Performance, behavior, and health of male broilers and laying hens of 2 dual-purpose chicken genotypes

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ABSTRACT Dual-purpose chicken where both sexes are reared together, before males are separated for final fattening, while females are kept for an entire laying period, may provide an economic alternative under certain production and marketing conditions. Two genotypes, purebred Bresse-Gauloise (PURE, n = 300) and crossbred Bresse-Gauloise × New Hampshire (CROSS, n = 300), were compared. One-day-old mixed-sex chicken were raised for 12 wk under floor husbandry conditions on a broiler diet. Thereafter, males were transferred to a mobile chicken house with free-range access. Males were slaughtered at weekly intervals from 12th to 19th wk of age. Hens were kept for 1 laying period in a mobile house. Growth performance, feed consumption, carcass, meat quality, health and welfare traits were measured in both sexes. In females layers' performance, egg quality and behavior were recorded, too. At 12 wk, males of PURE reached a live weight of 2,075 g and CROSS of 1,865 g ($P < 0.05$), while at 16 wk both weighed more than 2,500 g ($P > 0.05$). Dressing percentage increased with slaughter age and was above 68% in both genotypes when slaughtered at 18 to 19 wk of age. Proportion of legs, breast, and wings was 34.3, 16.0, and 11.0% in PURE and 34.7, 15.5, and 12.1% in CROSS ($P > 0.05$). Laying performance was 54.5% in PURE and 54.2% in CROSS ($P > 0.05$). Egg breaking strength decreased during the laying period, but remained above 30 N. Feed conversion was 3.4 kg feed/kg egg. On average, 25% of the animals stayed outdoors during daytime ($P > 0.05$). Keel bone deformations were observed in 10% and breast blisters in 20% of the hens. Under the specific conditions of marketing products with added value, performances resulted in an overall economic benefit, which was higher for PURE than CROSS. The use of dual-purpose chicken to avoid the killing of 1-d-old chicken and mobile housing may substantiate premium prices in such a system.

Key words: dual-purpose, broiler, laying hen, performance, health

INTRODUCTION

The killing of male chicks from layer lines raises increasing welfare and ethical concerns. The breeding progress reached in layer as well as broiler lines, however, resulted in modern poultry farming systems, in which the fattening of male layer lines is challenged by various, not only economic, reasons (Kaufmann and Andersson, 2013; Ammer et al., 2017). Given the many limitations of fattening male chicks from layer lines, other alternatives are underway. One promising method in the future, but still not available in practice, is the in ovo sex determination before incubation (Krautwald-Junghanns et al., 2018).

Currently, a feasible alternative are dual-purpose chicken with a satisfying laying performance of females and growth performance of males comparable to extensive broiler lines, so that both sexes gain an economic profit. On the one hand, breeds not solely selected for either egg or meat and on the other hand, crosses of layer and broiler hybrid lines are used in dual-purpose production systems. Regarding the use of hybrid lines, comparisons of these crosses to conventional hybrid lines have shown the economic deficit of this strategy (Icken and Schmutz, 2013; Damme et al., 2015). Problems arise mainly because of small egg sizes and low breast percentage of males.

The large pool of chicken genetic resources contains a large number of breeds suitable for dual-purpose production across multiple countries (FAO, 2015). Examples of breeds used as dual-purpose chicken are Sussex, Sulmtaler, Mechelner, Sundheimer, Plymouth Rock, Rhode Island Red, New Hampshire, Australorps, and Vorwerk. A breed of interest is Bresse-Gauloise, originating from the French region Bresse, with an appropriate laying performance (up to 250 eggs per year)

and growth performance of males (final body weight up to 3.0 kg) with a superior meat quality (De Jong, 2007; Galster, 2011). If raised in the region of origin and under certain production conditions, meat is marketed under the protected designation of origin certification. The feasibility of this breed under specific production and marketing conditions, i.e., organic production, marketing as "ready-to-grill/cook" carcasses, has been shown (Muth et al., 2016). Its economic competiveness when produced for a niche market was also presented by Pinent et al. (2015).

Though still produced only for a niche market and only feasible if products can be marketed with premium prices to compensate for higher production costs, dual-purpose chicken are currently the only practical alternative to the culling of male chicks. Certainly, it has to be considered as one of different possible solutions to avoid chicken culling, but a high consumers' willingness to pay for such a system was recently reported from different European countries (Gremmen and Blok, 2016; Gangnat et al., 2018). It can be assumed that the economic potential of dual-purpose chicken is highest for small-scale farmers, selling products directly to consumers, which are willing to pay for regional and welfare-friendly produced poultry meat and eggs. Under these production conditions, the use of technology, i.e., control of environmental conditions including climate, light, nutritional requirements, is less advanced than in commercial farming systems, and thus requires robust genotypes. In addition, advisory and veterinary services may be limited for small-scale farms.

The optimal production system for dual-purpose chicken is still widely unknown and, of course, depends on many different factors (Urselmanns and Damme, 2011). One possibility is to raise both sexes together during the first weeks, so that the routinely practiced sex sorting is not necessary. A mixed-sex rearing period, however, requires an adequate growth performance of the males, which might only be reached if broiler diets are provided. Given that broilers in such a system are generally fattened for an extended period of 12 to 16 wk, because weight gains of these breeds/genotypes are comparably low and slaughter weights high, the final fattening period may be separated by sex after males and females can be differentiated based on feather and comb condition. The aim of this study was to compare 2 dual-purpose genotypes in a production system with a mixed-sex rearing period, before males are separated for final fattening, while females are kept for an entire laying period.

MATERIALS AND METHODS

Birds and Husbandry System

The study was conducted from June 2016 until December 2017 under practical conditions on a commercial laying hen farm located in South Tyrol, Northern Italy (46°34′ N; 11°34′ E; 1,060 m above sea level). Following the Guide for the Care and Use of Agricultural Animals in Research and Teaching, animals were treated in a way that unnecessary discomfort by the use of proper management was avoided.

Mixed-sex 1-d-old non-beak-trimmed purebred Bresse-Gauloise (PURE) and crossbred Bresse-Gauloise × New Hampshire (CROSS) chicken were reared under floor husbandry conditions. PURE were purchased from the breeder Christian Hetzenecker (Neumarkt-Sankt Veit, Germany) and CROSS from Ökologische Tierzucht gGMBH (Mainz, Germany). A total of 300 animals of each genotype were reared under floor husbandry conditions in 4 pens (4 × 4 m; 2 per genotype) with 150 animals each. An infrared radiation lamp was installed in each pen. Feed and water was available ad libitum from 2 drinkers and 4 feeders. Until 14 d of age, animals were raised in a brooder guard. Chopped straw was used as litter. The temperature was reduced from 32°C at the first day to 26°C at 14 d and the relative humidity ranged between 60 and 75%. Natural light was provided via 2 windows. In the hatchery, animals were vaccinated against Marek and at 4 wk of age against Newcastle's disease. No other veterinary treatments were applied during the study.

Commercial standard diets were used. During the first 6 wk of age animals received a starter diet (12.9 MJ ME, 22.0% CP; 8.5% EE; 6.0% CA; 1.2% lysine; 0.55% methionine; 1.0% calcium; 0.12% potassium; 0.80% phosphorous; 0.1% herbal extracts). From the 7th week on, a broiler diet was provided (12.3 MJ ME; 18.0% CP; 7.5% EE; 3.5% CF; 5.5% CA; 1.0% lysine; 0.50% methionine; 0.80% calcium; 0.20% potassium; 0.70% phosphorous). At 6 wk of age, water provision was changed to nipple drinkers, perches were available and animals were wing-tagged.

