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Effect of High and Low Stocking Density on Age of Maturity, Egg Production, Egg Size Distribution in White and Brown Layer Hens: A Meta-analysis

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Abstract
Data of four layers flocks (#31-34) from North Carolina Layer Performance and Management Test of the Department of Agriculture and Consumer Services were used in the meta-analysis to find if an increase in space allowance can affect egg production traits in white and brown layers. Effects of space allowance of 310 and 413 cm^2/bird on layers performance were compared in this study. The increase in space allowance resulted in a significant improvement in egg production, egg mass and daily feed intake in both white and brown layers throughout the first (approximately 490-d; $P < 0.001$) and second (approximately till 760-d; $P < 0.05$) cycles of egg production. Space allowance did not affect age of maturity and final body weight at the end of first egg production cycle in both types of layers. Increasing birds space allowance resulted in a reduction in the mortality rate of white layers ($P < 0.001$) in the first egg production cycle and in the first (P=0.015) and second (P=0.027) egg production cycles in brown layers. The increase in space allowance significantly improved egg weight ($P < 0.001$) in white layers in the first egg production cycle. A significant increase in egg weight was observed in the first (P=0.014) and second (P=0.050) egg production cycles in brown layers in response to increasing birds space allowance. Egg size distribution was significantly influenced by the space allowance during both egg production cycles in white and brown layers. Space allowance is a management tool that can be used to optimize egg production traits, mortality and egg size distribution in both white and brown layers. Space allowance of 413 cm^2/bird could significantly improve egg production and egg size distribution in first and second egg production cycle compared to 310 cm^2/bird.

Introduction

Although it is well-known that stocking density can influence the performance of laying hens (Leeson and Summers, 1984), many egg producers have a tendency to use the housing facilities at maximum capacity by increasing the number of birds per cage. This is based on the assumption that improved income can be obtained by increasing birds population and subsequently total egg production per house regardless of the possible adverse impact of increasing cage density (Hester and Wilson, 1986; Saki *et al*., 2012). Effects of cage density, size and number of birds per cage have been investigated and inconsistent results have been reported (Adams and Jackson, 1970;

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Cunningham, 1982; Adams and Craig, 1985; Hester and Wilson, 1986; Saki *et al*., 2012). Adams and Craig (1985) performed a direct comparison of results obtained from published papers since 1971 till 1983 and concluded that increasing cage density from 387 to 310 cm^2/bird, significantly reduced egg production, feed consumption and increased the rate of mortality. However, Cunningham (1982) observed no difference in egg production, egg weight, egg mass, mortality rate, and feed consumption in white leghorn layers that were allocated to deep cages at 484 and 387 cm^2/bird throughout 20 to 60 weeks of age. Moreover, reduction of space allocation resulted in an increase in the number of cracked eggs (Hill and Hunt, 1978). Furthermore, the number of broken shell, soft shell, and shell-less eggs are negatively associated with increasing cage density (Hester and Wilson, 1986). However, inconsistent results have been reported by other researchers, who illustrated that cage density did not influence uncollectable eggs (Dorminey and Arscott, 1971; Hill and Hunt, 1978; Ouart and Adams, 1982). In addition, Adams and Jackson (1970) reported that mortality rate increased in response to cage crowding of 700 to 310 cm^2/bird. However, Anderson and Havenstein (2007), as well as Ouart and Adams (1982) observed no effect on mortality rate in response to decreased cage density. The response of layer hens to different cage densities can be strikingly different due to discrepancies of cage densities, types, and house environments as well as bird strains and ages (Adams and Jackson, 1970; Cunningham, 1982; Ouart and Adams, 1982).

In 1999, the United Egg Producers (UEP) (UEP, 2006) assembled the UEP Committee for Animal Welfare a scientific advisory committee to develop guidelines based on existing information to the egg industry. This recommendation was established one year later and made a considerable impact on layer hens' management especially on their housing. The UEP guideline increased former US industry standard of 348 to range from 432 to 555 cm^2/bird (Cook, 2004).

A body of information regarding responses of layers to different cage densities has reported in the literature. For drawing a comprehensive inference from many of these experiments that were conducted in various conditions, application of logic and statistical method is indispensable. Meta-analysis is an approach aimed to find the solution for main research quandary by re-analyzing compiled data from relevant publications (Faridi *et al*., 2015) and it can effectively eliminate factors that are variable through different studies such as genetic selection, diets, environment, etc. Therefore, the aim of this study was to re-analyzing the collected data of experiments under commercial conditions from several strains of white and brown layers reared at lower cage density compared to UEP (United Egg Producers, 2006) and almost close to the current recommendations of cage density (Cook, 2004) with the lowest possible divergence to answer what productive factors can be influenced by stocking density in white and brown layer hens.

Materials and Methods

Animal Care and Use Committee approval was not required since data obtained from an existing data set.

Description of data-set

The sources of data were four flocks from the North Carolina Layer Performance and Management Test (NCLP&MT) conducted at the North Carolina Department of Agriculture and Consumer Services, Piedmont Research Station-Poultry Unit (https://poultry.ces.ncsu.edu/layer-performance). These four reports represent a total number of 26442 white layers and 13324 brown layers from four layer flocks were placed in two cage densities (310 vs. 413 cm^2/bird). The four layer flocks (31st through 34th) maintained in production throughout April 1994 to November 2000 in layer house number four (environmentally controlled facility with three banks of four-deck high cages) and five (totally enclosed force ventilated open-sided house two banks of triple deck cages and two banks with four levels of cages).

