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The Effect of Housing Environment on Egg Production, USDA Egg Size, and USDA Grade Distribution of Commercial White Egg Layers

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Abstract: The housing environment has become a critical issue for consumers of eggs and egg products. Therefore, it is imperative to understand how various housing environments can affect the modern laying hen. In this study, alongside the 40th NC layer performance test, four different housing environments were chosen based on industry prevalence, which include conventional cages, barren, enrichable colony cages, enriched colony cages, and cage-free environments. Hens in these environments were raised following standard feeding and lighting practices. This study found that conventional cage and enriched colony cage hens had the highest egg production level, while hens from the barren colony cages had the lowest production level. Feed efficiency followed a similar trend, where conventional cage and cage-free hens had the best feed efficiency, followed by enriched colony cage and barren colony cage hens. This study also found that conventional cage hens had the largest eggs, while cage-free hens had the smallest eggs. Cage-free and conventional cage hens had the lowest mortality rate, while hens in the barren colony cage had the highest mortality rate. From the data shown, it appears that standard, conventional cages provide white egg layers with the most optimal environment for production performance. However, a further evaluation of health and stress is needed to determine which environment provides the hen with optimal welfare.

Keywords: white egg layers; egg production; housing environment; management and production; cage-free; USDA egg quality

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1. Introduction

Eggs are a staple of the American diet, as both a standalone food and an ingredient. In 2021 alone, the United States produced over almost 100 trillion shell eggs [1]. One constantly changing aspect of the egg industry are the housing environments in which the birds are raised in. New technologies are constantly being developed to improve the hen's environment, improve welfare, and alleviate stress. Pressures from lawmakers, as well as consumer and retail groups, have been the main driving factor in moving the industry towards greater adoption of these housing systems and away from conventional cage systems. In May of 2020, approximately 25% of the United States' flocks were housed in cage-free housing [2]. This trend will continue to increase as many large grocers and restaurants have made pledges to only serve cage-free eggs by 2025 [3–9]. Furthermore, many states in the USA have passed laws banning the sale of eggs from battery cages, such as the laws in California and eight other states [10,11]. Fortunately for the egg industry, consumers appear to want eggs from these extensive housing systems more now than they have done in the past, as consumers are not willing to pay increased prices [12,13].

Regardless of the socioeconomic factors, it is understood that there can be differences between housing environments in terms of production parameters. Several studies have been performed over the years that have shown a difference between all of these housing systems and many seem to generally agree that white egg layers see the best performance in traditional conventional cages and worse performance as the systems become more extensive [14–16].

Unfortunately, research analyzing the difference in housing environments utilizing modern layer genetic strains and American diets and practices is severely lacking, particularly with white egg layers. It has been shown that as technology and genetics improve, performance changes as well [17]. In addition, a USDA research blueprint has noted that applying research from one country to another can be problematic because of confounding practices, nutrition, and genetics between regions [18]. Furthermore, many of these studies do not evaluate USDA egg sizes and grades, which is a major marketing and quality tool for producers within the United States of America.

The goal of this paper is to identify and rank the production parameters of four housing systems: conventional cages (CC), enrichable colony cages (CS), enriched colony cages (ECS), and cage-free (CF) environments, while using typical modern husbandry practices, genetic strains, and nutrition found in the United States. We hypothesize that hens in intensive housing systems, such as the conventional cages, will have more desirable production traits than hens in extensive systems such as the cage-free system will. We aim to provide a complete and comprehensive look at white egg layer production performance in the most common commercial housing systems.

2. Materials and Methods

This trial was conducted at the North Carolina Department of Agriculture and Consumer Services, Piedmont Research Station Poultry Unit in Salisbury NC in conjunction with the 40th NC Layer Performance and Management Test [19]. The chicks were sexed, vaccinated following a standard industry vaccination schedule, tagged with individual identification numbers, weighed, and placed in pullet rearing houses in accordance with the laying environment in which they would be housed in. The vaccine schedule is presented in the 40th NC layer performance and management test grow report [20]. The birds that were destined for CC, CS, or ECS systems were reared in a pullet cage system, and those birds that were destined to be in the CF system were reared in the same environment they would be in during the laying phase. During their 17th week of life, the pullets were moved from the pullet houses to the lay houses. Egg quality and feed weigh backs were performed every 4 weeks during the laying cycle from 17 to 89 weeks of age. The rearing phase was performed in conjunction with the 40th North Carolina Layer Performance Test, which can be found in the growth report [20].

The environmentally controlled CF house had a high-rise design with a slat/litter floor, with a manure pit beneath the slats. Each 2.43 m × 3.05 m (8 ft × 10 ft) pen had 7.4 m^2 (80 ft^2) of floor space, half of which were covered in shavings, and half was covered slats. A total of 14 replicates of CF birds were used for this study. When the laying period began at 17 weeks of age, the replicate population was adjusted to 60 birds per pen, which yielded a stocking density of 1233 cm^2 (192 in^2) per bird. After subtracting the space utilized for the feeders, the area per hen was 1141 cm^2 (177 in^2). The birds were provided with feed and water space in accordance with UEP guidelines. Each hen was provided 16 cm of roosting space, and each pen contained 12 nesting boxes for a total of 1 nest box per 5 hens.

A single windowless, force-ventilated house contained 42 replicate cages of each of the two types of colony cages. This house contained 3 tiered banks of either CS or ECS cages. This house utilized a system that controlled the amount of feed (amount and diet) available for each replicate, and each cage was equipped with nipple waterers. There was no difference in size between the CS and the ECS systems. Each cage was 53.3 cm (21 in) tall by 66 cm (26 in) deep by 243.8 cm (96 in) wide, thus providing 1.6 m^2 (17.3 ft^2) for 36 birds per cage at a stocking density of 445 cm^2 (69 in^2) of cage space per bird. The CS cages were barren colony cages, with only the feeder and waterer system in them. In contrast, ECS cages contained several environmental enrichments, including a curtained nest area, roosts, and a scratch area. The enriched cages used in this study were similar to those used in the commercial layer industry.

The CC laying system was designed as a standard closed-sided house with forced ventilation. The cages were arranged in 3 tiers, and there were manure belts under each tier. Each cage measured 40.6 cm (16 in) high by 50.8 cm (20 in) deep by 121.9 cm (48 in) wide, thus providing 6131.6cm^2 (959.04 in^2) for 14 hens per cage, with a stocking density of 445 cm^2 (69 in^2) per bird. There was a total of 56 replicate units of 2 cages of 14 hens (28 hens per replicate) that were used for this trial. Each replicate unit of birds was fed by a trough system located on the outside of the cage. Nipple drinkers in each cage provided the birds with water.

Seven white egg layer strains were utilized for this study: Hendrix-Genetics Dekalb, Hendrix-Genetics Babcock (Hendrix-Genetics BV, Boxmeer, The Netherlands), Hy-Line W-36 (Hy-Line International, West Des Moines, IA, USA), Lohman LSL-Lite, Lohman Nick Chick (Lohmann Tierzuckt GmbH, Cuxhaven, Germany), Novogen Novowhite (Novogen, Pledran, France), and Tetra-Americana White (Tetra Americana LLC, Lexington, GA, USA). Because the objectives of this study were to evaluate the effect of housing systems on white egg laying hens in general, strain effects were not identified in the data tables. Table 1 shows the strains and the number of replicates per environment. Strains were chosen based on availability. The chicks were sexed based on breeder recommendations (feather, color, or vent sexing), and the females were kept. Each strain was identified by a strain code for record keeping, data analysis, and anonymity. At 69 weeks of age, some birds molted as part of another study. Our study is not concerned with the molted birds. Therefore, at 69 weeks of age, the data regarding the molted birds were removed from analysis. Table 1 shows the number of replications that were not molted in parenthesis.