At 12 wk of age, animals were divided by sex, and the male animals were transferred to a mobile chicken house equipped for alternate use for fattening and egg production (Modell HM-300, Stallbau Weiland GmbH & Co. KG, Bad Sooden-Allendorf, Germany). The house has 2 floors with a dimension of 10.15 × 2.28 m (top floor, 23.14 m²) and 10.05 × 2.73 m (ground floor, scratching area, 27.44 m²). The maximum capacity for broilers based on a final live weight of 3.2 kg and a stocking density of 30 kg/m² is 463 animals. In the top floor, perches with a total length of 60 m, 1 feeding line (9 m) with 12 single oval feeding bowls and 1 water line (9 m) with 36 single nipples and 9 cup drinkers were installed. The height of the feeding and watering line could be adjusted to animal size. The house was divided into 2 equally sized compartments to house animals of the 2 genotypes separately, but under identical conditions. Each compartment had a pop hole with a total length of 1.95 m to enter the free-range, which was also separated for each genotype. Pop holes were opened at 9:30 in the morning and closed at sunset. A free-range area of 4 m² per animal was available. Because of the technical equipment, the feed consumption could only be

recorded for both compartments together and not separately for the genotypes. The mobile house was not used prior to the study and the free-range never used for poultry before.

After sex separation at 12 wk of age, females remained in the rearing stable under floor husbandry conditions with natural lighting as described for the mixed-sex rearing period. They were fed with a pullet diet (12.0 MJ ME; 17.0% CP; 4.2% EE; 3.5% CF; 6.0% CA). After slaughter of the broilers, 103 CROSS and 86 PURE hens were transferred to the mobile house in the 19th wk of age, after the house was moved to a new free-range area. For hens, the maximum capacity based on a space allowance of 9 hens per square meter is 352 animals. The total nest area is 3.78 m^2. A free-range area of 4 m^2 per animal was provided. Four different adjacent free-range areas were rotated at intervals of approximately 4 wk by moving the mobile house. In the mobile house hens received a laying hen diet (11.4 MJ ME; 17.0% CP; 5.5% EE; 3.5% CF; 14.8% CA), which was changed at 58 wk of age to a second laying hen diet (11.4 MJ ME; 16.5% CP; 5% EE; 3.5% CF; 16% CA). Because of an influenza outbreak, animals did not have access to the free-range from January 7 until March 13, 2017. Temperature and relative humidity inside and outside the mobile house were recorded continuously with data loggers (Tinytag Plus 2 TGP-4500; Gemini data Loggers Ltd., Chichester, United Kingdom).

Measurements in Male Broilers

Body Weight and Feed Consumption Until 12 wk of age, all individuals were weighed weekly. After sexes were separated and males moved to the mobile house, only males were weighed at weekly intervals. Because of a water leakage in week 9, weights were not recorded in this week. Feed consumption in the mobile house was measured daily, but due to the technical equipment of the mobile house with only 1 feeding line for both groups, it could not be separated per genotype.

Slaughter Traits and Meat Quality From the 12th until the 19th wk of age, approximately 10 animals per group were slaughtered weekly. At each slaughter date, the heaviest animals of each genotype were selected and slaughtered in a commercial slaughterhouse using electrical stunning. All animals were weighted before slaughter and after evisceration to calculate dressing percentage, and weights of heart, liver, gizzard, and abdominal fat were recorded. Additionally, 10 animals per genotype at the slaughtering at week 12 were used for further recording of slaughter and meat quality traits. After slaughter, carcasses were cut into legs, breast (without skin), and wings and weights of these cuts were recorded.

Meat quality traits were measured in the right breast fillet. At 24 h, ultimate pH (HI 99,161, Hanna Instruments Inc., Woonsocket, RI, USA) and color (CR-400, Minolta Inc., Osaka, Japan) was measured at 6 different points per sample free of obvious color defects. Color was expressed in the CIELAB space as L^*- (lightness), a^*- (redness), and b^*- (yellowness) values. In duplicate, moisture content, drip, thawing, and cooking loss was measured. Moisture content was measured using an infrared moisture analyzer (MA30, Sartorius, Göttingen, Germany). To determine drip loss, samples were put in a plastic bag, hung for 24 h at 4°C, then blotted dry and weighed. For thawing loss, samples were vacuum-packed and stored at –20°C. After defrosting at 4°C for 24 h and dry blotting, samples were weighed to record thawing loss. Samples were cooked for 30 min in a water bath at 80°C and after dry blotting, samples were weighed and cooking loss expressed as the weight after cooking relative to the initial sample weight.

Welfare and Health Measures At the weightings of week 3, 7, and 11 animal-based welfare indicators including wounds, foot pad lesions, plantar abscesses, toe wounds, missing toes, lameness, and comb color were recorded according to Hinrichsen et al. (2016). Plumage condition was assessed from week 12 on and breast blisters at slaughter. Five to 10 fecal samples per genotype were collected at week 3, 4, 5, 11, and 16 and analyzed for endoparasitic infections applying a modified McMaster method using saturated salt solution where 1 egg counted represents 50 eggs per gram of feces. Mortality was recorded daily.

Economic evaluation Based on the measured traits and under consideration of current costs and revenues in the studied region of South Tyrol, Northern Italy, genotypes were compared.

Measurements in Laying Hens

Body Weight and Feed Consumption Hens were weighed individually at 16, 42, and 75 wk of age. Feed consumption in the mobile house was measured daily as described for male broilers.

Laying Performance and Egg Quality The number of saleable eggs produced per genotype was recorded daily and egg size classification recorded once a week. Thereby, eggs sizes were classified into S (< 53 g), M (53 to 63 g), L (63 to 73 g), and XL (> 73 g). Egg quality was measured at intervals of 3 wk for 10 randomly selected eggs per genotype. Eggs were analyzed within 24 h of laying using the Futura measuring set 3/A (Futura, Lohne, Germany). The individual eggs were weighed to the nearest 0.01 g. Length and width was measured with the help of a digital caliper to the nearest 0.01 cm. Shape index was calculated as the ration of width to length multiplied by 100. Egg shell color expressed as L^*-, a^*- and b^*-values was measured with a colorimeter (CR-400, Minolta Inc., Osaka, Japan). Shell thickness was measured by using a micrometer to the nearest of 0.001 mm at 3 different measuring points around the egg equator. Breaking strength was assessed in N and kg. Using a tripod micrometer, albumen height was measured and Haugh unit was calculated as $100 \times \log_{10}$ (albumen height (mm) $- 1.7 \times$ egg weight (g) $^{0.37}$ $+7.6$). Albumen length and width and yolk diameter

were measured with a digital caliper to the nearest of 0.01 cm. Albumen index was calculated as (albumen height (mm)/(albumen length (mm) + albumen width (mm))/2) × 100. Yolk color was expressed as L^*-, a^*- and b^*-values and Roche-value (1 to 15). Yolk and albumen were separated and yolk weight determined. After shells were dried until they reached constant weight, shell weight was recorded and yolk, albumen and shell ratio calculated relative to egg weight. Egg shell index was calculated from shell weight (g) and egg surface area (4.67 × egg weight $(g)^{0.666}$). The number of blood and meat spots was noted, too.

Slaughter Traits and Meat Quality At 75 wk of age, hens were slaughtered as described for male broilers and slaughter and meat quality was recorded in 10 animals per genotype. Slaughter traits (dressing percentage, proportions of legs, breast, wings, heart, liver, gizzard, and abdominal fat) and meat quality (ultimate pH, color, moisture content, drip, thawing, and cooking loss) were also measured as described above for male broilers.