Hens of the 31st NCLP&MT (Anderson, 1996) flock included Hy-line W36, Hy-line W77, Bovans white, Dekalb Delta, Shaver white, Shaver 2000, and ISA Babcock strains for the white layers experiment and Hy-line brown, Bovans brown, and ISA brown strains for the brown layer experiment were moved to the laying facilities on April 1994 at 17 weeks of age and data were collected till 462-d as end of the first egg production cycle and till 735-d as the end of second egg production cycle. The 32nd

NCLP&MT (Anderson, 1998) flock included Hy-line W36, Hy-line W77, Bovans white, Shaver white, Shaver 2000, and ISA Babcock strains for the white layer experiment and Hy-line brown, Bovans brown, ISA brown, and Shaver brown 579 for the brown layer experiment were moved to the laying facilities on April 1996 at 17 weeks of age and data were collected till 469-d as the end of first egg production cycle and till 770-d as the end of second egg production cycle. The 33rd NCLP&MT (Anderson, 2000) flock included Hy-line W36, Hy-line W98, and Bovans white strains for the white layers experiment and Hy-line brown, Bovans brown, and Bovans gold strains for the brown layer experiment were moved to the laying facilities in November 2000 at 17 weeks of age and data were collected till 462-d as the end of first egg production cycle and till 770-d as the end of second egg production cycle. The 34th NCLP&MT (Anderson, 2002) flock included Hy-line W36, Hy-line W98, Bovans white, Dekalb white, and Dekalb sigma strains for the white layer experiment and Hy-line brown, Bovans brown, and Dekalb brown strains for the brown layer experiment were moved to the laying facilities in November 2000 at 17 weeks of age and data were collected till 462-d as the end of first egg production cycle and till 749-d as the end of second egg production cycle. In flocks 31st and 32nd, each nipple drinker covered water consumption of 2.30 birds, and during flocks 33rd and 34th, each nipple drinker provided water consumption of four birds.

The 310 cm^2/b density was provided by keeping seven hens in a cage of 61 cm × 35.5 cm (W×D) for the 31st and 32nd flocks with 8.7 cm feeder space per bird; four birds in a cage of 30.5 cm × 40.7 cm (W×D) in the 33rd and 34th flocks with 7.6 cm feeder space per bird. Whereas the 413 cm^2/bird density was provided by keeping seven hens in a cage of 82 cm × 35.5 cm (W×D) for the 31st and 32nd flocks with 11.7 cm feeder space per bird; four birds in a cage of 40.7 cm × 40.7 cm (W×D) in the 33rd and 34th flocks with 10.2 cm feeder space per bird.

Diets compositions were similar during all of these experiments. Feed and water were provided for ad-libitum consumption. The age of maturity, production performance, mortality, final body weight and egg size distribution during 1st and 2nd egg production cycles were recorded. More comprehensive detail of data set of the white and brown layers flocks of the first and second egg production cycles as well as molting periods are shown in Tables 1 through 4.

Table 1. Input data-set of population number and average of response variables in white layer strains kept in two cage densities during the first egg production cycle.

	North Carolina layers flocks							
Flock Number	31st (1)		32nd (2)		33rd (3)		34th (4)	
Density (cm^2)[5]	310	413	310	413	310	413	310	413
Population (bird)	3395	3395	2910	2910	3276	3276	3640	3640
Feed Intake (g/b/d)	108±4.14	112±3.55	101±3.83	107±5.46	97±3.21	105±3.61	108±3.78	121±5.02
Egg Production (%)	74.1±1.87	78.5±1.22	76.1±1.62	79.3±1.52	79.4±2.53	82.9±4.16	81.7±2.91	84.5±3.07
Egg Mass (g/b/d)	44.9±1.62	47.5±1.15	46.1±0.97	48.2±1.54	45.2±0.67	47.5±1.61	47.9±1.58	49.8±1.88
FCR	2.41±0.07	2.30±0.05	2.20±0.06	2.21±0.05	2.14±0.08	2.21±0.15	2.3±0.08	2.4±0.10
Age of 50% Production (d)	152±5.96	155±6.24	148±4.26	147±3.97	139±5.21	139±4.34	138±5.02	138±4.79
Mortality (%)	8.3±5.96	3.7±6.24	12.5±5.52	9.10±5.88	10.5±4.35	8.0±3.99	16.5±10	10.4±.10
Final Body Weight (kg)	1.82±0.09	1.84±0.08	2.08±0.41	2.02±0.08	1.77±0.17	1.79±0.11	1.81±0.09	1.86±0.11
Egg Weight (g)	59.9±1.48	60.1±1.13	59.9±1.33	60.1±1.17	56.7±2.11	57.1±1.75	58.4±1.88	58.6±1.82
Pee Wee (%)	2.0±0.74	1.8±0.82	1.2±0.66	1.3±0.56	3.8±1.93	3.9±1.57	1.3±0.79	1.4±1.00
Small (%)	4.0±0.54	3.9±1.13	7.5±0.80	6.8±0.98	8.6±1.23	8.4±0.90	6.8±1.94	6.8±2.05
Medium (%)	14.2±3.82	15.1±3.03	13.7±2.62	13.6±1.56	26.1±7.28	22.8±5.65	20.9±5.25	19.5±4.33
Large (%)	42.4±3.85	37.9±6.33	33.3±4.29	31.7±5.02	37.4±1.95	39.6±3.01	46.1±4.89	45.5±4.96
Ex- Large (%)	37.0±8.00	37.6±6.33	43.9±7.48	46.3±6.64	23.9±11.50	25.1±10.84	24.6±11.38	26.6±10.67
Grade A (%)	95.6±0.76	95.5±0.97	95.6±0.50	96.0±0.52	97.7±0.35	98.3±0.15	97.6±059	98.0±0.53
Grade B (%)	1.8±0.32	2.0±0.60	1.9±0.38	1.8±0.37	0.4±0.20	0.2±0.15	1.2±0.43	0.8±0.25
Crack (%)	2.6±0.84	2.4±0.48	2.2±0.33	2.0±0.34	1.7±0.32	1.4±0.26	1.1±0.29	1.0±0.37

[1]Pullets were moved to the laying facilities on April 1994 and they were comprised of the same numbers of Hy-line W36; Hy-line W77; Bovans white; Dekalb Delta; Shaver white; Shaver 2000; ISA Babcock strains.

[2]Pullets were moved to the laying facilities on April 1996 and they were comprised of the same numbers of Hy-line W36; Hy-line W77; Bovans white; Shaver white; Shaver 2000; ISA Babcock strains.

