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# Incubation characteristics, growth performance, carcass characteristics and meat quality of Saxonian Chicken and German Langshan bantam breeds in a free-range rearing system

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## Abstract

**Background/introduction:** In the absence of evidence-based findings for Saxonian Chicken (SaChi) and German Langshan bantam (GLB), which are indigenous endangered German fancy chicken breeds, the objective of the present study was to characterise their growth performance and meat potential in an extensive free-range system

**Methods:** A total of 340 hatching eggs from SaChi and 439 eggs from GLB were provided by private breeders, from which 263 SaChi (77.3%) and 174 GLB (39.6%) hatched ($p < 0.001$)

**Results:** By week 20, SaChi reached body weights of 2362.3 ± 315.3 g (mean ± SD; roosters) and 1624.7 ± 158.9 g (hens), while GLB weighed 1089.7 ± 148.3 g (roosters) and 820.4 ± 89.5 g (hens). Fitting the non-linear regression of growth data to the Gompertz function estimated asymptotic body weights of 3131.4, 2363.9, 1359.2 and 1107.3 g, with inflection point times of 10.5, 10.3, 9.2 and 9.3 weeks in male SaChi, female SaChi, male GLB and female GLB, respectively. Moderate plumage damage was observed on days 18, 35, 53, 70 and 105 in SaChi and on days 53, 70 and 105 in GLB, while all birds presented completely intact plumage on day 140. Using a binary logistic regression model, breed, age and sex were shown to affect the plumage condition ($p < 0.001$ each). Roosters were slaughtered in week 20. No breed effects were detected in the carcass yield (SaChi: 68.8 ± 1.7%, GLB: 69.7 ± 1.8%) ($p = 0.135$) or abdominal fat share (SaChi: 0.89 ± 0.15%, GLB: 1.08 ± 0.14%) ($p = 0.281$). The percentage of valuable cuts (breast fillets and legs) in the carcass was 43.8 ± 1.9% for SaChi and 43.1 ± 3.0% for GLB ($p = 0.490$)

**Discussion/conclusions:** In conclusion, this study provides insights into the performance traits and welfare indicators during the rearing of two endangered German chicken breeds.

**KEYWORDS**
animal genetic resources, growth curves, hatching, meat quality, poultry, sensory assessment, slaughter performance

## 1 | INTRODUCTION

As a result of the increasing divergence between fancy and commercial poultry breeding, the production of chicken meat and eggs in developed countries is currently realised predominantly by using hybrid strains from commercial breeding companies, in which breeding products are based on a few nucleus lines (Preisinger, 2021). On the other hand, indigenous chicken breeds are preserved by private breeders without commercial interests (Weigend et al., 2014). Scientific morphological comparisons have recently been made to accurately differentiate between breeds that appear roughly visually similar (Lukanov & Pavlova, 2021). Major problems in the small populations of indigenous chicken breeds include a rapid increase in inbreeding (Malomane et al., 2019), a lack of systematic performance testing and the absence of controlled breeding management (BLE, 2017). The need for the global conservation of animal genetic resources was recognised long ago in the Convention on Biological Diversity (CBD, 1992) and the Global Plan for Animal Genetic Resources, as well as the Interlaken declaration (FAO, 2007); this need was recently confirmed by Pilling et al. (2020). Due to their independent breeding histories and different selection criteria, indigenous chicken breeds can possess genetic traits that are potentially useful for commercial breeding programs (Malomane et al., 2019; Weigend et al., 2014). Indigenous chicken breeds are characterised by a high adaptability to different environmental conditions, robustness and improved integument conditions (Ajayi, 2010; Tiemann et al., 2020). Further potential uses of poultry genetic resources relate to agricultural niche production and the preservation of old, endangered breeds as a component of cultural–historical heritage (Weigend et al., 2014). Thus, in addition to the fattening of so-called brother roosters of egg layers and in-ovo sexing, niche production with dual-purpose chickens is currently being discussed as a possible alternative to the killing of male day-old chicks from laying strains, which will be abolished in Germany in 2022 (Preisinger, 2021; Tiemann et al., 2020).

In Germany, indigenous poultry breeds of particular preservation interest were identified in the National Program for the Conservation and Sustainable Use of Animal Genetic Resources (BLE, 2019). These breeds cover a wide range of the global genetic diversity of domestic chickens (Malomane et al., 2019). Among the 39 chicken breeds, Saxonian Chicken (SaChi), bred around 1880 in the Ore Mountains (Saxony/Germany), are classified as extremely endangered, with a breeding population of only 81 roosters and 334 hens from 44 breeders (BLE, 2019). The German Langshan bantam (GLB) is one of the three listed bantam breeds and was bred in northern Germany in 1910. GLB are classified as critically endangered, with 161 roosters and 517 hens from 82 breeders (BLE, 2019).

In the agricultural use of fancy chickens, individual studies have shown advantages among indigenous breeds in terms of egg quality (Di Rosa et al., 2020; Ianni et al., 2021; Lordelo et al., 2017; Lordelo et al., 2020; Rizzi & Marangon, 2012), animal-welfare-related indicators (Damme & Schreiter, 2020; Tiemann et al., 2020), immunological properties (Habimana et al., 2020) and meat quality (Escobedo del Bosque et al., 2020; Müller et al., 2018; Nguyen Van et al., 2020) compared with high-performing hybrid strains. However, valid data are currently limited to a few breeds. In the absence of evidence-based findings for SaChi and GLB with respect to their hatching characteristics, body mass development, integument conditions, meat performance and quality, the objective of the present study was to characterise these traits over the rearing period in an extensive free-range system considered typical for fancy chicken rearing.

## 2 | MATERIALS AND METHODS

In this study, hatching characteristics, performance traits during rearing, the integument conditions, carcass performance and meat quality of two local German chicken breeds were characterised. For this purpose, we selected the local chicken breeds SaChi and GLB (Figure 1), which are officially considered indigenous and endangered chicken breeds by the Advisory Board for Animal Genetic Resources of the German Society for Breeding Science (BLE, 2019). The original plumage colours of the breeds were black, white, and cuckoo in SaChi and black, white, blue-laced and red in GLB chickens (BLE, 2019).

