Effects of feeder space on broiler feeding behaviors

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ABSTRACT Providing adequate feeder space in broiler production is important to ensure bird performance and well-being; however, the effect of feeder space on behavior responses of broilers remains unclear. The objective of this research was to investigate feeding behaviors of broilers provided with 4 feeder spaces, that are 2.3 cm/bird with one feeder (2.3FSO); and 2.3, 4.6, and 6.9 cm/bird with 3 feeders (2.3FST, 4.6FST, and 6.9FST, respectively). Number of feeder slots per feeder was 14 at 2.3FSO, 5 at 2.3FST, 9 at 4.6FST, and 14 at 6.9FST. Sixteen identical pens, each with 45 broilers (Ross 708, mixed sex), were used to accommodate the 4 feeder space treatments. Feeding behaviors were continuously monitored from weeks 4 to 8 using an ultra-high-frequency radio frequency identification system. The results show that the daily feeding time and number of feeder visits for broilers at 2.3FST were similar to those at 4.6FST and 6.9FST but higher than those at 2.3FSO ($P < 0.01$). The feeder utilization ratio was the highest at 2.3FST, indicating the feeder being used most efficiently among the 4 treatments ($P < 0.01$). Coefficient of variations (33.0–65.1%) of the feeding behavior responses was similar among the treatments (P $\geq$ 0.06), suggesting similar group uniformity of feeding behaviors of individual broilers. Feeders among all treatments may not be fully used because for most of the time, less than 6 birds chose to eat simultaneously at a more-than-five-slot feeder in all treatments. Given the same feeder space, increasing feeder number can accommodate more birds to eat simultaneously. The outcomes of this study provide insights into improvement of feeder design and management for broiler production.

Key words: broiler, feeder space, feeding behavior, radio frequency identification system

2021 Poultry Science 100:101016
https://doi.org/10.1016/j.psj.2021.01.038

INTRODUCTION

The United States is the largest broiler producer in the world with over 9 billion broilers produced in 2018 at a value of 31.7 billion dollars (USDA National Agricultural Statistics Service, 2019). Broilers need to access feed to meet their daily nutrient requirements. Adequate feeder space that allows birds to eat at will is important for efficient and welfare-oriented broiler production. Insufficient feeder space may cause competition, aggression, and frustration among hens and downgrade their well-being (Sirovnik et al., 2018), while excessive feeder space leads to inefficient resource utilization for hens (Oliveira et al., 2019). Feeder spaces of 1.2 to 5.1 cm/bird for typical US broiler production have been recommended by governmental agencies, breeding companies, and scientific institutes (Table 1). However, little research has been conducted to validate these space recommendations through continuous monitoring of broiler feeding behaviors which are crucial indicators of feeder usage (Li et al., 2020a). With the assistance of precision agriculture tools, researchers are now able to monitor feeding time, feeder visit frequency, and feeding location of individual birds in group settings of small-scale pens (Li et al., 2019; Oliveira et al., 2019). Understanding the aforementioned feeding behavior responses to different feeder spaces could provide insights into broiler feeder design and management.

Earlier research examined feeder spaces mostly from broiler production standpoints. In general, decreasing feeder spaces from 6.1 to 1.9 cm/bird did not compromise growth rate, body weight, body weight uniformity, feed consumption, feed conversion ratio, and mortality (McCluskey and Johnson, 1958; Hansen and Becker, 1960; Reed and Ringrose, 1960). As broiler genetics, nutrition, and management have been improved, more recent studies showed inadequate feeder space (e.g.,

Received May 18, 2020.

Accepted January 14, 2021.

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less than 2.0 cm/bird) may lower body weight but not impair feed conversion ratio (Malone et al., 1980; Lemons and Moritz, 2015). When provided with the feeder space of 1.47 cm/bird (one feeder per pen) and 2.94 cm/bird (2 feeders per pen), broilers of the former feeder space had less but more severe leg defects (gross skeletal defects in hip-leg-foot regions) (Wilson et al., 1984). As the concerns of animal welfare keep growing, recent studies started to examine the agonistic behaviors (e.g., head pecks, steps, pushes, threats, and chases) as affected by feeder spaces and reported that the agnostic behaviors may be reduced by increasing feeder spaces from 2.4 cm/bird to 3.6 cm/bird (Olukosi et al., 2002). Oliveira et al. (2019) reported that no significant differences among the feeder spaces of 12.0, 9.5, and 8.5 cm/hen were detected in daily time spent at feeder and maximum percentage of hens feeding simultaneously, and inter-hen variability in daily time spent at feeder was observed, indicating the behavior repertoire and time budget of individual animals to be varied greatly. However, little research has been conducted to examine effects of feeder space on feeding behavior responses of group-housed broilers.

Our previous study has demonstrated an ultra-high-frequency radio frequency identification (**UHF-RFID**) system and data analysis algorithms that can continuously register broilers at feeders and report the feeding behaviors of individual broilers (Li et al., 2019). With the help of the UHF-RFID system, the objective of this research was to investigate feeding behaviors of individual broilers (weeks 4–8) at 4 feeder spaces (2.3 cm/bird with one fully open tube feeder shared by 45 broilers in a pen, **2.3FSO**; and 2.3, 4.6, and 6.9 cm/bird with 3 fully open or partially blocked tube feeders shared by 45 broilers in a pen abbreviated as **2.3FST**, **4.6FST**, and **6.9FST**, respectively; Figure 1). The 4 selected feeder spaces represent a good coverage of the recommended range in Table 1. As a part of a series of publications from a cooperative project, this study only focused on the feeding behaviors, while the other publications focused on the feeder space effects on production performance and bird physiology.