[3]Pullets were moved to the laying facilities on October 1998 and they were comprised of the same numbers of Hy-line W36; Hy-line W98; Bovans white strains.

[4]Pullets were moved to the laying facilities on November 2000 and they were comprised of the same numbers of Hy-line W36; Hy-line W98; Bovans white; Dekalb white; Dekalb sigma strains.

[5]Density of 310 cm^2 obtained by keeping seven hens in a cage of 61 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 8.7 cm feeder space per bird; four hens in a cage of 30.5 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 7.6 cm feeder space per bird; Density of 413 cm^2 obtained by keeping seven hens in a cage of 82 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 11.7 cm feeder space per bird; four hens in a cage of 40.7 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 10.2 cm feeder space per bird.

Table 2. Input data-set of average of weight loss and mortality rate in molting period and response variables in white layer strains kept in two cage densities during the second egg production cycle.

	North Carolina layers flocks							
Flock Number	31st (1)		32nd (2)		33rd (3)		34th (4)	
Density (cm^2)[5]	310	413	310	413	310	413	310	413
Molting Period								
Weight loss in molting (%)	32.3±2.13	30.3±1.79	29.5±1.79	27.9±2.94	24.4±4.06	23.0±2.96	22.7±1.13	23.0±2.96
Mortality rate during molting (%)	3.32±2.03	4.1±2.64	3.2±1.78	2.2±1.45	3.0±1.91	2.4±1.42	2.7±1.00	2.36±1.42
Feed Intake (g/b/d)	110±5.46	114±5.77	109±4.98	114±7.74	107±2.65	113±8.54	116±4.18	131±5.17
Egg Production (%)	69.4±2.68	72.4±2.79	71.3±2.07	73.2±1.45	68.2±1.50	71.3±0.95	69.5±2.59	72.4±2.82
Egg Mass (g/b/d)	46.4±2.46	48.8±2.24	45.2±1.27	46.5±1.46	46.2±1.14	46.2±1.14	46.1±0.12	48.0±0.92
FCR	2.37±0.08	2.34±0.09	2.41±0.13	2.46±0.14	2.32±0.08	2.45±0.24	2.50±0.12	2.70±0.10
Mortality (%)	8.5±3.46	8.1±3.90	10.4±2.48	8.8±2.75	7.5±1.65	3.9±2.42	9.7±2.65	10.0±3.14
Egg Weight (g)	66.9±1.13	67.4±1.03	64.3±1.41	64.1±1.14	64.8±2.31	64.8±1.93	64.6±2.16	65.1±1.99
Pee Wee (%)	0.1±0.11	0.1±0.09	0.0±0.00	0.0±0.05	0.0±0.00	0.0±0.00	0.2±0.04	0.1±0.04
Small (%)	0.4±0.39	0.2±0.18	0.5±0.04	0.3±0.05	0.4±0.12	0.4±0.17	0.6±0.33	0.5±0.05
Medium (%)	2.1±0.73	1.8±0.63	0.8±0.55	0.7±0.55	3.0±3.75	2.6±1.47	3.8±2.88	3.5±1.99
Large (%)	13.5±3.43	12.9±3.43	15.4±4.57	13.7±4.68	35.0±13.13	34.8±13.96	45.0±12.88	41.0±12.13
Ex- Large (%)	83.9±4.03	85.0±3.17	83.3±5.18	85.3±5.26	61.6±16.76	62.2±15.49	50.4±15.36	54.9±14.17
Grade A (%)	93.7±1.09	93.5±1.19	95.8±0.89	96.5±0.76	96.2±0.55	97.5±0.23	95.4±0.77	96.6±0.93
Grade B (%)	3.9±1.01	3.5±0.92	0.9±0.29	0.8±0.38	1.2±0.21	0.5±0.10	2.3±0.68	1.6±0.84
Crack (%)	2.4±0.49	2.8±0.58	3.0±0.58	2.4±0.60	2.5±0.32	1.8±0.17	1.80±0.19	1.5±0.24

[1]Pullets were moved to the laying facilities on April 1994 and they were comprised of the same numbers of Hy-line W36; Hy-line W77; Bovans white; Dekalb Delta; Shaver white; Shaver 2000; ISA Babcock strains.

[2]Pullets were moved to the laying facilities on April 1996 and they were comprised of the same numbers of Hy-line W36; Hy-line W77; Bovans white; Shaver white; Shaver 2000; ISA Babcock strains.

[3]Pullets were moved to the laying facilities on October 1998 and they were comprised of the same numbers of Hy-line W36; Hy-line W98; Bovans white strains.

[4]Pullets were moved to the laying facilities on November 2000 and they were comprised of the same numbers of Hy-line W36; Hy-line W98; Bovans white; Dekalb white; Dekalb sigma strains.

[5]Density of 310 cm^2 obtained by keeping seven hens in a cage of 61 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 8.7 cm feeder space per bird; four hens in a cage of 30.5 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 7.6 cm feeder space per bird; Density of 413 cm^2 obtained by keeping seven hens in a cage of 82 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 11.7 cm feeder space per bird; four hens in a cage of 40.7 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 10.2 cm feeder space per bird.

Table 3. Input data-set of population number and average of response variables in brown layer strains kept in two cage densities during the first egg production cycle.

