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Dual-purpose production of eggs and meat—part 2: hens of crosses between layer and meat breeds show moderate laying performance but choose feed with less protein than a layer hybrid, indicating the potential to reduce protein in diets

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Abstract The use of modern chicken genotypes with high egg or meat performance results in the ethically unacceptable practice of culling day-old male layer chicks because of their inefficient fattening performance. Dual-purpose genotypes with a balanced performance profile for eggs and meat are one option to avoid this practice. In this study, the performance of four crosses of a layer breed (White Rock or New Hampshire) and the meat breed Bresse Gauloise, purebred Bresse Gauloise and the layer hybrid Lohmann Sandy was compared under organic husbandry conditions. Part 2 focuses on the laying performance of the hens until the age of 72 weeks and their feed choices when offered energy-rich and protein-rich feed mixtures. Feed consumption was generally high (133–143 g day^{-1}), but the crosses consumed less protein feed than Lohmann Sandy, indicating a potential to reduce the proportion of high-protein components. Bresse Gauloise × White Rock showed severe plumage loss due to feather pecking, which was most likely caused by their low consumption of protein feed. Apparently, free-choice feeding did not agree with this genotype. Average laying performance of the crosses was 68–73% total eggs per average hen, which can be considered moderate. Average egg weights and egg size distribution were comparable with Lohmann Sandy, while slaughter performance of the senior hens was comparable with purebred Bresse Gauloise. Based on these findings, egg production with dual-purpose laying hens can be an ethically desirable alternative to high-performance genotypes, but will require further research on optimal feeding strategies and animal behaviour.

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Keywords Laying hen · Dual-purpose chicken · Feeding

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Introduction

Breeding chickens for eggs and meat is a comparatively recent practice and only gained momentum in the nineteenth century, with most birds then being dual-purpose breeds (Wood-Gush 1959). The discovery of the Mendelian principles, the application of crossbreeding and the development of sexing methods for day-old chicks resulted in the specialized, highly efficient layers and broilers we know today (Leenstra and Sambeek 2014). Because of the negative genetic correlation between growth and reproductive performance, the downside of high-performance layers is the poor fattening performance of their males. The resulting practice of culling day-old male layer chicks, however, has recently raised strong moral concerns in Germany and other European countries (Reithmayer et al. 2019), despite the fact that most of the chicks are fed to zoo animals and pets. The search for alternatives is still in progress, with in ovo sexing, the fattening of brother roosters and the use of dual-purpose chickens as the main options (Krautwald-Junghanns et al. 2018). Dual-purpose chickens are characterized by their ability to produce both eggs and meat, albeit at a lower efficiency than specialized layers and broilers.

When comparing two different strains of the dual-purpose hybrid Lohmann Dual in an organic system, Kaufmann et al. (2017) found a laying performance of 64.7 and 69.9% total eggs per average hen until week 72, respectively. The authors also noted the remarkably calm temperament of the birds, which is supported by Giersberg et al. (2017) reporting only minor feather loss in Lohmann Dual, while the plumage condition of the layer hybrid Lohmann Brown-Plus deteriorated due to feather pecking. In a performance comparison of the dual-purpose chickens Lohmann Dual, Novogen experimental and Walesby Special with the layer hybrid Lohmann Brown Classic, Schmidt and Damme (2017) found a laying performance of 73.9, 73.5 and 74.3% per average hen, while it was 90.2% in the layer control. On a medium-scale farm in Ethiopia, Ibrahim et al. (2019) found a considerably lower laying performance of 45% until week 60 of Lohmann Dual hens, while the local control Koekoek achieved a laying performance of 55%. The breed Bresse Gauloise, which originates from the Bresse region in France, combines high meat quality with a laying performance of 200–240 eggs per year and is also popular as a dual-purpose chicken. Lambertz et al. (2018) compared purebred Bresse Gauloise and the cross of Bresse with New Hampshire, a heavy layer breed, and found a laying performance of 54.5 and 54.2% saleable eggs per average hen until week 73, respectively. Lambertz et al. (2018) estimated a profit based on feed and egg prices at the time of the study but emphasized the importance of marketing the added value of avoiding the killing of day-old male layer chicks to achieve premium prices.

Based on these reports, we see the need for further work on the performance and husbandry of currently available dual-purpose chickens in order to supply information for interested farmers as well as breeding organizations. In Germany, crosses of the meat breed Bresse Gauloise and the layer breeds White Rock and New Hampshire were developed by Ökologische Tierzucht gGmbH (ÖTZ), a breeding organization founded by the organic farming associations Bioland and Demeter. The focus of our study was to compare crosses of Bresse Gauloise × White Rock and Bresse Gauloise × New Hampshire from ÖTZ stock, as well as their reciprocal versions, under organic housing and feeding conditions. Purebred Bresse Gauloise and the layer hybrid Lohmann Sandy were used as controls. The research questions included the fattening performance of males and laying performance of females, differences in animal welfare indicators and differences caused by the position of the parents (e.g. Bresse Gauloise mother vs Bresse Gauloise father). The feeding of the laying hens was carried out as a version of free-choice feeding in order to gain insight into their feed choices and adapt future diets accordingly. The laying performance of the females is covered in this article; for the fattening performance of the males, see companion paper "Dual-purpose production of eggs and meat – Part 1: cockerels of crosses between layer and meat breeds achieve moderate growth rates while showing unimpaired animal welfare" in this issue.

Animals, materials and methods

Animals and experimental design

The study was conducted between March 2017 and August 2018 to compare the performance of four dual-purpose chicken crosses under the conditions of organic agriculture. Each one was the cross of a layer breed (White Rock or New Hampshire) and the meat breed Bresse Gauloise, resulting in the following crosses (♂ × ♀): Bresse Gauloise × White Rock (Bresse × WR), White Rock × Bresse Gauloise (WR × Bresse), Bresse Gauloise × New Hampshire (Bresse × NH) and New Hampshire × Bresse Gauloise (NH × Bresse). Animal husbandry followed the rules of EU Directive EC 834/2007 (European Union 2007) and the production guidelines of the German organic farming association (Bioland 2014). The description of the experiment was submitted to the Schleswig Holstein Ministry of Energy Transition, Agriculture, Environment and Rural Areas on May 9, 2017, and acknowledged on July 7, 2017 (reference number V 241–26,532/2017).

The 15-week mixed-sex rearing period on an organic farm (Bauckhof Klein Süstedt, Uelzen, Lower Saxony) ended with the slaughter of the last cockerels on June 28, 2017. A total of 358 pullets and eight roosters were then moved to the experimental farm of Thünen Institute of Organic Farming (Westerau, Schleswig-Holstein). They remained there until the age of 72 weeks, at which the laying period (week 21–72) ended with the slaughter of the senior laying hens. The hens were kept in groups of 40–47 with one rooster. Because of the chosen group size, not all of the reared pullets were kept. The selection was based on body weight at the age of 12 weeks, and the lightest and the heaviest birds were excluded in order to achieve homogenous groups. Two groups of the crosses with the largest number of birds, WR × Bresse (44 + 1 and 43 + 1) and NH × Bresse (47 + 1 and 46 + 1), were kept for laying. Due to space limitations, only one group of all other genotypes was kept (Bresse × WR 42 + 1; Bresse × NH 43 + 1; Bresse 40 + 1; Sandy 43 + 1). For further information about the provenance of the birds and the mixed-sex rearing period, see companion paper "Dual-purpose production of eggs and meat – Part 1: cockerels of crosses between layer and meat breeds achieve moderate growth rates while showing unimpaired animal welfare" in this issue.