Table 1. Housing system and replicate allocation of strains during the lay cycle (n).

Strain	Conventional Cages	Enrichable Colony Cages	Enriched Colony Cages	Cage-Free
Dekalb	8 (4)	6 (3)	6 (3)	2 (2)
Babcock	8 (4)	6 (3)	6 (3)	2 (2)
W-36	8 (4)	6 (3)	6 (3)	2 (2)
LSL-Lite	8 (4)	6 (3)	6 (3)	2 (2)
Lohman Nick Chick	8 (4)	6 (3)	6 (3)	2 (2)
NovoWhite	8 (4)	6 (3)	6 (3)	2 (2)
Tetrawhite	8 (4)	6 (3)	6 (3)	2 (2)
Total	56 (28)	42 (21)	42 (21)	14 (14)

Numbers indicated within ( ) are post-molt replications (after 69 weeks of age).

The layers used in this study were fed according to standard industry practices, consisting of several different dietary phases that met or exceeded NRC [21] recommendations allocated based on current production and feed consumption rates. Table 2 shows how the diets were fed based on production and consumption, and Table 3 details the composition of these different diets. Hens in all the different housing system environments followed the same *ad libitum* feeding program. All hens were provided the same supplemental lighting program throughout the duration of the trial in accordance with standard industry practices.

Table 2. Feeding program of diets according to egg production rate and ad libitum consumption rate.

Rate of Production	Feed Consumption kg/100 Birds/Day	Diet Fed
Pre-production	<9.52	Pre-Lay
Pre-peak and >90%	<10.43 10.43–12.20 >12.20	Pre-Lay Pre-Peak Layer 1
90–80%	<11.29 11.29–12.20 >12.20	Layer 1 Layer 2 Layer 3
70–80%	<11.29 11.29–12.20 >12.20	Layer 3 Layer 4 Layer 5
<70%	<11.29 11.29–12.20 >12.20	Layer 5 Layer 6 Layer 7 [1]

[1] Layer 7 was not used during this study.

Table 3. Ingredient composition and calculated nutrient analysis of diets fed to all hens according to the feeding program described in Table 2.

Ingredients	Pre-Lay	Pre-Peak	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Corn	48.7	58.3	60.1	62.0	68.0	66.5	65.8	65.2
Soybean Meal	35.2	28.2	26.7	25.3	25.0	22.0	20.9	18.9
Wheat Midds	-	-	-	-	-	-	5.70	12.9
Fat (Lard)	0.55	0.50	-	-	0.83	-	-	-
Soybean Oil	2.54	1.29	1.81	1.25	0.095	-	-	-
Lysine 78.8%	-	-	-	-	-	0.11	0.005	-
D.L. Methionine	0.17	0.15	0.12	0.10	0.095	0.078	0.062	0.057
Ground Limestone	6.87	6.12	6.08	5.53	-	5.78	5.96	6.18
Course Limestone	3.87	3.50	3.5	3.75	3.97	3.75	3.75	3.75
Bicarbonate	0.11	0.10	0.10	0.15	0.11	0.10	0.10	0.10
Phosphate mono/D	1.21	1.07	0.90	1.30	1.26	1.09	0.99	0.82
Salt	0.39	0.32	0.29	0.25	0.31	0.26	0.26	0.24
Vit. Premix [1]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Min. Premix [2]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
HyD3 Broiler (62.5 mg/lb)	-	-	0.025	-	-	-	-	-
Prop Acid 50% Dry	0.055	0.05	0.05	0.05	0.053	0.05	0.05	0.05
T-Premix	0.055	0.05	0.05	0.05	0.053	0.05	0.05	0.05
0.06% Selenium Premix [3]	0.055	0.05	0.05	0.05	0.053	0.05	0.05	0.05
Choline Cl 60%	0.090	0.097	0.080	0.050	0.046	0.026	0.005	-
Avizyme	0.055	0.050	-	-	-	-	-	-
Ronozyme P-CT 540%	0.022	0.020	0.020	-	-	-	-	-
Calculated Values								
Crude Protein %	19.43	18.1	17.5	17	16.37	15.87	15.49	14.93
Calcium %	4.1	4.05	4	3.95	3.95	4	4.05	4.1

Table 3. *Cont.*

Ingredients	Pre-Lay	Pre-Peak	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
A. Phos. %	0.45	0.44	0.4	0.38	0.35	0.33	0.31	0.28
Total Lysine %	1.1	1	0.96	0.91	0.87	0.91	0.8	0.75
Total Sulfur Amino Acids %	0.8	0.74	0.69	0.66	0.63	0.6	0.58	0.56
ME kcal/kg	2926	2904	2860	2843	2843	2822	2800	2778

[1] Vitamin premix supplied the following per kilogram of feed: vitamin A, 26,400 IU; cholecalciferol, 8000 IU; niacin, 220 mg; pantothenic acid, 44 mg; riboflavin, 26.4 mg; pyridoxine, 15.8 mg; menadione, 8 mg; folic acid, 4.4 mg; thiamin, 8 mg; biotin, 0.506 mg; vitamin B12, 0.08 mg; ethoxyquin, 200 mg. The vitamin E premix provided the necessary amount of vitamin E as DL-α-tocopheryl acetate. [2] Mineral premix supplied the following per kilogram of feed: 120 mg of Zn as $ZnSO_4H_2O$, 120 mg of Mn as $MnSO_4H_2O$, 80 mg of Fe as $FeSO_4H_2O$, 10 mg of Cu as $CuSO_4$, 2.5 mg of I as $Ca(IO_3)_2$, and 1.0 mg of Co as $CoSO_4$. [3] Selenium premix provided 0.3 ppm Se from sodium selenite.

For this study, a period (28 days) was the unit of measurement of time. Data were analyzed utilizing JMP 14.1 using ANOVA, and treatments were determined statistically different from one another by using Tukeys HSD [22]. Housing system, age, and the interaction between the two factors were the main effects and were noted as statistically significant ($p \leq 0.05$).

All mathematical formulas are presented in Table 4. Hen-housed production is the percentage of eggs produced based on the number of hens at the beginning of the laying period. Hen-day production is the number of eggs laid based on the number of hens still in the trial after accounting for those removed because of morbidity or mortality. Feed consumption was calculated on an average grams/hen/day basis. The feed allocated was weighed during each period, and a weigh back was performed at the end of each period. Feed efficiency was calculated as a function of the mass of eggs produced relative to the feed consumed by those in the experimental unit. The overall mortality rate was calculated as the percentage of mortality that accumulated per replicate unit over the 19 observation periods relative to the total hens housed. Mortality was transformed to normalize the distribution prior to statistical analysis. Mortality rate data were transformed for statistical analysis to normalize the distribution prior to statistical analysis.

Table 4. Mathematical formulas associated with this study.

Parameter Measured	Mathematical Formula
Hen-housed Egg Production (%)	((Egg produced)/(hens housed × 28)) × 100
Hen Day Egg Production (%)	((Eggs produced)/(period hen days)) × 100
Feed consumption (g/bird/day)	(Total grams of feed consumed)/(hen days)
Feed efficiency (egg g/feed g)	(Egg production × average egg weight grams)/(feed consumption)
Mortality (%)	((Hens housed–hens remaining)/(hens housed)) × 100
Transformed mortality	ASIN(SQRT(mortality%/100)) + 1
Egg weight (g)	(Total grams of eggs weighed)/(number of eggs weighed)
USDA grade/size (%)	((Number of grade/size eggs)/(total number of sampled eggs)) × 100

During the third week of each observational period, all the eggs produced by each replicate treatment group within the previous 24 h were collected to determine the average egg weight and the proportion of USDA egg size and grade categories. Sampled eggs were weighed as a composite, and then the average period egg weight was calculated.