	North Carolina layers flocks							
Flock Number	31st (1)		32nd (2)		33rd (3)		34th (4)	
Density (cm^2)	310	413	310	413	310	413	310	413
Population (bird)	1092	1092	1748	1748	1638	1638	2184	2184
Feed Intake (g/b/d)	116±3.51	122±1.53	107±3.46	114±1.89	102±1.53	110±1.73	120±2.08	129±4.16
Egg Production (%)	74.5±0.91	80.4±2.40	77.7±2.21	81.7±2.10	82.4±1.51	87.7±0.93	84.5±1.90	86.8±1.18
Egg Mass (g/b/d)	46.2±0.74	50.2±2.25	48.3±0.97	51.4±1.46	48.8±0.40	52.5±0.21	51.6±1.50	53.2±1.06
FCR	2.56±0.00	2.47±0.13	2.21±0.05	2.22±0.05	2.08±0.01	2.10±0.04	2.32±0.03	2.43±0.04
Age of 50% Production (d)	150±2.31	151±1.00	145±2.45	145±2.63	138±1.11	136±1.25	133±2.95	132±2.36
Mortality (%)	9.3±3.97	8.0±1.90	15.1±5.56	11.7±5.97	11.8±1.97	5.9±2.57	25.2±2.76	9.2±1.64
Final Body Weight (kg)	2.13±0.04	2.20±0.11	2.25±0.11	2.29±2.29	2.04±0.07	2.04±0.05	2.13±0.03	2.12±0.07
Egg Weight (g)	61.5±1.01	61.7±0.95	61.6±0.22	62.4±0.46	59.0±0.61	59.6±0.61	60.9±0.55	61.2±0.55
Pee Wee (%)	1.2±0.23	1.3±0.44	0.3±0.19	0.3±0.05	1.9±0.44	1.4±0.12	0.2±0.12	0.2±0.10
Small (%)	3.4±0.44	3.1±0.36	4.9±0.67	4.9±0.44	6.4±0.50	5.5±0.66	2.7±0.40	2.5±0.38
Medium (%)	12.4±1.82	11.0±2.00	12.6±1.03	9.9±0.51	20.2±2.11	17.8±1.65	14.0±1.72	13.8±1.04
Large (%)	38.6±5.75	40.4±4.48	31.1±1.17	28.6±1.67	37.4±1.99	37.7±1.44	46.0±2.52	45.8±3.27
Ex- Large (%)	44.4±6.15	44.2±2.95	51.1±1.66	56.3±2.34	34.1±4.32	37.6±3.09	37.1±4.20	37.7±4.28
Grade A (%)	94.8±0.60	95.0±1.32	95.9±0.22	96.5±0.30	98.3±0.17	98.4±0.12	97.5±0.12	98.1±0.15
Grade B (%)	2.4±0.59	1.6±0.47	2.4±0.30	1.8±0.26	0.3±0.06	0.3±0.06	1.2±0.12	0.7±0.26
Crack (%)	2.90±0.36	3.4±1.47	1.6±0.24	1.7±0.17	1.4±0.21	1.3±0.17	1.3±0.06	1.1±0.15

[1]Pullets were moved to the laying facilities on April 1994 and they were comprised of the same numbers of Hy-line brown; Bovans brown; ISA brown strains.

[2]Pullets were moved to the laying facilities on April 1996 and they were comprised of the same numbers of Hy-line brown; Bovans brown; ISA brown; Shaver brown 579 strains.

[3]Pullets were moved to the laying facilities on October 1998 and they were comprised of the same numbers of Hy-line brown; Bovans brown; Bovans gold strains.

[4]Pullets were moved to the laying facilities on November 2000 and they were comprised of the same numbers of Hy-line brown; Bovans brown; Dekalb brown strains.

[5]Density of 310 cm^2 obtained by keeping seven hens in a cage of 61 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 8.7 cm feeder space per bird; four hens in a cage of 30.5 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 7.6 cm feeder space per bird; Density of 413 cm^2 obtained by keeping seven hens in a cage of 82 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 11.7 cm feeder space per bird; four hens in a cage of 40.7 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 10.2 cm feeder space per bird.

Table 4. Input data-set of response variables in brown layer strains kept in two cage densities during the second egg production cycle.

	North Carolina layers flocks							
Flock Number	31st (1)		32nd (2)		33rd (3)		34th (4)	
Density (cm²)	310	413	310	413	310	413	310	413
Molting Period								
Weight loss in molting(%)	30.9±2.11	28.5±0.80	29.7±2.80	28.5±0.80	24.2±4.20	22.8±2.05	20.8±0.47	20.5±1.31
Mortality rate during molting(%)	4.0±5.05	6.7±0.59	4.8±1.33	6.67±0.59	2.7±0.86	1.83±0.38	2.4±0.78	1.9±0.45
Feed Intake (g/b/d)	120±4.58	124±.00	118±6.68	124±4.35	111±3.21	119±4.04	128±4.04	136±3.06
Egg Production (%)	64.3±3.61	69.8±4.33	65.4±1.97	65.8±1.71	67.7±0.72	70.7±0.60	66±1.48	69±2.40
Egg Mass (g/b/d)	44.3±2.45	48.2±3.36	42.3±1.02	43.0±1.48	45.6±0.10	47.9±0.35	44.6±1.39	46.8±1.55
FCR	2.7±0.12	2.6±0.19	2.8±0.11	2.9±0.14	2.43±0.7	2.49±0.10	2.86±0.11	2.90±0.05
Mortality (%)	12.3±1.08	15.06±3.23	10.8±2.95	14.15±4.14	6.42±1.61	8.2±3.06	8.3±0.95	8.1±2.08
Egg Weight (g)	69.0±1.07	69.0±0.81	65.4±0.57	66.3±0.43	67.2±0.81	67.7±0.90	67.3±0.55	67.5±0.15
Pee Wee (%)	0.1±0.12	0.2±0.25	0.0±0.00	0.0±0.00	0.1±0.06	0.1±0.06	0.0±0.00	0.0±0.0
Small (%)	0.2±0.15	0.4±0.31	0.1±0.06	0.1±0.06	0.2±0.10	0.1±0.10	0.0±0.0	0.1±0.06
Medium (%)	1.2±0.12	1.3±0.26	0.6±0.25	0.9±0.34	2.0±0.55	2.0±0.59	1.7±0.49	1.8±0.29
Large (%)	11.3±1.32	10.1±1.45	12.9±3.07	10.7±0.82	23.1±4.22	21.9±4.45	31.9±3.60	31.4±1.21
Ex- Large (%)	87.2±1.42	88.0±2.25	86.4±3.13	88.3±1.23	74.6±5.01	75.9±5.14	66.4±3.96	66.7±1.53
Grade A (%)	92.1±2.62	93.0±1.36	95.9±0.22	95.9±0.61	97±0.26	97.3±0.35	96.1±0.47	96.5±0.47
Grade B (%)	5.1±2.18	4.5±1.25	1.2±0.22	1.7±0.39	1.2±0.15	0.8±0.10	2.4±0.64	1.8±0.10
Crack (%)	2.5±0.95	2.40±0.42	2.6±0.39	2.3±0.37	1.7±0.31	1.8±0.25	1.4±0.26	1.6±035

[1]Pullets were moved to the laying facilities on April 1994 and they were comprised of the same numbers of Hy-line brown; Bovans brown; ISA brown strains.

