Interaction between oviposition time, age, and environmental temperature and egg quality traits in laying hens and broiler breeders

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ABSTRACT: An experiment with laying hens and broiler breeders of two ages (young 22 vs. 36 weeks, old 83 vs. 64 weeks) and at temperatures of 20 and 28°C was carried out to evaluate the interactions between oviposition time (7:30; 11:30, and 15:30 h), age, and temperature on the one hand and egg quality on the other. A significant interaction ($P \leq 0.011$) was determined in oviposition time. The highest number (25.8%) of eggs was laid at 7:30 h by young laying hens kept at 20°C and the lowest (3.7%) by young layers at 15:30 h kept in the same temperature. Time of oviposition was delayed by age and a higher temperature. Egg weight was significantly influenced by production type ($P \leq 0.001$; 60.5 vs. 68.1 g), age ($P \leq 0.001$; 59.4 vs. 69.3 g), oviposition ($P \leq 0.001$; 66.5, 63.7, 62.8 g), and temperature ($P \leq 0.022$; 65.1 vs. 63.6 g). The significant three-way interaction of age, oviposition, and temperature in Haugh unit score ($P \leq 0.013$) and four-way interaction of production type, age, oviposition, and temperature ($P \leq 0.05$) in specific gravity show that rather than by a single factor the valuable characteristics of egg quality are considerably affected by a combination of factors.

Keywords: hen; production type; age; temperature; oviposition

Egg quality traits are of similar importance in laying hens and broiler breeders, however, for different reasons. In laying hens, egg weight and shell quality are important for the producers because these traits are related to the economics of production, and the internal quality of eggs is of concern to the consumers. A high quality of both external and internal characteristics needs to be maintained in broiler breeder eggs because these influence embryo development. Egg quality depends on numerous factors which combine to influence the final product. Time of oviposition, genotype, age, ambient temperature, and nutrition are all known to influence internal and external characteristics, as well as interactions between these factors.

The distribution of oviposition times in domestic hens is restricted to an 8 h period of the day (Lillpers, 1991) with eggs being laid normally between 7:30 and 16:00 h under standard lighting conditions (Campo et al., 2007). The highest proportion of eggs is laid between 10:00 and 12:00 h (Washburn and Potts, 1975). Time of oviposition affects egg weight, with eggs laid in the morning being heavier than those laid in the afternoon (Pavlovski et al., 2000; Tůmová and Ebeid, 2005; Tůmová et al., 2009; Zakaria et al., 2009; Gumulka et al., 2010). Yolk percentage is slightly lower in eggs laid in the afternoon (Tůmová and Ebeid, 2005; Tůmová et al., 2007, 2009) but they contain significantly more albumen (Yannakopoulos et al., 1994) and exhibit better egg shell characteristics (Yannakopoulos et al., 1994; Tůmová and Ebeid, 2005; Tůmová and Ledvinka, 2009).

Egg weight is positively related to the age of the hen, but egg composition does not change in the same way. Rizzi and Chiericato (2005) reported that

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the proportion of albumen decreased with advancing age, whereas the proportion of yolk is positively related to age (Johnston and Gous, 2007; Tůmová and Ledvinka, 2009) and reflects an increase in yolk : albumen ratio. Egg shell quality deteriorates with advancing age, which is presumably related to the increasing size of the egg and shell surface area (Tůmová and Ledvinka, 2009). Time of oviposition and age interact to influence egg quality traits – Tůmová and Ledvinka (2009) observed significant interactions between time of oviposition and age in egg shell weight, yolk : albumen ratio, and shell index.

Recent investigations have shown that a high ambient temperature plays a negative role in egg weight (Franco-Jimenez et al., 2007; Ajakaiye et al., 2011) and egg shell quality (Roberts, 2004; Oguntunji and Alabi, 2010). However, interactions between environmental temperature and age or between the temperature and time of oviposition that would influence egg quality or egg composition have been unknown. Differences in egg quality traits between laying hens and broiler breeders have not been described, too.

The aim of the study was to determine whether there exist interactions between oviposition time, age, and environmental temperature reflected in egg weight, egg composition, and egg shell quality in broiler breeders and laying hens.