Weights of individual eggs from each of these replicate sample groups were determined, and then segregated into the USDA egg size categories of Pee Wee (<42.6 g), Small (42.6–49.7 g), Medium (49.7–56.8 g), Large (56.8–63.9 g), and Extra Large (>63.9 g) [23]. Jumbo was not used for this study. The distribution of eggs within each USDA egg size category was calculated as a percentage of the total number of eggs collected within each treatment replicate group. These same sampled eggs were assessed by trained individuals for exterior and interior quality based on the USDA egg grading manual [23]. The distribution of eggs within each USDA grade category was calculated as a percentage of the total number of eggs collected within each treatment replicate group. Finally, individual body weights were taken only once at the end of the study and measured in kg per bird. Twenty-five hens per replicate were weighed for the CF environment, while thirteen birds were weighed per replicate from the CC, EC, and ECS environments.

3. Results

3.1. Egg Production

Overall egg production is presented in Table 5, while hen-day production averages by age are shown in Figure 1 and hen-housed egg production averages by age are shown in Figure 2. The housing environment had a significant effect ($p < 0.0001$) on hen-day and hen-housed production of white egg layers. CC hens have higher hen-day production values than the CF hens and CS hens do by 1.2% and 3.3%, respectively. CS hens also have lower hen-day production values than the CF hens and ECS hens do by 2.1% and 2.9%, respectively. These differences manifested as peak production values through the mid-cycle through weeks 57–60. Similarly, overall CS hens have worse hen-housed production values than CC hens, ECS hens, and CF hens do by 10.2%, 9.1%, and 9.2%, respectively. Both hen-day and hen-housed egg production followed the same trends across all ages. Egg production began low, quickly peaked, and then slowly declined for the rest of the trial. By age, all hens reached peak production at similar times and followed similar patterns, although hens in the ECS system experienced a sharp decline in both hen-day and hen-housed egg production beginning at 37 weeks of age. While hen-day production recovered, hen-housed production did not recover, which indicates an increase in mortality during this age.

Table 5. Effect of housing system environment on production parameters of brown egg layers.

Housing Environment	Hen-Day Prod. (%)	Hen-Housed Prod. (%)	Feed Cons. (g/Bird/Day)	Feed Conv. (Egg g/Feed Cons)	Egg Weight (g)	Bird Body Weight (kg)	Mortality (%)
Conventional Cages	$84.6^{a} \pm 0.2$	$80.2^{a} \pm 0.3$	$105.4^{c} \pm 0.3$	$0.50^{a} \pm 0.002$	$61.6^{a} \pm 0.1$	$1.76^{b} \pm 0.01$	$15.3^{bc} \pm 2.6$
Enrichable Colony Cages	$81.3^{c} \pm 0.3$	$70.0^{b} \pm 0.3$	$111.4^{a} \pm 0.3$	$0.45^{c} \pm 0.002$	$61.2^{b} \pm 0.1$	$1.76^{b} \pm 0.012$	$31.3^{a} \pm 3.0$
Enriched Colony Cages	$84.2^{ab} \pm 0.3$	$79.1^{a} \pm 0.3$	$107.4^{b} \pm 0.3$	$0.48^{b} \pm 0.002$	$60.9^{b} \pm 0.1$	$1.70^{c} \pm 0.12$	$15.6^{b} \pm 3.0$
Cage-free	$83.4^{b} \pm 0.4$	$79.2^{a} \pm 0.5$	$101.8^{d} \pm 0.5$	$0.50^{a} \pm 0.003$	$60.5^{c} \pm 0.1$	$1.82^{a} \pm 0.017$	$5.2^{c} \pm 3.6$
p-Value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

[a,b,c,d] Mean values within a column with different letter superscripts are significantly different ($p < 0.05$).

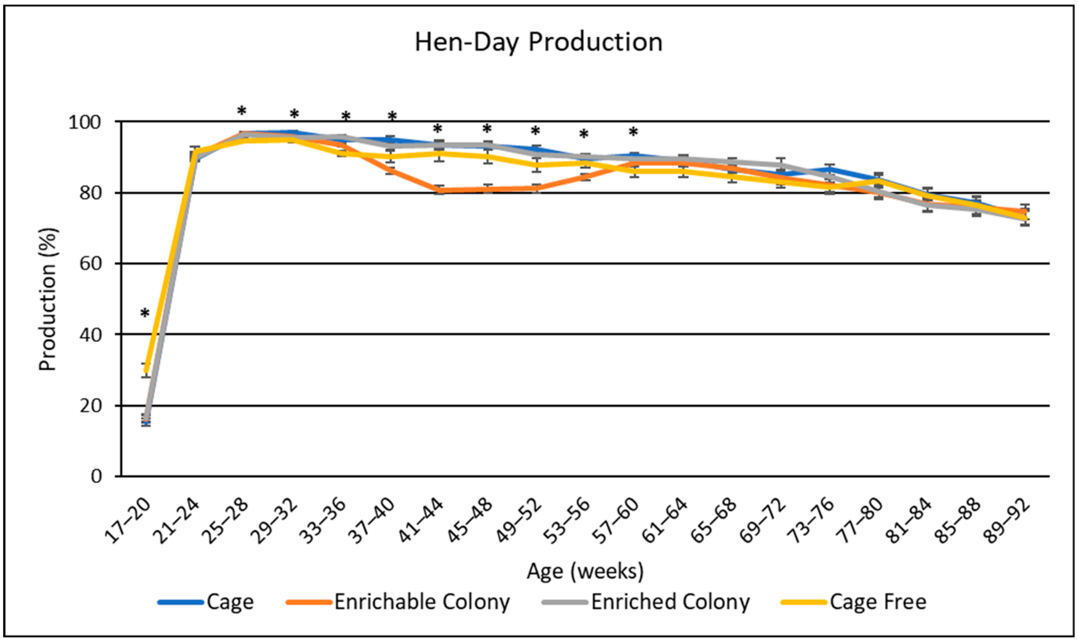

Figure 1. The effect of housing system on hen-day production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range.

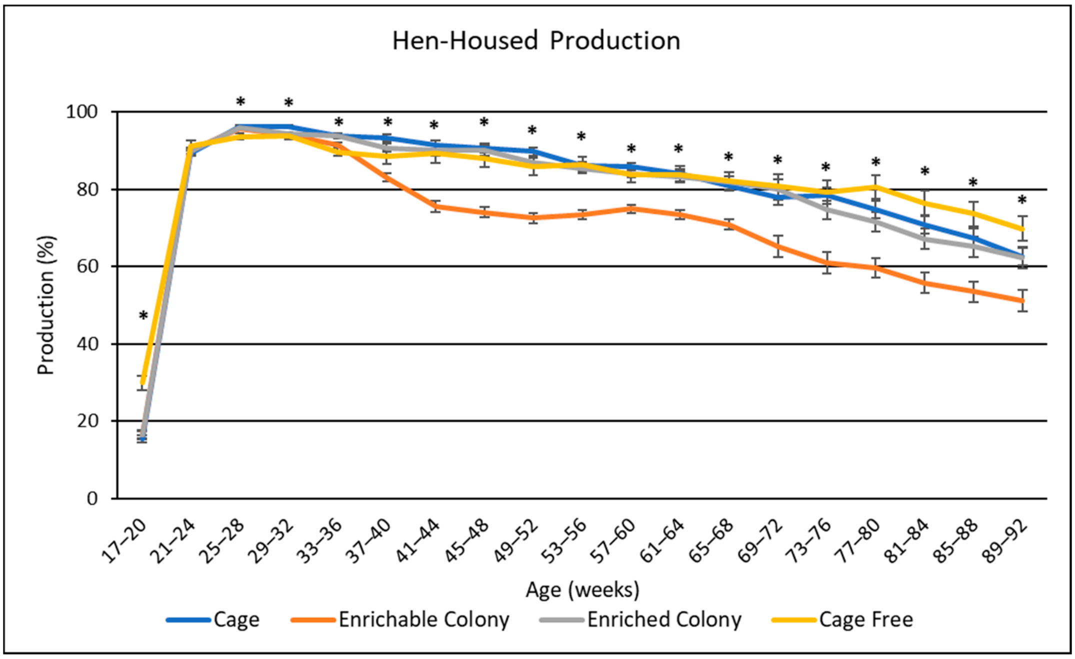

Figure 2. The effect of housing system on hen-housed production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range.