[2]Pullets were moved to the laying facilities on April 1996 and they were comprised of the same numbers of Hy-line brown; Bovans brown; ISA brown; Shaver brown 579 strains.

[3]Pullets were moved to the laying facilities on October 1998 and they were comprised of the same numbers of Hy-line brown; Bovans brown; Bovans gold strains.

[4]Pullets were moved to the laying facilities on November 2000 and they were comprised of the same numbers of Hy-line brown; Bovans brown; Dekalb brown strains.

[5]Density of 310 cm² obtained by keeping seven hens in a cage of 61 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 8.7 cm feeder space per bird; four hens in a cage of 30.5 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 7.6 cm feeder space per bird; Density of 413 cm² obtained by keeping seven hens in a cage of 82 cm × 35.5 cm (W×D) in the flocks 31st and 32nd with 11.7 cm feeder space per bird; four hens in a cage of 40.7 cm × 40.7 cm (W×D) in the flocks 33rd and 34th with 10.2 cm feeder space per bird.

One egg size category standard was used throughout this four-layer flocks. The pee wee (< 42.5 g), small (42.5 – 49.5 g), medium (49.5 – 55.4 g), large (55.4 – 63.7 g) and extra-large (> 63.7 g) are the five egg size categories were used in these experiments. Grade-A egg had thick and reasonably firm albumin, high and round yolk, and practically free from defects and shells were clean and unbroken. Grade-B egg had albumin that may be thinner and yolk may be wider and flatter than eggs of A grade. The shells were unbroken but may showed slight stains or ridges which compromises strength. All grading procedures were done by trained personnel in the USDA grading standards.

There is no clear definition for high and low cage density, so the cage density of 310 cm^2/bird that is lower than UEP (United Egg Producers, 2006) was considered as a representative of high-density cage and 413 cm^2/bird as low cage density. The data separated into white and brown layers for the first and second egg production cycles.

Data analysis

Averaged data of white layer strains considered as white layer data as well as the brown layers. The analysis was performed by Comprehensive Meta-Analysis (CMA) version 3 software (Borenstein *et al.*, 2015). The random-effects model was used in this analysis, since the data was not obtained from a single population at the same time. Differences between means for birds kept in low cage density (X_P) and birds kept in high cage density (X_C) were calculated by CMA for each response variable based on a standardized effect size formula of Hedges' *g* (Hedges and Olkin, 2014).

$$\text{Hedges' } g = \frac{\overline{X}_p - \overline{X}_c}{\mathrm{SD}}$$

The standard deviation was calculated according to following formula:

$$\mathrm{SD} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

In addition, the true effect size (low vs. high density) can be varied from one population to the next and includes the true heterogeneity and sampling error. Therefore, the I^2 quantifies the amount of observed variance that relates to the differences in true effects rather than sampling error (Huedo-Medina *et al.*, 2006). The estimated of variance between-experiments in true effects presented as T^2 (Borenstein *et al.*, 2015). Both I^2 and T^2 were calculated by the CMA.

Results

First egg production cycle

Production performance

The effect of cage densities (413 vs. 310 cm^2/bird) on production performance in white and brown layers during the first egg production cycle is shown in Tables 5 and 6, respectively. Cage density had significant impacts (P < 0.001) on egg production, egg mass and feed intake in both white and brown layers. Although, feed conversion ratios were not affected by the cage densities in the white (P=0.473) and brown (P=0.310) layers throughout the first egg production cycle. According to the Hedges' *g* index, a decrease in stocking density increased egg production, egg mass and feed intake in both white and brown layers.

Table 5. Cage density effect (Hedges' *g index*) and heterogeneity indices calculated between birds kept in two cage densities (413 vs. 310 cm^2) on white layers response variables in the first egg production cycle.

Response variable	Hedges's g index[2]	95 % confidence interval		Standard error	Variance	*P*-Value	I^{2} (3)	T^{2} (4)
		Lower limit	Upper limit					
Egg production	1.615	0.886	2.343	0.372	0.138	<0.001	99.5	0.552
Egg mass	1.610	1.232	1.989	0.193	0.037	<0.001	99.5	0.148
Feed intake	1.829	0.871	2.788	0.489	0.239	<0.001	99.9	0.956
Feed conversion ratio	0.414	-0.717	1.544	0.577	0.333	0.473	99.9	1.330
Age of maturity[1]	-0.101	-0.219	0.016	0.060	0.004	0.091	95.7	0.014
Final body weight	0.344	-0.122	0.811	0.238	0.057	0.148	99.7	0.226
Mortality rate	-0.870	-1.262	-0.479	0.200	0.040	<0.001	99.6	0.159
Egg weight	0.156	0.116	0.196	0.021	0.001	<0.001	64.0	0.001
Pee wee	0.019	-0.166	0.203	0.094	0.009	0.843	98.2	0.035
Small	-0.270	-0.595	0.055	0.166	0.028	0.104	99.4	0.110
Medium	-0.146	-0.471	0.179	0.166	0.027	0.380	99.4	0.109
Large	0.042	-0.489	0.572	0.271	0.073	0.878	99.8	0.293
Ex-large	0.177	0.069	0.286	0.055	0.003	0.001	95.0	0.012
Grade A	0.902	0.018	1.787	0.451	0.204	0.046	99.9	0.814
Grade B	-0.530	-1.280	0.221	0.383	0.147	0.166	99.9	0.586
Crack	-0.555	-0.891	-0.218	0.172	0.029	0.001	99.5	0.117

[1]Day of 50% egg production.
[2] A quantitative measure of the difference between two cage densities.
[3] Observed variance between flocks due to the real differences in the effect of cage densities.
[4] "Between-flocks" variance that was used in computing weights.