MATERIAL AND METHODS

An experiment with 96 birds housed in separate cages lasted for seven weeks. Lohmann Brown laying hens and Cobb 500 broiler breeders were the two production types used. Birds of each type were split into two groups according to age. The young and old laying hens were 22 and 83 weeks of age at the start of the trial, while the two groups of broiler breeders were 36 and 64 weeks old. Birds were placed into four environmental chambers in which temperature and humidity could be controlled. Two of the chambers were maintained at a temperature of 20°C and the others at 28°C (12 birds in each type, age, and temperature). A 14-hour lighting regime corresponding to the photoperiod used for all birds prior to their moving was applied in all chambers. Feed (174 g crude protein, 11.65 MJ ME, and 32.6 g Ca/kg) and water were supplied to the laying hens *ad libitum* while the broiler breeders were fed 160 g/day a commercial feed mixture containing 174 g crude protein, 11.31 MJ ME, and 32.8 g Ca/kg.

Time of oviposition was evaluated by collecting eggs daily at three times: 7:30 h, 11:30 h, and 15:30 h. Weekly, on the same day, all laid eggs were weighed and analyzed for egg shape index, shell surface, specific gravity, albumen, yolk and shell percentage, yolk/albumen ratio, Haugh unit score, and egg shell index (196 eggs in total). After weighing, length and width of each egg were measured for egg shape index calculation (width/length × 100). Specific gravity was determined by the method of Richards and Swanson (1965) using the weight of the egg in air and in water and the formula: dry weight/(dry – wet weight). The weights of yolk, albumen, and shell were used for calculation of their proportions. Haugh unit score was calculated based on egg weight and albumen height (Haugh, 1937). The surface area was determined by the equation 4.67 × (egg weight)$^{2/3}$ of Thompson et al. (1985). Egg shell index was calculated as (shell weight/shell surface) × 100 (Ahmed et al., 2005).

The GLM procedure of SAS (Statistical Analysis System, Version 9.1.3, 2003) was used for the data analysis. Mean numbers of eggs laid and egg quality characteristics were evaluated using a four-way analysis of variance (production type × age × temperature × oviposition time).

RESULTS AND DISCUSSION

All factors interacted significantly in determining the number of eggs laid (Table 1). In laying hens, the

Table 1. Proportion of laid eggs from laying hens and broiler breeders (%)

Time of oviposition (h)	Age	Temperature (°C)	Laying hens	Broiler breeders
7:30	young	20	25.8	9.6
		28	16.8	7.4
	old	20	11.4	10.2
		28	12.3	6.6
11:30	young	20	10.2	9.3
		28	21.0	10.6
	old	20	14.2	9.3
		28	14.6	10.9
15:30	young	20	3.7	10.7
		28	7.7	22.1
	old	20	15.3	8.0
		28	15.0	17.5

time of oviposition × age × temperature × production type, significance $P = 0.011$

highest number of eggs was collected at 7:30 h from young birds kept at the optimal temperature of 20°C. The higher ambient temperature postponed mean time of oviposition in laying hens, with the highest number of eggs being collected at 11:30 h. Mean oviposition time was delayed with advancing age, and in old laying hens the highest number of eggs was collected at 15:30 h, with similar numbers being laid at both temperatures. Broiler breeders laid eggs later in the day than did laying hens, and the difference in time of oviposition between broiler breeders' ages was less in comparison with laying hens. In both young and old breeders the highest number of eggs was collected at 15:30 h. On the other hand, there were no differences in eggs laying of young broiler breeders reared at 20°C. Also, temperature did not affect the number of eggs laid as was the case in layers because in young and old breeders the highest number of eggs was collected at 15:30 h in the high temperature rooms. It is clear from these results that each production type has a particular laying pattern.

The laying hens laid their eggs earlier in the day compared to broiler breeders, which is in agreement with Lewis et al. (2004) who stated that broiler breeders laid eggs by 1 h later than white-egg and by 2.5 h later than brown-egg hybrids. This earlier egg laying in egg-type hens is likely a consequence of

Table 2. Main effects of production type, age, oviposition time, and environmental temperature on egg weight and egg internal quality parameters, and significance of main effects and interactions of each parameter