MATERIALS AND METHODS

Housing, Animals, and Management

The experiment was conducted in the USDA-ARS Poultry Research Unit at Mississippi State. A total of 720 broilers (Ross 708, mixed sex) were obtained from a commercial hatchery and randomly distributed to 16 identical pens with 45 birds per pen. Sixteen pens yielded 4 replicates per feeder space treatment (total 4 treatments) and were placed in the middle of a house to control variations of ventilation and lighting conditions. They were separated equally into 2 sides, and birds on the same sides could have visual contact through the wire fences. Each pen measured 323 cm long and 137 cm wide and was equipped with one or 3 tube feeders. The tube feeder was 33 cm in diameter with fourteen 7.3-cm-wide feeder slots. Room temperature, light intensity, and light program were adjusted following the schedule shown in Table 2. Caretakers inspected the birds daily and removed the abnormal birds, such as lame birds that were unable to walk to feeders. Therefore, the tagged birds were those without leg issues. Broilers were kept in pens from day old to day 56 and provided with corn-soy diets *ad libitum* (National Research Council, 1994). Diet ingredients were previously described by Dozier et al. (2005). All procedures in this experiment were approved by the USDA-ARS Institutional Animal Care and Use Committee at Mississippi State (license number: 19-3).

Experimental Treatment

The 4 feeder space treatments were 2.3 cm/bird with one feeder per pen and 2.3, 4.6, and 6.9 cm/bird with 3 feeders per pen (Figure 1). The feeder space treatments were achieved by granting birds access to all (for 2.3FSO and 6.9FST) or partial (for 2.3FST and 4.6FST) feeder slots (Figure 1). A few feeder slots of tube feeders for 2.3FST and 4.6FST were filled with sand and blocked using partition plates. The sand could stabilize the hanging feeder and block electromagnetic emission of the RFID antenna, thus avoiding false

Table 1. Feeder space recommendations for broilers from different sources.

Recommendation (cm/bird)	Number of birds per feeder	Bird age (weeks)	Diameter of a tube feeder (cm)	Reference
1.2-2.1	45-80	—	30	USDA Animal and Plant Health Inspection Service (2013)
1.6	65	—	33	Canadian National Farm Animal Care Council (2016)
1.3-1.8	70-100	—	40	European Commission Health & Consumer Protection Directorate-General (2000)
1.5-2.1	50-70	—	33	Cobb (2018)
1.7	70		38	Aviagen (2015)
2.5	—	1	—	SASSO (2018)
3.8	—	2-3	—	SASSO (2018)
5.1	—	3-8	—	SASSO (2018)

Note: '—' indicates information not to be provided in the reference.

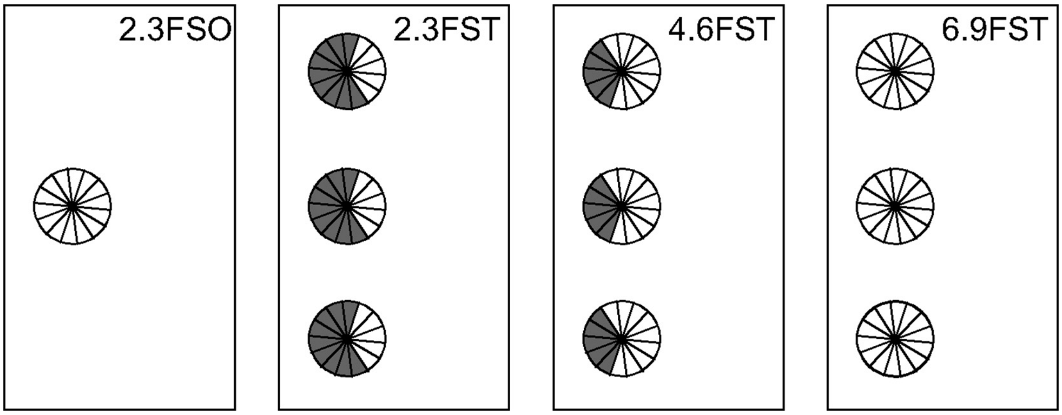

Figure 1. Illustration of the experimental pens and treatments. Round objects are feeders. Dark gray areas of the feeders represent blocked feeder slots and white areas represent open feeder slots. 2.3FSO = 2.3 cm/bird feeder space with one fully open feeder shared by 45 birds in a pen; 2.3FST = 2.3 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; 4.6FST = 4.6 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; and 6.9FST = 6.9 cm/bird feeder space with 3 fully open feeders shared by 45 birds in a pen.

detections. The reason for the usgage of 3 feeders was to ensure that available floor space per bird was equal among the treatments (2.3FST, 4.6FST, and 6.9FST), while the single feeder pen was essentially a negative control (2.3FSO). Number of feeder slots per feeder was 14 at 2.3FSO, 5 at 2.3FST, 9 at 4.6FST, and 14 at 6.9FST. The number of total available feeder slots was 14 at 2.3FSO, 15 at 2.3FST, 27 at 4.6FST, and 42 at 6.9FST.