Welfare and Health Measures At these times, animal-based welfare indicators including plumage, wounds, keel bone deformations, foot pad lesions, plantar abscesses, toe wounds, missing toes, lameness, and comb color were scored according to Hinrichsen et al. (2016). Ten fecal samples per genotype were collected at weeks 18, 28, 39, 58, and 63 and analyzed for endoparasitic infections as described above. At slaughter (week 75), gastrointestinal tracts of 10 animals per genotype were subjected to a post mortem analysis as described in detail in Wuthijaree et al. (2017). Briefly, crop, proventriculus, gizzard, small intestine, and caeca were opened longitudinally and mucosa and contents washed in a 100-μm mesh sieve. All parasites were identified based on morphology. Mortality was recorded daily.

Behaviour At 43 and 44 wk of age, the behavior of the hens was observed for a total of 6 d during daytime from 9:30 until 18:00. The behavior on the free-range was assessed by direct observation of 2 assessors using the time-sampling method with 5-min intervals. Alternating after every observation time, each observer observed one of the 2 free-range areas. The behaviors sitting/lying, standing, walking, foraging, and dust bathing/comfort behavior were assessed according to Chielo et al. (2016). At the time of the behavioral observations, 76 PURE and 78 CROSS animals were in the mobile house and each genotype had access to a rectangular free-range area measuring 19 × 16 m. One week before behavioral observations started, the free-range area was alternated. To characterize the use of free-range area, it was divided into 3 different areas based on the distance from the pop hole into (1) close with max 8 m distance from the pop hole; (2) medium with 8 to 15 m; and (3) far with 15 to the max distance of 23 m from the pop hole. Distances were visualized using colored wood sticks. At each observation time, the number of animals performing the

specific behaviors in the different areas of the free-range was recorded.

The upper floor of the mobile house, in which perches, feeders, drinkers, and nests are located, was video-recorded with 4 video cameras (Bullet IP Full HD 1080P, Sunell Technology Crop., Shenzhen, China) during the observation period. Two cameras per compartment were fixed at the ceiling of the mobile house. Videos were analyzed using the software program Interact, version 16 (Mangold International GmbH, Arnstorf, Germany). At 5-min intervals, the behaviors sitting on the perches, sitting on the floor, standing on the perches, standing on the floor, standing at the nest entrance, walking, feeding, and drinking according to Chielo et al. (2016) were observed using the time-sampling method for the same period of the direct observations (09:30 to 18:00). Animals being in the nest and in the lower floor (scratching area) could not be observed with this method.

Economic Evaluation Based on the measured traits and under consideration of current costs and revenues in the studied region of South Tyrol, Northern Italy, genotypes were compared.

Statistical Analyses

All data were analyzed using the software package SAS, version 9.3 (Statistical Analysis Systems, Cary, North Carolina, USA). Schematic boxplots and proc UNIVARIATE was used to test normal distribution of data. For all analyses, α was set at 0.05.

Body weights until week 6 of age were not differentiated between sexes. For data of the weekly individual body weight recordings a linear mixed model was fitted separately for each week with the procedure GLM including the fixed effects of genotype (PURE, CROSS) and week. After animals were individually marked at 6 wk of age, the analysis of the weight gain was separated for males and females with the same statistical model. Daily weight gain until week 12 of age was calculated and analyzed in the same manner. Least squares means were calculated and compared using the Student's t-tests. The same model was applied for the body weight measurements of the laying hens. Data are presented as least squares means ± standard deviation. Animal was the experimental unit.

For the analysis of the slaughter traits, results were analyzed after data were classified based on the age at slaughtering into 3 classes (12 to 15, 16 to 17, and 18 to 19 wk of age). Data were analyzed using the GLM procedure including the fixed effect of genotype (PURE, CROSS) and slaughter ages (1, 2, 3) and its interaction. Animal served as the experimental unit. Meat quality traits of the 10 selected animals per genotype were analyzed using the GLM procedure including the fixed effect of genotype (PURE, CROSS) with animal as the experimental unit. Frequencies of health parameters were compared between genotypes using Pearson's χ^2 tests, separately at each sampling age.

Egg quality traits were analyzed using the MIXED procedure including genotype, week and its interaction as fixed effects. Egg within the genotype was considered a repeated factor, and for each analyzed trait, egg within genotype was subjected to 3 variance-covariance structures: compound symmetry, autoregressive order 1, and unstructured. The covariance structure that minimized Schwarz's Bayesian information criterion was considered the most desirable analysis. Pearson's correlation coefficients between egg quality traits were calculated with the CORR procedure.

For each observation time, the percentage of animals performing the different behaviors was calculated separately for the indoor and outdoor observation. Additionally, the percentage of animals being outdoors was calculated and the proportion of animals in the area close, medium, and far from the pop hole was calculated based on the total number of animals being outdoors. Data were analyzed with the MIXED procedure including the genotype as fixed effect and observation day as random effect. Applying this analysis, genotypes were compared regarding the different behaviors outdoors and indoors and the distance from the pop hole.

RESULTS AND DISCUSSION

Male Broilers

Body Weight and Feed Consumption Figure 1 presents the body weight development during the mixed-sex rearing period until week 6. From the second week on, PURE showed a greater body weight than CROSS ($P < 0.05$). At 5 wk of age, this difference was greater than 90 g and at 6 wk more than 140 g. For the following weeks until week 16, the body weight development is presented for male broilers separately (Figure 2). At 7 and 8 wk, the body weight of PURE was 100 g greater than that of CROSS ($P < 0.05$). This difference ($P < 0.05$) increased to 200 g from the 10th to the 12th wk. Thereafter, the difference diminished, whereas it has to be considered that starting
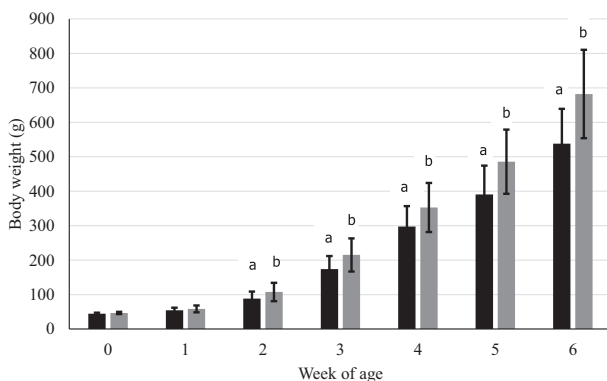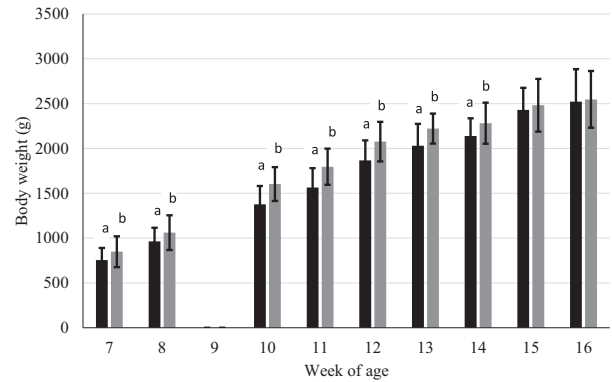

Figure 2. Body weight development of male broilers of Bresse-Gauloise (grey) and Bresse-Gauloise × New Hampshire (black) from the 7th until 16th wk of age (least squares means ± standard deviation; [a,b]Genotypes differ at $P < 0.05$). n = 150 at week 7 and starting from week 12 animals were slaughtered at weekly intervals (n = ~10 per week).

from the 12th wk the heaviest animals of each genotype were slaughtered every week. Until week 12, daily weight gains were 21.7 g in CROSS and 24.1 g in PURE ($P < 0.05$). Animals that were fattened until week 16, reached a daily weight gain of 22.1 (CROSS) and 22.3 g (PURE) ($P > 0.05$). These values are greater than those obtained for Bresse-Gauloise with the final fattening stage in a mobile house by Pinent et al. (2015). Comparing male Bresse-Gauloise with slow-growing commercial broilers (ISA 657) under organic conditions, Muth et al. (2016) reported a weight gain of 31 g/d for Bresse-Gauloise and of 34 g/d for the slow-growing broilers. Values are far above weight gains observed for the 2 dual-purpose breeds Padovana and Polverara (Tasoniero et al., 2017). Until week 19, the average body weight of both genotypes increased to more than 3,000 g, though the number of animals was limited given that the majority of animals was slaughtered before. The increase in body weight observed during the late fattening stage emphasizes the suitability of the studied production system with an extended slaughtering period of at least 1 mo starting at 10 to 12 wk of age, especially for small-scale farming and direct marketing. The greater inhomogeneity in body weight can thus be compensated by the extended period of slaughter.