### 2.1 | Hatching eggs and hatching

Hatching eggs were provided by private German hobby chicken breeders on a voluntary basis. Since the eggs came exclusively from noncommercial farms, there was no standardised husbandry in terms of housing type, group size, litter, feed and feeding of the parent birds. We agreed with the breeders in advance that the hatching eggs would be collected for a maximum of 12 days and stored at 70% relative humidity with a temperature between 8 and 14°C. The breeders were instructed to mark the eggs individually before delivery. Hatching eggs were stored on egg racks (Ovobest Eiprodukte GmbH & Co. KG, Neuenkirchen-Vörden/Germany) and transported to the hatchery in hatching egg cartons (Jens Bernhardt, Penig, Germany). The maximum transport time from the breeders to the hatchery was 7 h. After transport, the eggs were stored for 24 h at room temperature for acclimatisation. Eggs were then hatched artificially in incubators (Favorit-Olymp 660; Heka, Rietberg/Germany) in a private hatchery specialising in fancy chickens (Heiner Nipper's Hatchery Inc., Großschirma/Germany), according to current guidelines (Brown, 2009). Hatchery personnel performed egg candling on days 10 and 18

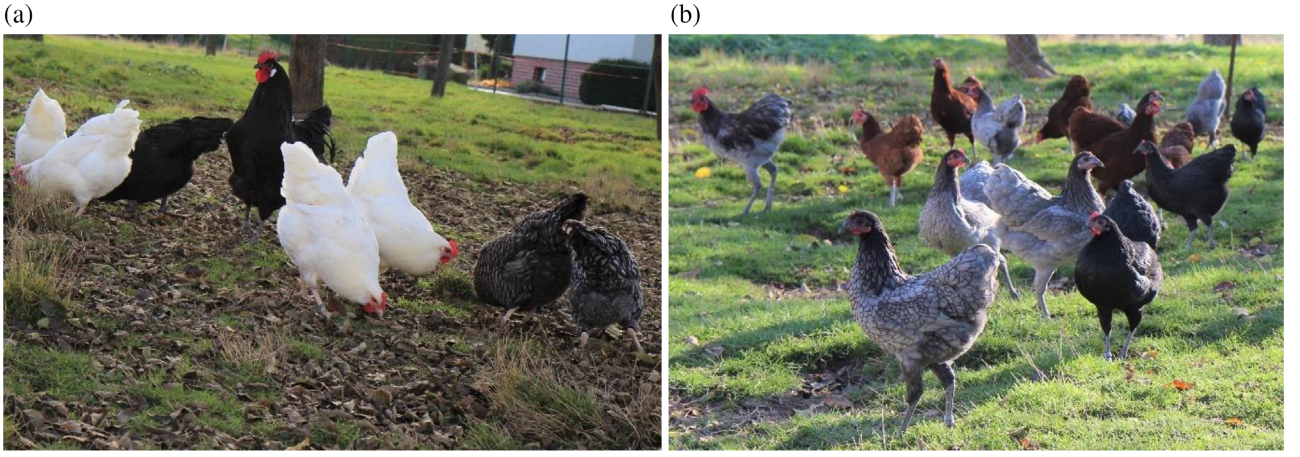



**FIGURE 1** Phenotype of Saxonian Chickens (a) and German Langshan bantams (b)

using a Powerlux egg tester (Olba, Coevorden/The Netherlands). On day 10, eggs without visible embryonic development were declared as 'unfertilised'. Subsequently, on day 18, all eggs that did not show timely embryonic development were grouped as showing 'early embryonic death' (Brown, 2009). Unfertilised eggs and those with a dead or severely retarded embryo are removed at each candling. After a total incubation period of 21 days, that hatched from the eggs were categorised under the groups 'hatched' (i.e., that left the egg alive) or 'late embryonic death' (i.e., found dead in the shell after egg transfer). The hatching date was 16 May 2020. Individual animal identification of the chicks was performed using wing tags (Rista Kükenmarke, Sollfrank KG, Nuremberg/Germany). All of the hatched chicks were marked without a previous selection. The vaccination program (see below) started at the hatchery with a vaccination against Marekt's disease.

## 2.2 | Animals, housing and management

The animals were kept on a private farm (Rump's Agricultural Farm, Dresden-Ockerwitz/Germany), which was a project farm at the Dresden University of Applied Sciences. A total of 263 SaChi and 174 GLB were housed in the farm's mixed-sex rearing pens. In a solid barn, a compartment with a floor area of 7 × 4 m was available for each breed as a single-level housing system. Electric radiant heaters (Siepmann GmbH, Herdecke/Germany) were used as the heating source to achieve the recommended ambient temperature for the chicks (Lohmann Breeders, 2017). For this purpose, chicks were located in an area of 2 × 2 m around the heat source in a chick ring formed by partition grids (Siepmann GmbH) until day 10. Thereafter, the animals had access to the entire barn area. The floor area was littered with softwood shavings and straw pellets (Einstreuprofi, Seelingstädt/Germany). A total length of 10.5 m of wooden perches (3 × 5 cm) was available per compartment. From week 9, the animals had access to a free-range area (15 × 25 m per group) with grass vegetation for 8 h daily.

Each compartment had a window area of 1.5 × 0.5 m. The lighting program was based on a regime specified for fancy chickens according to Damme and Schreiter (2020), with high-frequency light sources (aviary lamps; Tageslichtlampen24.de, Kiel/Germany). Feed was provided in four round feeders per compartment (Heka), each with a feeding surface of 125 cm. For the water supply, a nipple drinking system (Kari Farming, Herzebrock/Germany) with 12 nipples was available in each compartment. As additional environmental enrichment materials, pecking stones (Vilolith medium; Deutsche Vilomix Tierernährung GmbH, Neuenkirchen-Vörden/Germany) and hard-pressed alfalfa blocks (Einstreuprofi, Seelingstädt/Germany) were offered ad libitum in the barn.

A two-phase feeding program was provided with a complete diet for the chicks from weeks 1 to 10 (Küken Premium, Agrargenossenschaft Dorfchemnitz, Zwönitz/Germany; 11.4 MJ ME/kg, 18.7% crude protein, 4.5% crude fibre, 0.44% methionine, 1.1% calcium, 0.7% phosphorus, 0.18% sodium) and a complete diet for the pullets from weeks 11 to 20 (Junghennen Premium, Agrargenossenschaft Dorfchemnitz, Zwönitz/Germany; 11.2 MJ ME/kg, 15.8% crude protein, 4.7% crude fibre, 0.36% methionine, 1.0% calcium, 0.7% total phosphorus, 0.18% sodium). All diets were offered ad libitum in mash form. In addition, 2 g of grit per animal with a particle size of 2–4 mm (Geflügel-Magenkies, Einstreuprofi, Seelingstädt/Germany) was provided once a week. To prevent infectious diseases, the flock veterinarian carried out a vaccination program tailored to the farm. The prophylaxis included vaccination against Marek's disease (Nobilis Rismavac + CA126; MSD Tiergesundheit, Unterschleißheim/Germany), Newcastle disease (Nobilis ND Clone 30; MSD Tiergesundheit), infectious bronchitis (Poulvac IB Primer; Zoetis Deutschland GmbH, Berlin/Germany; Nobilis IB MA5; MSD Tiergesundheit; AviPro IB H52, Elanco Animal Health, Bad Homburg/Germany), infectious laryngotracheitis (Nobilis ILT; MSD Tiergesundheit), coccidiosis (Paracox 8; MSD Tiergesundheit), Mycoplasma gallisepticum infection (Nobilis MG 6/85; MSD Tiergesundheit) and infectious bursal disease (AviPro Gumboro vac, Elanco Animal Health, Bad Homburg/Germany).