Behavioral Data Acquisition System

A UHF-RFID system was used to monitor feeding behaviors of individual broilers. The system consisted of 40 antennas (TIMES-7 A6034S; Impinj Inc., Seattle, WA), 360 tags (PT-103; TransTech Systems Inc., Wilsonville, OR), 3 hubs (IPJ-A6001-000; Impinj Inc., Seattle, WA), 3 readers (IPJ-REV-420; Impinj Inc., Seattle, WA), and 3 Python-based data acquisition systems. An antenna was placed underneath each tube feeder as described in our previous study (Li et al., 2019). All 45 birds in 4 pens (one pen per treatment) and 15 birds in each of the remaining 12 pens (3 pens per treatment) were tagged. A total of 360 birds were tagged. The lightweight RFID tags (less than 5 g for each) were placed using one simple-interrupted full-thickness throw of nonabsorbable nylon suture (Ethilon size 1), attaching the tag to the skin on midline of the ventral neck, approximately one inch from the bottom beak. Tags were applied by the attending veterinarian with care to avoid the underlying structures of the neck, as an experienced caretaker gently restrained the bird for a blood draw. As this minor procedure is analogous to a blood draw, no anesthetics were applied. Besides, before the study, a pilot study with 20 birds being sutured was conducted. Based on 14-day observation, only a couple of birds were observed preening around the tags soon after placement, and after that, there was seemingly no significant attention paid to the tags. In addition, our previous test showed that performance (feed consumption and conversion ratio) of birds wearing tags was similar to those without tags. Therefore, the suturing tag method should be suitable for the behavior study. The system registered birds eating at all feeders continuously. The tag IDs, feeding time, and feeder codes were saved into .csv files and processed in Microsoft Excel using Visual Basic for Application. The previous study reported a greater than 92% accuracy for monitoring broiler feeding behaviors through the UHF-RFID system (Li et al., 2019). Except for the operation of the RFID tags, we followed the similar setups with the previous study; therefore, the registration accuracy should be similar to the previous study as well.

Behavior Responses and Definitions

Birds were tagged on day 24, and their behaviors were continuously monitored through day 54. In a continuous feeding event, a bird may temporarily withdraw from a feeder or drinker for swallowing, which cannot be registered by the UHF-RFID system. To correct the misidentification of feeding behaviors, the gaps of 2 consecutive

Table 2. Air temperature and lighting conditions.

Week of age	D of age	Temperature (°C)	Light program (L:D)	Intensity (lux)
1	1–3	32	23L:1D	30
1	4–7	31	23L:1D	30
2	8–13	29	20L:4D	10
3	14–20	27	20L:4D	10
4	21–27	24	20L:4D	10
5–8	28–54	21	18L:6D	5

Table 3. The behavior responses and definitions.

Behavior responses	Unit	Definition
Daily time spent at feeder (DTSF)	$\text{min}\cdot\text{bird}^{-1}\ \text{d}^{-1}$	Overall time spent at feeder(s) per pen within a day
Daily number of feeder visits (DNFV)	$\text{times}\cdot\text{bird}^{-1}\ \text{d}^{-1}$	Number of visits to feeder(s) per pen within a day
Duration per feeder visit (DFV)	$\text{min}\cdot\text{visit}^{-1}$	DTSF ÷ DNFV
Hourly time spent at feeder (HTSF)	$\text{min}\cdot\text{bird}^{-1}\cdot\text{h}^{-1}$	Overall time spent at feeder(s) per pen within an hour
Hourly number of feeder visits (HNFV)	$\text{times}\cdot\text{bird}^{-1}\cdot\text{h}^{-1}$	Number of visits to feeder(s) per pen within an hour
Feeder utilization rate (FUR)	%	DTSF × 45 ÷ (lighting minutes × number of total available feeder slots)

Note: Number of total available feeder slots is 14 at 2.3FSO, 15 at 2.3FST, 27 at 4.6FST, and 42 at 6.9FST. The lighting minutes are 1,200 in week 4 and 1,080 in weeks 5 to 8.

RFID readings that spanned 20 s or less were filled. The 20-s threshold could cover 95% of the RFID reading gaps induced by the intermittent swallowing behaviors (Li et al., 2019). After filling the time gaps, time spent and visit frequency for a feeding event were summarized for all tagged birds.

Broilers rarely eat during the dark period (Li et al., 2020a); therefore, feeding behaviors of broilers were analyzed only during the lighting period. Feeding behaviors for individual birds were summarized into daily or hourly time spent at feeder (**DTSF or HTSF**), daily or hourly number of feeder visits (**DNFV** or **HNFV**), duration per feeder visit (**DFV**), and feeder utilization rate (**FUR**). Mean values and coefficient of variations (**CV**) of these behavior responses were calculated for each pen. The CV of behaviors reflects behavior differences of individual broilers, and a lower CV indicates a better group uniformity (Li et al., 2020b). The aforementioned behavior responses were summarized using 3 d of data every week from weeks 5 to 8 and then averaged in each week. Because the light program, light intensity, and temperature setpoint in week 4 were different from those of the following weeks, data in week 4 were not included in these behavioral analyses. Details of behavior responses are provided in Table 3.

Simultaneously feeding birds were determined for the 4 pens with all birds tagged and examined using data of week 4 because of the least tag loss. Figure 2 shows the cumulative lost tags from days 24 to 57, and average 1-2 tags were lost daily.

Statistical Analysis

The effect of feeder space on the mean and CV of DTSF, DNFV, DFV, and FUR was examined using data of weeks 5 to 8 in 16 pens (Equation 1). The experimental unit was the treatment pen in each week. Broilers may perform the feeding behaviors differently in days, therefore, the data in days were averaged weekly to reduce day variations.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (1)$$

where Y_{ijk} is the behavior response of concern; μ is the least square mean of the behavior response; α_i is the feeder space, i = 2.3FSO, 2.3FST, 4.6FST, 6.9FST; β_j is the bird ages, j = 5, 6, 7, 8; $(\alpha\beta)_{ij}$ is the interaction effect of feeder space and bird age; and ε_{ijk} is the random error. Bird age was taken as a categorical variable.