Feed consumption during the mixed-sex rearing period averaged 1.9 kg of starter diet (week 1 to 6), equaling to a daily consumption 45 g. From the 7th until 12th wk, animals consumed 3.3 kg of broiler diet, equaling to 70 g/d. In the mobile house male broilers fed 90 g daily, which sums up to a further consumption of 1.9 kg until the end of week 16. Overall, feed conversion related to the slaughter weight at 16 wk of age was calculated at 2.8, whereas it has to be considered that male broilers were raised together with their female counterparts, so that the feed consumption is underestimated given that growth performance of females was lower (as presented in the following). It has to be stressed that feed consumption, though a crucial parameter for broiler production, could not be

Figure 1. Body weight development of male and female Bresse-Gauloise (n = 300, grey) and Bresse-Gauloise × New Hampshire (n = 300, black) during the first 6 wk of age (least squares means ± standard deviation. [a,b]Genotypes differ at $P < 0.05$).

Table 1. Least squares means of slaughter traits of Bresse-Gauloise (PURE) and Bresse-Gauloise × New Hampshire (CROSS) slaughtered at 12 to 19 wk of age and classified according to their slaughter age (12 to 15 wk; 16 to 17 wk; 18 to 19 wk).

| | Genotype | | | | | | PSE[1] | P-value | | |
| | PURE | | | CROSS | | | | | | |
Slaughter age	12 to 15 wk	16 to 17 wk	18 to 19 wk	12 to 15 wk	16 to 17 wk	18 to 19 wk		Genotype (G)	Slaughter age class (S)	G × S
n	24	11	17	20	40	72				
Live weight at slaughter (g)	2330	2673	3139	2441	2641	3281	88.5	–	–	–
Slaughter weight (g)[2]	1562	1806	2135	1586	1801	2247	67.1	–	–	–
Dressing (%)	67.06	66.68	68.05	65.38	68.11	68.53	0.864	0.87	0.01	0.05
Abdominal fat (%)	1.87	2.07	2.30	1.93	2.54	1.99	0.181	0.51	0.02	0.01
Heart (%)	0.75	0.74	0.67	0.80	0.77	0.78	0.039	0.02	0.31	0.30
Liver (%)	2.28	2.47	2.35	3.04	2.96	2.43	0.183	0.01	0.04	0.07
Gizzard (%)	2.36	3.04	2.88	3.73	3.61	3.14	0.327	0.01	0.35	0.11

[1]Pooled standard error.
[2]Eviscerated and plucked carcass without head and feet.

differentiated between genotypes in this study. The obtained values are comparable to those of Stadig et al. (2016) for mixed-sex slow-growing broiler chicken. The competitiveness of mixed-sex Bresse-Gauloise broilers compared with slow-growing broilers was also found by Pinent et al. (2015). Clearly, feed conversion is diminished in dual-purpose chicken compared with commercial broilers with large differences between genotypes (Pinent et al., 2015; Castellini et al., 2016; Tasoniero et al., 2017).

Slaughter Traits and Meat Quality Dressing percentage did not differ between genotypes, but increased with increasing slaughter age especially in CROSS ($P < 0.01$) (Table 1). Values are comparable to the 69.1% reported for male Bresse-Gauloise by Muth et al. (2016) and 66.6% for male and female Bresse-Gauloise by Pinent et al. (2015), but higher than those reported by Jaturasitha et al. (2008) for Bresse-Gauloise broilers fattened until 16 wk of age. Compared to slow-growing commercial genotypes dressing percentage is at least 2% lower (Pinent et al., 2015; Muth et al., 2016). The interaction between genotype and slaughter age class affected ($P < 0.01$) the proportion of abdominal fat, which increased with increasing slaughter age in PURE, but not in CROSS. The ratio of the heart relative to the carcass weight was higher in CROSS than PURE ($P < 0.01$), whereas the ratio of liver remained constant between slaughter age classes in PURE, but decreased in CROSS ($P < 0.01$, interaction effect). The ratio of gizzard was higher in PURE than in CROSS ($P < 0.01$). The measured ratios are greater than that observed in Italian dual-purpose breeds (Tasoniero et al., 2017).

Genotypes did not differ with regard to the ratios of legs, breast, and wings related to carcass weight ($P < 0.05$) (Table 2). Values are similar to those observed in other studies for Bresse-Gauloise (Jaturasitha et al., 2008; Pinent et al., 2015; Muth et al., 2016) and clearly emphasize that the marketing as whole carcasses because of the relatively low breast percentage seems favorable for Bresse-Gauloise and its crossbreds. Regarding meat quality traits, a difference between genotypes ($P < 0.05$) was

Table 2. Slaughter and meat quality traits assessed at the breast muscle of Bresse-Gauloise (PURE) and Bresse-Gauloise × New Hampshire (CROSS) slaughtered at 12 wk of age and classified according to their live weight at slaughter (least squares means; n = 10; [a,b]Genotypes differ at $P < 0.05$).

| | Genotype | | |
Trait	PURE	CROSS	PSE[1]
Breast (% of carcass weight)	34.3	34.7	2.7
Legs (% of carcass weight)	16.0	15.5	1.7
Wings (% of carcass weight)	11.0	12.1	1.9
pH$_{24h}$	5.81	5.83	0.04
Lightness (L*-value)	54.8	53.6	1.0
Redness (a*-value)	4.9	6.2	0.6
Yellowness (b*-value)	5.0	5.9	0.5
Moisture content (%)	58.9	59.1	1.1
Drip loss (%)	7.8	7.9	0.6
Cooking loss (%)	20.7[b]	18.2[a]	0.7
Thawing loss (%)	6.6	6.7	0.8

[1]Pooled standard error.

only observed for cooking loss, which was greater in PURE (20.7%) than in CROSS (18.2%). With reference to the literature, it was lower than observed by Jaturasitha et al. (2008) (22.1%), but higher than reported by Muth et al. (2016) (17.8%) for Bresse-Gauloise and by Stadig et al. (2016) (16.6%) for slow-growing commercial broilers. Drip losses were similar to those of Jaturasitha et al. (2008), but thawing losses about 2% higher than in the mentioned study, in which Bresse-Gauloise were slaughtered at 16 wk of age. Overall, crossbreeding Bresse-Gauloise with New Hampshire lead to a reduced growth performance but did not affect carcass composition or meat quality compared to purebreds.

Welfare and Health Measures All foot pad lesions recorded at 3, 7, or 11 wk of age were scored as 2, i.e., < 0.2 cm (Table 3). The prevalence of lesions increased from less than 5% at 3 wk of age to more than 13% at 7 wk independent from genotype. Until week 11 it decreased, but was higher in CROSS (9.3%) than in PURE (1.6%). At 7 wk of age, 6.0% of the PURE and less than 1.0% of the CROSS animals were dirty ($P = 0.01$). Respective values at week 11 were 11.5% for PURE and 7.6% for CROSS ($P = 0.31$). Lameness, toe

Table 3. Welfare measures assessed at 3, 7, and 11 wk of age in Bresse-Gauloise (PURE) and Bresse-Gauloise × New Hampshire (CROSS) during the mixed-sex rearing period (n = 150).