Housing

The hens were kept under floor husbandry conditions in two mobile barns (type Regio, Wördekemper GmbH & Co. KG, Rietberg, North Rhine-Westphalia) divided into a total of eight compartments of 8 m^2 indoor area each. The stocking density in the mobile bans was 5.0–5.9 hens per m^2. The barns were equipped with group nests, drinkers and feeders and located on permanent pasture. Each group of birds had access to a green outdoor area of 10 m^2 per hen. The barns were moved every 6–8 weeks, except for the winter period between December and February, during which the barns stayed in one location. Access to the green outdoor area was granted daily between 10:00 am and dusk. In the mobile barns, artificial light was provided for 16 h day^{-1}. The hens had access to pick blocks inside the mobile barns, and sand baths (Cumbasil®) were offered under small shelters in the green outdoor area.

Feeding

In week 19 and 20, the pullets received a pre-lay diet (calculated concentrations: 198 g crude protein, 10.1 g lysine, 2.9 g methionine, 10.9 MJ AME_N, 16.3 g Ca kg^{-1} feed, as fed basis). Small amounts of whole wheat grains (78 g crude protein, 12.6 MJ AME_N kg^{-1} feed) were introduced in week 16, and a lime-grit mixture was available from week 19 onwards (Gallugold® Geflügelgrit, 299 g calcium, 0.05 g phosphorus, 2.3 g sodium kg^{-1}). Prior to the experiment, the potential laying performance of the dual-purpose laying hens was unknown. Therefore, free-choice feeding was implemented during the laying period in order to enable the hens to compose their total diet as they needed. The feeding regimen was divided into two periods (period 1: week 21–34, period 2: week 35–72). In both periods, an energy-rich feed mixture (mainly) consisting of wheat, maize and faba beans (energy feed), and a protein-rich feed mixture consisting of press cakes and other high-protein components (protein feed) were offered ad libitum to the hens. While in period 1, the mineral and vitamin premix and alfalfa meal were only included in the protein feed; these components were present in both feed mixtures in period 2 to avoid deficiencies (see Table 1). Both feed mixtures were pelleted and of 100% organic origin and were produced at the feed mill of the experimental farm of Thuenen Institute of Organic Farming.

In addition to these two feed mixtures, the hens had access to the above-mentioned grit-lime mixture in the barn. Also, they were offered whole wheat grains (nutrient concentration, see above) in the outdoor area daily in amounts corresponding to 10% of their total feed consumption (amounts were adjusted every 2 weeks). During summer, hay was offered in the barn as an additional source of roughage and manipulable material, while grass-clover silage was used during winter.

Data collection

All birds were marked with foot rings to enable individual documentation of body weight and animal welfare indicators. During rearing, all pullets were weighed at the age of 6, 12 and 16 weeks. During the laying period, data collection included feed consumption, live weight and animal welfare indicators, laying performance, egg weights and sizes, slaughter performance and animal losses. The consumption of the two feed mixtures, grit-lime mixture and wheat grains in each group was documented by collecting feed refusals once a week. Because the grit-lime mixture is usually fed on-top, total feed consumption was calculated as the sum of energy feed, protein feed and wheat grains. Considerable amounts of the grit-lime mixture were lost into the litter, but at least part of it was consumed and supplied minerals to the hens. Therefore, the calculation of the nutrient composition of the total diets was based on the total feed consumption

Table 1 Analysed nutrient composition of the feed mixtures, g kg^{-1} (as fed) unless stated otherwise

Components/nutrients	Energy feed 1 Week 21–34	Protein feed 1 Week 21–34	Energy feed 2 Week 35–72	Protein feed 2 Week 35–72
Wheat	546		498	
Maize	227		205	
Faba beans	227		205	
Soybean cake		363		458
Sunflower cake		243		304
Rice gluten		146		137
Alfalfa meal		85	36	38
Premix[a]		49	25	24
Lime		97	31	30
Monocalcium phosphate		17		9
Crude protein	132	266	136	303
Ether extracts	31	82	25	79
Crude fibre	34	.	44	94
Starch	552	54	502	120
Sugar	24	52	27	69
MJ AME_N	12.7	8.5	11.7	10.3
Lysine	5.8	11.8	6.3	16.0
Methionine	1.8	5.0	1.7	5.3
Cysteine	2.5	4.5	2.3	4.9
g methionine MJ^{-1} AME_N	0.14	0.59	0.15	0.51
Calcium	1.6	51.9	15.8	21.3
Phosphorus	4.1	14.3	6.3	11.2

[a] 185 g calcium, 110 g phosphorus, 65 g sodium, 7 g magnesium, 500,000 iU vitamin A, 100000 iU vitamin D3 1000 mg vitamin E, 600 mg copper kg^{-1}

plus 50% of the lost grit-lime mixture. At the age of 20, 32 and 72 weeks, all hens were weighed and animal welfare indicators were assessed. Assessment of animal welfare indicators was based on M-Tool (Keppler et al. 2017) and included the indicators comb colour, cleanliness and completeness of back feathers, cleanliness and completeness of feathers on the belly and around the cloaca, keel bone damages, toe damages, bumble feet and signs of laying activity. Except for laying activity (yes/no), a score “0” indicated an unimpaired state, score “1” indicated minor changes and score “2” indicated major damages. Laying performance was documented daily and included the total number of eggs per group, the number of saleable eggs and their size classification. Egg sizes were classified into S (< 53 g), M (53 to 63 g), L (63 to 73 g) and XL (> 73 g). Once a week, the sum of all eggs per group was weighed to calculate the average egg weight. Every 4 weeks, three eggs per size per group (usually resulting in nine eggs per group) were randomly selected and weighed individually; yolk and shell weight were recorded, and yolk, albumen and shell ratio relative to egg weight were calculated. Yolk colour was assessed by using a DSM YolkFan™ (Basel, Switzerland) with a range of 1–15. The feed conversion ratio was calculated as total feed consumption (g) divided by egg mass (g), which was the product of laying performance (%) and egg weight (g) of the respective week. At the age of 72 weeks, all hens were slaughtered, and the carcass weight of each hen was documented. Of each group, three hens were cut up for weighing of the valuable cuts (whole legs, breast fillet). From every feed mixture, as well as wheat grains, one bulk sample was collected and sent to a commercial laboratory for nutrient analysis (see companion paper for details).

Statistical analysis

All statistical analyses were conducted using SAS 9.4. proc glimmix, and P values < 0.05 were interpreted as indicating significant differences.