Table 6. Cage density effect (Hedges' *g index*) and heterogeneity indices calculated between birds kept in two cage densities (413 vs. 310 cm²) on brown layers response variables in the first egg production cycle.

Response variable	Hedges's g index²	95 % confidence interval Lower limit	95 % confidence interval Upper limit	Standard error	Variance	*P*-value	$I^{2(3)}$	$T^{2\,(4)}$
Egg production	2.695	1.539	3.852	0.590	0.348	<0.001	99.8	1.388
Egg mass	4.399	2.331	6.467	1.055	1.113	<0.001	99.9	4.447
Feed intake	3.087	2.146	4.028	0.480	0.230	<0.001	99.7	0.919
Feed conversion ratio	0.802	-0.746	2.349	0.790	0.623	0.310	99.9	2.492
Age of maturity²	-0.377	-1.213	0.459	0.427	0.182	0.377	99.8	0.727
Final body weight	0.421	-0.033	0.874	0.231	0.054	0.069	99.4	0.213
Mortality rate	-2.669	-4.819	-0.519	1.097	1.203	0.015	99.9	4.811
Egg weight	0.990	0.202	1.778	0.402	0.162	0.014	99.8	0.645
Pee wee	-0.558	-1.446	0.331	0.453	0.206	0.218	99.8	0.821
Small	-0.593	-1.178	-0.008	0.298	0.089	0.047	99.6	0.355
Medium	-1.244	-2.323	-0.165	0.550	0.303	0.024	99.8	1.211
Large	-0.298	-1.181	0.585	0.451	0.203	0.508	99.8	0.810
Ex-large	0.900	-0.144	1.944	0.533	0.284	0.091	99.8	1.113
Grade A	1.911	0.272	3.550	0.836	0.699	0.022	99.9	2.795
Grade B	-1.489	-2.661	-0.317	0.598	0.358	0.013	99.8	1.428
Crack	-0.328	-1.363	0.707	0.528	0.279	0.535	99.8	1.114

[1] Day of 50% egg production.
[2] A quantitative measure of the difference between two cage densities.
[3] Observed variance between flocks due to the real differences in the effect of cage densities.
[4] "Between-flocks" variance that was used in computing weights.

Mortality rate

Mortality rate was influenced by cage density in the white ($P < 0.001$) and brown layers (P=0.015), in which low cage density resulted in a reduction in white layers mortality rate (Hedges' g index= −0.870) and more drastically for brown layers (Hedges' g index= −2.669).

Age of maturity and final body weight

Age of maturity was not altered by stocking density either white or brown layers. In addition, cage density did not have an impact on final body weight in the first egg production cycle for the white and brown layers. Although, cage density had a tendency to significantly affect the final body weight of brown layers (P=0.069).

Egg weight, sizes and grades distribution

Egg weight, extra-large, cracked and percentage of Grade-A eggs were significantly affected by cage density in white layers. The low cage density resulted in an increment of egg weights (Hedges' g index= 0.156) and percentage of extra-large eggs (Hedges' g index= 0.177) which were concomitant with a reduction in the percentage of cracked eggs (Hedges' g index= −0.555). An increase in extra-large eggs and a decrease in cracked eggs resulted in more percentage of Grade-A eggs in response to low stocking density (413 cm^2/bird). Percentage of pee wee, small, medium, large and Grade-B eggs were not different among the two cage densities.

Cage density significantly affected egg weight as well as percentage of small, medium, Grade-A and B eggs in brown layers. An increase in space allocated led to an increase in egg weight with concomitant reduction in percentage of small and medium eggs. This reduction in the percentage of small and medium egg size resulted in an increase in Grade-A eggs and decrease in Grade-B eggs. The percentages of pee wee, large, extra-large and cracked eggs were not influenced by cage density.

Molting period

Cage density did not affect mortality rate in either white or brown layers throughout the molting period (Table 7). The percentage of weight loss throughout the molting period was significantly affected by cage density in white (P=0.046) and brown (P=0.002) layers. The low stocking density (413 cm^2/bird) reduced weight loss as −0.476 and −0.702 Hedges' g indices for the white and brown layers, respectively.

Second egg production cycle

Production performance

The effects of cage density (413 vs. 310 cm^2/bird) on egg production, egg mass and feed intake of white and brown layers in second egg production cycle are shown in Tables 8 and 9, respectively. Egg production, egg mass, and feed intake of white and brown layers have significantly influenced by the cage density. Egg production, egg mass and feed intake were improved by 1.425, 0.971 and 1.405 Hedges' g indices, respectively in response to reduced cage density in white layers. Improvement of 1.937, 3.157 and 1.906 Hedges' g indices were observed in egg production, egg mass and feed intake, respectively when brown hens kept at 413 cm^2/b as compared to 310 cm^2/bird in the second egg production cycle. However, feed conversion ratio was not affect by stocking density in white or brown layers throughout the second egg production cycle.

Table 7. Cage density effect (Hedges' *g index*) and heterogeneity indices calculated between birds kept in two cage densities (413 vs. 310 cm²) on white and brown layers weight loss and mortality rate in the molting period.

Response variable	Hedges's g index[1]	95 % confidence interval		Standard error	Variance	*P*-Value	$I^{2(2)}$	$T^{2(3)}$
		Lower limit	Upper limit					
White layers								
Weight loss percentage throughout molting	-0.476	-0.965	0.012	0.249	0.062	0.046	99.6	0.170
Mortality rate during molting	-0.250	-0.655	0.154	0.206	0.043	0.225	99.7	0.248
Brown layers								
Weight loss percentage throughout molting	-0.702	-1.142	-0.261	0.225	0.051	0.002	99.3	2.004
Mortality rate during molting	0.116	-1.272	1.504	0.708	0.501	0.870	99.9	0.201

[1] A quantitative measure of the difference between two cage densities.
[2] Observed variance between flocks due to the real differences in the effect of cage densities.
[3] "Between-flocks" variance that was used in computing weights.