Measure	Score				P-value (χ^2 test)
	1	2	3	4	
Foot pad lesions		Week 3			
CROSS	0.0	0.0	4.0	96.0	0.32
PURE	0.0	0.0	2.6	97.4	
		Week 7			
CROSS	0.0	0.0	13.1	86.1	0.46
PURE	0.0	0.0	13.9	86.9	
		Week 11			
CROSS	0.0	0.0	9.3	90.8	0.01
PURE	0.0	0.0	1.6	98.4	
Dirtiness		Week 3			
CROSS	2.3			97.7	0.88
PURE	2.6			97.5	
		Week 7			
CROSS	0.7			99.6	0.10
PURE	6.0			94.0	
		Week 11			
CROSS	7.6			92.4	0.31
PURE	11.5			88.5	

Figure 3. Laying performance of Bresse-Gauloise (grey) and Bresse-Gauloise × New Hampshire (black) hens from the 18th to the 75th wk of age (weekly averages; calculated based on the effective number of hens).

wounds, missing toes, and an abnormal comb color were only observed rarely and were not subjected to further analysis. At slaughter, 11.7% of PURE and 18.3% of CROSS broilers had breast blisters. Collisions of the animals with perches in the mobile house may have caused this high prevalence of breast blisters. Except for coccidia, which were observed in more than 90% of the samples in weeks 4 and 5, all feces samples were free of *Capillaria* spp., *Heterakis gallinarum*, and *Ascaridia galli* eggs. Overall, crossbreeding did not affect the studied health and welfare measures. Mortality rates until week 16 were 11.2% in PURE and 5.3% in CROSS. Deaths predominantly occurred during the first 2 wk of age. In the mobile house, only 1 male broiler died. In the 9th wk, a water leakage resulted in mortalities, which are not included in the mentioned values. In general, free-range systems and especially mobile housing is often associated with increased mortality rates (Wongrak et al., 2014; Pinent et al., 2015).

Economic Evaluation Based on a fattening period of 16 wk, the measured carcass traits, effective costs for chicks, feed (0.42€/kg) and slaughtering and under assumptions of fixed costs according to Pieper (2016), production costs corrected for mortalities of 11.76€ per kg of slaughter weight for PURE and 13.39€ for CROSS were estimated. This calculation is limited by 2 factors: (1) feed consumption was differentiated between genotypes and (2) feed consumption during the mixed-sex rearing period was not differentiated between males and females. With a realistic marketing price of 13€ per kg of slaughter weight at direct marketing under the current conditions of the study region, profit was 6.02€ for PURE and 4.49€ for CROSS. Despite the high production costs, which are even higher than that estimated for male layer hybrids by Kaufmann and Andersson (2013), the studied system presents an economic alternative if premium prices can be achieved, given the high demand for regionally produced poultry meat. In
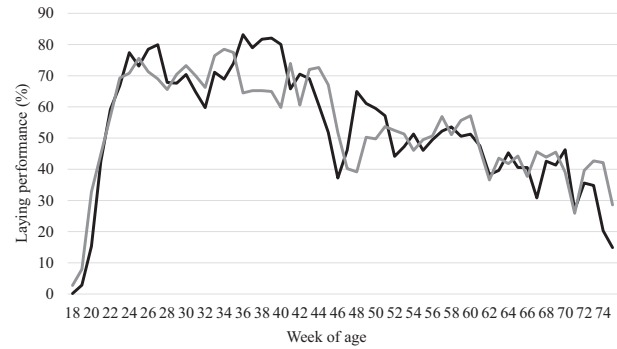
this context, mobile housing as an attractive system to consumers, might be 1 way to substantiate prices at direct marketing. Nevertheless, this economic estimation should be interpreted with care, as it is specific to the studied region being characterized with a very low production of poultry meat and at the same time a rising demand for meat produced within the region. However, the market potential and willingness to pay for alternative poultry meat production, with the increasing awareness of chicken culling in mind, increase steadily in various regions (Gremmen and Blok, 2016; Gangnat et al., 2018). Independent whether raised in a mobile house or static stable, free-range husbandry of dual-purpose broilers should be considered as an important markerting argument. This undermines the need for robust genotypes.

Laying Hens

During the laying period, inside temperature and relative humidity in the mobile house averaged 14.0°C and 59.9%, respectively. The according values outdoors were 9.9°C and 56.8%. During hours with an outside temperature below 10°C, which occurred on 5 d, inside temperatures averaged 4.8°C and did not fall below 0°C. This is an important issue for mobile housing to ensure that water in the storage tanks does not freeze.

Laying Performance and Egg Quality Until 24 wk of age, the laying performance of CROSS increased to 77%, which was reached by PURE 1 wk later (Figure 3). The laying performance ranged between 60 and 83% until 45 wk of age, whereas CROSS peaked at a higher level. Both genotypes showed an increased brooding behavior between week 45 and 48 and during this period laying performance decreased below 40%. Consequently, current and future breeding programs for dual-purpose chicken should consider brooding behavior as an important selection criterion to limit the negative effects on laying performance. After the laying performance dropped for 2 wk, it increased at 49 wk of age to 65% in CROSS and 50% in PURE. At the end of the laying period from week 61 to 73 of
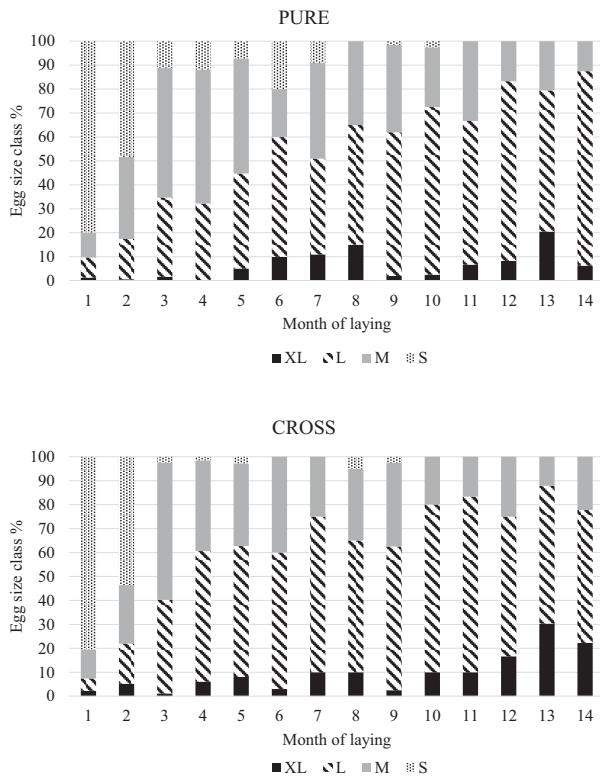
Figure 4. Distribution of egg size classes (S: < 53 g; M: 53 to 63 g; L: 63 to 73 g; XL: > 73 g) of Bresse-Gauloise (top) and Bresse-Gauloise × New Hampshire (bottom) during the laying period (18 to 75 wk of age).

age, the performance of both genotypes varied between 25 and 47%. With on average 54.5% for PURE and 54.2% for CROSS, the threshold of 200 eggs laid per year was not reached by any of the genotypes. Performance was slightly lower than that observed by Schmidt et al. (2016) recorded under mobile housing conditions for Bresse-Gauloise and far below that of other dual-purpose genotypes (Lohmann Dual 1, Walesby Special, Novogen Experimental). The egg size distribution changed drastically during the laying period (Figure 4). In the first month of the laying period, S-sized eggs (<53 g) amounted more than 80% of the eggs in both genotypes, which proportion decreased below 50%. In the subsequent months, the percentage of S-sized eggs was with less than 5% lower in CROSS than PURE. Over the whole laying period, CROSS laid larger eggs compared with PURE, whereas in the 10th month of laying 20% of the eggs were M-sized, 70% L-sized, and 10% XL-sized. The respective values for PURE were 3% S, 25% M, 70% L, and 2% XL. During the last months of the laying period, the proportion of XL-sized eggs was larger in CROSS compared with PURE. Compared to findings of Schmidt et al. (2016) with an overall S-size ratio of 17%, the egg size distribution was more favorable in this study. In general, a larger variation of egg sizes in dual-purpose chicken when compared to commercial laying hybrids has to be considered in terms of marketing strategies, for example selling eggs

of varying sizes in the same package. Crossbreeding in this study positively affected the egg size distribution, but did not improve laying performance. However, the reduction of S-sized eggs may be an important compensation for the diminished growth performance of the male CROSS when compared to PURE broilers.