**TABLE 1** Sample size for determination of the individual animal's body weights and integument scoring during the rearing period

| | Number of animals[a] (male/female) | | | | | |
|---|---|---|---|---|---|---|
| **Breed/plumage colour** | **Day 18** | **Day 35** | **Day 53** | **Day 70** | **Day 105** | **Day 140** |
| Saxonian Chickens | | | | | | |
| Black | 82 (40/42) | 82 (40/42) | 81 (39/42) | 75 (33/42) | 64 (22/42) | 61 (21/40) |
| White | 46 (26/20) | 46 (26/20) | 46 (26/20) | 29 (10/19) | 25 (8/17) | 25 (8/17) |
| Cuckoo | 51 (30/21) | 51 (30/21) | 51 (30/21) | 38 (17/21) | 31 (11/20) | 31 (11/20) |
| Total | 179 (96/83) | 179 (96/83) | 178 (95/83) | 142 (60/82) | 120 (41/79) | 117 (40/77) |
| German Langshan bantams | | | | | | |
| Black | 60 (32/28) | 60 (32/28) | 60 (32/28) | 48 (24/24) | 33 (10/23) | 33 (10/23) |
| White | 18 (12/6) | 18 (12/6) | 17 (12/5) | 15 (10/5) | 12 (7/5) | 12 (7/5) |
| Blue-laced | 53 (26/27) | 51 (24/27) | 51 (24/27) | 44 (20/24) | 31 (9/22) | 31 (9/22) |
| Red | 29 (15/14) | 29 (15/14) | 29 (15/14) | 24 (13/11) | 19 (8/11) | 19 (8/11) |
| Total | 160 (85/75) | 158 (83/75) | 157 (83/74) | 131 (67/64) | 95 (34/61) | 95 (34/61) |

[a]Since the study was part of a project on the conservation of animal genetic resources, breeding animals were also provided to interested persons during rearing, which explains the reduction of the sample size beyond the animal losses.

## 2.3 | Study design and data collection

The animals were kept in accordance with the legal requirements of the EU (Council Directive 1999/74/EC, minimum standards for the protection of laying hens) (Council Directive 1999/74/EC of 19 July 1999) and Germany (Animal Welfare Act, available online: https://www.gesetze-im-internet.de/tierschg/BJNR012770972.html ; Order on the protection of animals and the keeping of production animals, available online: https://www.gesetze-im-internet.de/tierschnutztv/ ). In particular, the principles and specific guidelines of the Guide for the Care and Use of Agricultural Animals in Research and Teaching (American Dairy Science Association, 2010) were implemented. In accordance with Directive 2010/63/EU of the European Parliament and the Council on the protection of animals used for scientific purposes (Council Directive 2010/63/EU), no invasive treatment of the hens was performed. The roosters were slaughtered for human consumption as part of the normal agricultural use after completion of rearing at the age of 20 weeks. The following legal requirements were met during slaughter: Regulations (EC) No. 853/2004, No. 1099/2009, and the German Ordinance on the Protection of Animals at Slaughter or killing and on the implementation of Council Regulation (EC) No. 1099/2009.

Feed consumption was determined for each of the two groups via continuous initial and back-weighing (scale: Defender 3000, Ohaus, Parsippany, NJ/USA) in 35-day periods. Animal losses were recorded daily.

To indirectly quantify the occurrence of feather pecking and cannibalism, integument scoring was performed in all animals during rearing at six time points (days 18, 35, 53, 70, 105 and 140). The sample size at each observation date is shown in Table 1. Since the study was part of a project on the conservation of animal genetic resources, breeding animals were also provided to interested persons during rearing, which explains the reduction in the sample size beyond animal losses. In addition to integument scoring, the individual body mass of each animal was recorded (scale BAT1; Veit Electronics, Moravany/Czech Republic). At the same time, the uniformity among each sex within the breed was calculated on the basis of the individual animals' masses according to Pottgüter et al. (2018). Uniformity indicates the proportion of sample animals presenting body mass weights within ±10% of the arithmetic mean of the sample (Jeroch & Müller, 2018). As a further measure of homogeneity within the group, we determined the percentage of deviation of each individual animal mass from the arithmetic mean of body masses for each plumage colour and sex within the breed.

Integument scoring was based on Keppler (2017) for the traits of plumage damage, skin and feather follicle injuries, foot pad condition and keel bone condition. The scoring of the plumage was differentiated according to the back, belly (including cloacal region and ventral rump), dorsal neck and wing feathers. In addition to the four individual scores, a total plumage score was calculated for each individual animal by adding the individual scores (Schreiter et al., 2020b). The feathers on the front of the neck and the breast were not included in the scoring, as feather damage in these areas due to mechanical stress from the feeding trough does not provide strong evidence for severe feather pecking (Bilcik & Keeling, 1999). To assess skin injuries and injuries of the blood-filled feather follicles in the pullets, all body regions except for the head and feet (including toes) were considered relevant. For all traits, a three-level rating scale (Keppler, 2017) was applied, with a score of 0 representing an intact condition, a score of 1 representing moderate damage and a score of 2 representing severe damage. Integument scoring was performed by three observers who completed a training period on 300 animals to determine inter-observer reliability.

The roosters ($n = 22$ per breed) were slaughtered at day 140 according to regulation (EC) No. 853/2004 and No. 1099/2009. After 8 h of fasting, the birds were weighed alive, electrically stunned (9 s, 100–150 mA), bled via neck incision, scalded (58°C, 170 s), defeathered, gutted and cooled at 4°C for 2 h. Weights of the carcasses, abdominal fat, gizzard, liver and heart were determined according to Damme et al. (2015) (scale: Navigator NV1101; Ohaus). The relative share of internal organs was calculated on the basis of the carcass weights. After chilling, all carcasses were transported at 4°C for ca. 2 h to the laboratory facilities of the Department of Animal Sciences of the Georg-August-University Göttingen/Germany and treated as previously described by Siekmann et al. (2018) and Altmann et al. (2020). Briefly, 24 h after slaughter (24 h *post mortem* [p.m.]), the carcasses were weighed and manually dissected. The *Musculi pectorales superficiales* (MPS) were used to analyse the meat quality traits. The MPS (skinless) and both legs (with bones) were weighed. The MPS and leg yields were calculated as the percentage of carcass weight. The pH values were determined 24 h and 6 days p.m. with a pH meter by inserting the pH electrode and a thermometer (Portamess 913; Knick, Berlin/Germany) into the center of the MPS. Beforehand, the pH meter was calibrated using standardised buffers (pH 4.0, 7.0). Lightness ($L^*$), redness ($a^*$) and yellowness ($b^*$) values were determined with a chromameter CR-400 (Konica Minolta, Langenhagen/Germany) in triplicate on the ventral non-defected (no discolourations or petechial haemorrhages) surface of the MPS. The aperture size was 8 mm, the illuminant D65 was used, and standard observer angle was 10°. For subsequent analysis of the cooking loss and shear force, as well as for the sensory assessment (see below), the meat samples were sealed under 80% $O_2$/20% $CO_2$ atmosphere and stored for 5 days at 4°C. Packaging films were made of polyethylene terephthalate/polypropylene (PP) film (<3 $cm^3/m^2$/24 h/bar $O_2$ transmission rate and <12 $cm^3/m^2$/24 h/ bar $CO_2$ transmission rate). The breast was further used to determine the cooking loss and shear force. After being trimmed of exterior fat, the breast was cooked sous vide at 77°C for 60 min in a hot-water bath (incubation/deactivation bath, Gesellschaft für Labortechnik mbH, Burgwedel/Germany) to reach a core temperature of approximately 75°C. Samples were cooled to room temperature outside the vacuum bag, and cooking loss was expressed as the percentage of the initial weight. Afterwards, the samples were stored overnight at 4°C until shear force was measured using the razor blade method (Stable Micro Systems, Godalming/UK) according to Altmann et al. (2020).