3.2. Feed Consumption

The whole study feed consumption is presented in Table 5, and feed consumption by age is shown in Figure 3. The housing environment had a highly significant effect ($p < 0.0001$) on feed consumption. CS hens consumed more feed than ECS hens did by 4 g. ECS hens consumed more feed than CC hens did by 2 g. Finally, CC hens consumed more feed than CF hens did by 3.6 g. By age, feed consumption by CC, CS, and ECS hens increased, while consumption by CF hens remained constant. From 29 weeks of age to 44 weeks of age, the hens from all environments consumed similar amounts of feed;

however, after 44 weeks of age, consumption by CC, CS, and ECS hens began to increase, with CS hen's consumption increasing quicker than those of CC and ECS hens. CF hens remained consistent in their feed consumption throughout the entire trial.

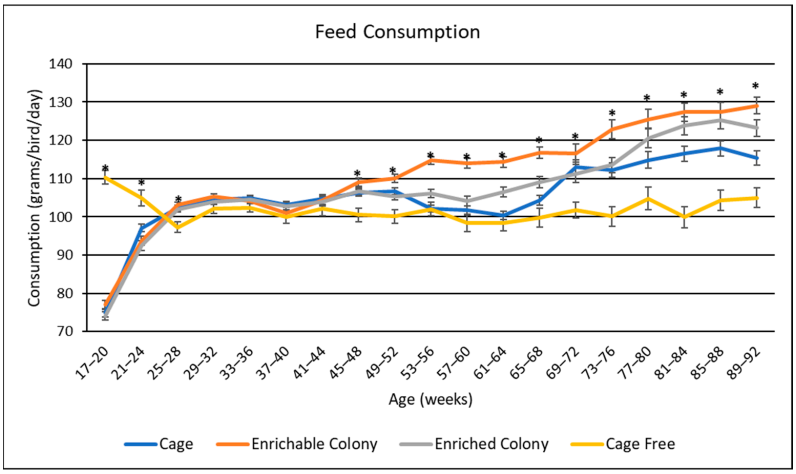

Figure 3. The effect of housing system on feed consumption of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on feed consumption.

3.3. Feed Efficiency

Feed efficiency averages across the whole study are presented in Table 5, and feed efficiency trends by age is shown in Figure 4. The housing environment had a highly significant effect ($p < 0.0001$) on feed efficiency. Overall, both CC and CF hens had a higher feed efficiency than ECS hens and CS hens did by 0.02 g of egg per gram of feed and 0.05 g of egg per gram of feed, respectively. By age, feed efficiency started low, then peaked with egg production. Feed efficiency remained consistent for both CF and CC hens, although CC hens, which had higher feed efficiency than CF hens did through the beginning for the study, began to lose efficiency, and therefore, had lower efficiency than the CF hens did at the end of the study. ECS hens had similar feed efficiency to CC hens during the first third of the study, after which they decreased to have similar efficiency to the CF hens during the second third, and then decreased again in the last third. Finally, CS hens had the worst feed efficiency than hens from the other environments did throughout most of the study.

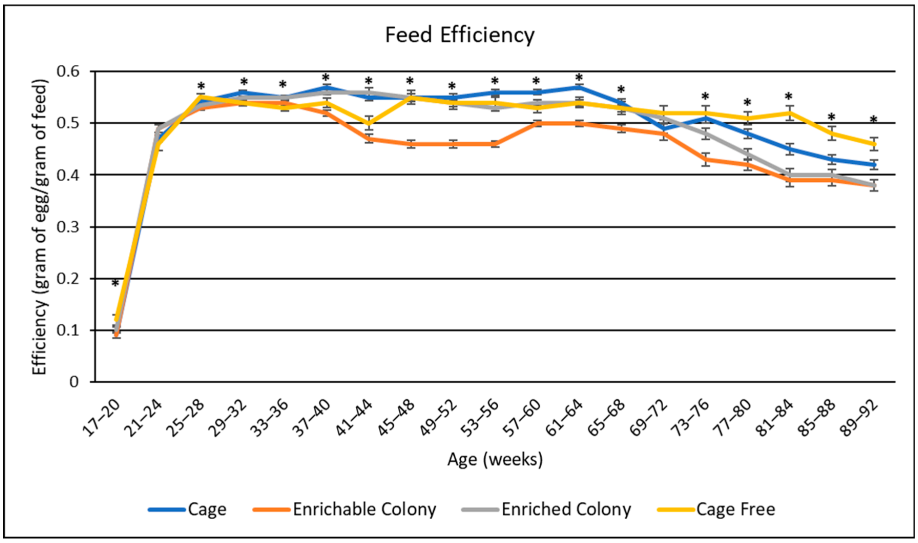

Figure 4. The effect of housing system on feed efficiency of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on feed efficiency.

3.4. Egg Weights

The overall egg weights are presented in Table 5, and egg weight averages by age are shown in Figure 5. The housing environment had a significant effect ($p < 0.0001$) on the egg weights of white eggs. CC hens laid heavier eggs than CS, ECS, and CF hens did by 0.4 g, 0.7 g, and 1.1 g, respectively, while CF also laid lighter eggs than CS and ECS hens did by 0.7 g and 0.4 g, respectively. By hen age, egg weights followed a trend typical of breeder standards, increasing over time. CF hens had the heaviest eggs by weight until peak production, after which CF hens had the lightest eggs by weight. After the peak of the lay period, CC hens had the heaviest eggs by weight until 53 weeks of age. After 53 weeks of age, CS and ECS hens had similar egg weights to those of CC hens.

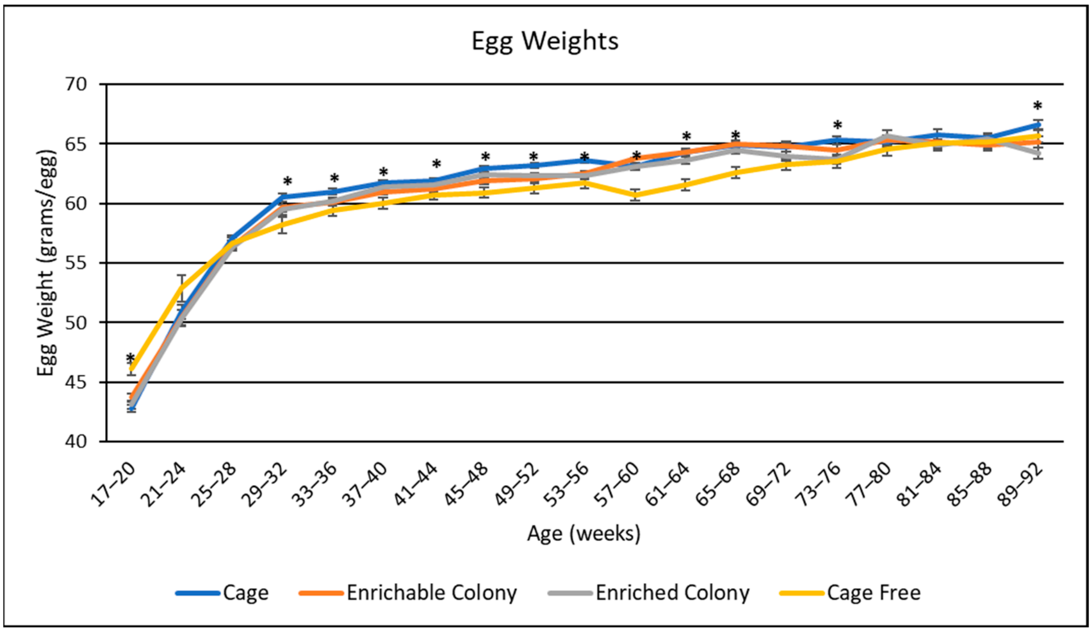

Figure 5. The effect of housing environment on egg weight of commercial white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on egg weight.