Factor	Treatment	Egg weight (g)	Albumen percentage	Yolk percentage	Yolk : albumen ratio (%)	Haugh units score
Production type	layers	60.5^{b}	61.5^{a}	26.7^{b}	43.9^{b}	74.2
	broiler breeders	68.1^{a}	58.8^{b}	30.8^{a}	53.6^{a}	73.9
SEM		0.723	0.676	0.409	1.204	2.043
Age	young	59.4^{b}	59.9	28.5	47.7	80.3^{a}
	old	69.3^{a}	60.4	28.9	48.6	66.8^{b}
SEM		0.728	0.674	0.407	1.197	2.030
Oviposition time (h)	7:30	66.5^{a}	60.6	29.0	48.4	73.9
	11:30	63.7^{b}	59.4	29.2	49.1	74.3
	15:30	62.8^{c}	60.4	28.0	46.2	73.9
SEM		0.696	0.898	0.896	1.518	2.581
Temperature (°C)	20	65.1^{a}	60.0	28.4	47.5	76.2^{a}
	28	63.6^{b}	60.3	29.1	48.8	71.1^{b}
SEM		0.723	0.673	0.407	1.195	2.025
Production type		0.001	0.001	0.001	0.001	0.679
Age		0.001	0.777	0.278	0.199	0.001
Oviposition		0.001	0.263	0.066	0.080	0.990
Temperature		0.022	0.765	0.172	0.264	0.024
Temperature × age		0.297	0.325	0.473	0.776	0.091
Temperature × oviposition		0.018	0.822	0.706	0.819	0.852
Age × oviposition		0.877	0.250	0.245	0.303	0.681
Temperature × type		0.415	0.858	0.834	0.789	0.580
Age × type		0.006	0.888	0.782	0.844	0.297
Oviposition × type		0.984	0.936	0.589	0.471	0.348
Temperature × age × oviposition		0.143	0.617	0.481	0.472	0.013
Temperature × age × type		0.059	0.348	0.922	0.705	0.609
Temperature × oviposition × type		0.167	0.922	0.547	0.698	0.299
Age × oviposition × type		0.763	0.145	0.191	0.237	0.085
Age × oviposition × temperature × type		0.491	0.453	0.585	0.493	0.245

$^{a–c}$statistically significant differences ($P \leq 0.05$) within columns are indicated by different superscripts the intense selection for increased egg production in modern hybrids (Gow et al., 1984), and as this has not been applied to broiler breeders, egg formation is a longer process than in laying hens (Lewis et al., 2004). In both production types, advancing age delayed time of oviposition, which has been observed previously. Patterson (1997) reported that young flocks (33 weeks old) of laying hens laid 50% of their eggs within 13 h after the beginning of the dark cycle, while in older flocks (76 weeks old) oviposition was delayed by additional 30–60 min. Similar findings are described in broiler breeders by Zakaria et al. (2005) who found that a young flock (34 weeks of age) produced the majority of eggs between 7:00 and 13:00 h while the older flock (59 weeks) distributed eggs between 7:00 and 15:00 h. In more recent experiments Zakaria et al. (2009) described a significant interaction between age and time of oviposition in broiler breeders. The negative effect of higher temperature on time of oviposition in laying hens could be considered as an environmental stressor which, according to Hughes et al. (1986) and Reynard and Savory (1999), can delay oviposition. Also Yoshida et al. (2011) suggested a possible effect of heat stress on ovarian function and consequently egg production in laying hens. Interestingly, the negative effect of a higher temperature was not evident in this experiment in older broiler breeders. It is probable, given their low egg production, that heat stress was not considerable so the hypothalamo-pituitary-gonadal axis, and hence the ovary, were not directly influenced by the high temperature (Oguntunji and Alabi, 2010).

Egg weight (Tables 2, 3) was significantly affected by production type ($P \leq 0.001$) and age ($P \leq 0.001$), which was not surprising given that egg weight is correlated with body weight and age. However, there was a significant interaction ($P \leq 0.006$) between

Table 3. Mean egg weight and internal quality characteristics of eggs as influenced by production type, age, oviposition time, and environmental temperature