A consensus sensory evaluation was conducted at the YYY as an external service. This evaluation fulfilled the requirements of ISO 858944. Evaluation was performed by 12 trained panelists, who were experienced in the descriptive sensory profiling of pork and poultry products (data not shown). The assessors, selected according to ISO 8586:2012 (ISO, 2012), carried out consensus descriptive sensory profiling of the SaChi and GLB legs and breast fillets. Assessors were first exposed to the products during a training period, during which a list of attributes was collectively defined. In total, 26 attributes (legs) and 29 attributes (breast fillets) were chosen to be evaluated according to Siekmann et al. (2018). The meat of the legs ($n$ = 12 from six roosters, one leg with skin per panelist) and breast fillets ($n$ = 12 from six roosters, two pieces from the middle of the fillet without skin per panelist, 2 × 2 × 2 cm each) was used for the final assessments. The differences in preparation between the breeds resulted from their different weights, with the legs prepared in an oven (SaChi: 190°C, 40 min, final core temperature 80°C; GLB: 190°C, 30 min, final core temperature 80°C), and one piece of each breast fillet prepared in an oven using different parameters (SaChi: 190°C, 30 min, final core temperature 75°C; GLB: 190°C, 20 min, final core temperature 80°C) or in a frying pan (SaChi: 10 ml of plant oil [Mazola Keimöl; Peter Kölln GmbH & Co. KgaA, Elmshorn/Germany], roasted 1 min per side; GLB: 5 ml of plant oil, roasted 30 s per side). Each sample was served on a warmed plate. Sensory evaluation was conducted using a 10 cm unmarked line scale (scale: from 0 – no perception to 10 – strongest perception), and the data were electronically recorded using the EyeQuestion survey software (Logic8 BV; Elst, The Netherlands). A moderated discussion via video chat, in which the panelists shared their individual impressions with the other panelists, resulted in a consensus on intensities, reflecting differences in the samples.

## 2.4 | Statistical analyses

Microsoft Excel (Version 2013; Microsoft Corporation, Redmond, WA/USA) was used for the data collection and processing and the creation of the selected diagrams. For further descriptive and inferential statistical analyses, the IBM SPSS Statistics program (Version 23; SPSS Inc., Chicago, IL, USA) was used.

Cross tabulations and Fisher's exact test were used to analyse the nominal data (i.e., to compare hatching results between breeds and between plumage colours within breeds).

The body weights and slaughter characteristics (slaughter weight, carcass yield, share of valuable cuts in the carcass, pH 24 h p.m., pH 6 days p.m., $L^*$ 24 h p.m., $a^*$ 24 h p.m., $b^*$ 24 h p.m., cooking loss and shear force) were found to be normally distributed, as determined by a Kolmogorov–Smirnov test and graphical analysis using Q–Q plots, but not for the percentage of deviation from the mean body mass (Weiß, 1999).

*T*-tests for independent samples (du Prel et al., 2010) were used to compare the slaughter traits between the SaChi and GLB chickens. Error correction to adjust the significance level due to multiple testing was performed using the Benjamini–Hochberg procedure (Victor et al., 2010).

ANOVA linear models with a between-subject effect (plumage colour) and a within-subject effect (age) (one-within-one-between ANOVA) were used to compare the courses of the individual animal body masses over the rearing period between the different plumage colours within each breed and sex (Rasch et al., 2010). For the body weights in week 20, a test for the homogeneity of variance between the breeds and between the sexes within each breed was performed using Levene's test (Weiß, 1999). The percentage of deviation from the mean body mass in week 20 (i.e., the end of the rearing period) was tested as a non-normally distributed trait using a Kruskal–Wallis test with the effects of breed and colour within breed (du Prel et al., 2010). As a test between the breeds, and in the presence of significant differences between the plumage colours, a pairwise comparison was made using a Mann–Whitney *U*-test (du Prel et al., 2010).

The time-dependent individually recorded growth data were fitted to the growth function of Gompertz (1825). For this process, we used the following re-parameterisation $W(t) = A\ \exp(-\exp(-kG(t - T_i)))$, where $W(t)$ is the expected value (body mass) as a function of time, and $t$ is time (i.e., weeks since hatching); $A$ represents the upper asymptote (mature value); $kG$ is the growth-rate coefficient (which affects the slope); and $T_i$ represents the time at inflection (Tjørve & Tjørve, 2017). To obtain valid growth curves, we included data from the first laying period in this analysis (i.e., individual body weights at weeks 25, 30, 35 and 40). Parameter estimations were performed in the IBM SPSS Statistics program (Version 23; SPSS Inc., Chicago, IL, USA). The Gompertz model was characterised by an inflection point such that the $A/e$ of the total growth occurred before the inflection point, with the remainder occurring after (Grimm & Ram, 2009). The coordinates of the point of inflection, inflection point time (IPT) and weight at inflection point (IPW) were obtained as follows (Rizzi et al., 2013; Tjørve & Tjørve, 2017): IPT = $T_i$ and IPW = $A/e$ (with $e$ is Eulert's number). The maximum daily weight gain was computed by substituting the genotype-specific calculated IPT in the derivative of the cumulative growth function of the associated genotype and sex.

A concordance analysis was performed to quantify the degree of agreement in integument scores. For this purpose, the prevalence-adjusted and bias-adjusted kappa (PABAK) was calculated as a characteristic of the inter-observer reliability according to Gunnarsson et al. (2000). With regard to the extent of agreement, the generated PABAK values were interpreted according to Landis and Koch (1977) and Kwiecien et al. (2011) as follows: ≤0.20 insufficient, 0.21–0.40 low, 0.41–0.60 moderate, 0.61–0.80 good and > 0.80 very good. A Mann–Whitney $U$-test was used to evaluate the effect of the fixed factor of breed on the ordinally scaled integument characteristics at each observation date (du Prel et al., 2010).