With the data from the 4 pens having 45 tagged birds in week 4, we compared the frequencies of number of birds simultaneously eating at one feeder or in a pen. Percentage data (i.e., FUR, CV, frequency of simultaneously feeding birds) were arcsine transformed into degrees before statistical analysis, and the resultant values were back-transformed into percentages. The aforementioned

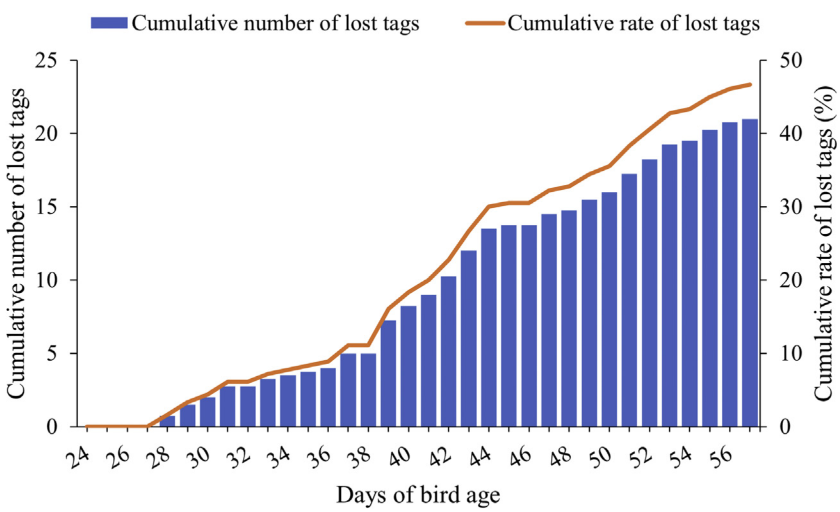

Figure 2. Cumulative lost tags from days 24 to 57. Each data point is the average of the 4 pens with 45 tagged birds.

Table 4. Broiler feeding behaviors at different feeder spaces and bird ages.

Treatment	DTSF ($min \cdot bird^{-1} \cdot day^{-1}$)	DNFV ($times \cdot bird^{-1} \cdot d^{-1}$)	DFV ($min \cdot visit^{-1}$)	FUR (%)
Feeder space[1]				
2.3FSO	73.7^{b}	73^{b}	1.1	21.5^{b}
2.3FST	113.2^{a}	122^{a}	0.9	31.1^{a}
4.6FST	119.1^{a}	114^{a}	1.5	18.0^{c}
6.9FST	119.6^{a}	118^{a}	1.0	11.5^{d}
SEM[2]	4.7	3	0.3	0.01
Bird age				
Week 5	144.4^{a}	125^{a}	1.2	27.6^{a}
Week 6	128.7^{b}	119^{a}	1.6	24.5^{b}
Week 7	80.0^{c}	97^{b}	0.8	15.2^{c}
Week 8	72.4^{c}	85^{c}	0.8	14.1^{c}
SEM[3]	4.6	3	0.4	0.01
P value				
Feeder space	<0.01	<0.01	0.50	<0.01
Bird age	<0.01	<0.01	0.15	<0.01
Feeder space × bird age	0.15	0.78	0.55	0.73

[a,b,c,d]Values within the same column that lack a common superscript differ significantly ($P \leq 0.05$).

Abbreviations: DTSF, daily time spent at feeder; DNFV, daily number of feeder visits; DFV, duration per feeder visit; and FUR, feeder utilization rate.

[1]2.3FSO = 2.3 cm/bird feeder space with one fully open feeder shared by 45 birds in a pen; 2.3FST = 2.3 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; 4.6FST = 4.6 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; and 6.9FST = 6.9 cm/bird feeder space with 3 fully open feeders shared by 45 birds in a pen.

[2]Standard error for the effect of feeder space (n = 16 pens).

[3]Standard error for the effect of bird age (n = 16 pens).

statistical analyses were conducted with ANOVA using the PROC MIXED statement in the Statistical Analysis Software (SAS 9.3; SAS Institute Inc.). Fixed effects in the model were feeder space and bird age treatments, and random effects were not included in the model. Least square mean comparisons of the behavior responses were conducted using Fisher's least significant difference with PDMIX800 (Saxton, 1998), with significance considered at $P \leq 0.05$.

Table 5. The coefficient of variations of broiler feeding behaviors at different feeder spaces and bird age.

Treatment	CV (%)		
	DTSF	DNFV	DFV
Feeder space[1]			
2.3FSO	50.3	37.3	44.2
2.3FST	57.0	35.2	42.7
4.6FST	62.3	37.4	46.1
6.9FST	56.2	37.0	38.6
SEM[2]	0.10	0.03	0.05
Bird age			
Week 5	43.1^{c}	33.0^{b}	41.4
Week 6	53.2^{b}	34.6^{b}	43.9
Week 7	64.2^{a}	39.6^{a}	42.9
Week 8	65.1^{a}	39.8^{a}	43.3
SEM[3]	0.10	0.03	0.05
P value			
Feeder space	0.06	0.77	0.09
Bird age	<0.01	0.01	0.85
Feeder space × bird age	0.88	0.76	0.94

[a,b,c]Values within the same column that lack a common superscript differ significantly ($P \leq 0.05$).

Abbreviations: DTSF, daily time spent at feeder; DNFV, daily number of feeder visits; DFV, duration per feeder visit.

[1]2.3FSO = 2.3 cm/bird feeder space with one fully open feeder shared by 45 birds in a pen; 2.3FST = 2.3 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; 4.6FST = 4.6 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; and 6.9FST = 6.9 cm/bird feeder space with 3 fully open feeders shared by 45 birds in a pen.

[2]Standard error for the effect of feeder space (n = 16 pens).

[3]Standard error for the effect of bird age (n = 16 pens).