For the analysis of feed consumption, the model included the fixed effects of genotype (Bresse × WR, WR × Bresse, Bresse × NH, NH × Bresse, Bresse, Sandy) and the week of life (21, …, 72). Diets changed in week 35, and the feed mixtures were fed in ground form instead of pellets during week 35 and 36 due to technical problems in the feed mill. The change in texture caused increased feed selection and huge feed losses, and the time it took to restore normal feeding behaviour differed between the genotypes. Therefore, values of feed consumption > 180 g day^{-1} were removed from the dataset.

For the analysis of live weight, daily weight gain and egg weight and composition, the model included the fixed effects of genotype, the week of life (body weight and daily weight gain: 20, 32, 72; egg weight and composition: week 20, 24, …, 72) and their interaction. For body weight and daily weight gain, the random effect of the individual hen nested within genotype was added. Only data from birds that were weighed at least twice remained in the dataset. Laying performance is given as arithmetic means per 4-week period per hen alive (week 16–20, 21–24, …, 68–72). Slaughter performance of senior laying hens was analysed with a model including only the fixed effect of genotype. Multiple comparisons of means were made using the Tukey's test.

For the analysis of animal welfare indicators, the frequency of scores 0, 1 and 2 was compared for each sampling date using proc glimmix (Chi^2 test, multinomial distribution). The model included only the fixed effect of genotype, and P values in multiple comparisons of means were adjusted according to Bonferroni-Holm.

Results

Feed consumption and feed choices

Throughout the laying period, total feed consumption as the sum of energy feed, protein feed and wheat grains did not differ between the genotypes and increased from 129 to 138 g day^{-1} in period 1 to 137–146 g day^{-1} in period 2 (see Table 2). Calculated over the whole laying period, total feed intake was 135, 133, 139, 138, 138 and 143 g for Bresse × WR, WR × Bresse, Bresse × NH, NH × Bresse, Bresse and Sandy, respectively, and did not differ from each other (P = 0.054).

Consumption of energy feed and protein feed, however, differed significantly. In period 1, Bresse hens consumed the highest amount of energy feed, while WR × Bresse consumed the lowest; the values of all other genotypes were in the range between and did not differ from each other. In period 2, Bresse and Bresse × WR hens consumed the significantly highest amount of energy feed and Sandy hens the lowest, with the values of all other genotypes in the range between. Consumption of protein feed did not differ in period 1 but was significantly highest in Sandy hens and significantly lowest in Bresse and Bresse × WR hens in period 2. The New Hampshire crosses and WR × Bresse did not differ from each other, and their values were in the range between Sandy and Bresse and Bresse × WR hens. Expressed as percentages of total feed consumption over the whole laying period, Sandy hens consumed the significantly highest proportion of protein feed (32.1%) and Bresse and Bresse × WR hens the lowest (17.5 and 16.7%, P < 0.001). The values of all other genotypes were in between and did not differ from each other (WR × Bresse: 23.6%; Bresse × NH 25.5%, NH × Bresse 23.2%).

Calculated over the whole laying period, wheat grains made up between 9.4 (NH × Bresse) and 11.1% (Bresse and Bresse × WR) of total feed consumption, with the values of other genotypes in the range between (WR × Bresse 10.8%, Bresse × NH 9.7%, Sandy 11.0%). In addition to the feed mixtures and wheat grains, the hens also had ad libitum access to grit-lime mixture. The documented loss ranged between 3 (Bresse) and 10 g day-1 (Sandy) for the whole laying period, but it cannot be equalled with consumption because considerable amounts were lost into the litter.

The nutrient composition of the total diets was calculated assuming that 50% of the disappeared grit-lime mixture was consumed (see Table 2). Total diets of Bresse and Bresse × WR hens had the lowest methionine concentration (period 1: 0.17 g, period 2: 0.20–0.21 g MJ^{-1} AME$_N$), while WR × Bresse hens and the New Hampshire crosses chose a total diet with a higher methionine concentration (period 1: 0.17–0.18 g, period 2: 0.23–0.24 g methionine MJ^{-1} AME$_N$). The total diet of the Sandy hens had the highest methionine

Table 2 Least square means of feed consumption of dual-purpose laying hens and nutrient composition of calculated total diets, g kg^{-1} (as fed) unless stated otherwise (*WR* White Rock, *NH* New Hampshire, *Bresse* Bresse Gauloise, *Sandy* Lohmann Sandy)

	Genotype						SEM[a]	*P* value[b]
	Bresse × WR	WR × Bresse	Bresse × NH	NH × Bresse	Bresse	Sandy		
Feed consumption (g day^{-1})								
Week 21–34								
Energy feed	105[ab]	95[a]	105[ab]	103[ab]	114[b]	100[ab]	2.6–4.7	0.002
Protein feed	12	17	16	14	12	24	1.8–3.2	0.059
Wheat grains	11[c]	11[b]	11[ab]	10[a]	12[c]	11[b]	0.1	< 0.001
Total[c]	129	123	131	128	138	134	3.3–6.0	0.127
Week 35–72								
Energy feed	95[c]	84[ab]	83[ab]	88[bc]	93[c]	74[a]	1.7–3.4	< 0.001
Protein feed	26[a]	38[b]	44[b]	40[b]	29[a]	54[c]	1.4–2.8	< 0.001
Wheat grains	16[c]	15[b]	14[ab]	14[a]	16[c]	19[d]	0.1–0.2	< 0.001
Total[c]	137	137	141	142	138	146	1.9–3.8	0.159
Calculated nutrient composition of total diets (week 21–34[d])								
Crude protein	130	136	135	133	135	141		
Methionine	1.9	2.1	2.0	2.0	2.0	2.2		
MJ AME_N	11.4	11.4	11.4	11.5	12.0	11.1		
Meth. (g MJ^{-1} AME_N)	0.17	0.18	0.18	0.17	0.17	0.20		
Calculated nutrient composition of total diets (week 35–72[d])								
Crude protein	154	167	174	168	161	179		
Methionine	2.2	2.5	2.7	2.5	2.4	2.8		
MJ AME_N	11.0	10.8	10.9	10.9	11.3	10.5		
Meth. (g MJ^{-1} AME_N)	0.20	0.23	0.24	0.23	0.21	0.27		

Least square means with no letter in common indicate significant differences

[a] Standard errors of the means given as range

[b] *P* value of the interaction genotype × week

[c] Total feed consumption = energy feed + protein feed + wheat grains

[d] Calculated total diets = energy feed + protein feed + wheat grains + 50% of lime-grit mixture

concentration, with 0.20 g in period 1 and 0.27 g methionine MJ^{-1} AME_N in period 2.