A binary logistic regression (BLR) model (Baltes-Götz, 2012) with total plumage score as the dependent variable and breed, sex and age as independent variables was fitted to the data. In the second step, additional BLR models were calculated separately for each of the two breeds with the independent variables of plumage colour, sex and age. For the models, independent variables and interactions were retained using a backward selection approach when $p < 0.1$ in an attempt to reduce the type II error risk while maintaining a stringent type I error risk of 5% (Hosmer & Lemeshow, 2000). Multiple logistic, rather than ordinal, regression models were used because some scores were occupied by only very few observations. For multiple logistic regressions, the ordinal data scaling (as defined by Keppler, 2017) was transformed into nominal scaling (the total plumage score was 0 for scores of 0 and 1 for scores of ≥1). The absence of multicollinearity was ensured by calculating the Pearson's correlation coefficient and performing a collinearity diagnosis with the variance inflation factor and condition index (Field, 2013; Menard, 2002). We also calculated Nagelkerke's $R^2$ values to explain the extent of variation in the dependent variables explained by the model. Nagelkerke's $R^2$ values ≥0.5 were considered 'very good', and values in the range of $0.4 \geq R^2 < 0.5$ were considered 'good' (Backhaus et al., 2016).

Furthermore, the breed effect on the occurrence of plumage damage was examined based on survival-time analysis using a Kaplan–Meier curve and log-rank test (Zwiener et al., 2011). The first occurrence of plumage damage (total plumage score of an animal ≥1) was considered as the event, and the observation period ranged from hatching to week 20. Animals that left the study before the occurrence of the event were treated as censored data.

In all of the described inferential statistical analyses, differences were considered statistically significant for $p \leq 0.05$ and tended to be significant at $0.05 > p \leq 0.1$.

## 3 | RESULTS

### 3.1 | Hatching eggs and hatching characteristics

A total of 340 hatching eggs from SaChi (eight breeders with 13 breeding groups) and 439 eggs from GLB (seven breeders with 18 breeding groups) from parents with different plumage colours as follows: SaChi: black – $n = 189$ eggs, five breeders, six breeding groups, white – $n = 55$ eggs, three breeders, four breeding groups, cuckoo – $n = 96$ eggs, two breeders, three breeding groups; GLB: black – $n = 120$ eggs, four breeders, five breeding groups, white – $n = 34$ eggs, one breeder, one breeding group, blue-laced – $n = 164$ eggs, two breeders, six breeding groups, red – $n = 121$ eggs, two breeders, six breeding groups) were provided by the breeders. Hatching outcomes are visualised in Figure 2. Significant differences were found between the breeds ($p < 0.001$) with significantly higher proportions of unfertilised eggs and early embryonic death, and a lower proportion of hatched chicks in GLB (SaChi 9.7, 4,4, 8.6 and 77.3% and GLB 29.7, 18.9, 11.8 and 39.6% for unfertilised eggs, early embryonic death, late embryonic death and hatched chickens, respectively). Furthermore, significant differences were found between the plumage colours within both breeds ($p < 0.001$). In SaChi, the proportion of hatched chicks was higher in the white plumage colour in comparison with black (SaChi – black 11.6, 6.3, 11.6 and 70.4%, SaChi – white 7.3, 0.0, 3.6 and 89.1%, SaChi – barred 7.3, 3.1, 6.3 and 83.3% for unfertilised eggs, early embryonic death, late embryonic death and hatched chickens, respectively). In GLB, the proportion of early embryonic death was higher in the red plumage colour in comparison with black, and the proportion of hatched chicks was lower in the red plumage colour in comparison with black and white (GLB – black 25.0, 12.5, 14.2 and 48.3%, GLB – white 17.6, 17.6, 8.8 and 55.9%, GLB – blue-laced 34.8, 16.5, 9.1 and 39.6%, GLB – red 29.8, 28.1, 13.2 and 28.9% for unfertilised eggs, early embryonic death, late embryonic death and hatched chickens, respectively). Ultimately, 263 SaChi and 174 GLB hatched successfully.

### 3.2 | Performance characteristics

During the 20-week rearing period, the average feed consumption per animal was 7.32 kg for SaChi and 5.14 kg for GLB (data not shown). Throughout the entire test period, the registered mortality was 2.3% for SaChi and 5.2% for GLB, respectively.

The body masses of day-old chicks were 41.1 ± 3.0 g (mean ± standard deviation) for SaChi and 25.3 ± 2.2 g for GLB. In week 20, SaChi

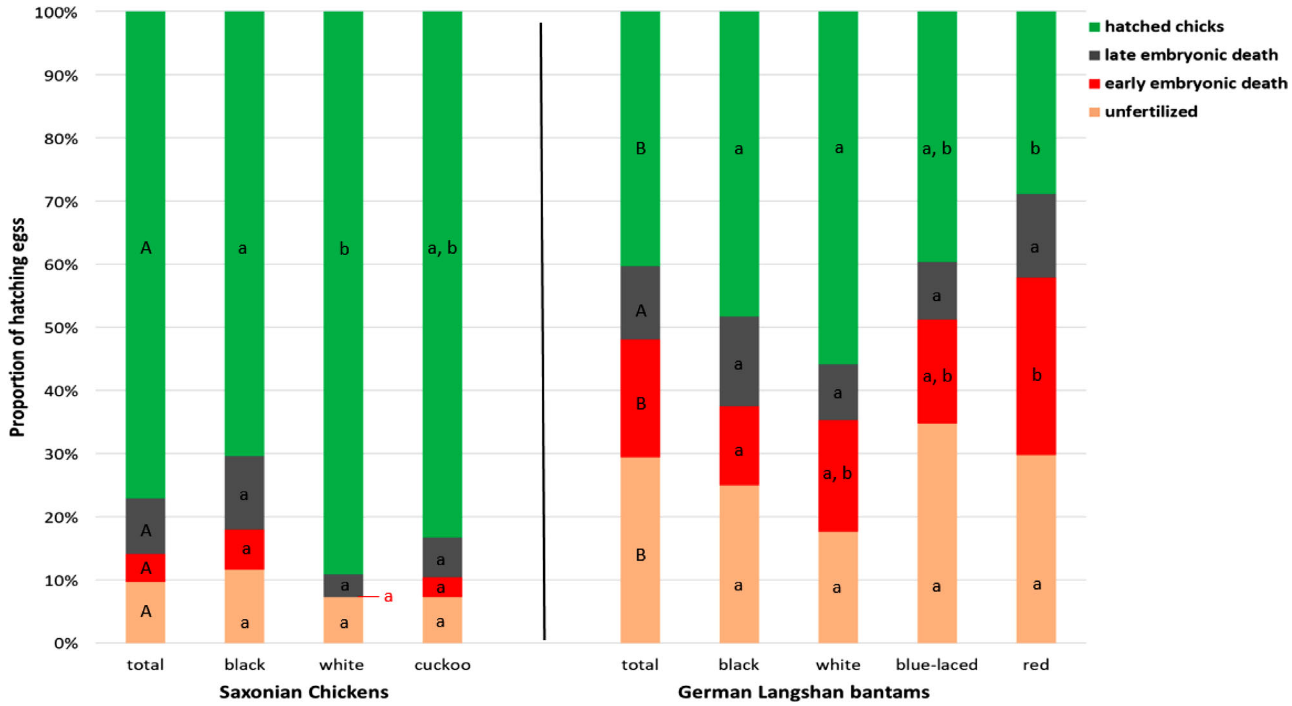



**FIGURE 2** Hatching results of the two endangered German chicken breeds Saxonian Chickens and German Langshan bantams in different plumage colours. Different indices indicate significant differences within the respective category between breeds (uppercase letters) or between colours within a breed (lowercase letters)