Production type	Age	Oviposition time (h)	Temperature (°C)	Egg weight (g)	Albumen percentage	Yolk percentage	Yolk : albumen ratio (%)	Haugh unit score
Layers	young	7:30	20	57.8	61.7	26.2	42.7	80.4
			28	55.8	61.8	26.1	42.2	81.4
		11:30	20	54.5	61.8	26.4	42.8	80.9
			28	52.4	60.3	27.6	46.3	79.0
		15:30	20	53.9	59.8	27.1	45.5	80.2
			28	52.8	62.3	26.4	42.5	87.0
	old	7:30	20	70.1	61.6	26.6	43.5	66.6
			28	65.7	61.9	27.7	45.4	64.3
		11:30	20	68.2	60.3	27.7	47.4	72.3
			28	64.8	61.0	27.3	44.9	69.3
		15:30	20	64.8	63.0	24.4	39.1	75.3
			28	65.1	62.1	26.6	43.1	64.6
Broiler breeders	young	7:30	20	68.7	58.3	31.2	54.2	79.8
			28	63.0	56.4	32.2	57.2	80.3
		11:30	20	64.9	59.3	30.2	51.0	76.0
			28	62.6	58.8	30.0	51.1	71.7
		15:30	20	64.1	59.4	29.8	50.2	75.2
			28	61.8	58.6	30.1	51.5	80.7
	old	7:30	20	78.6	59.2	29.6	50.2	74.1
			28	71.8	63.8	32.4	57.2	59.6
		11:30	20	70.6	56.8	32.1	56.9	65.9
			28	71.9	57.0	32.2	56.8	63.0
		15:30	20	64.6	58.4	29.6	54.6	75.5
			28	74.8	59.6	30.1	50.5	68.8
SEM				1.39	2.11	1.26	3.02	5.14

production type and age, with the increasing egg weight with age being higher in laying hens than in broiler breeders. This may result from the age difference between young and old hens being greater in laying hens than in broiler breeders. Egg weight decreased significantly ($P \leq 0.001$) with time of oviposition, which is in agreement with Tůmová and Ebeid (2005), Zakaria et al. (2005, 2009), Tůmová et al. (2007, 2009), and Gumulka et al. (2010), and at higher temperature ($P \leq 0.022$). The negative effect of high temperature on egg weight was described, among others, by Franco-Jimenez et al. (2007). Interestingly, the old layers and broiler breeders in this trial produced heavier eggs in the afternoon and at the higher temperature. This result was presumably affected by the significant interaction of age and oviposition ($P \leq 0.018$). In broiler breeders, the weight difference in eggs laid at 20 and 28°C made almost 10 g. Presumably, in old broiler breeders the higher temperature delayed time of oviposition and therefore egg formation lasted longer which resulted in an increased egg weight. This assumption is supported by the higher percentage of albumen found in eggs from old broiler breeders at the higher temperature. There was a significant interaction of age and oviposition ($P \leq 0.006$) which revealed laying of the heaviest eggs by old hens in the morning and the lightest by young birds in the afternoon. This is in contrast with Tůmová and Ledvinka (2009) who did not detect significant interaction of these factors in laying hens.

Albumen and yolk contents (Tables 2, 3) were highly significantly ($P \leq 0.001$; $P \leq 0.001$) affected only by the production type with eggs from laying hens having a higher albumen content, and those from broiler breeders having a higher yolk content. The findings correspond precisely with those of Tůmová et al. (2008). On the other hand, there were no changes in albumen or yolk content related to age, which is in contrast to the results of Johnston and Gous (2007) and Tůmová and Ledvinka (2009) who reported that the proportion of yolk is negatively related to egg size but positively to age. Data from our experiment show differences in the proportions of egg components in laying hens and broiler breeders as well as changes with age in both production types. Differences in albumen and yolk proportions associated with age resulted in an increase in the yolk : albumen ratio (Tables 2 and 3), which corresponds with the investigations of Silversides and Scott (2001) and van den Brand et al. (2004). Also, the lacking effect of oviposition time on albumen and yolk proportion and yolk : albumen ratio coincides with the reports of Tůmová et al. (2007, 2008). Temperature did not alter the proportions of albumen and yolk in the eggs, although that of yolk was insignificantly elevated at higher temperature which is in contrast with Franco-Jimenez et al. (2007) who reported significantly smaller yolks in hens kept under heat stress. Furthermore, Oguntunji and Alabi (2010) described a significant reduction in large yellow follicles, small white follicles, and defective ovarian morphology in response to heat stress. A higher proportion of yolk was found in the eggs of old laying hens but mainly in broiler breeders. We may assume that in old broiler breeders, because the higher temperature did not cause heat stress, egg production was in a range which allowed the proportion of yolk to remain high in eggs.