Live weight development and slaughter performance

Table 3 summarizes the live weights of the hens throughout the rearing and laying period and the slaughter performance of the senior hens. During rearing, Bresse pullets were always significantly heavier and Sandy pullets significantly lighter than all other genotypes. The White Rock crosses never differed from each other. Bresse × NH pullets were significantly heavier than WR × Bresse at the age of 12 weeks and heavier than WR × Bresse and NH × Bresse at 16 weeks. During the laying period, a significant interaction between genotype and age was found. Sandy hens always had the significantly lowest live weight, while Bresse hens were the significantly heaviest birds at the age of 20 and 32 weeks but did not differ from the crosses (except WR × Bresse) at the age of 72 weeks. The crosses did not differ from each other at the age of 20 weeks, but at 32 weeks, the NH × Bresse hens were significantly heavier than the others. At the age of 72 weeks, WR × Bresse hens were significantly lighter than the other crosses.

Regarding the slaughter performance of the senior laying hens, Sandy hens had the significantly lightest carcasses and the lowest dressing percentage. Except for a lower carcass weight in WR × Bresse and a lower dressing percentage in Bresse × WR, slaughter traits

Table 3 Least square means of live weight and slaughter performance of dual-purpose laying hens (*WR* White Rock, *NH* New Hampshire, *Bresse* Bresse Gauloise, *Sandy* Lohmann Sandy)

	Genotype						SEM[a]	*P* value
	Bresse × WR	WR × Bresse	Bresse × NH	NH × Bresse	Bresse	Sandy		
Live weight (g) during rearing, at age…								
6 weeks	586[b]	556[b]	573[b]	594[b]	721[c]	380[a]	10.7–16.3	< 0.001
12 weeks	1350[bc]	1310[b]	1403[c]	1400[c]	1619[d]	990[a]	10.9–16.3	
16 weeks	1845[bc]	1882[b]	1969[c]	1837[b]	2120[d]	1423[a]	12.0–18.0	
Live weight (g) during laying, at age…								
20 weeks	2173[b]	2192[b]	2133[b]	2244[b]	2476[c]	1661[a]	22.8–34.0	< 0.001[b]
32 weeks	2451[b]	2445[b]	2470[b]	2620[c]	2872[d]	1865[a]	23.3–34.6	
72 weeks	2837[c]	2659[b]	2781[bc]	2864[c]	2839[c]	2006[a]	25.5–41.5	
Slaughter performance of selected hens								
Live weight (g)	2944[cd]	2631[b]	2773[bc]	2887[c]	2809[bc]	2045[a]	38.3–69.9	< 0.001
Carcass weight (g)	1685[c]	1543[b]	1603[bc]	1715[c]	1691[c]	1109[a]	23.6–43.1	< 0.001
Dressing (%)	57.2[b]	58.6[bc]	57.9[bc]	59.5[c]	60.2[c]	54.3[a]	0.39–0.71	< 0.001
Breast (%)[c]	29.2	26.6	20.4	26.2	31.7	21.0	1.86–3.22	0.061
Legs, (%)[c]	34.6	33.2	34.2	32.5	32.2	31.5	0.54–0.94	0.093

Measured on 3–6 hens per genotype; least square means with no letter in common indicate significant differences

breast breast fillets, *legs* whole legs

[a] Standard errors of the means given as range

[b] *P* value of the interaction genotype × week

[c] % of carcass weight

from the crosses did not differ from Bresse. The proportions of breast fillets and legs did not differ between the genotypes.

Animal welfare

Assessment of animal welfare indicators showed significant differences between the genotypes with regard to plumage condition on the back and the belly (see Fig. 1). While plumage in both areas was complete or almost complete for most hens in week 20 and week 32, only Sandy hens showed hardly any plumage loss in week 72. Regarding cleanliness of the plumage, Bresse hens showed the highest prevalence of soiled plumage on the back in week 20 and 32 (15 and 23% received score 0, respectively), while 67–84% of the New Hampshire crosses, Sandy and WR × Bresse received score 0 and did not differ from each other. In week 72, cleanliness of plumage on the back did not differ between the genotypes. Cleanliness of the plumage on the belly differed between the genotypes in week 20 and 72 but not in week 32. In week 20, Bresse hens showed the highest prevalence of soiled plumage on the belly (40% received score 0), while NH × Bresse showed the lowest prevalence (96% with score 0). The values of all other genotypes were in the range between Bresse and NH × Bresse and did not differ from each other. In week 72, Bresse × WR showed the highest prevalence of soiling on the belly (30% with score 0), while Bresse showed the least (75% with score 0). The values of all other genotypes were in the range between Bresse × WR and Bresse and did not differ from each other.

Injuries around the cloaca were found both in week 32 and 72 but were not affected by genotype. In week 32, the prevalence of score 1 ranged from 1 (NH × Bresse) to 7% (Sandy), with the White Rock crosses and Bresse ranging in between (5–6%) and no injuries in Bresse × NH hens. In week 72, score 1 injuries were only found in Bresse (5%) and Bresse × WR hens (15%). Foot pad lesions did not differ between genotypes and were rarely found in week 20 and 32 but were present in all genotypes at the age of 72 weeks. The lowest prevalence was found in Bresse × NH (4% received score 1) and the highest in Bresse × WR, Bresse and Sandy (20% received score 1).

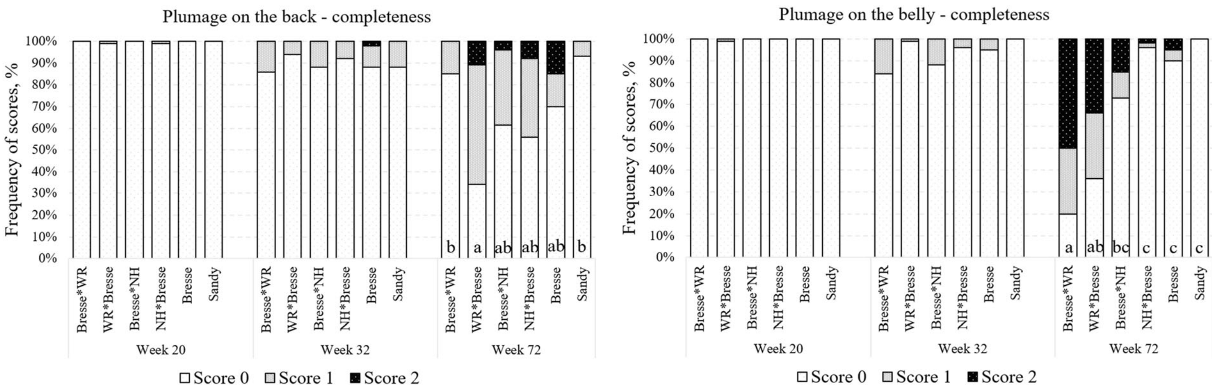

Fig. 1 Completeness of plumage on the back and the belly of dual-purpose laying hens, % of animals with the respective score (WR, White Rock; NH, New Hampshire; Bresse, Bresse Gauloise; Sandy, Lohmann Sandy; least square means with no letter in common indicate significant differences)

Keel bone damages were found in all genotypes at all ages but were not affected by genotype. In week 20, the prevalence of score 1 (= deviation) ranged from 14 (Sandy) to 33% (Bresse × WR), and keel bones receiving score 2 (= fracture) were found in the New Hampshire crosses (2–7%) and WR × Bresse (3%). In week 32, the prevalence of score 1 ranged from 15 (Bresse) to 42% (WR × Bresse), and the prevalence of score 2 ranged from 5 (White Rock crosses) to 23% (Bresse × NH). In week 72, the prevalence of score 1 ranged from 20 (Bresse) to 40% (Sandy), with the crosses in the range of 22–35%. The prevalence of score 2 ranged from 4 (Bresse × NH) to 15% (Bresse).