3.5. Body Weight

Table 5 contains the average body weight of each treatment at the end of the study. The housing environment had a highly significant ($p < 0.0001$) effect on the hens' body weight. The largest hens came from the CF environment, at 1.815 kg/bird, followed by CC, CS, and ECS hens at 1.76 kg/bird, 1.76 kg/bird, and 1.70 kg/bird, respectively. CF hens were statistically heavier than all other hens, ECS hens were statistically lighter than all other hens, and CS and CC hens were not statistically different from each other.

3.6. Mortality

The whole study mortality data are shown in Table 5, but mortality by age was not analyzed for mortality. The housing environment was found to have a highly significant effect ($p < 0.0001$) on total mortality. CF hens had lower mortality rates than CS hens and ECS hens did by 26.1% and 10.4%, respectively. CS hens also had higher mortality rates than CC hens and ECS hens did by 16% and 15.7%, respectively.

3.7. USDA Egg Grades

The USDA egg grade proportion averages (A, B, and loss) throughout the whole study are presented in Table 6, while egg grade proportions by age are presented in Figure 6 (grade A) and Figure 7 (loss). The housing environment had a significant effect ($p < 0.0001$) on the proportions of grade A and loss. CF hens had 2%, 1.4%, and 3.5% higher proportions of grade A eggs than CS, ECS, and CF hens did, respectively. CC hens also laid a higher proportion of grade A eggs than CS and ECS hens did by 2.0% and 1.4%, respectively. Conversely, CF hens laid 3.6%, 5.5%, and 4.8% lower proportions of loss eggs than CC, CS, and ECS hens did, respectively. CC hens also laid a lower proportion of loss eggs than CS and ECS hens did by 1.9% and 1.2%, respectively. Grade B proportions were unaffected by the housing environments. By age, grade A proportions fell slightly, and the loss proportions rose slightly for all environments as the hens aged. CF hens consistently laid the highest proportions of grade A eggs and lower proportions of loss eggs. ECS hens laid lower proportions of grade A eggs and higher proportions of loss eggs during the beginning of the study; however, after 40 weeks of age, CS hens laid lower proportions of grade A eggs and higher proportions of loss eggs than hens from the other environments did between 37 and 68 weeks of age. The CC hen grade A and loss proportions remained the same between the CF hens and both colony cage hens for the majority of the study.

Table 6. The effect of housing system environment on USDA grades and sizes of white layers.

Housing Environment	Grade A%	Grade B%	Loss%	XL%	L%	M%	S%
Conventional Cages	91.7 ^{b} ± 0.2	0.6 ± 0.1	7.7 ^{b} ± 0.2	70.1 ^{a} ± 0.5	22.7 ^{c} ± 0.5	3.6 ± 0.2	3.6 ^{a} ± 0.2
Enrichable Colony Cages	89.7 ^{c} ± 0.3	0.8 ± 0.1	9.6 ^{a} ± 0.3	67.3 ^{b} ± 0.5	24.7 ^{b} ± 0.5	4.1 ± 0.3	3.8 ^{a} ± 0.2
Enriched Colony Cages	90.3 ^{c} ± 0.3	0.8 ± 0.1	8.9 ^{a} ± 0.3	65.8 ^{b} ± 0.5	26.2 ^{b} ± 0.5	4.4 ± 0.3	3.6 ^{a} ± 0.2
Cage-free	95.2 ^{a} ± 0.4	0.7 ± 0.1	4.1 ^{c} ± 0.4	61.1 ^{c} ± 0.8	31.9 ^{a} ± 0.8	4.6 ± 0.4	2.4 ^{b} ± 0.3
p-Value	0.0001	0.0606	0.0001	0.0001	0.0001	0.0675	0.0024

^{a,b,c} Mean values within a column with different letter superscripts are significantly different ($p < 0.05$).

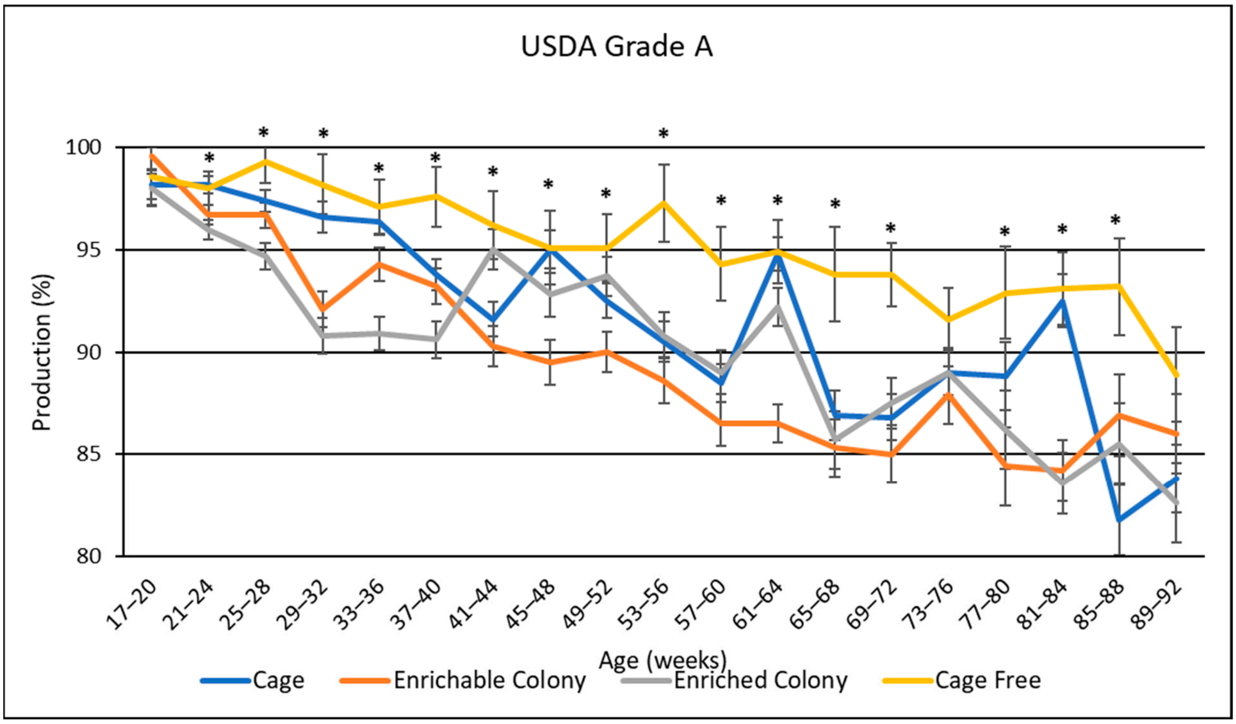

Figure 6. The effect of housing environment on USDA grade A egg production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on USDA grade A egg production.