Table 8. Cage density effect (Hedges' *g index*) and heterogeneity indices calculated between birds kept in two cage densities (413 vs. 310 cm²) on white layers response variables in the second egg production cycle.

Response variable	Hedges's g index[1]	95 % confidence interval		Standard error	Variance	*P*-Value	$I^{2(2)}$	$T^{2(3)}$
		Lower limit	Upper limit					
Egg production	1.425	0.821	2.029	0.308	0.095	<0.001	99.8	0.379
Egg mass	0.971	0.200	1.742	0.394	0.155	0.014	99.9	0.619
Feed intake	1.405	0.419	2.391	0.503	0.253	0.005	99.9	1.011
Feed conversion ratio	0.661	-0.241	1.564	0.461	0.212	0.151	99.9	0.848
Mortality rate	-0.585	-1.344	0.175	0.388	0.150	0.131	99.9	0.600
Egg weight	0.133	-0.131	0.397	0.135	0.018	0.322	99.1	0.072
Pee wee	<0.001	-0.033	0.033	0.017	0.001	1.000	0.0	0.000
Small	-0.220	-0.604	0.165	0.196	0.038	0.263	99.6	0.153
Medium	-0.410	-0.896	0.075	0.248	0.061	0.098	99.7	0.245
Large	-0.292	-0.483	-0.101	0.098	0.010	0.003	98.4	0.037
Ex-large	0.257	0.112	0.403	0.074	0.006	0.001	97.2	0.021
Grade A	1.290	0.419	2.391	0.618	0.382	0.037	99.9	1.152
Grade B	-1.424	-2.685	-0.164	0.643	0.414	0.027	99.9	1.653
Crack	-1.126	-2.525	0.272	0.714	0.509	0.114	99.9	2.036

[1] A quantitative measure of the difference between two cage densities.
[2] Observed variance between flocks due to the real differences in the effect of cage densities.
[3] "Between-flocks" variance that was used in computing weights.

Table 9. Cage density effect (Hedges' *g index*) and heterogeneity indices calculated between birds kept in two cage densities (413 vs. 310 cm^2) on brown layers response variables in the second egg production cycle.

Response variable	Hedges's g index[1]	95 % confidence interval		Standard error	Variance	*P*-Value	$I^{2(2)}$	$T^{2(3)}$
		Lower limit	Upper limit					
Egg production	1.937	0.520	3.354	0.723	0.522	0.007	99.7	2.088
Egg mass	3.157	1.377	4.937	0.908	0.825	0.001	99.9	3.290
Feed intake	1.906	0.998	2.813	0.463	0.214	<0.001	99.7	0.641
Feed conversion ratio	0.294	-0.338	0.927	0.323	0.104	0.361	99.6	0.415
Mortality rate	0.669	0.074	1.263	0.303	0.092	0.027	99.6	0367
Egg weight	0.664	-0.001	1.330	0.340	0.115	0.050	99.7	0.460
Pee wee	0.407	-0.392	1.207	0.408	0.166	0.318	99.5	0.331
Small	-0.060	-1.036	0.916	0.498	0.248	0.904	99.8	0.743
Medium	-0.041	-0.797	0.714	0.385	0.149	0.915	99.7	0.593
Large	-0.625	-1.083	-0.166	0.234	0.055	0.008	99.4	0.217
Ex-large	0.496	0.202	0.790	0.150	0.023	0.001	98.5	0.080
Grade A	0.608	0.159	1.057	0.229	0.052	0.008	99.4	0.208
Grade B	-0.735	-2.441	0.969	0.870	0.757	0.397	99.9	3.024
Crack	-0.001	-0.656	0.656	0.334	0.112	0.999	99. 7	0.446

[1] A quantitative measure of the difference between two cage densities.
[2] Observed variance between flocks due to the real differences in the effect of cage densities.
[3] "Between-flocks" variance that was used in computing weights.

Mortality rate

The use of cage of 413 cm^2/bird density did not have an impact on the mortality rate of white layers (P=0.151) in the second egg production cycle. Although, the use of low cage density (413 cm^2/bird) resulted in a significant increase in mortality rate (0.027) in brown layers during the second egg production cycle.

Egg weight, sizes and grades distribution

Egg weight was not influenced by stocking density throughout the second egg production cycle in the white layers. However, the use of low stocking density resulted in an increase in egg weight (Hedges' *g* index= 0.133, P=0.050) in brown layers throughout the second egg production cycle. Reduced cage density resulted in a significant increase in extra-large eggs and percentage of Grade-A eggs and a decrease in large and the percentage of Grade-B eggs in white layers throughout the second egg production cycle. In addition, the low cage density for brown layers resulted in a significant improvement in extra-large and percentage of Grade-A eggs as well as the reduction in the percentage of large eggs.

Heterogeneity indices

The I^2 that reflects the proportion of true variance to observed variance of cage density effect ranged from 99.9 to 95.7 in all of the response variables for white and brown layers in both egg production cycles with the exception of egg weight in white layers at first egg production cycle. This range of I^2 indicates that 99.9 to 95.7 percent of the observed variance was related to the real difference in cage density effect for different response variables.

High proportions of variance in all variables were related to the true density effect and thus the sampling error had a negligible impact on the observed variation. Only the I^2 of the egg weight item in the white layers in the first egg production cycle was relatively lower (Table 5, I^2=64.0). However, the between-flock variance (T^2) of true effect for the egg weight was 0.001, which indicates that there was a negligible variation between different flocks with regard to the true effects of cage density on egg weight (Table 5). The T^2 is an indicator of the variation existed among true effect of different flock records that was high ($T^2 > 4$) for egg mass and mortality rate for the brown layers in the first egg production cycle (Table 6). The I^2 and T^2 values for the percentage of pee-wee egg in white layers during the second egg production cycle was zero. Thus, the percentage of pee-wee eggs was exactly the same for the white layers that kept in two cage densities during the second egg production cycle (Table 2) that resulted in zero values for I^2 and T^2 (Table 8).