Laying performance, egg sizes and composition

Sandy hens consistently showed the highest laying performance, while Bresse hens always had the lowest laying performance, except for week 25–28 (Fig. 2). The dual-purpose crosses were always between the Sandy and Bresse hens, except for the above-mentioned period. Averaged over the whole laying period, the laying performance per hen alive was 68 and 73% for Bresse × WR and WR × Bresse and 72 and 69% for Bresse × NH and NH × Bresse, respectively. Bresse and Sandy hens had an average laying performance of 55 and 95%, respectively. Peak production was 89 and 87% in week 37 and 31 for Bresse × WR and WR × Bresse and 88 and 84% in week 35 and 27 for Bresse × NH and NH × Bresse, respectively. Both Bresse and Sandy peaked in week 26, but peak performance was 79% for Bresse and 100% for Sandy.

The sum of laid eggs for an average hen alive at the age of 72 weeks was 248 and 267 for Bresse × WR and WR × Bresse and 262 and 253 for Bresse × NH and NH × Bresse, respectively. Bresse hens laid on average 200 eggs, and Sandy hens laid 328. Expressed as saleable eggs, the performance was 210 and 233 eggs for Bresse × WR and WR × Bresse and 228 and 229 eggs for Bresse × NH and NH × Bresse, respectively. Bresse hens produced on average 163 and Sandy hens 305 saleable eggs.

Egg weight increased with time (see Fig. 2). Statistical analysis revealed a significant interaction between genotype and time, with the only significant difference being that eggs from Bresse hens were the lightest and eggs from Sandy, WR × Bresse and Bresse × NH hens the heaviest in week 21–24. Average egg weight over the whole laying period was 65 g for the White Rock crosses, 63 and 65 g for Bresse × NH and NH × Bresse and 61 and 65 g for Bresse and Sandy, respectively.

Yolk percentage increased significantly with time (Fig. 2) and differed significantly between the genotypes. The White Rock crosses showed the lowest yolk percentage (both 29.7%), while NH × Bresse and Bresse showed the highest (32.6 and 32.7%, respectively). The values of Bresse × NH (31.6%) and Sandy (30.5%) were in the range between. Albumen percentage decreased with time, and statistical analysis revealed a significant interaction between genotype and time. In weeks 36, 48 and 68, the White Rock crosses had the highest albumen percentage, while Bresse × NH (week 36) and Bresse (week 48 and 68) had the lowest. On average, albumen made up 58.9 and 58.7% of Bresse × WR and WR × Bresse eggs and 57.6 and 56.2% of Bresse × NH and

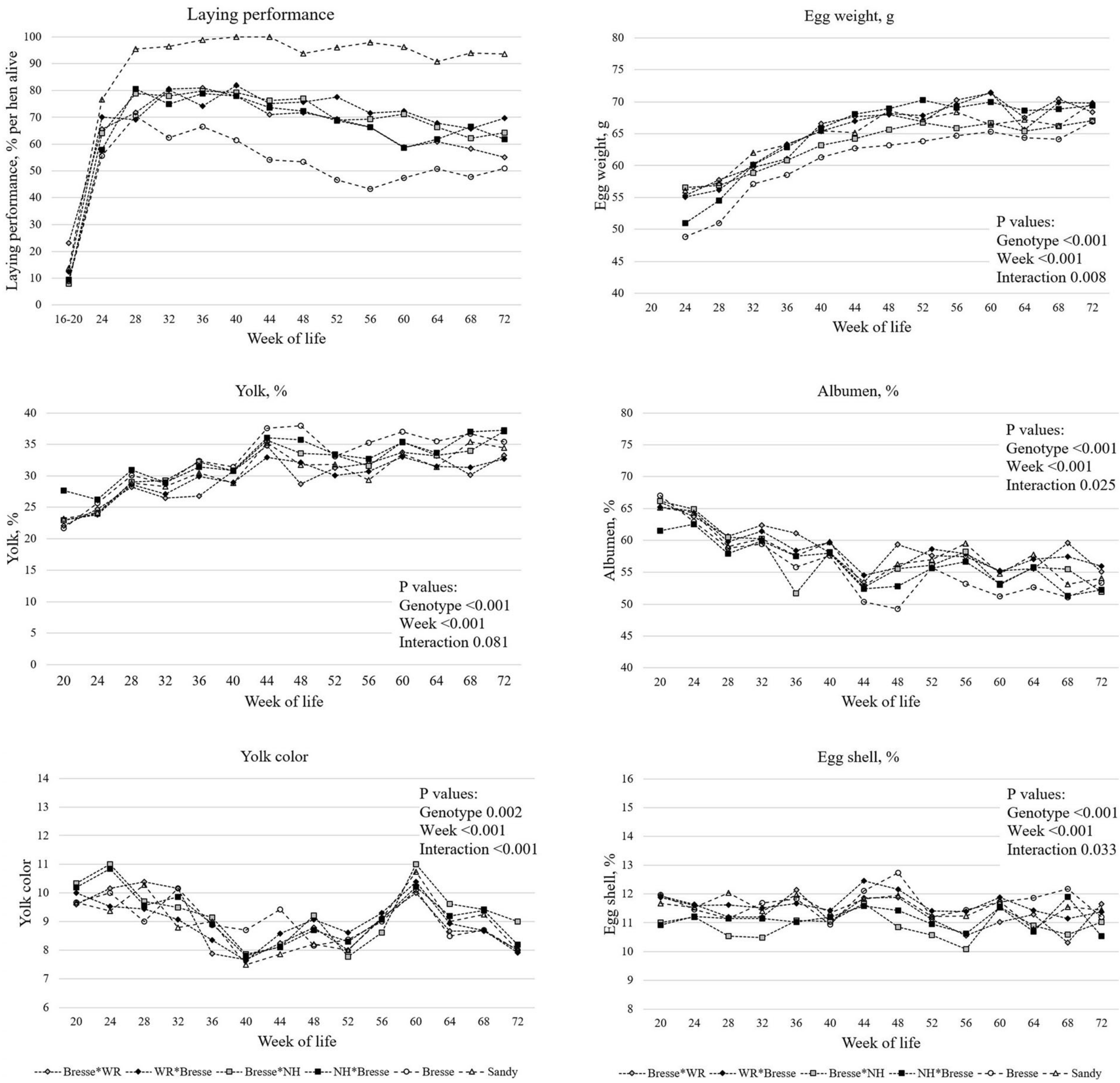

Fig. 2 Laying performance (% per hen alive), egg composition and yolk colour (assessed with a DSM YolkFan™ with a range of 1–15) of dual-purpose hens (WR, White Rock; NH, New Hampshire; Bresse, Bresse Gauloise; Sandy, Lohmann Sandy; least square means with no letter in common indicate significant differences)