Haugh unit score, which is an important characteristics of internal egg quality, was unaffected (Tables 2 and 3) by production type but decreased significantly ($P \leq 0.001$) with age, which agrees with Silversides and Scott (2001), Suk and Park (2001), Ledvinka et al. (2012), among many others. The effect of oviposition time on Haugh unit score was not significant which corresponds with Pavlovski et al. (2000), Tůmová and Ebeid (2005), and Tůmová et al. (2007, 2008). Haugh unit score was significantly ($P \leq 0.024$) reduced at the higher temperature whereas Franco-Jimenez et al. (2007) found the opposite. However, the highest Haugh unit scores were detected in young laying hens in the afternoon at 28°C and the lowest in old broiler breeders at 11:30, also at the higher temperature. This indicates that a combination of factors plays a more important role rather than any single factor. This is underlined by the significant three-way interaction ($P \leq 0.013$) between age, oviposition time, and temperature where the highest score (84.3) was in the afternoon eggs of young layers and the lowest of old broiler breeders (55.2), in both at higher temperature. Significant interactions have been reported previously between age and genotype by van den Brand et al. (2004), between oviposition time, genotype, and housing by Layendecker et al. (2001), Singh et al. (2009), and Tůmová et al. (2009), between housing and genotype (Tůmová et al., 2011), and between age and housing (Ledvinka et al., 2012).

Egg shell quality characteristics (Tables 4 and 5) varied between production types, with the weight of shell as a proportion of egg weight (shell percent-

Table 4. Main effects of production type, age, oviposition time, and environmental temperature on egg shell quality parameters and significance of main effects and interactions for each parameter

Factor	Treatment	Shell percentage	Specific gravity	Egg surface (cm^2)	Egg shell index (g/cm^2)	Egg shape index (%)
Production type	layers	11.8[a]	1.085[a]	71.6[b]	9.9	77.03
	broiler breeders	10.9[b]	1.073[b]	77.8[a]	9.6	75.9
SEM		0.278	0.003	0.621	0.249	0.908
Age	young	11.5	1.083[a]	70.6[b]	9.6	77.7[a]
	old	11.2	1.076[b]	78.6[a]	9.9	75.2[b]
SEM		0.278	0.003	0.618	0.247	0.903
Oviposition time (h)	7:30	11.2	1.075	75.6	9.7	76.6
	11:30	11.4	1.082	73.6	9.7	76.4
	15:30	11.6	1.085	72.9	9.9	76.5
SEM		0.498	0.004	0.785	0.315	1.134
Temperature (°C)	20	11.6	1.085[a]	75.2[a]	9.9	75.7[b]
	28	11.2	1.074[b]	73.5[b]	9.5	77.5[a]
SEM		0.277	0.003	0.617	0.247	0.900
Production type		0.002	0.001	0.001	0.114	0.193
Age		0.336	0.029	0.001	0.242	0.005
Oviposition		0.752	0.230	0.065	0.990	0.925
Temperature		0.215	0.007	0.034	0.105	0.039
Temperature × age		0.050	0.127	0.329	0.107	0.050
Temperature × oviposition		0.293	0.222	0.042	0.382	0.964
Age × oviposition		0.739	0.578	0.627	0.562	0.844
Temperature × type		0.383	0.606	0.956	0.297	0.380
Age × type		0.425	0.329	0.002	0.313	0.003
Oviposition × type		0.991	0.017	0.956	0.910	0.818
Temperature × age × oviposition		0.724	0.823	0.088	0.587	0.784
Temperature × age × type		0.565	0.623	0.134	0.536	0.180
Temperature × oviposition × type		0.957	0.696	0.143	0.933	0.806
Age × oviposition × type		0.864	0.955	0.552	0.824	0.805
Age × oviposition × temperature × type		0.719	0.050	0.588	0.795	0.565