RESULTS

Daily Feeding Behavior Responses

Average of Daily Feeding Behavior Responses The average feeding behavior responses of broilers are shown in Table 4. Overall, broilers spent on average 72.4 to 144.4 min at feeders daily, translating into 5.0 to 10.0% of time in 24 h. The broilers visited the feeder 73 to 125 times per day and stayed at the feeder for 0.8 to 1.6 min per visit. Feeder space and bird age had significant effects on DTSF, DNFV, and FUR ($P < 0.01$), while their interaction did not significantly affect any feeding behavior responses ($P \geq 0.15$). The broilers at 2.3FSO spent less time at feeder and visited feeder less frequently than the broilers at other feeder space treatments ($P < 0.01$), while no difference of the 2 responses was observed among treatments with 3 feeders per pen. Feeder utilization rate was the highest for the 2.3FST treatment (FUR = 31.1%, $P < 0.01$). Feeding time, number of feeder visits, and FUR decreased as the broiler age increased ($P < 0.01$).

Coefficient of Variations of Daily Feeding Behavior Responses The CV of feeding behavior responses of the tagged broilers in each pen is shown in Table 5. The CV was 43.1 to 65.1% for DTSF, 33.0 to 39.8% for DNFV, and 38.6 to 46.1% for DFV. The CV of all feeding behaviors responses was similar among the treatments ($P \geq 0.06$). The CV of DTSF and DNFV significantly increased as broilers got older ($P \leq 0.05$), and the CV of DFV was similar across all bird ages ($P = 0.21$).

Frequency of Duration per Feeder Visit Figure 3 shows the frequency distribution of duration per feeder visit at the 4 feeder spaces and 4 bird ages. Overall, broilers showed similar patterns of duration per feeder visit across the 4 feeder spaces and bird ages. The

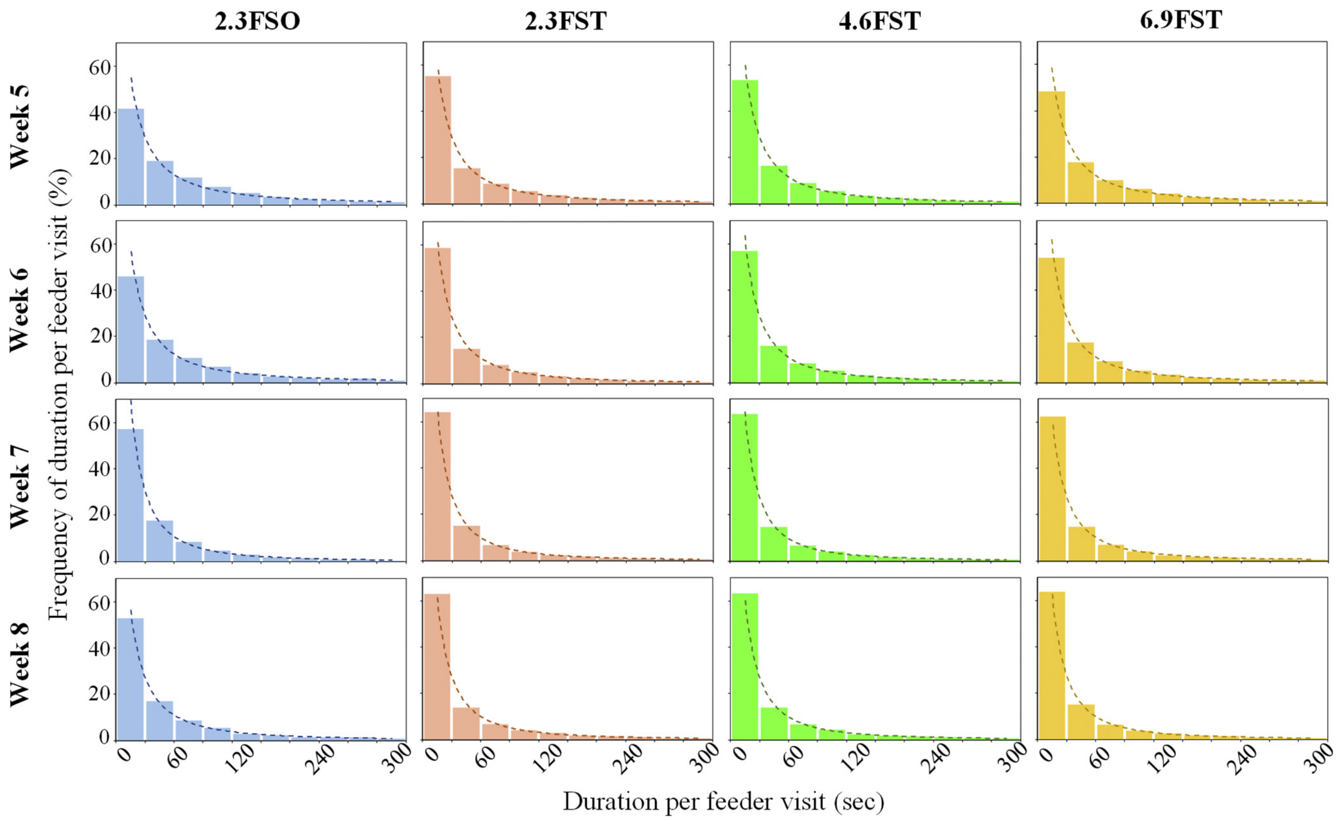

Figure 3. Frequency distribution of feeding duration per feeder visit with 4 feeder spaces and at 4 bird ages. 2.3FSO = 2.3 cm/bird feeder space with one fully open feeder shared by 45 birds in a pen; 2.3FST = 2.3 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; 4.6FST = 4.6 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; and 6.9FST = 6.9 cm/bird feeder space with 3 fully open feeders shared by 45 birds in a pen.

frequency of <60 s, 60 to 120 s, 120 to 180 s, 180 to 240 s, and >240 s for each feeding event were 67.7 to 77.5%, 11.1 to 15.6%, 4.3 to 6.8%, 2.3 to 3.8%, and 4.8 to 6.0% across all feeder spaces and bird ages.