NH × Bresse eggs, respectively. Bresse and Sandy eggs contained 55.6 and 58.0% albumen, respectively. Yolk colour varied throughout the laying period and was within the range of 7.5 and 11. Despite a significant interaction between genotype and time, pairwise comparison of means only revealed a tendency towards a darker yolk colour in NH × Bresse eggs than in WR × Bresse and Sandy in week 24. On average, yolk colour was 9.0 in the White Rock crosses and 9.3 and 9.2 in Bresse × NH and NH × Bresse, respectively. The yolk in both Bresse and Sandy eggs was on average categorized as 9.0. Egg shell percentage varied only slightly and was within the range of 10 and 13%. Despite a significant interaction between genotype and time, the only significant difference was a higher egg shell percentage in Bresse eggs than in Bresse × NH eggs in week 48. On average, egg shells made up 11.3 and 11.6% of Bresse × WR and WR × Bresse eggs and 11.3 and 11.1% of Bresse × NH and NH × Bresse eggs, respectively. Bresse eggs had 11.7%, and Sandy eggs 11.6% egg shell.

The distribution of egg sizes given for the sum of all produced eggs is shown in Fig. 3. The dual-purpose crosses had a slightly higher proportion of S and XL eggs than Sandy, while the differences between the crosses were not considerable. Bresse eggs had by far the highest proportion of size S and only very little size XL. The sum of M and L eggs was 80.6 and 74.9 for Bresse × WR and WR × Bresse and 79.7 and 76.4% for Bresse × NH and NH × Bresse, respectively. Of the Bresse and Sandy eggs, 74.2 and 84.2% were classified as M or L.

Efficiency of egg production

Calculated over the whole laying period, the total egg mass-produced by an average hen alive was 16.2 and 17.3 kg for Bresse × WR and WR × Bresse and 16.6 and 16.4 kg for Bresse × NH and NH × Bresse, respectively. Bresse hens produced an average of 12.1 kg egg mass, and Sandy hens produced 21.2 kg. The feed conversion ratio for egg production was significantly affected by genotype ($P < 0.001$) and was the lowest in Sandy hens (2.35 kg feed kg^{-1} egg mass) and the highest in Bresse hens (4.30 kg feed kg^{-1} egg mass). The dual-purpose genotypes showed feed conversion ratios of 3.08, 2.82, 3.06 and 3.16 for Bresse × WR, WR × Bresse, Bresse × NH and NH × Bresse, respectively, and differed significantly from both Sandy and Bresse. Between the dual-purpose crosses, WR × Bresse had a significantly lower feed conversion ratio than Bresse × WR and NH × Bresse.

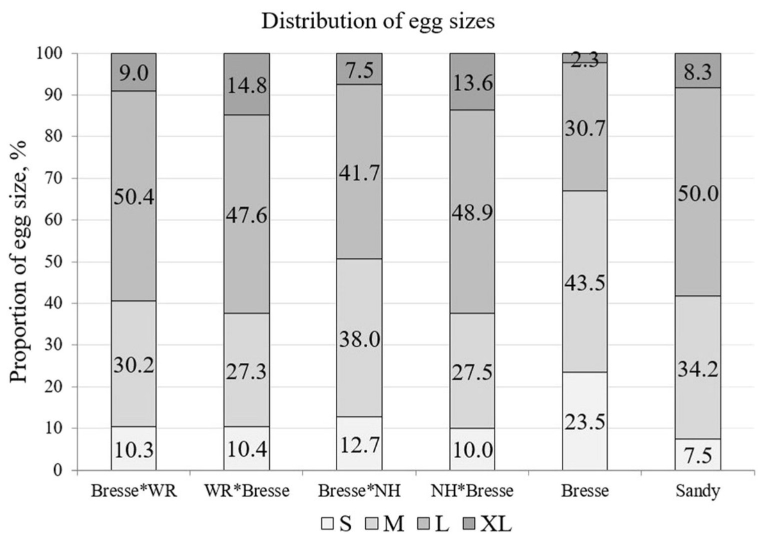

Fig. 3 Distribution of egg sizes ($S < 53$ g; $M = 53$ to 63 g; $L = 63$ to 73 g; $XL > 73$ g) of dual-purpose hens, sum of all produced eggs week 20–72 (WR, White Rock; NH, New Hampshire; Bresse, Bresse Gauloise; Sandy, Lohmann Sandy)

Animal losses

Reasons for animal losses were predators (55 hens), accidents (5 hens), culling due to cloaca prolapses (2 hens) and unknown reasons (112 hens), of which a high proportion can be assumed to be predator losses as well. Losses until week 44 amounted to 19, 11, 7 and 12% for Bresse × WR, WR × Bresse, Bresse × NH and NH × Bresse. The losses for Bresse and Sandy hens were 23 and 35%. Until the end of the laying period, the total losses were 26, 16, 9 and 13% for the crosses and 23 and 44% for Bresse and Sandy.

Discussion

This study was conducted in order to compare four chicken crosses between a meat breed (Bresse Gauloise) and a layer breed (White Rock or New Hampshire) with regard to their performance under the conditions of organic husbandry. Because of space limitations, group size was 40–47 hens, and only one group of most crosses was kept (two groups of Bresse × WR and Bresse × NH were kept).

Feed consumption and feed choices

Total feed consumption was generally high in our study and did not differ between the genotypes. The layer type control Sandy consumed an average of 143 g feed, which is much higher than the value of 115–118 g given by the breeding company (Lohmann 2017). There are no previous reports available about the feed consumption of the dual-purpose crosses, which was 133–139 g in our study. For the dual-purpose hybrid Lohmann Dual, both Kaufmann et al. (2017) and Mueller et al. (2016b) reported much lower feed intakes of 103–110 g and 104 g, respectively. In both studies, the energy concentration of the diet was higher (11.2 and 11.5 MJ AME_N, respectively) than in our study (10.8–11.0 MJ AME_N in week 35–72). As shown by van Krimpen et al. (2015), laying hens are able to adjust their energy intake based on their demand and the energy concentration of the diet, which to some extent explains the differences between the studies by Kaufmann et al. (2017) and Mueller et al. (2016b) and ours, in addition to the effect of the genotype. On the other hand, Gerzilov et al. (2018) fed diets containing 11.5–11.8 MJ AME_N to dual-purpose laying hens under free-range conditions and found feed intakes comparable or even higher to our observations, with values reaching from 113 to 129 g for Bielefelder hens (38–52% laying) to 169–149 g for Tetra Super Harco hens (63–75% laying).