reached body weights of 2362.3 ± 315.3 g (roosters) and 1624.7 ± 58.9 g (hens), while GLB weighed 1089.7 ± 148.3 g (roosters) and 820.4 ± 89.5 g (hens) (Table 2). There was no homogeneity of variance between the sexes among the SaChi ($p < 0.001$) and GLB ($p = 0.002$). The body masses for the different plumage colours during rearing are summarised in Table 2. Among SaChi, white roosters had lower body masses than those of the other two colours ($p < 0.001$), and barred hens were heavier than black and white hens ($p \leq 0.004$). Black and red GLB roosters had higher body masses than white and blue-laced roosters ($p \leq 0.005$), while red GLB hens were heavier than the hens of other colours ($p < 0.001$). In week 20, SaChi showed 57.5% uniformity in body mass among the roosters and 69.2% among the hens, while GLB achieved uniformity of 58.8% among roosters and 68.9% among hens. The percentage of deviation from the mean of the body mass did not differ between breeds (median [1st-3rd quartile]: SaChi: 5.4% [3.3–9.7%], GLB: 5.2% [2.6–9.3%]) ($p = 0.456$). Among GLB, there were no differences ($p = 0.799$) in this trait between colour types (black: 5.4% [2.6–8.9%], white: 6.4% [4.0–10.3%], blue-laced: 6.3% [2.3–10.5%], red: 4.4% [2.3–9.3%). However, white SaChi chickens (11.4% [5.7–14.7%]) were less homogenous than black (4.9% [3.0–8.6%]) and barred chickens (4.7% [3.3–7.3%]) ($p < 0.001$).

The estimated growth and daily weight gain curves after non-linear regression of the growth data were fitted to the re-parameterised Gompertz function (Gompertz, 1825; Tjørve & Tjørve, 2017) and are visualised in Figure 3. The asymptotic body weights were 3131.4 g (95% confidence interval: 3045.2–3217.6 g), 2363.9 g (2321.8–2405.9 g), 1359.2 g (1309.2–1409.1 g) and 1107.3 g (1090.9–1123.7 g); the IPT was 10.5, 10.3, 9.2 and 9.3 weeks; the IPW was 1152.0 g, 869.6 g, 500.0 g and 407.4 g; and the maximum daily weight gain was 21.7, 14.1, 9.8 and 7.3 g among male SaChi ($R^2 = 0.959$), female SaChi ($R^2 = 0.954$), male GLB ($R^2 = 0.930$) and female GLB ($R^2 = 0.960$) chickens, respectively.

### 3.3 | Integument condition

PABAK values of 0.92 for plumage condition, 0.96 for skin lesions, 0.91 for foot condition and 0.90 for breastbone deformities indicated very good inter-observer reliability.

The animals showed intact foot pads and keel bones at all observation times (100% score 0). However, moderate plumage damage was observed already by day 18 in SaChi (0.3% score 1, 99.7% score 0), which increased towards days 35 (0.7% score 2, 5.7% score 1, 93.6% score 0) and 53 (0.3% score 2, 5.9% score 1, 93.8% score 0). On day 53, plumage damage was detected in GLB for the first time (0.2% score 1, 99.8% score 0). After days 70 (SaChi: 1.1% score 1, 98.9% score 0; GLB: 0.8% score 1, 99.2% score 0) and 105 (SaChi: 0.2% score 2, 5.4% score 1, 94.4% score 0; GLB: 0.5% score 1, 99.5% score 0), plumage damage was observed, all birds showed completely intact plumage on day 140. Skin injuries were observed only in SaChi on day 35 (0.6% score 1, 99.4% score 0) and 105 (5.0% score 1, 95.0% score 0). In the univariate statistical analyses, a breed effect in the occurrence of plumage damage was evident on days 35, 53 and 105 and for the presence of skin lesions on day 105 (Figure 4). Breed-specific differences were confirmed in the survival-time analysis for the first occurrence of plumage damage ($p < 0.001$; Figure S1).

**TABLE 2** Development of body mass (mean ± standard deviation) of two endangered German fancy chicken breeds during the rearing period and effect of plumage colour within breed and sex