Discussion

Production performance

The improvement in egg production, egg mass and feed intake in response to decreased cage density in our study were similar to observation of other investigators (Adams and Jackson 1970; Cunningham and Ostrander, 1981; Cunningham, 1982; Adams and Craig, 1985; Saki *et al*., 2012). The most considerable impact of reduction in stocking density was the dramatic increase in feed consumption of birds at more liberal density. This effect may be related to the enhancement of maintenance energy requirement that is originated from birds activity or decreased in micro-environmental temperature (Mench *et al*., 1986). Anderson *et al*. (1995) reported the increase of 9 g/bird and 3.5 g/bird in daily feed intake and egg mass, respectively when hens kept at 482 cm^2/bird compared to those kept at 361 cm^2/bird. Saki *et al*. (2012) observed an increase of 1.33 g/bird, 7.09 g/bird, and 16.96% in daily feed intake, egg production and egg mass, respectively when crowding density was reduced from 500 to 2000 cm^2/bird. However, Cook (2004) observed no change in daily feed consumption among four stocking densities of 348, 387, 426, and 465 cm^2/bird in Hy-line W36 layers hens. Cunningham and Ostrander (1981) reported a significant reduction in body weight, feed consumption, egg weight and egg mas through increased cage density (484 vs. 323 cm^2/bird) in white leghorn layers from 22 weeks till 455 day of age. Although in our study, there were no effects of cage densities on feed conversion ratio in white and brown layers during first and second egg production cycles. Cunningham (1982) observed 4.16, 5.19 and 11.73% reduction in egg production, egg mass and feed consumption, respectively, in response to reduction in space allocation (484 vs. 323 cm^2/bird). However, similar to our study in white layers during second egg production cycle mortality rate and egg weight were not altered by the cage density (Table 8).

Generally, it has been widely accepted that the deterioration of egg production characteristics resulted from increased stocking density is associated with physiological stressful conditions as well as intensified competition for feed and water and decreased available feeder space per bird and increased competition for feed and water (Hester and Wilson, 1986; Saki *et al*. 2012). Mashaly *et al*. (1984) stated that complex alteration in various adrenal glands and plasma constituents may be a well-description of physiological stress. A change in serum corticosterone concentration is considered as a valid indicator of physiological stress assessment. The findings of Mashaly *et al*. (1984) demonstrated that based on corticosterone measurement, white layers housed at 310 cm^2/bird were under more stress than those kept at 387 or 516 cm^2/bird. They concluded that reduction of egg production in response to increasing cage density is another indicator of physiological stress in response to increased population density (Mashaly *et al.* 1984).

There is a lack of information concerning the effects of cage density in brown layers. However, based on Hedges' *g* index in our study, the differences in egg production, egg mass, and daily feed intake were more remarkable in brown layers than in white layers kept at 413 vs. 310 cm^2/bird cage density. This phenomenon can illustrate that brown layers are more sensitive to cage density than white layers.

Mortality rate

Generally, mortality rate, as well as other production characteristics, are adversely affected by increased cage density. Cannibalism is considered as a major cause of increased mortality rate. In addition, several researchers stated that the increase in mortality rate may be influenced by general stress (Adams and Jackson, 1970). Similar to our observations, Adams and Craig (1985) reported that increased cage density from 516 to 387 cm^2/bird significantly increased the rate of mortality by 2.8% in white layers. In contrast, Cunningham and Ostrander (1981) and Cunningham (1982) reported that stocking density did not have an impact on mortality of layers. However, mortality has been shown to be strain related in low- or high-density cages (Anderson, 1996, 1998, 2000, 2002). Anderson and Jenkins (2011) showed that higher density in cages reduced the livability of the flock of brown layers. However, our study demonstrated that Hedges' *g* index indicated that in the brown layers were more sensitive to cage density than white layers, which showed that the rate of mortality in brown layers is strongly correlated to cage density compared to white layers (−2.669 vs. −0.870). In addition, this impact was observed throughout the second egg production cycle in brown layers.

Age of maturity and body weight

The ineffectual impact of cage density on body weight was similar to the report of Patterson and Siegel (1998), and Jalal *et al*. (2006), but inconsistence with Saki *et al*. (2012) and Keeling *et al*. (2003). Differences in body weight in various studies can be attributed by different strains and ages of layers as well as differences existed within housing conditions and environment such as seasons, feeder spaces and cage systems.

There is a lack of information regarding the effects of cage density on age of maturity of layers, but Anderson *et al*. (1995) observed a reduction in age of maturity in brown layers from 152 to 151 days in response to lowering stocking density from 361 to 482 cm^2/bird.

Egg weight, sizes and grades distribution

Our results regarding the positive effect of decreasing cage density on egg weight in white and brown layers were in agreement with Anderson *et al*. (1995) who observed an improvement in egg weight in response to reducing stocking density from 361 to 482 cm^2/bird in brown layers. These findings are also support the observation of some other investigators, whom stated a reduction in cage density caused an improvement in egg weight in white layers (Cunningham and Ostrander, 1981; Cunningham, 1982; Saki *et al*., 2012).

Modification of egg size in response to decreased cage density did not follow any observable pattern and so it is difficult to draw a conclusion with regard to these changes. However, Grade-A eggs were dramatically altered by a change in stocking density in both types of hens during both egg production cycles. Similar to our observation, Anderson *et al*. (1995) reported an improvement in the percentage of Grade-A eggs by reducing stocking density from 361 to 482 cm^2/bird in brown layers.

Conclusions

The results of this study demonstrated that the cage density imposes a considerable impact on egg production, egg size distribution regardless of age, cage type and strain of hens during first and second egg production cycles. Reducing stocking density improved egg production, egg mass and feed consumption in concomitant with a decrease in mortality rate in white and brown layers during both cycles. In addition, the production of Grade-A eggs is influenced by birds space allocation and can be enhanced by a decrease in cage density. Therefore, cage density is a key factor in management and should be considered to optimize net profit.

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