The weight of the eggs that were subjected to egg analysis were heavier in CROSS than in PURE ($P = 0.009$) and increased from 50 g at the beginning to 68 g at the end of the laying period (Figure 5). The egg shape index was particularly from week 60 to 66 of age higher in CROSS than in PURE ($P = 0.046$). The decrease of the egg shape index, which is caused by a stronger increase of the egg length in relation to the egg width, is well in agreement with recent findings of Molnar et al. (2016). Generally, eggs with an index of 72 to 76% are defined as normal, below as sharp and above as round. Accordingly, the eggs of the present study were at the threshold to sharp eggs, which are associated with an altered breaking strength (Duman et al., 2016). The 2 genotypes did not differ regarding the albumen height ($P = 0.059$), which decreased from more than 80 to 60 Haugh units at the end of the laying period ($P < 0.001$, week effect). After the change of the laying hen diet in week 58, it decreased below 60 and increased steadily until week 63 of age. Independent of the genotype ($P = 0.871$), the breaking strength decreased from its peak in week 33 (40 N) to 30 N in week 60 ($P = 0.002$, week effect). In comparison to commercial laying hybrids, the breaking strength was lower (Lolli et al., 2013), though remained above 30 N during the last weeks of the laying period. Given that dual-purpose genotypes might compensate their lower laying performance by a prolonged laying period, genetic improvements in terms of breaking strength are warranted. In the present study, however, the persistency of laying did not warrant an extension of the laying period beyond 75 wk of age.

Yolk color did not differ between genotypes ($P = 0.88$) (Figure 6), and ranged with few exceptions between 11.5 and 12.5, corresponding to a yellow to yellow–orange yolk color. After the diet change in week 58, Roche-values decreased for 6 wk and thereafter increased again. Eggs of both genotypes were creamy in color, with greater L^*- and lower a^*- and b^*-values of PURE compared with CROSS at the beginning of the laying period ($P = 0.05$, interaction effect, data only shown for L^*-value).

The shell ratio ranged between 10.0% at the beginning and 9.5% at the end of laying ($P = 0.118$, genotype effect). In contrast, the yolk ratio increased from 25 to 30% at week 48 and then remained constant at 29% in both genotypes until the end of laying ($P = 0.99$, genotype effect). Shell thickness varied between 0.31 and 0.37 mm, whereas PURE had thicker shells than CROSS ($P = 0.039$). This course in combination with shell ratio depicts the decreasing breaking strength and emphasizes the need for genetic improvement. To the author's knowledge, there are no comparable data available in the literature for the 2 tested genotypes, yet.
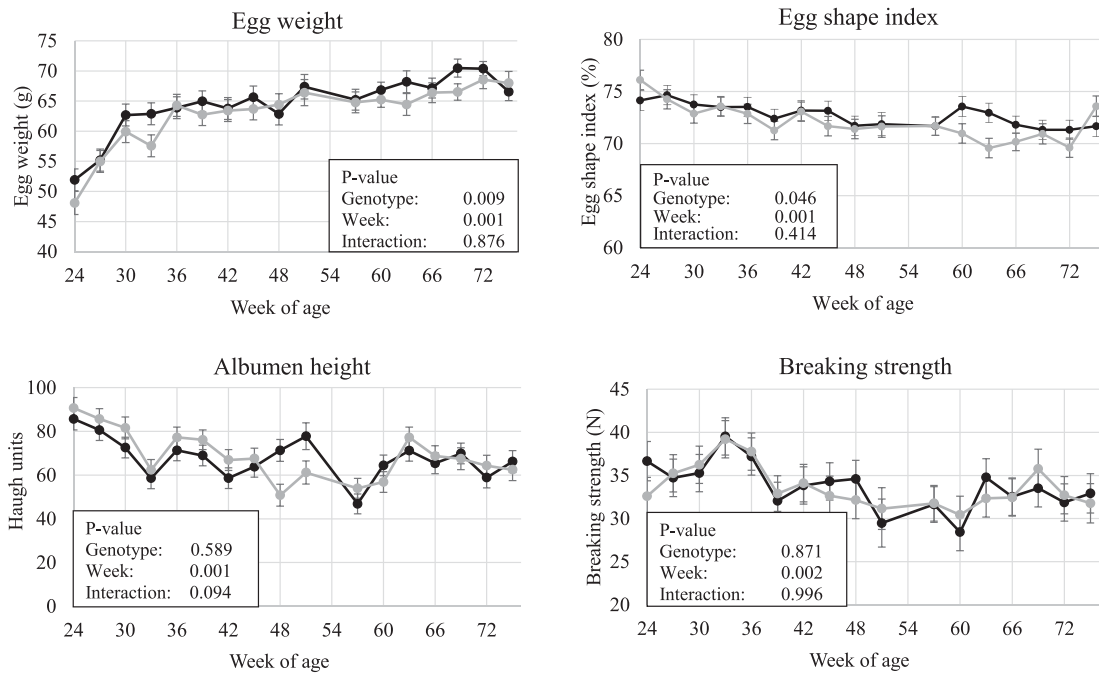
Figure 5. Egg weight (g), egg shape index (%), albumen height (Haugh units), and breaking strength (N) of Bresse-Gauloise (grey line) and Bresse-Gauloise × New Hampshire (black line) hens from 24 to 75 wk of age (least squares means ± standard error).