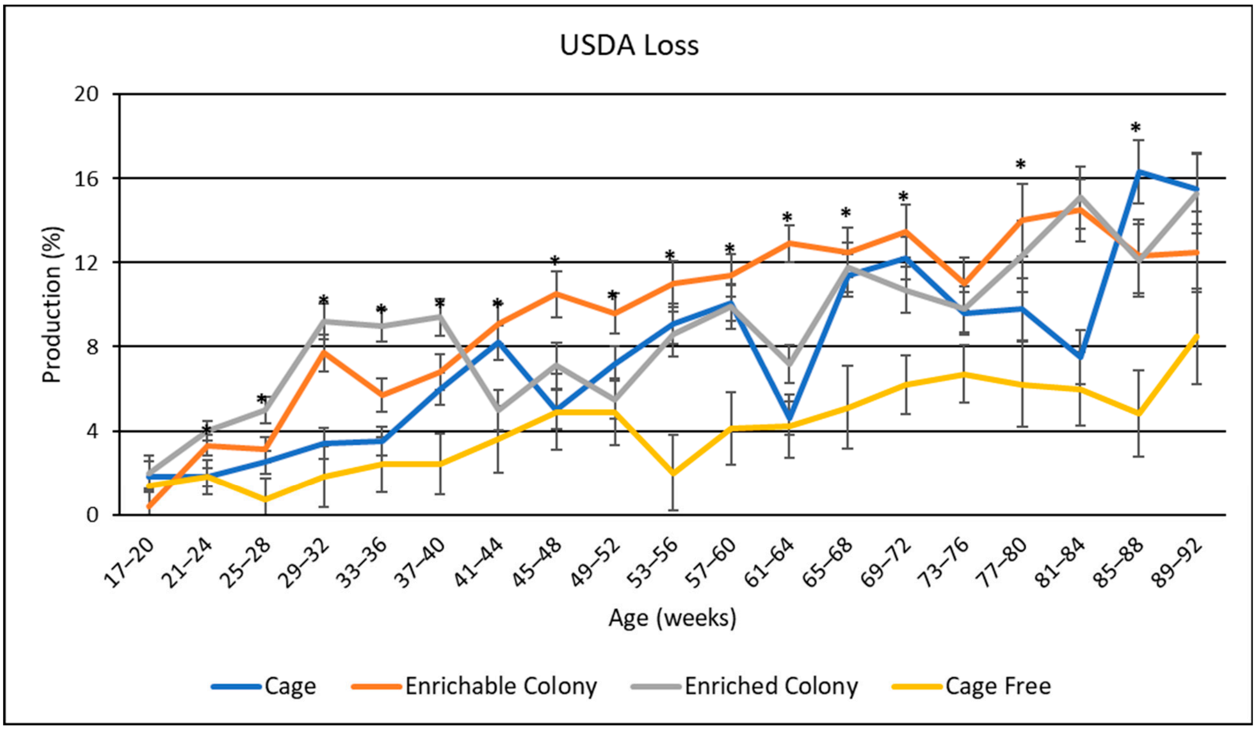

Figure 7. The effect of housing environment on USDA loss egg production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on USDA loss egg production.

3.8. USDA Egg Size Distribution

The USDA egg size proportions for each housing environment throughout the lay cycle are presented in Table 6, whereas the USDA egg size proportions for each housing environment by age are presented in Figure 8 (USDA XL), Figure 9 (USDA L) and Figure 10 (USDA S). The housing environment had a significant effect on proportion of XL eggs ($p < 0.0001$), proportion of L eggs ($p < 0.0001$), and proportion of S eggs ($p < 0.001$) from white egg layers. CC hens laid 2.8%, 4.3%, and 9.0% more XL eggs than CS, ECS and CF hens did, respectively. CF hens also laid proportionally fewer XL than CS and ECS hens did by 6.2% and 4.7%, respectively. Conversely, CC hens laid proportionally fewer L eggs than CS, ECS, and CF hens did by 2.0%, 3.5% and 9.2%, respectively, while CF hens also laid proportionally fewer loss eggs than CS and ECS hens did by 7.2% and 5.7%, respectively. Furthermore, CF hens laid 1.2%, 1.4%, and 1.2% fewer S eggs than CS, CS, and ECS hens did, respectively. Following the same trend as egg weights, proportions of XL eggs increased as the hens aged, while proportions of L, M, and S eggs decreased. CC hens consistently produced the highest proportions of XL eggs and lowest proportions of L eggs during the study, while CF hens consistently produced the lowest proportions of XL eggs and highest proportions of L eggs during the study.

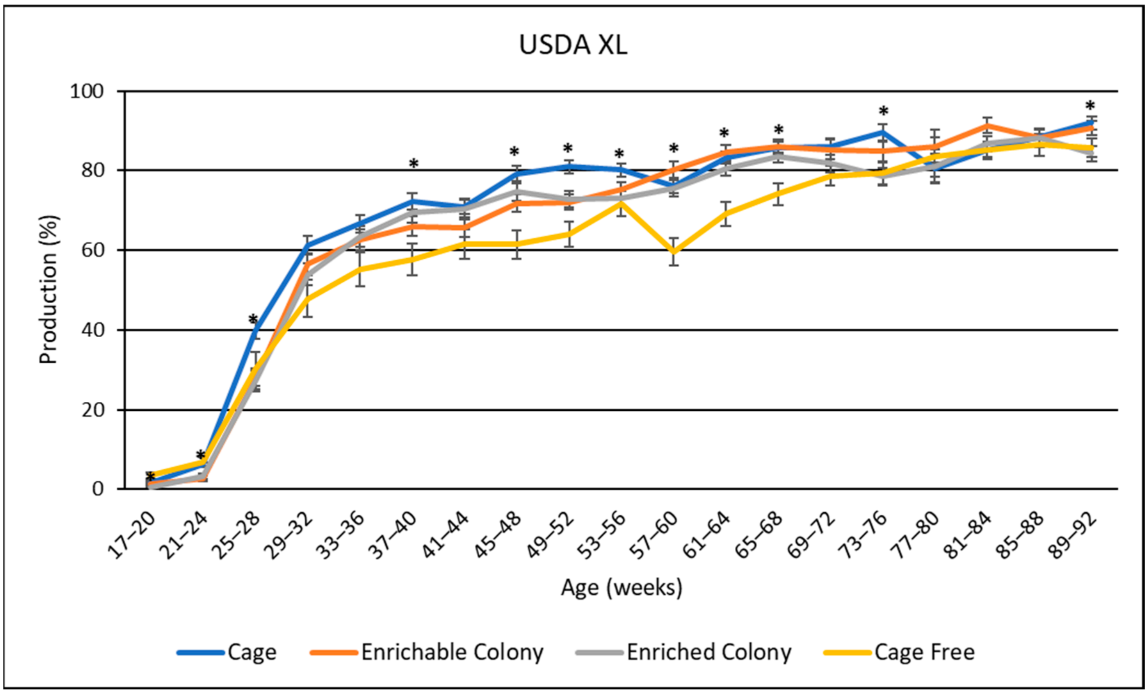

Figure 8. The effect of housing environment on USDA extra-large egg production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on USDA XL egg production.