Chickens are able to select a balanced diet when they are offered clear feed choices (Pousga et al. 2005), which was done in our study by providing energy-rich feed, protein-rich feed, and lime-grit mixture. For the majority of the laying period (week 35–72), the dual-purpose hens consumed significantly less protein feed than the Sandy hens, which can be attributed to their lower laying performance and therefore lower protein demand. Despite the highest consumption of protein feed, the total diet of the Sandy hens still had a lower methionine concentration (0.27 g MJ^{-1} AME_N) than recommended by the breeding company (Lohmann 2017, 0.32–0.30 g MJ^{-1} AME_N in week 46–65), which might be explained by the safety margin usually added to feeding recommendations. When Mueller et al. (2016b) reduced the methionine concentration in diets of dual-purpose laying hens (Lohmann Dual, Mechelner and Schweizerhuhn) and the layer hybrid Lohmann Brown-Plus from 0.37 to 0.27 g MJ^{-1} AME_N, they found no effect on the performance of the animals. In our study, laying hens of WR × Bresse and the New Hampshire crosses chose a total diet with an even lower methionine concentration of 0.23–0.24 g MJ^{-1} AME_N. Due to small animal numbers and only one laying period in our study, additional experiments are needed to confirm the actual nutrient demands of the tested dual-purpose crosses, but it seems that feeding a diet with lower methionine concentration than for layer hybrids might be more adequate in view of their lower laying performance. This approach could reduce the need for high-protein feed components and thereby simplify the composition of 100% organic diets.

Live weight development and slaughter performance

Throughout the laying period, the crosses rarely differed with regard to live weight but were always significantly heavier than the Sandy hens and significantly lighter than Bresse hens in week 20 and 32. Compared with the recommendations of the breeding company (Lohmann 2017), Sandy hens were overweight by about 200 g at the beginning of lay but on the upper limit of the range given for week 32 (1752–1860 g) and only slightly overweight at the end of the laying period. For Bresse Gauloise hens, Lambertz et al. (2018) found live weights of 2040 and 2817 g at the beginning and the end of the laying period, respectively. Compared with these reports, the Bresse hens in our study were considerably heavier at the beginning of the lay (2476 g) but had similar weights at the end (2839 g). Information about live weight of the crosses is very limited; in a previous fattening trial, Bremer and Günther (2016) documented a live weight of 2000 g for NH × Bresse pullets at the age of 16 weeks, which is higher than our observation of 1837 g. For Bresse × NH hens, Lambertz et al. (2018) found a live weight of 1820 g at the beginning of the laying period, which was lower than in our study (2135 g). While our study only covers one generation of hens, it is clear that the hens of all tested dual-purpose crosses were considerably heavier than the layer hybrid, with the New Hampshire crosses not differing from Bresse at the of the laying period. Therefore, marketing of the senior hens for meat can support economic dual-purpose production.

With carcass weights of 1543–1715 g and a dressing percentage of 57.2–59.5%, the slaughter performance of our dual-purpose hens was comparable with reports of Mueller et al. (2016a) for the dual-purpose breed Schweizerhuhn (carcass weight 1600 g, dressing percentage 57%). Breast percentage, however, was higher than reported for Schweizerhuhn (Mueller et al. 2016a; 18%), and also higher than in the dual-purpose cockerels slaughtered at the age of 15 weeks in our study (20.4–29.2 vs 10–17%). For Bresse × NH, Lambertz et al. (2018) found higher live weights at slaughter (2857 vs 2773 g), which led to higher carcass weights, dressing percentage and breast percentage than in our study (1836 g, 63.3% and 32.3% vs 1603 g, 57.9% and 20.4%). Carcass weight and breast percentage of Sandy hens (1109 g, 21.0%) were slightly higher than reported for 54-week old Lohmann Brown-Plus hens by Mueller et al. (2016a; 1000 g, 21.0%). While meat quality of senior hens is very different from cockerels slaughtered at an early age, heavy hens have been found to produce better quality products than lightweight birds (Kondaiah and Panda 1992), underlining the potential for marketing the meat of dual-purpose hens after the laying period.

Animal welfare

Feather pecking is one of the most prevalent behavioural disorders found in laying hens and is strongly influenced by breed (Rodenburg et al. 2004). Plumage loss, especially when observed on the back, tail and around the cloaca, is a valid indicator of feather pecking (Kjær and Sørensen 2002). In our study, plumage on the back and the belly (including the area around the cloaca) was mostly complete in week 20 and 32 but deteriorated until week 72. Since every group of hens included a rooster, their activity added to the plumage losses on the back, which ranged from 7 to 55% of hens receiving score 1 in week 72. Plumage losses on the belly, however, can be fully attributed to feather pecking, and the worst scores were recorded for Bresse × WR hens. Half of the Bresse × WR hens had naked bellies at the end of the laying period (50% received score 2). Bresse × WR hens had the significantly lowest intake of protein feed of all dual-purpose crosses in week 35–72 but showed a similar laying performance. Therefore, the high prevalence of plumage loss on the belly can most likely be explained by a lack of methionine in the diet, which acted as a stressor to the hens. Apparently, free-choice feeding is not a feeding system that agrees with this genotype. In the New Hampshire crosses, the prevalence of plumage loss on the belly was significantly lower than in Bresse × WR, which is in agreement with findings of Kjær and Sørensen (2002) that purebred New Hampshire hens exhibited less feather pecking than commercial layer hybrids.

Keel bone damage is frequently observed in commercial laying hens and is considered an important welfare issue due to their painful nature and influence on performance (Hardin et al. 2019). While the appearance of keel bone damage is multifactorial, it is found both in conventional and organic housing systems. When comparing conventional and organic flocks in Austria and Germany, Staack et al. (2009) found no difference between the systems, with 28 and 27% of the birds showing keel bone deviations or fractures. In a study including 49 flocks of organic layers in Denmark, Bestman and Wagenaar (2014) documented keel bone damage in 4–48% of the assessed hens, with an average of 21%. In our study, 34–45% of the dual-purpose hens showed keel bone deviations (score 1) or fractures (score 2) at the end of the laying period, and the genotypes did not differ. Therefore, our observation is within the range reported by Bestman and Wagenaar (2014). However, Jung et al. (2019) found that aviary housing and high laying performance are positively correlated with keel bone damage; therefore, the comparatively low laying performance of our floor-housed dual-purpose crosses should have resulted in less damage. With even lower laying performances of 54.5 and 54.2% in Bresse Gauloise and Bresse × NH hens, Lambertz et al. (2018) found keel bone damage in only 1.1 and 13.5% of the birds. Apparently, other factors than housing and laying performance affected the appearance of keel bone damage in our study. Genetic dispositions for keel bone damage have previously been found by several authors (e.g. Heerkens et al. 2016); for this reason, keel bone damage should be considered in future breeding of the parent breeds for the tested crosses.