[a,b]statistically significant differences ($P \leq 0.05$) within columns are indicated by different superscripts

age) being significantly higher ($P \leq 0.002$) in laying hens compared to broiler breeders. In contrast to our previous findings (Tůmová and Ebeid, 2005; Tůmová et al., 2007, 2008) we did not find a significant effect of oviposition time on shell percentage. However, there was a significant interaction ($P \leq 0.050$) between temperature and age – higher shell percentage was measured in old birds at 20°C (11.7%) but the lowest also in old hens but at 28°C (10.8%). Specific gravity was higher ($P \leq 0.001$) in laying hens, and decreased ($P \leq 0.029$) with age, which differed from the results of Arpášová et al. (2010) where no relationship between specific gravity and age was found. Specific gravity was also reduced ($P \leq 0.007$) by temperature, which was frequently reported in the past, e.g. by Roberts (2004), Franco-Jimenez et al. (2007), and Oguntunji and Alabi (2010). Poorer egg shell quality in hens under heat stress was shown to be the result of hyperventilation and a lack of bicarbonate ions (Lorcher and Hodges, 1969; Makled and Charles, 1987). The highest specific gravity exhibited the

Table 5. Effect of production type, age, oviposition time, and environmental temperature on shell quality measurements

Type	Age	Oviposition time (h)	Temperature (°C)	Shell percentage	Specific gravity	Egg surface (cm^2)	Egg shell index (g/cm^2)	Egg shape index (%)
Layers	young	7:30	20	12.0	1.086[b]	69.1	9.9	77.1
			28	12.1	1.077[c]	68.0	9.9	81.8
		11:30	20	11.9	1.097[b]	66.9	9.6	76.9
			28	12.0	1.082[b]	65.1	9.6	81.1
		15:30	20	13.2	1.128[a]	66.5	10.6	76.6
			28	11.3	1.082[b]	65.6	9.1	83.3
	old	7:30	20	11.8	1.077[c]	79.2	10.4	74.9
			28	10.3	1.068[d]	75.9	8.9	75.6
		11:30	20	11.9	1.080[bc]	77.7	10.4	73.5
			28	11.6	1.079[bc]	75.2	10.0	74.6
		15:30	20	12.6	1.081[bc]	74.1	10.4	74.3
			28	11.3	1.087[b]	75.4	9.7	71.8
Broiler breeders	young	7:30	20	10.5	1.081[b]	78.1	9.2	74.8
			28	11.4	1.060[d]	73.6	9.7	76.3
		11:30	20	10.5	1.080[bc]	75.2	9.0	75.8
			28	11.2	1.076[c]	73.4	9.5	75.8
		15:30	20	10.9	1.081[b]	74.6	9.3	74.8
			28	11.2	1.069[d]	73.1	9.5	76.1
	old	7:30	20	11.2	1.074[c]	85.5	10.3	75.4
			28	10.3	1.072[c]	80.2	9.1	75.5
		11:30	20	11.0	1.072[c]	79.5	9.7	76.7
			28	10.8	1.079[c]	80.5	9.6	76.3
		15:30	20	12.0	1.082[b]	76.6	10.9	76.8
			28	10.2	1.050[e]	82.5	9.2	78.4
SEM				0.83	0.008	1.56	0.63	2.27

[a–e]statistically significant differences ($P \leq 0.05$) within columns are indicated by different superscripts

eggs from young laying hens collected in the afternoon at 20°C (1.128) and the lowest the eggs laid in the afternoon by old broiler breeders (1.050); this four-way interaction proved to be significant ($P = 0.050$). It is possible to assume that, like in Haugh unit score, specific gravity of eggs is influenced more by the interaction of factors than by any of the factors separately. Specific gravity is an indirect indicator of egg shell quality, but shell strength is an even more accurate predictor. Based on the literature, shell strength, like specific gravity, is also affected by interacting factors, for example, the interaction between temperature and genotype (Franco-Jimenez et al., 2007), between oviposition, genotype, and housing (Tůmová et al., 2009), housing and genotype (Tůmová et al., 2011), age and genotype (Ledvinka et al., 2011), and between age, genotype, and housing (Ledvinka et al., 2012).

In summary, the data presented here revealed differences in egg quality in laying hens and broiler breeders which presumably depend not only on the differences in live weight but also on the specific traits used during the selection for improved performance in these two strains. The higher environmental temperature of 28°C used in this trial did not cause heat stress to the extent which would reduce egg production. However, the significant three-way interaction between age, oviposition time, and temperature manifested in Haugh unit score, and the four-way interaction between production type, age, oviposition, and temperature reflected in specific gravity indicate that the significant egg quality characteristics are more extensively affected by a combination of different aspects than by a single factor.

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