Hourly Feeding Behavior Responses

Figure 4 shows the hourly feeding time and number of feeder visits under the 4 feeder spaces and at the 4 bird ages. Overall, broilers ate for 4.2 ± 1.3 min at 2.3FSO, 7.1 ± 1.6 min at 2.3FST, 6.1 ± 1.6 min at 4.6FST, and 6.4 ± 2.2 min at 6.9FST within each hour of a day. Broilers visited the feeders for 4 ± 1 times at 2.3FSO, 7 ± 1 times at 2.3FST, 6 ± 1 times at 4.6FST, and 6 ± 1 times at 6.9FST. Broilers ate consistently throughout the lighting period.

Simultaneous Feeding Birds

Figure 5 shows frequency of number of birds simultaneously feeding at a feeder or in a pen with the 4 feeder space treatments. The data in this section were reported for week 4 only. The feeder of the 2.3FSO treatment pen was simultaneously used by 2 broilers for the majority of time (19.9%), while the feeder of other treatment pens was mostly used by no broiler (38.3–58.4%). The frequency distributions of simultaneous feeding bird numbers at a feeder were similar among the 2.3FST, 4.6FST, and 6.9FST treatments. For the most time, the feeders in a pen were simultaneously used by 2 broilers at 2.3FSO, 0 at 2.3FST, 1-2 at 4.6FST, and 2-3 at 6.9FST. For 94.2 to 99.9% of the time, less than 6 birds chose to eat simultaneously at a feeder, and less than 10 birds ate simultaneously in a pen. The maximum numbers of birds simultaneously feeding at a feeder were 13 at 2.3FSO, 9 at 2.3FST, 10 at 4.6FST, and 12 at 6.9FST. The maximum numbers of birds simultaneously feeding in a pen were 13 at 2.3FSO, 18 at 2.3FST, 19 at 4.6FST, and 20 at 6.9FST. Detailed frequencies of the number of birds simultaneously feeding in week 4 can be found in Figure 5.

DISCUSSION

In this study, we intended to cover a wide range of feeder spaces that have been recommended previously (USDA Animal and Plant Health Inspection Service, 2013; Aviagen, 2015; Lemons and Moritz, 2015) and examined their effect on feeding behavior responses of individual broilers. The 2.3FST, 4.6FST, and 6.9FST treatments had 3 feeders, which can ensure equivalent floor space for birds, while the 2.3 FSO treatment with a single feeder was used as a negative control.

Group Sizes

The group size was 45 birds in a pen that is much smaller than that in commercial broiler houses. Birds

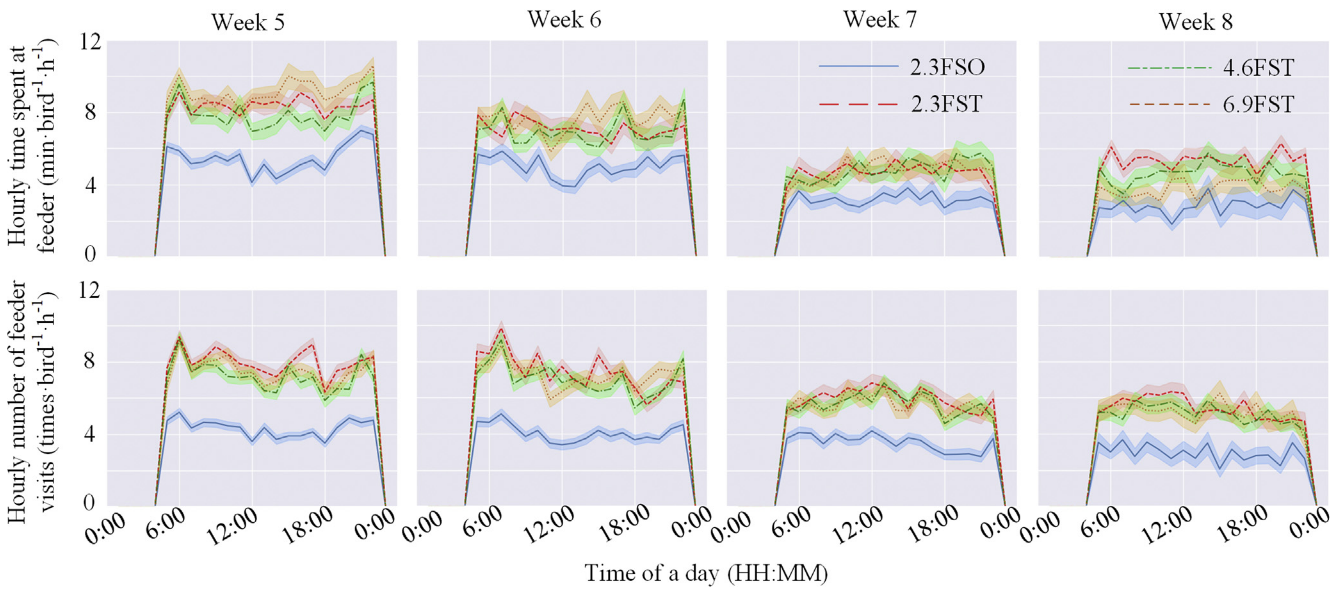

Figure 4. Hourly time spent at feeder and hourly number of feeder visit with the 4 feeder spaces and in the 4 bird ages. 2.3FSO = 2.3 cm/bird feeder space with one fully open feeder shared by 45 birds in a pen; 2.3FST = 2.3 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; 4.6FST = 4.6 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; and 6.9FST = 6.9 cm/bird feeder space with 3 fully open feeders shared by 45 birds in a pen. Lights ON at 5:00 and OFF at 22:00.

in larger groups may have more chances to see other birds eating than those in smaller groups; therefore, they may be attracted more frequently to eat, resulting in higher feeder utilization efficiency. Perhaps, fewer feeders are required in commercial farms than in laboratories. Meanwhile, birds in larger groups may have fewer chances to recognize individuals clearly and to build a stable dominant-subordinate social hierarchy; hence, they may adopt the low-aggression tolerant social strategies (Estevez et al., 2003). As a result, low feeder allowance in commercial farms may not cause severe bird aggression and frustration and still be acceptable for bird welfare. More research is advisable when the experimental results of the feeder space are applied to commercial farms.