Laying performance, egg sizes and composition

As expected, laying performance of the dual-purpose crosses was considerably lower than the performance of the layer hybrid Sandy. Laying performance of Sandy hens closely followed the laying curve reported by the breeding company (Lohmann 2017), indicating that housing, feeding and management enabled high performance. Laying performance of Bresse hens also met the standards of the breeding association (Ökologische Tierzucht gGmbH 2020). With an average laying performance of 55% total eggs per average hen, the performance of our Bresse was comparable with Lambertz et al. (2018), who reported 54.5% saleable eggs for Bresse hens in a conventional free-range system. Laying performance of the four dual-purpose crosses evolved quite similar to each other, and differences were probably related to the limited number of animals. With an average laying performance of 68–73% until week 72, the crosses were in the same range as previous reports for the dual-purpose genotypes Lohmann Dual (Kaufmann et al. 2017, 64.7%; Schmidt and Damme 2017, 73.9%), Novogen experimental (Schmidt and Damme 2017, 73.5%) and Walesby Special (Schmidt and Damme 2017, 74.3%).

In the study of Schmidt and Damme (2017), all dual-purpose genotypes produced smaller eggs than the layer hybrid Lohmann Brown Classic, which the authors declared problematic due to the negative effect on produced egg mass and saleability of the eggs. In contrast to these finding, the egg weights of the dual-purpose crosses tested in our study never differed from the layer hybrid Lohmann Sandy, which, in turn, matched the performance data given by the breeding company (Lohmann 2017). While the proportion of S and XL eggs was indeed slightly higher in the dual-purpose crosses than in Sandy, the sum of M and L eggs ranged from 74.9 to 80.6% and was therefore only slightly lower than in Sandy (84.2%). We therefore conclude that both average egg weight and egg size distribution of the tested genotypes are comparable with those found in a common layer hybrid and do not impair saleability of the eggs.

The proportion of yolk significantly increased with time, while the albumen proportion decreased and the egg shell proportion stayed quite constant despite a significant interaction between genotype and week. Yolk colour was in the range of 7.5 and 11 on the DSM YokFan™ throughout the laying period, corresponding to a yellow to light orange colour. Yolk colour is the result of feeding, not genetics (Grashorn 2016); consequently, the genotypes in our study did not differ. Compared with reports about European consumers preferring egg yolk colours between 12 and 14, the yolks in our study were quite light (Hernandez 2005). Between December (week 40) and March (week 52), yolk colour was the lightest (7.5–9.5), which can be explained by less intake of carotenoid-rich fresh grasses and herbs (Hammershøj and Johansen 2016). Improving the supply of carotenoids during winter could therefore be an option to improve the attractiveness of the eggs.

Efficiency of egg production

Due to their higher live weight and lower laying performance as compared with layer hybrids, dual-purpose laying hens generally have a lower efficiency of egg production. As expected, feed conversion ratio (FCR) of the dual-purpose crosses in our study was significantly higher than in the layer hybrid Sandy but significantly lower than in Bresse hens, which are still used as dual-purpose chicken despite being considered a meat breed. Bresse hens consumed 4.3 kg feed kg^{-1} egg mass, which was even higher than the reports for Bresse and Bresse × NH hens in conventional free range (Lambertz et al. 2018, FCR 3.4). The significantly lowest feed conversion ratio was found in Sandy hens, which only consumed 2.35 kg feed kg^{-1} egg mass. While the breeding company reports an even lower FCR of 2.0–2.1 for Sandy hens (Lohmann 2017), our observation is close to reports for Lohmann Brown-Classic under organic conditions (Schmidt et al. 2016, FCR 2.24). The feed conversion ratio of the crosses ranged from 2.82 to 3.16, with the significantly lowest value in WR × Bresse. While the efficiency of WR × Bresse was in line with reports about Lohmann Dual (Röhe et al. 2019), FCR 2.87 (Kaufmann et al. 2017, 2.8) and Walesby Special (Schmidt et al. 2016, 2.82), FCR was higher in all other crosses. Although the comparatively low efficiency of dual-purpose laying hens can be criticized, their use is first and foremost an ethical choice. Still, we do see the potential to adjust the diet composition to their lower demand for essential amino acids (see discussion on feed choices). Thereby, their high feed conversion ratio could be mitigated, at least with regard to the scarce high-quality feed components.

Animal losses

When laying hens have access to an outdoor run, animal losses due to predators pose a real risk. In Germany, Gayer et al. (2004) compared production and slaughter records on six free-range farms and estimated predation losses of 0.8–12.5% over the course of one laying period. In a Danish study including 49 flocks of organic layers, Bestman and Wagenaar (2014) found losses due to predators in 39% of the flocks. For dual-purpose laying hens of Lohmann Dual, Novogen experimental and Walesby Special, Schmidt et al. (2016) reported total losses of 11.1–27.7% under organic housing conditions. Even higher losses of 44.5 and 51.8% until the age of 95 weeks have been reported by Kaufmann et al. (2017) for two strains of the dual-purpose hybrid Lohmann Dual. In our study, predation by hawks caused high animal losses, ranging from 9 to 26% in the crosses, 23% in Bresse and 44% in Sandy hens until the end of the laying period. The site where the experiment took place had not been used for a long-term trial with laying hens before, and unfortunately efforts to protect the birds from the hawks were only partly successful. The observation of the farm staff was that the Sandy hens as the smallest birds were the preferred prey for the hawks, resulting in the highest losses.

Conclusion

Based on the observation that the dual-purpose crosses consumed less protein feed than the layer hybrid Sandy, we see the possibility to adjust the diet composition in order to reduce the need for high-protein feed components and thereby mitigate the high feed intake of the hens. Carcass weights of most dual-purpose senior hens were as high as in the meat breed Bresse, underlining the potential for marketing the meat of dual-purpose hens after the laying period. Bresse × WR hens appeared ill-suited for choice feeding and consumed the least protein feed and reacted to the resulting lack of methionine with increased feather pecking. The reciprocal version of the cross, WR × Bresse, showed considerably less feather pecking; therefore, the cross with White Rock as the mother does not seem recommendable for organic husbandry. With an average laying performance of 68–73% total eggs per average hen, the crosses were in line with previous reports about other dual-purpose genotypes and can therefore be considered promising. Average egg weights did not differ from the layer hybrid Sandy, and egg size distribution was found to be comparable as well; for this reason, the eggs should sell well.

To summarize our findings on the laying performance of the hens and the fattening performance of the cockerels (see companion paper "Dual-purpose production of eggs and meat – Part 1: cockerels of crosses between layer and meat breeds achieve moderate growth rates while showing unimpaired animal welfare" in this issue), the cockerels showed moderate growth rates and unimpaired animal welfare, while the laying hens achieved an equally moderate laying performance but chose feed with a lower concentration of protein. We found no effect of the position of the parents on the fattening performance of the cockerels, but hens of the Bresse × WR cross showed a high prevalence of plumage loss related to feather pecking. All other performance indicators showed little or no differences between the crosses, and most values were in the range between the meat breed Bresse and the layer hybrid Sandy. Further research on appropriate feeding of the dual-purpose crosses seems necessary in order to adjust the diet composition to their needs. In practice, successful implementation of a dual-purpose production system will depend not only on the performance of the cockerels and hens but on the ethical value that our society puts on raising both sexes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval No invasive procedure of any kind was used; therefore, no ethics approval was necessary.

Consent for publication All authors agree with the content of the manuscript and have given their consent to submission.

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