| Breed/sex/plumage colour | Body mass (g) Day 18 | Day 35 | Day 53 | Day 70 | Day 105 | Day 140 | p Value (plumage colour)[a] |
|---|---|---|---|---|---|---|---|
| *Saxonian Chickens* | | | | | | | |
| *Roosters* | | | | | | | |
| Black | 164.6 ± 25.0 | 445.3 ± 67.7 | 667.7 ± 102.9 | 1169.8 ± 127.2 | 1704.4 ± 134.8 | 2258.4 ± 276.6 | <0.001 |
| White | 117.8 ± 32.7 | 368.1 ± 88.6 | 478.0 ± 132.9 | 1025.4 ± 178.7 | 1621.8 ± 369.1 | 2184.1 ± 402.5 | |
| Cuckoo | 170.4 ± 25.4 | 480.4 ± 68.4 | 690.6 ± 102.7 | 1322.2 ± 115.4 | 1977.5 ± 187.1 | 2614.6 ± 130.9 | |
| Total | 153.7 ± 35.0 | 415.5 ± 94.6 | 623.0 ± 142.6 | 1195.0 ± 163.9 | 1780.7 ± 244.1 | 2362.3 ± 315.3 | |
| *Hens* | | | | | | | |
| Black | 146.5 ± 17.6 | 398.2 ± 47.4 | 593.8 ± 71.1 | 969.4 ± 95.7 | 1368.6 ± 212.1 | 1618.9 ± 132.3 | <0.001 |
| White | 118.4 ± 21.1 | 326.7 ± 57.1 | 479.7 ± 85.6 | 842.3 ± 139.1 | 1249.4 ± 198.6 | 1531.4 ± 177.2 | |
| Cuckoo | 147.8 ± 19.9 | 396.3 ± 53.7 | 598.0 ± 80.5 | 1034.2 ± 118.3 | 1416.3 ± 127.6 | 1731.2 ± 133.6 | |
| Total | 139.9 ± 22.4 | 378.1 ± 60.7 | 567.4 ± 91.0 | 954.2 ± 130.6 | 1315.5 ± 198.4 | 1624.7 ± 158.9 | |
| *German Langshan bantams* | | | | | | | |
| *Roosters* | | | | | | | |
| Black | 89.3 ± 13.9 | 227.8 ± 37.3 | 362.1 ± 55.9 | 596.5 ± 79.1 | 900.3 ± 89.1 | 1147.7 ± 101.3 | 0.001 |
| White | 81.0 ± 12.8 | 204.3 ± 38.5 | 345.4 ± 49.3 | 517.4 ± 80.0 | 735.1 ± 98.3 | 950.2 ± 110.1 | |
| Blue-laced | 86.7 ± 14.4 | 205.3 ± 39.3 | 318.5 ± 14.8 | 541.2 ± 66.7 | 764.4 ± 104.8 | 1013.2 ± 139.4 | |
| Red | 94.2 ± 14.8 | 247.4 ± 34.1 | 383.0 ± 39.4 | 609.7 ± 72.5 | 911.2 ± 54.3 | 1152.3 ± 98.9 | |
| Total | 88.7 ± 13.0 | 239.9 ± 35.1 | 358.3 ± 53.2 | 573.9 ± 80.9 | 844.7 ± 121.7 | 1089.7 ± 148.3 | |
| *Hens* | | | | | | | |
| Black | 79.3 ± 11.9 | 215.2 ± 32.1 | 321.8 ± 48.2 | 492.4 ± 32.3 | 640.6 ± 38.4 | 776.8 ± 54.2 | <0.001 |
| White | 75.5 ± 11.7 | 215.1 ± 31.9 | 306.3 ± 47.9 | 505.8 ± 31.7 | 593.2 ± 51.8 | 762.4 ± 54.8 | |
| Blue-laced | 72.6 ± 12.1 | 199.4 ± 32.4 | 294.6 ± 48.6 | 492.4 ± 56.9 | 667.3 ± 64.9 | 830.1 ± 96.6 | |
| Red | 85.3 ± 11.2 | 209.2 ± 30.1 | 346.6 ± 45.1 | 502.1 ± 50.7 | 693.3 ± 66.4 | 881.2 ± 74.4 | |
| Total | 77.7 ± 12.7 | 210.0 ± 34.1 | 315.5 ± 51.0 | 497.9 ± 46.8 | 661.9 ± 64.4 | 820.4 ± 89.5 | |

[a]ANOVA linear models with a between-subject effect (plumage colour) and a within-subject-effect (age) were used to compare the course of the individual animal body masses over the rearing period between the different plumage colours within breed and sex.

The first BLR model included animals of both breeds (i.e., SaChi and GLB) and analysed the effect of breed, age and sex on the occurrence of plumage damage (Table 3). All factors of the model remained after variable selection in the significant overall model ($p < 0.001$). A Nagelkerke's $R^2$ of 0.337 indicated moderate explanatory power, and a Hosmer–Lemeshow test demonstrated the validity of the model ($p = 0.105$). Breed, age and sex were shown to affect plumage condition ($p < 0.001$ each). Within the SaChi breed, the second BLR model resulted in a Nagelkerke's $R^2$ of 0.376 (Hosmer–Lemeshow test: $p = 0.509$) and demonstrated the effect of plumage colour, age and sex ($p < 0.001$ each) (Table 3).

## 3.4 | Slaughter performance and meat quality

The characteristics of slaughter performance and meat quality are presented in Table 4. No breed effects were detected in the carcass yield (mean ± standard deviation: SaChi: 68.8 ± 1.7%, GLB: 69.7 ± 1.8%) ($p = 0.135$) or abdominal fat share (SaChi: 0.89 ± 0.15%, GLB 1.08 ± 0.14%) ($p = 0.281$). The percentage of valuable cuts (breast and legs) in the carcass was 43.8 ± 1.9% for SaChi and 43.1 ± 3.0% for GLB ($p = 0.490$) chickens. Relative to live weight, the proportion of liver (SaChi 1.72 ± 0.25%, GLB 2.08 ± 0.23%), heart (SaChi 0.41 ± 0.06%, GLB 0.53 ± 0.07%) and gizzard (SaChi 2.51 ± 0.25%, GLB 3.07 ± 0.38%) was higher among GLB compared with SaChi ($p < 0.001$ each).

The consensus sensual properties of the chicken meat samples are summarised in Figure 5. For the legs, the colour of GLB samples was more intense, while SaChi samples featured comparably higher odour intensity. However, roasted notes were more pronounced in GLB samples. In terms of taste, the SaChi meat was more intense. Likewise, a fattier, more fibrous, firmer and chewier mouthfeel was evident in this breed. In terms of aftertaste, however, higher intensities were experienced in the GLB meat. In the breast fillets, fewer differences were detected. The SaChi sample had higher values of overall intensity,