Effects of Feeder Space on Broiler Feeding Behaviors

Broilers had various feeding behavior responses among the feeder space treatments. Broilers in the 3-feeder pens (2.3FST) showed more daily feeding time and number of feeder visits than those in the one-feeder pens (2.3FSO), probably because they had more chances to see other birds eating and were attracted to eat. Collins and Sumpter (2006) also found that multiple birds eating at a feeder trough can induce other birds to arrive at the feeder. Given the same feeder amount, increasing feeder spaces from 2.3 to 6.9 cm/bird did not increase the feeding behaviors measured in the present study. The FUR of the 2.3FST treatment was the highest among the treatments because of higher feeding time with fewer feeder spaces. The CV of feeding behaviors was not significantly different across the feeder spaces, which may be helpful for group uniformity (Diarra and Devi, 2014).

Effects of Bird Age on Broiler Feeding Behaviors

The results of this study show that broiler feeding behaviors did not remain consistent throughout the second half of a production cycle. For weeks 5 to 8, broilers spent less time feeding and visited feeders less frequently as the bird age increased. Bokkers and Koene (2003) also reported that the percentage of time spent on eating for fast-growing broilers decreased from 15% in the first 6 wk to 10% in the following weeks. Younger birds have lower body weight and may have no problem walking to feeders (Sørensen et al., 2000). Nevertheless, broilers may be lazy in moving as they grow heavier, resulting in less number of feeder visits and feeding time. Bokkers and Koene (2003) also reported that for the fast-growing broilers, the percentage of time spent on walking decreased from 11% in week 1 to 1% in week 8. This could be an implication of proper feeder arrangement to ensure easy feeder access by older broilers.

Older broilers (>5 wk old) had more variations in feeding time and number of feeder visits in this case. Broilers with different social hierarchy could show individual variability within a group, in which dominant birds may have the priority to access resources while subordinate ones may not access resources at will. Higher individual variability leads to poorer group uniformity (Diarra and Devi, 2014). It is generally accepted that social hierarchy begins to establish at approximately 5 or 6 wk of age in the domestic fowl (Queiroz and Cromberg, 2006). Although a stable social group

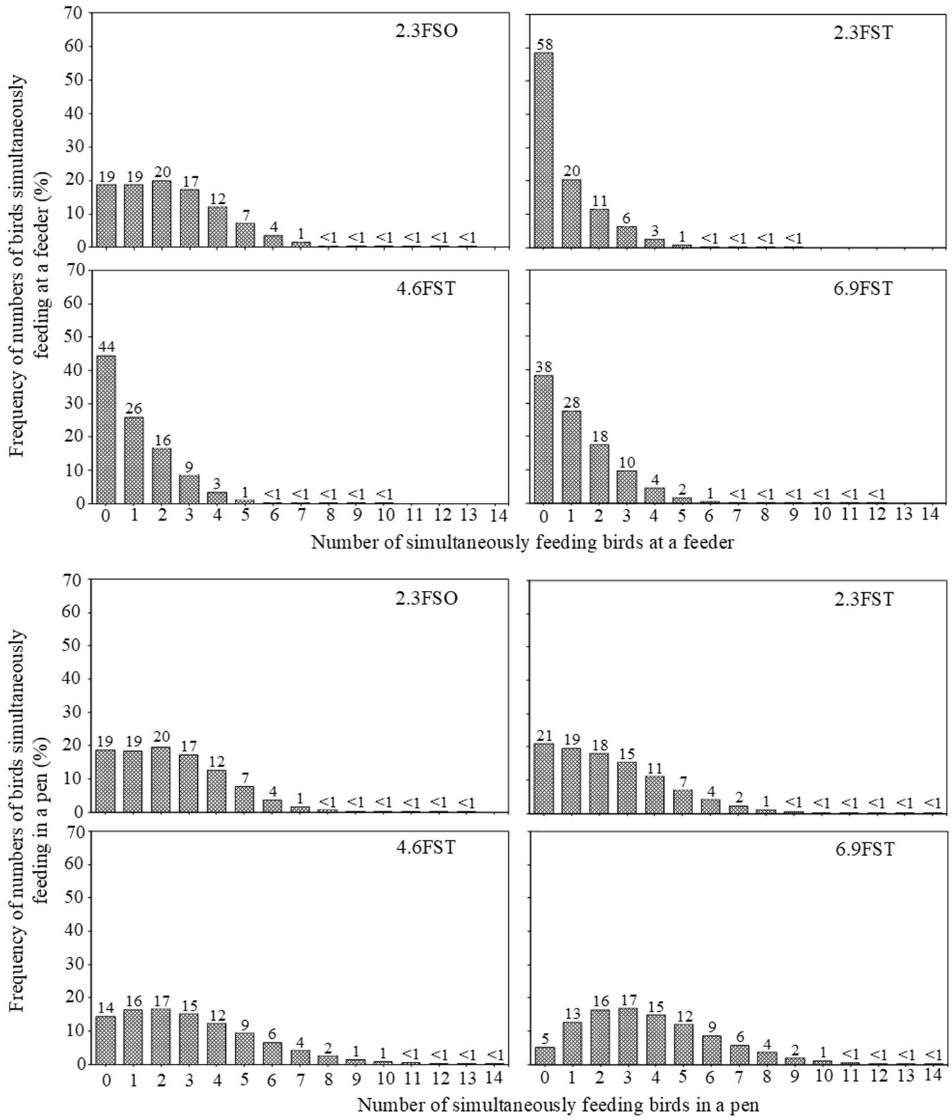

Figure 5. Frequency distribution of number of simultaneously feeding birds in week 4. 2.3FSO = 2.3 cm/bird feeder space with one fully open feeder shared by 45 birds in a pen; 2.3FST = 2.3 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; 4.6FST = 4.6 cm/bird feeder space with 3 partially blocked feeders shared by 45 birds in a pen; and 6.9FST = 6.9 cm/bird feeder space with 3 fully open feeders shared by 45 birds in a pen. Different numbers atop the bars indicate the frequencies of numbers of birds simultaneously feeding.