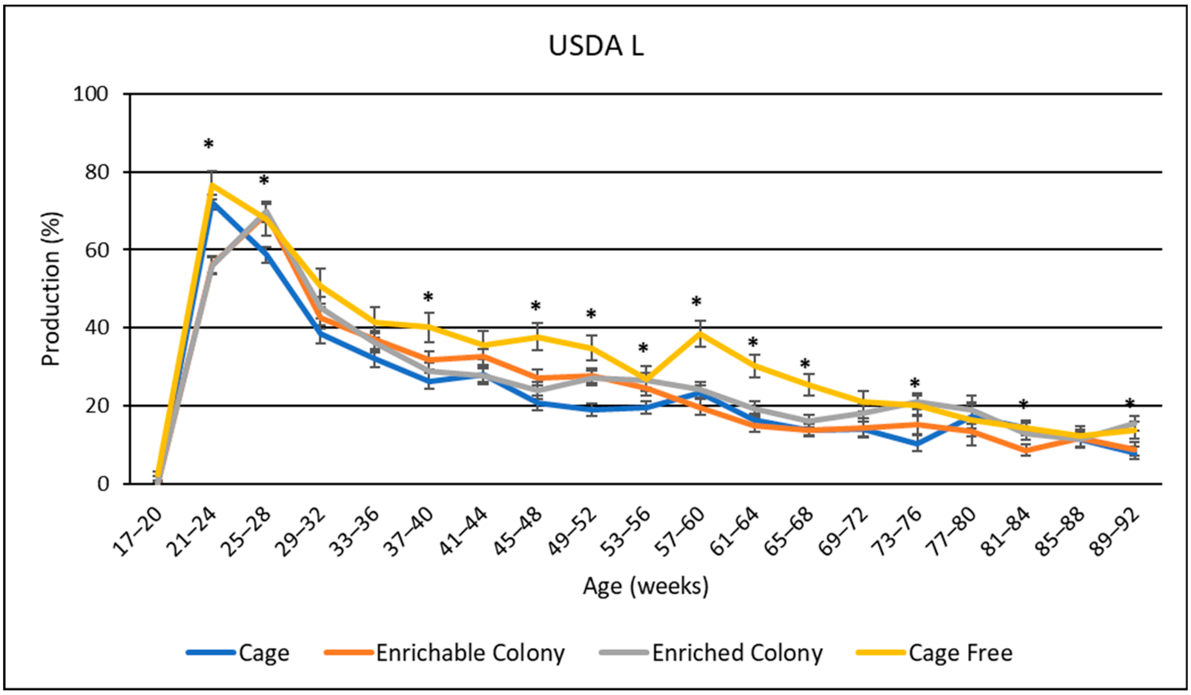

Figure 9. The effect of housing environment on USDA large egg production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on USDA L egg production.

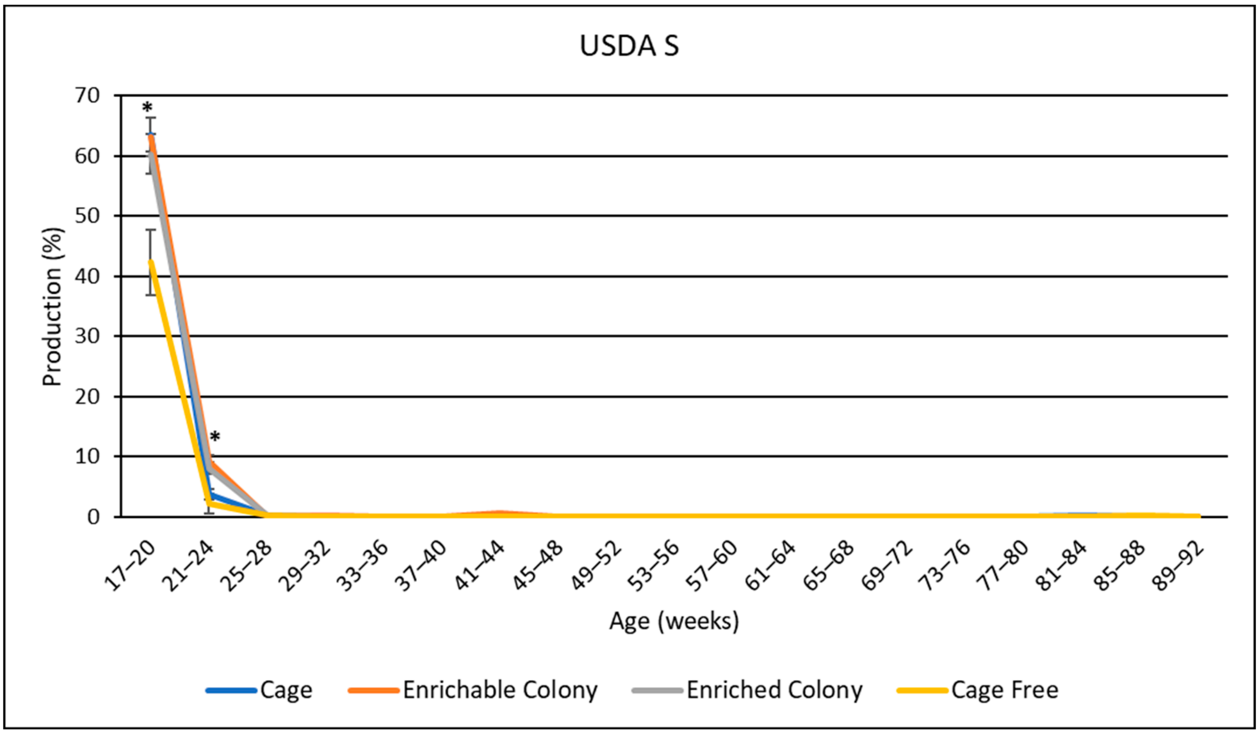

Figure 10. The effect of housing environment on USDA small egg production of white egg layers by age range. * Signifies a significant effect ($p < 0.05$) of housing environment by age range on USDA egg production.

4. Discussion

The commercial egg industry in the US is moving towards greater usage of extensive housing systems due to pressures from various interested parties. Therefore, egg companies have placed increased importance on understanding production performance to calculate profitability. Previous research has reported conflicting results regarding the effect of layer housing systems on the production parameters of white egg layers [16,24,25]. However, much of this research is 5 years old or older, and most papers do not evaluate more than two or three housing systems together. Furthermore, another major contribution of this study is the evaluation of USDA egg grades and sizes, as this comparison has not yet been performed. This current study evaluated four laying systems utilizing modern genetic strains of laying hens and found major differences between them in all parameters.

4.1. Egg Production

Our study agrees with previous studies, which found that CC hens and ECS hens had similar egg production levels [24,26,27]. However, this work demonstrated CS hens had lower egg production values than the hens in other environments did, which is in contrast to Onbaşılar et al. [28] who reported that the white egg layers in both ECS and CS systems had similar egg production levels. Most CF research is conducted utilizing the much newer aviary system and not the slat/litter system that was utilized in this trial, as we did not have access to aviaries. Karcher et al. [26] found that the egg production levels by white egg layers in CF aviaries were no different than it was for CC hens, which is contrary to findings where CC hens had higher egg production rates than CF hens did. Our study also disagrees with an older study, which found that CF hens had similar egg production rates to those of CC hens. The differences between studies may indicate a major change in the hen or that the strain utilized previously was better adapted for CF [14]. The research shows that the addition of enrichments to the laying hen's environment may reduce stress and startle responses [29,30]. Increased stress levels will reduce the egg production rate [31]. Therefore, we theorize that CS hens were subjected to higher levels of stress than ECS hens were simply because CS hens did not have access to enrichments, which caused CS hens to have lower egg production levels.

4.2. Feed Consumption

This study differs from Karcher et al. [26], who indicated no difference in the feed consumption between hens in CF aviaries, CC hens, and ECS hens. Our study found that CF hens consumed the least amount of feed, while CC hens consumed less feed than ECS hens did. Furthermore, our study also differed from Onbaşılar et al. [28], who showed that CS and ECS hens consumed similar amounts of feed, and with Neijat et al. [24], who found that CC hens consumed less feed than ECS hens did. However, Neijat theorized that aggressive feeding behaviors may have attributed to differences due to feeder space differences between the two systems, whereas the feeder space was standardized in our study. Tactacan et al. [27] reported no difference in the feed consumption between CC hens and ECS hens, contradictory to this study. The differences between studies could be due to several factors, such as the strains utilized, the region, and the diets used. In addition, many of these studies only evaluated two or three systems together. As previously mentioned, we believe the CS system resulted in a higher level of stress in the hens than the level of stress of hens in other environments, which would explain why these hens consumed more feed. Additionally, this study showed that CF hens consumed the least amount of feed, but they produced fewer eggs than the CC hens and ECS hens did, indicating a reduced nutrient demand compared to that which the more productive hens required. However, the results did show that CF hens had the highest consumption rates early in the study, which corresponds with the high-level early egg production in CF hens.