Figure 6. Yolk color, sheel color, and albumen index of Bresse-Gauloise (grey line) and Bresse-Gauloise × New Hampshire (black line) hens from 24 to 75 wk of age (least squares means ± standard error).
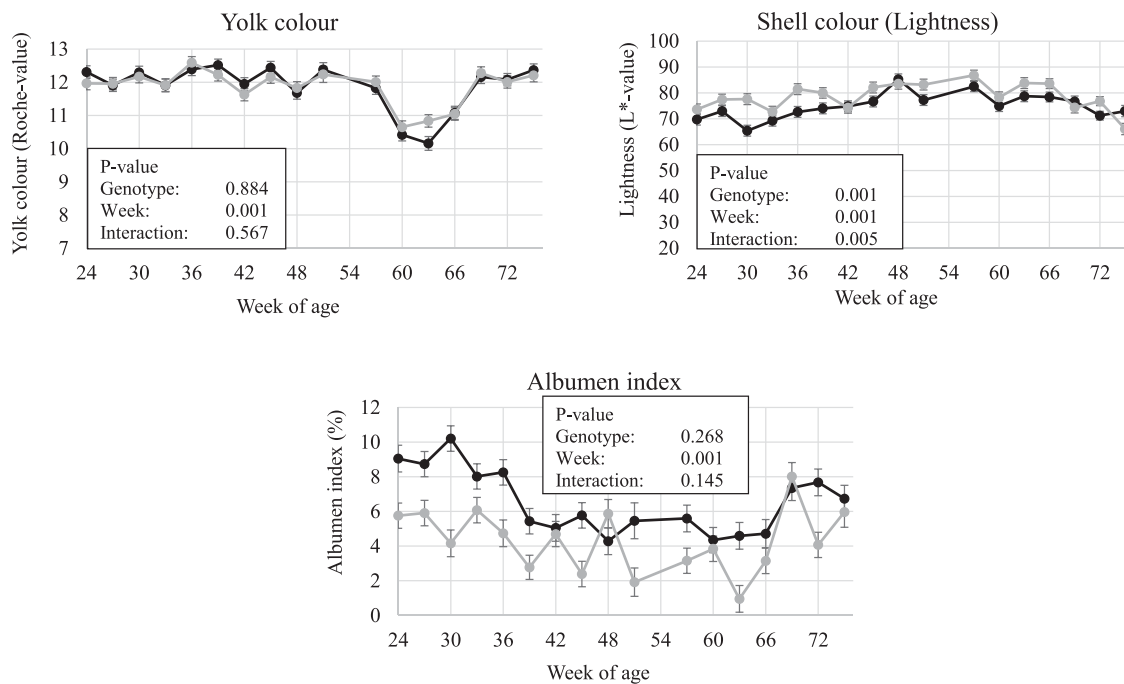
Genotypes did not differ regarding the egg shell index ($P = 0.858$). Compared to commercial hybrids, values were lower and did not show the characteristic course with an increase followed by a decrease during the laying period (Lolli et al., 2013; Molnar et al., 2016). Large variations were found for the albumen index during the course of the laying period, though without genotype differences ($P = 0.268$) (Figure 6). On average, meat

spots were found in 0.23% of CROSS and 0.14% of PURE, and blood spots in 0.17% and 0.11%, respectively ($P > 0.05$).

Egg weight was negatively correlated to albumen height (r = -0.36) and egg shape index (r = -0.27), so that bigger eggs were sharper in form. Correlation between egg size and breaking strength was low (r = −0.09). Egg size was negatively correlated to sheel ratio

Table 4. Slaughter and meat quality traits assessed at the breast muscle of Bresse-Gauloise (PURE) and Bresse-Gauloise × New Hampshire (CROSS) hens at 75 wk of age (least squares means ± standard error; n = 10; [a,b]Genotypes differ at $P < 0.05$).

	Genotype		
Trait	PURE	CROSS	PSE[1]
Live weight at slaughter (g)	2,957	2,857	90
Carcass weight at slaughter (g)	1,878	1,836	65
Dressing (%)	62.5	63.3	1.8
Breast (% of carcass weight)	31.5	32.3	1.5
Legs (% of carcass weight)	18.4	16.9	0.5
Wings (% of carcass weight)	10.0	10.2	1.1
pH_{24h}	5.44	5.61	0.21
Lightness (L*-value)	54.13	51.03	1.10
Redness (a*-value)	3.44	2.80	0.45
Yellowness (b*-value)	6.84	6.31	0.57
Moisture content (%)	62.48[b]	61.36[a]	0.38
Drip loss (%)	6.56	6.60	0.22
Cooking loss (%)	25.17	23.82	2.86
Thawing loss (%)	3.72	3.35	0.49

[1]Pooled standard error.

(r = –0.41) and positively to yolk ratio (r = 0.18). Egg shape index was positively correlated to breaking strength (r = 0.28) and negatively to yolk ratio (r = –0.15). Correlations between breaking strength and shell ratio, shell index and shell thickness varied between r = 0.43 and 0.47. Results are thus in wide agreement with Lolli et al. (2013), who proposed a stronger relationship between breaking strength and sheel thickness compared with egg size in commercial hybrids. For the genotypes of this study, coresponding data are not available, yet.

Body Weight and Feed Conversion At the beginning of laying, body weight of PURE hens was with 2,040 ± 194 g (least squares means ± standard deviation) higher than of CROSS (1,820 ± 162; $P < 0.05$). Genotypes did neither differ at 42 wk of age or 6 mo of laying, (PURE: 2,981 ± 306 g; CROSS: 2,934 ± 297 g; $P > 0.05$) nor at the end of laying at week 75 of age (PURE: 2,817 ± 330 g; CROSS: 2,771 ± 297 g; $P > 0.05$).

Measured for both genotypes together, feed consumption during the laying period ranged between 118 and 143 g/d and averaged 124 g/d. Considering the average laying performance and egg size of the eggs, which were weighed individually during egg quality measurements (PURE = 62.9 g vs. CROSS = 64.5 g), feed conversion was 3.61 in PURE and 3.54 in CROSS. Overall, animals consumed more than 1 kg of feed more per kg of egg mass compared to the crosses between meat and layer lines Lohmann Dual (2.60) or Walesby Special (2.46) and more than 1.5 kg more compared to commercial layer hybrids (2.19) (Schmidt et al., 2016). Low conversion rates can mainly be explained by the comparably low laying performance.

Slaughter and Meat Quality Traits Genotypes did not differ for any of the measured slaughter traits ($P > 0.05$, Table 4). With an average slaughter weight of 1,850 g, carcasses of both genotypes were much heavier than commercial hybrids. Marketing of slaugh-

Table 5. Welfare measures assessed at 16, 42, and 75 wk of age in Bresse-Gauloise (PURE) and Bresse-Gauloise × New Hampshire (CROSS) hens raised under mobile housing conditions.

	Score				P-value
Measure	1	2	3	4	(χ^2 test)
Plumage at back, belly, and neck		Week 16			
CROSS	0.0	0.0	0.0	100.0	1.00
PURE	0.0	0.0	0.0	100.0	
		Week 42			
CROSS	5.1	15.4	3.9	75.6	0.02
PURE	1.3	4.0	12.0	82.7	
		Week 75			
CROSS	2.7	20.3	12.1	64.9	0.16
PURE	1.7	8.0	17.9	73.4	
Plumage at tail		Week 16			
CROSS	0.0	0.0	3.1	96.9	0.88
PURE	0.0	0.0	4.6	95.4	
		Week 42			
CROSS	9.0	10.3	3.9	76.9	0.10
PURE	14.7	2.7	9.3	73.3	
		Week 75			
CROSS	5.4	8.1	6.8	79.7	0.68
PURE	3.6	14.3	5.4	76.7	
Foot pad lesions		Week 16			
CROSS	0.0	3.0	7.3	89.8	0.70
PURE	0.0	3.5	5.7	90.8	
		Week 42			
CROSS	2.6	24.4	25.6	47.4	0.02
PURE	5.3	36.0	34.7	24.0	
		Week 75			
CROSS	2.4	18.9	23.0	55.7	0.04
PURE	2.3	30.6	29.3	37.8	

ter hens consequently bears a large potential, though limited to a niche market. With more than 7%, the percentage of abdominal fat was higher compared with commercial hybrids (Urselmanns and Damme, 2011). Except for moisture content, which was higher in PURE ($P < 0.05$), genotypes did also not differ in meat quality traits ($P > 0.05$) (Table 4). In comparison to the male broilers, drip, cooking, and thawing loss were lower.

