
RDP supplied (g/d)	2,141	2,154
RDP balance (g/d)	363	481
RUP required (g/d)	2,016	2,134
RUP supplied (g/d)	1,526	1,469
RUP balance (g/d)	−490	−665
MP – bacterial (g/d)	967	911
MP – RUP (g/d)	780	733
MP – endogenous (g/d)	84	79

[1]Changes to starling exposed TMR based upon a mass decrease of 0.14 kg/cow of Propel energy nugget (Nestle Purina, St. Louis, MO) and 0.75 kg/cow of steam-flaked corn.

[2]NE_I refers to net energy intake and it is measured in megacalories per day.

Starling consumption of 0.953-cm (3/8-in) diameter pellets or larger inhibited starling consumption of feed. Pelleted feed of 0.553 (7/32 in) and 0.396 cm (5/32 in) in diameter did not deter starlings from consuming food relative to their pretreatment consumption rates ($F_{1,22} = 1.80$, $P < 0.1934$). Thus, pelleted feed of 0.953 cm in diameter or larger reduced starling consumption of feed by $\geq 79\%$.

DISCUSSION

Commercial dairies formulate TMR primarily to maximize milk production. Our results suggest that large foraging flocks of starlings can alter the nutritional characteristics of TMR, and these changes may be large enough to reduce milk production in dairies based upon our NRC production model equations. Unfortunately dairies lack the tools necessary to measure these effects and take corrective actions. With precise estimates of site-specific bird damage (i.e., nutritional depletion and the corresponding changes in available net energy),

producers could be better equipped to decide upon an appropriate course of action to mitigate losses caused by foraging flocks of birds.

Our component selection assessment suggests significant variability exists in the TMR components consumed by starlings. Additionally, it appears that the amount of feed consumed by starlings varies by food quality. When EN was available, the 5 group-housed starlings only ate 21.5 g of TMR/bird per day. When EN was absent, these same birds shifted feed selection to SFC and DDG and consumed 31.1 g/bird per day; this is a 45% increase in per-bird feed consumption. Unfortunately, the component assessment was not replicated and should be viewed with some caution. Regardless, this information will likely be important because the cost of lost feed will be heavily influenced by the amount of components consumed and the cost of those components. We suspect component selection will differ in dairies depending upon the ration offered. We recommend dairies experiencing bird damage work with their dairy nutritionists and extension agents to better gauge feed loss and identify least-cost rations to minimize economic losses to birds.

The nutrition data suggest that starlings are avoiding fibrous feed sources (i.e., hay, straw, and corn silage minus the kernels) and selecting food sources high in ME. This information may be enough for producers to make educated guesses as to what components birds will be consuming from their own TMR formulations. For example, high-energy components, such as EN, SFC, DDG, and corn chop from silage, are likely to be consumed by starlings. Some bakery and distillery products may attract starlings, and others may be bird resistant if they exist in sizes that inhibit starling consumption (≥ 0.953 cm in diameter). Preventing starlings from obtaining the nutrients they need may force them to leave a dairy in favor of alternative feeding sites. Thus, the added time and cost of feeding milled or pelleted supplements may make economic sense when factored against the cost of lost feed and potential production losses.

Table 4. Assessment of pellet feed as a deterrent to starling consumption of livestock feed supplies

Pellet diameter (cm)	Sample size (n)	Feed offered (g)	Feed[1] consumed (g)	95% CI[2]	Bonferroni mean difference[3]
2.22	11	150	6.25	2.22–10.29	A
1.91	11	150	6.08	2.05–10.12	A
1.27	11	150	5.62	1.58–9.65	A
0.95	11	150	16.82	12.78–20.85	B
0.55	11	150	75.14	71.10–79.17	C
0.39	11	150	80.45	76.42–84.49	C

[1]Mean consumption/cage per treatment group. Each cage had 2 starlings.

[2]95% confidence intervals for the mean consumption/cage.

[3]Different letters identify non-overlapping confidence intervals based upon Bonferroni-adjusted LSM estimates.

The particle size analysis suggests dairies may be able to mitigate losses through the physical manipulations of TMR. Feeding cattle ≥1.27-cm (1/2-in) diameter pellets was effective at preventing starling consumption in a Kansas feed yard (Depenbusch et al., 2011). Our data suggests particle sizes as small as 0.953 cm (3/8 in) in diameter will be effective at deterring bird feeding. Alternatively, starlings provided 0.476-cm diameter pig pellets consumed the rations at a rate more than 8 times greater than granular hog meal (Twedt and Glahn, 1982). Our data suggests pellets of 0.553 (7/32) and 0.396 cm (5/32 in) did not inhibit nutrient sourcing by starlings. The totality of this information is important, because feed consumption rates by starlings appear to be strongly influenced by feed form and size (Glahn et al., 1983). In other words, starlings may be excluding nutritious food options when the food matrix is of a size or shape that is difficult to consume (e.g., pelleted or ground feed). Therefore, we believe that combining high-energy components into 0.953-cm diameter pellets may be a cost-effective and nonlethal strategy to reduce bird damage in dairies.

We recognize some limitations of the data presented in this manuscript. Because pest starlings may not nutritionally deplete all TMR consumed by cows daily, our results may overestimate the nutritional depletion caused by starlings at commercial dairies. Moreover, 5 starlings per 1 kg of TMR translates to starling numbers in excess of 100 birds per cow. This level of bird damage is equivalent to the highest levels of bird damage we have ever seen in the United States; approximately ≥100,000 birds per 1,000 dairy cows (e.g., California, Kansas, Texas in 1980–2000; USDA Wildlife Services, personal communication). Most commercial dairies will likely not experience such severe nutritional offsets or production effects as those estimated herein.

It is also important to note that nutritional effects and predictive models were constructed using late-lactation dairy rations. These animals were being offered less feed and they had already begun to produce less milk relative to their peak performance. Therefore, we recommend that future analyses include nutritional effects to rations offered to milk cows at peak performance. Additionally, our production model output assumes that the density of pest birds does not change throughout winter. This may not be sufficiently accurate for predictive models, because starling feeding in dairies varies depending upon ambient temperature and local weather conditions (Linz et al., 2007; Carlson et al., 2012; Shwiff et al., 2012). Typically the worst starling damage occurs on very cold days following severe winter storms (Carlson et al., 2011, 2012). This is likely due to the fact that the caloric requirements of birds, on a daily basis, is climatically constrained (Homan et al., 2013). Regardless of these shortcomings, our data demonstrates that we can measure the nutritional effects caused by depredating birds, and through these measurements dairy production models can be used to predict the production losses to dairies caused by bird depredation.

In conclusion, the data reported in this manuscript suggests that bird depredation of cattle feed by invasive European starlings causes nutritional depletion of dairy TMR, and these losses have the capacity to affect milk production. Additionally, we hypothesized that alternate components, less accessible to birds, may be supplemented in the TMR to repel birds and offset losses to animal performance and milk production. Bird-specific TMR could potentially be developed to maintain high levels of productivity using components and particle sizes less accessible or less desirable to pest birds. Additionally, site-specific data, similar to what we have produced in the current manuscript, could be used by dairies to help balance rations while accounting for bird damage. In other words, if we know the nutrient requirement of the offending bird species, we can predict losses, based on flock size, and modify feed formulations accordingly.

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