4.3. Egg Weight

In contrast to this study, several other studies showed no difference in the egg weights between environments [24,27,32]. This research agrees with Onbaşılar et al. [28], who found no difference in egg weights between CS and ECS hens. Moreover, Zita et al. [33] found were differences between CC and CF hens, but Zita showed that CF hens laid heavier eggs, which is contrary to our study. As stated before, we attribute variations between our study and previous studies to differences in management, nutrition, and genetics across regions and time. Figures 1 and 2 indicate that CF hens began laying sooner than the hens from other environments did. Although the CF hens reached peak production level at approximately the same time as the other environments, high-level pre-peak egg production could indicate that the CF hens reached sexual maturity sooner than the hens in other environments did. Studies have indicated that hens who reach sexual maturity sooner lay lighter eggs, which is possibly related to a smaller reproductive tract and fewer nutrient reserves [34,35]. Therefore, we postulate that CF hens laid lighter eggs than the hens in other environments did because CF hens laid sooner due to the lower reproductive tract weight of CF hens.

4.4. Feed Efficiency

Previous papers have asserted that as housing environments become more extensive, hens will become less feed efficient [36]. Some studies, such as that by Onbaşılar et al. [28], found no difference between CS hens and ECS hens, whereas Tactacan et al. [27] found that CC hens had better feed efficiency than ECS hens did. The dichotomy between these studies further exemplifies that current research of white egg layers in various housing environments is inconclusive. This study disagrees with the results from Neijat et al. [24], who showed no difference between CC hens and ECS hens, which may have been related to the aforementioned confounding factors or could be due to the higher number of replications and sampling dates in our study with greater representation of the laying hen flocks, thereby improving the analysis of variance. It was unexpected that CF hens had similar feed efficiency to that of CC hens. It is known that regular visual contact with humans will reduce fear response in layers [37]. It is also known that hens subjected to levels of stress and fear will suffer from lower production parameters [31,38]. Since workers had to go inside the CF pens and interact with the hens to collect eggs, this interface with the workers, over time, could mitigate the stress response, thereby explaining why CF hens had a higher feed efficiency later in the study. Thus, we hypothesize that human interactions with hens, particularly those in extensive environments, can be beneficial to those hens.

4.5. USDA Egg Grades

Observing the differences in egg grades between housing environments was a major novel contribution of this study. It is important to assess egg grades, as they directly relate to the profits of commercial egg companies. Although utilizing USDA egg grades as a measurement of quality is rather novel, many studies have determined the instances of broken and dirty eggs, which are included in the definition of USDA loss. Tactacan et al. [27] showed that ECS hens produced more cracked and dirty eggs than CC hens did, which agrees with the results found in our study, perhaps due to the elevated activity level. Conversely, Shimmura et al. [32] found no differences in the percentage of cracked eggs between housing environments. Our study found no difference in egg grade proportions between CS and ECS hens, although Onbaşılar et al. [28] found differences between these two cage environments, but they did not delineate the reason for downgrading eggs, which is worthy of a future study. The type of nesting enrichment likely had a significant impact on the variation between housing environments, as CF hens had access to nest boxes with softer material than those in the other environments. This appeared to be beneficial to egg grades from CF hens, as they had the highest proportion of grade A eggs. Previous research has also shown that hens in extensive housing environments lay eggs with stronger shells than their counterparts in intensive housing environments do, which could explain why the CF hens in our study laid a higher proportion of grade A eggs [32,39]. Furthermore, CF hens had access to their eggs before collection, while the hens in cages did not. Therefore, there is a possibility that CF hens ate any broken or cracked eggs that they produced, thereby underrepresenting the proportion of loss eggs.

4.6. USDA Egg Sizes

In the US, USDA egg size classifications are used to determine the sales price of table eggs for the consumer. According to the May 2020 report, large and extra-large eggs command higher sales prices than smaller eggs do [40]. In the United States, the table eggs sold are primarily large or extra-large, except for breaking eggs, but processors prefer the largest egg possible as a bigger egg means that there is more egg product. Breaker eggs make up about 30% of total egg production, and therefore, they are an important part of the egg industry [1]. Therefore, in this study, USDA egg grades are directly related to measured egg weights. CC hens had the heaviest egg weights, and therefore, highest proportion of XL eggs and lowest proportion of L eggs, while CF hens had the lowest egg weights, resulting in the lowest proportion of XL eggs and highest proportion of L eggs. Unfortunately, research utilizing USDA sizes in different housing environments is very limited and almost non-existent, as most of the research on this topic has taken place outside of the United States. Therefore, the utilization of USDA egg size distribution is rather novel. Interestingly, even though CF eggs had lower average egg weight than those from the other cage environments, they produced the fewest S eggs. This study showed that CF hens begin to lay heavier eggs than those in the other environments do, indicating CF hens may have been more sexually mature in the beginning of the study, but they could not continue laying heavier eggs as their reproductive system is smaller [34,35].

4.7. Mortality

Several studies [26,27] have shown that the housing environment did not affect the mortality of white egg layers, which is in contrast to what we found. In an older study, Bailey et al. [14] found no difference in mortality between CC and CF systems. Interestingly, our study seems to be one of the only studies that showed a difference in mortality but unfortunately, we did not record the cause of mortality. One study using industry egg laying operations did show a difference in the cause of mortality between laying systems. Fossum et al. [41] found that FR and CF hens suffered from more bacterial, parasitic, and cannibalistic problems than hens in cages did, while hens in cages suffered from more viral problems than their non-cage counterparts did. The cause of mortality in our study is unknown; however, we believe that stress and fear responses were a contributing factor to the increased mortality in the CS system. It was noted that most of the CS hens died from self-inflicted bone breakage trauma and the CS hens would run from wall to wall in the cage and sometimes crash into a wall. As stated previously, enrichments have been shown to mitigate stress and fear responses in hens [30]. Furthermore, other studies indicate that enrichments in the environment can positively affect the immune system of the laying hen [42]. Therefore, we believe the reason that CF hens had low mortality was due to the enrichments providing a lower stress environment, and the reason the CS hens had higher mortality than ECS hens was due to the lack of enrichments causing increased stress and fearfulness. CC hens also lacked enrichments, but CC hens also had higher mortality than the CF hens did, although it was not as high as that of the CS hens. The reason for the difference in mortality between the CC hens and CS hens is unknown; however, the difference could be related to cage size and population, indicating that larger cages with more hens causes more stress in the flock.

5. Conclusions

The results found from this study reveal that the housing environment has a significant effect on nearly all production metrics measured. We initially hypothesized that white egg layers would perform better in intensive housing environments, such as the CC environment. From the data presented in this paper, we can confirm that the data have validated our hypothesis, as we found optimal production parameters in the CC environment across the board. Furthermore, we observed that the CF environment allowed the hens to perform better in some aspects, such as feed efficiency, mortality, hen-housed production, and percentage of grade A eggs laid, as compared to those of the hens in colony cages. Finally, we observed that by simply adding enrichments, in the case of CS and ECS systems, hens had improved egg production, feed efficiency, and mortality. Adding enrichments should be considered when one is designing environments for laying hens.

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