could reduce aggressiveness among birds, it may also lead to greater individual variations. Properly sizing the group may help to reduce the social effect on individual variations. Estévez et al. (1997) and Li et al. (2020b) found that a group size of more than 50 birds could reduce performance variations of individual broilers.

Feeding Duration per Feeder Visit

The mean, CV, and individual pattern for the feeding duration per feeder visit were similar across all the feeder space treatments and bird ages. Previous research reported that the feeding duration per feeder visit could be affected by various leg conditions (Weeks et al., 2000), growth rate (Howie et al., 2009), and diet type (Li et al., 2020b). In this case, the broilers were fed with the same type of diets among the treatments and can walk to the feeder without leg issues based on observation; therefore, these may be the reasons for the similar performance of the DFV among the treatments. As broilers occupied feeders for mostly less than 60 s in each feeder visit, other birds did not need to wait for too long before they accessed feeders, which can avoid broiler feeding frustration (Duncan and Wood-Gush, 1972).

Hourly Feeding Behavior Responses

Diurnal feeding rhythm can reflect bird welfare status across a day (Savory, 1980). Broilers in weeks 5 and 6 increased their feeding behaviors after the lights ON and before the lights OFF, which coincides with that in the previous research (Ferket and Gernat, 2006; Thogerson et al., 2009; Widowski et al., 2017). The former peak may be caused by no food during the long-term darkness while the latter peak may be stimulated by the prediction of upcoming darkness (Savory, 1980). Besides the 2 periods, broilers also ate throughout other hours because of individual differences or preferences. As broilers tended to occupy feeder for more time during these periods, leading to subordinate birds awaiting available feeding space, feeder allowance may be evaluated during these periods to provide sufficient feeder space that can reduce resource competition and bird frustration.

Number of Simultaneously Feeding Birds

Understanding simultaneous feeding behaviors provides insights into feeder allowance evaluation (Sirovnik et al., 2018). Assuming one feeder slot serving one bird in this case, the feeders among the treatments were not fully used because for most of the time, the number of simultaneously feeding birds was smaller than the number of available feeder slots. Broilers may prefer larger feeder spaces even though they have access to feeders, especially during busy feeding periods (Buijs et al., 2011). The maximum number of simultaneously feeding birds in a 2.3FST treatment pen was larger than that in a 2.3FSO treatment pen (18 vs. 13). With the same feeder allowance (2.3 cm/bird), spreading the feeding space seemed to accommodate more birds to eat simultaneously. Increasing feeder spaces from 2.3 to 6.9 cm/bird with the same feeder amount in a pen did not proportionally increase the number of birds that ate simultaneously. Proper feeder arrangement or placement may be more important than increasing feeder allowances in terms of accommodating simultaneously feeding birds. The maximum number per feeder in the 2.3FSO treatment (13) was smaller than the available feeder slot number, while the numbers in the 2.3FST and 4.6FST treatments (9 and 10) were larger than available slot numbers. Broilers have preference for feeding location (Li et al., 2020a), and multiple birds may share the same feeding slots when they have strong preference in feeding at a preferred location. In sum, to ensure birds to eat at will, not only should the feeder allowance be considered but also proper arrangement of the feeder allowance.

The goal of this study is to present the bird feeding behavior responses under different feeder spaces. More research may be needed to conclude an optimal or recommended feeder space because feeding behavior metrics performed differently under the feeder spaces investigated and feeder management. Daily feeding time and feeder visits for broilers of the 2.3FST treatment were similar to those of the 4.6FST and 6.9FST treatments but higher than those of the 2.3FSO treatment. The feeders of the 2.3FST treatment were used most efficiently among all treatments as reflected by the highest feeder utilization ratio. The CV for all feeding behavior responses was similar among the treatments. Given the same feeder number, increasing the feeder space could accommodate more birds eating simultaneously. Producers may need to decide the feeder space based on the specific responses they desire.

CONCLUSIONS

Effects of 4 feeder spaces (i.e., 2.3FSO, 2.3FST, 4.6FST, and 6.9FST) on broiler feeding behaviors were researched from weeks 4 to 8 using a UHF-RFID system. The results show that broilers had less feeding time and visited feeders less frequently at 2.3FSO and in weeks 7 and 8, while the feeder utilization was the highest (31.1%) with the 2.3FST treatment. Individual broilers presented less behavioral variation at 2.3FSO and in week 5. Broilers stayed at the feeder for less than 60 s in most of the feeding events and increased their feeding behaviors after the lights ON and before the lights OFF in weeks 5 and 6. For most of the time, less than 6 broilers chose to eat simultaneously at a feeder. The maximum number of simultaneously feeding birds in a 2.3FST treatment pen was larger than that in a 2.3FSO treatment pen.

ACKNOWLEDGEMENTS

Financial support was provided through a USDA-ARS cooperative agreement (grant number 6064-32630-008-01-S). The authors acknowledge the dedicated assistance and cooperation provided by the animal caretaker and engineering technician staff at the USDA-ARS Poultry Research Unit.

DISCLOSURES

The authors declare no conflicts of interest.

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