Welfare and Health Traits At 42 wk of age, 5.1% of CROSS and 1.3% of the PURE hens were found with featherless areas of more than 5 cm² (score 1) at the back, belly or neck, whereas 75.6 and 82.7%, respectively, had a good plumage ($P = 0.02$, χ^2 test) (Table 5). At 75 wk of age, prevalence of score 2 and 3 increased in both genotypes ($P = 0.16$). For plumage at the tail, at neither of the observations a genotype difference was found. PURE had a higher prevalence of foot pad lesions compared with CROSS, whereas lesions were predominantly classified as score 2 or 3 ($P = 0.02$ at week 42 and $P = 0.04$ at week 75). Wounds were only observed at 42 and 75 wk of age, and in less than 4% of CROSS and 9% of PURE ($P = 0.72$ for week 42 and $P = 0.48$ for week 75). At week 42, keel bone deformations were found in less than 2% of the animals. Keel bone deformations at week 75 were found in 1.1% of PURE and 13.5% (4.1% score 1; 5.4% score 2; 4.1% score 3) of CROSS ($P = 0.72$). Breast blisters were found in 6.4 and 0.0% at week 42 ($P = 0.33$) and 22.6 and 13.3% at week 75 ($P = 0.47$) in CROSS and PURE, respectively. Other measures including dirtiness,
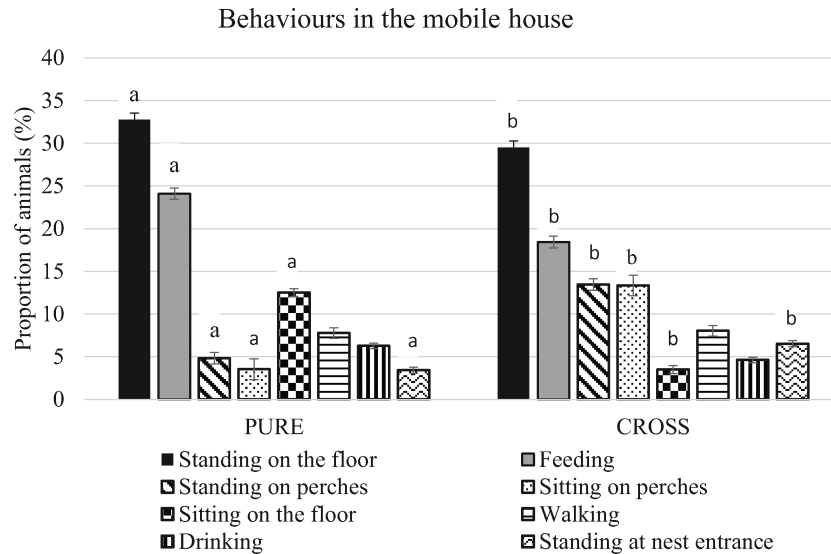
Behaviours in the mobile house

Figure 7. Behaviors observed in the upper floor of the mobile house of Bresse-Gauloise (PURE) and Bresse-Gauloise × New Hampshire hens raised in a mobile house ([a,b]Genotypes differ within behaviors at $P < 0.05$).

lameness, missing toes, toe wounds, plantar abscesses, and abnormal comb color were only observed rarely. The mortality rate during the laying period was 15.8% in PURE and 10.7% in CROSS. Values are high, but similar to studies conducted under mobile housing conditions (Schmidt et al., 2016).

Throughout the whole laying period, *Ascarida galli*, *Heterakis gallinarum*, *Capillaria* spp. eggs and Coccidia oocysts were rarely found in the fecal samples and not further analyzed. At slaughter, on average 0.05 and 0.15 *A. galli* worms were found in the small intestine in PURE and CROSS, respectively. In the large intestine, 3.75 and 6.30 *H. gallinarum* worms were counted. Low infection rates can be explained by the fact that the pasture area was not used as free-range area for poultry prior to the study. Generally, infection rates and intensities in commercial laying hybrids are high in the region (Wuthijaree et al., 2017).

Behaviour Averaged over the whole observation period, 25.3% of CROSS and 24.7% of PURE animals were observed on the free-range ($P > 0.05$). Compared to the 12.5% found in commercial free-range hens, this depicts a good use of the free-range (Chielo et al., 2016). Differentiated by the distance to the pop holes, CROSS animals stayed close to the pop holes at a higher proportion (75%) than PURE (69%) ($P < 0.05$). Only 3% of the animals on the free-range used the distant area, independent of the genotype ($P > 0.05$). On the free-range, foraging was the most often observed behavior. Thereby, PURE (38.8%) were foraging at a lower rate compared with CROSS (40.9%) ($P < 0.05$). Among the other behaviors, a difference was found for sitting/lying, which was performed more often in PURE (20.8%) than in CROSS (17.9%) ($P < 0.05$). Foraging together with pecking were also the most recorded behaviors of free-ranging hens raised in conventional sheds in the study of Chielo et al. (2016). Dust and

sand bathing were observed more often in this study, and may be explained by the fact that moving the mobile house to new free-range areas with fresh pasture attracts hens to stay on the free-range. In the mobile house, differences between genotypes were more pronounced than on the free-range. Standing on the floor followed by feeding were most often observed. PURE were standing (32.8%) and feeding (24.1%) more often than CROSS (29.5 and 18.4%) ($P < 0.05$) (Figure 7). In agreement with this study, Campbell et al. (2016) found more foraging/feeding performed on the free-range and more resting indoors under conventional husbandry conditions. Values for animals dust bathing outdoors were with 3 to 5% in dependence of the stocking density, and are thus similar to those observed in the present study. It has to be considered that dust bathing, which can be performed in the lower floor of the mobile house, was not assessed in this study. Data under mobile housing conditions are not available, yet. The small differences for behavioral traits measured between the 2 genotypes might also explain the limited variations for welfare and health traits. The applied methods to assess these traits are however not sufficient to draw further conclusions on the mentioned relationships and warrant further studies, especially focusing on the assessment of agonistic behavior in dual-purpose chicken.

Economic Evaluation Based on effective costs for chicks, feed (0.45€/kg feed) and slaughtering and under assumptions of fixed costs according to Pieper (2016), production costs corrected for mortalities of 47.33€ for PURE and 47.73€ for CROSS were estimated. Under consideration of a market price of 40 Cent per egg, the measured laying performance and the market price for slaughter hens (8€/kg slaughter weight), revenues of 102.22€ for PURE and 101.09€ for CROSS were calculated. Consequently, profit was 40.44€ per hen for

PURE and 38.91€ for CROSS. Despite of the high feed costs and low laying performance, the system gained profit, which is comparable to mobile housing using commercial laying hybrids with a laying performance of 280 eggs per year under German production conditions (Pieper, 2016). Again, it is emphasized that this economic estimation is specific to the studied region and has to be taken with care when transferred to other regions. As already pointed out for the broilers, the demand for alternative poultry production avoiding the killing of male layer hybrids will increase the willingness to pay in many regions.

CONCLUSIONS

Compared to crossbred Bresse-Gauloise × New Hampshire, purebred Bresse-Gauloise male broilers showed a superior growth performance resulting in an overall economic benefit, whereas carcass composition and meat quality did not differ. An extended fattening period with a continuous slaughtering over several weeks provides 1 possibility to compensate for the larger variation of body weights in dual-purpose broilers when compared with commercial hybrids.

Crossbreds were not able to compensate the lower growth performance of the male broilers with an increased laying performance. Egg quality was similar for both genotypes, and emphasized the need for genetic improvements in terms of shell breaking strength. Across all measured welfare and health parameters in the male broilers and laying hens, neither of the 2 genotypes proved to be superior to the other. Large body weights at the end of laying undermine the potential for sale as slaughter hens. Mortality rates in combination with the elevated prevalences of foot pad lesions and breast blisters have to be considered as the major welfare issues under mobile housing conditions. Overall, none of the studied genotypes proved to be superior in terms of welfare and health traits. The present study clearly demonstrated that the production of dual-purpose chicken is under certain conditions economic feasible, particularly at small-scale. Even if mobile housing is cost-intensive, it has to be considered as an important argument at direct marketing to sell both eggs and meat at premium prices.

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