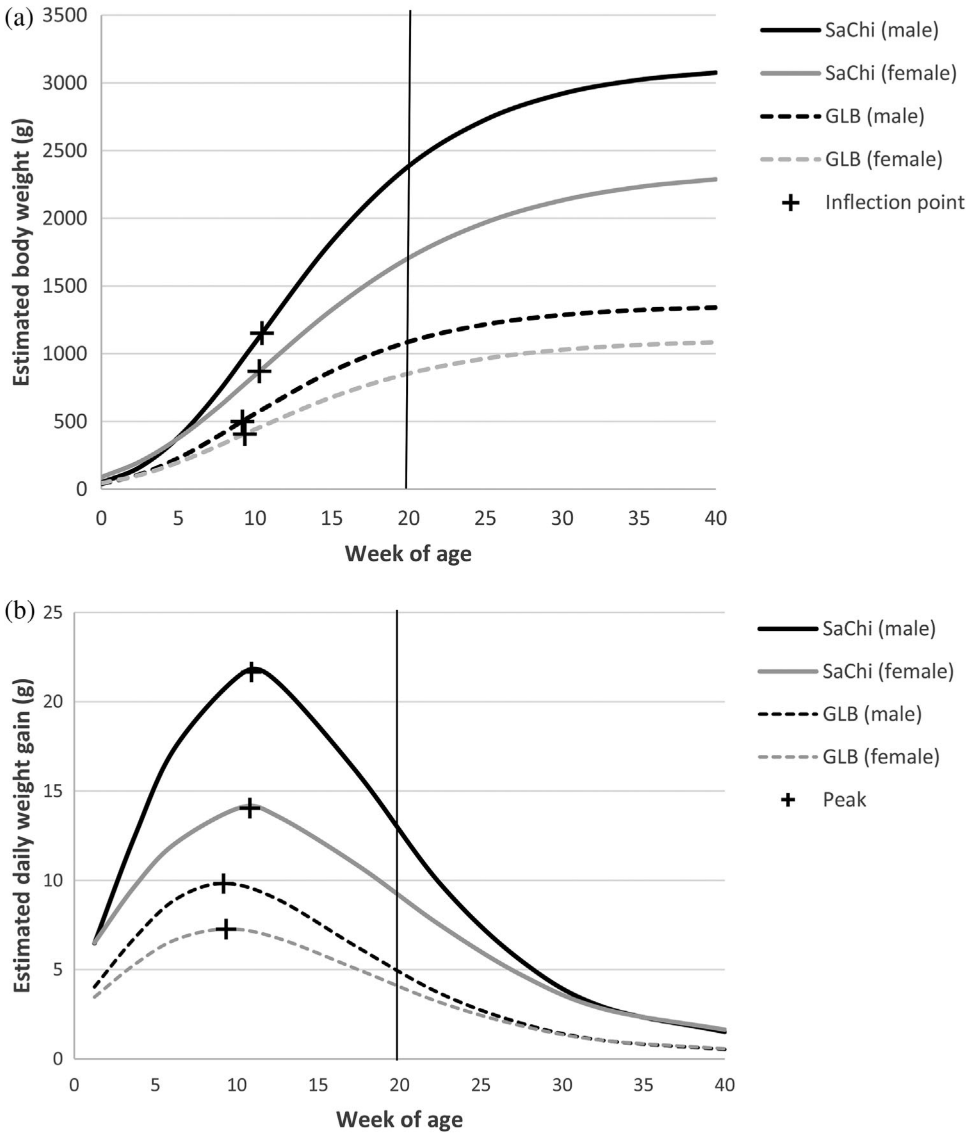



**FIGURE 3** Non-linear regression of growth data from hatching to week of age 40 of the local German chicken breeds Saxonian Chickens (SaChi) and German Langshan bantams (GLB) fitted to the Gompertz equation (a) and the derived course of daily weight gain (b). The vertical line in week 20 represents the end of the rearing period

chicken-like and roasted aromas and a sweeter taste. The taste of the GLB meat was more metallic and sour. Moreover, the breast meat of this breed was drier in terms of mouthfeel.

## 4 | DISCUSSION

In this study, the local German chicken breeds SaChi and GLB were characterised during hatching and rearing based on different traits of performance and animal welfare to obtain comprehensive information on these breeds, which may be valuable in terms of animal genetic resources, as well as providing data for possible regional niche production.

The hatching rates among the total number of hatching eggs of SaChi (~77%) and GLB (~40%) chickens were clearly lower than the results for commercial hybrid strains, which have hatching rates of ~85% (Lohmann Breeders, 2019). Damme and Schreiter (2020) also found a comparatively lower hatching rate of ~54% among the Augsburg chicken breed. The reasons for these results and the observed differences between plumage colours within the breeds are likely the non-standardised housing and feeding conditions of private breeders, in addition to genetic differences, inbreeding, targeted exterior selection, gender ratio and exterior specifics.

The body masses of the roosters at the slaughter age of 20 weeks were significantly lower among GLB than SaChi because GLB are a bantam breed. Differences in body mass between plumage colours could possibly be due to past cross-breeding to improve the exterior or indirectly due to different selection priorities. SaChi, as a non-dwarf breed, also showed decreased growth potential compared with fast-growing broilers, which reach 2376 g by week 5 (Aviagen, 2019);

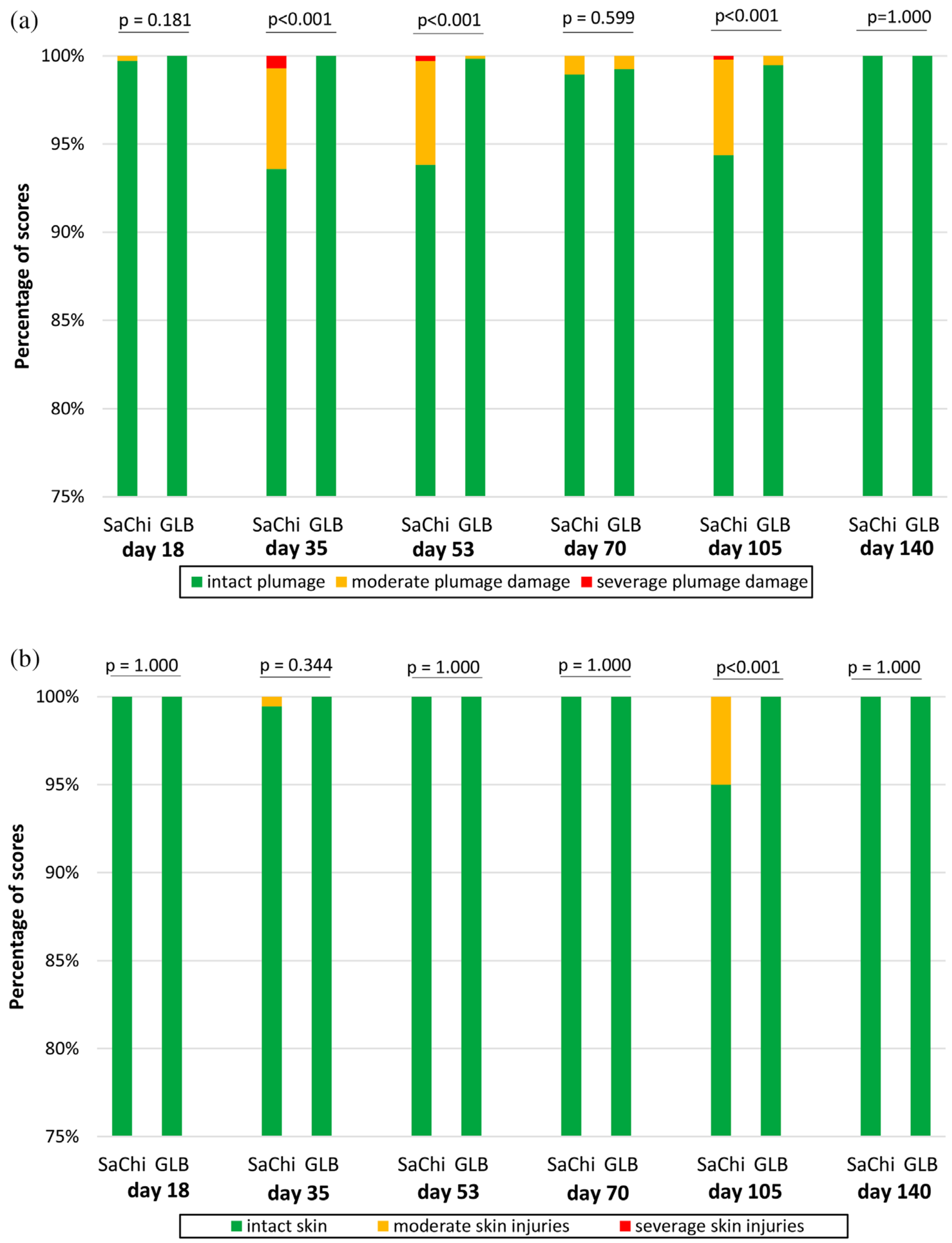
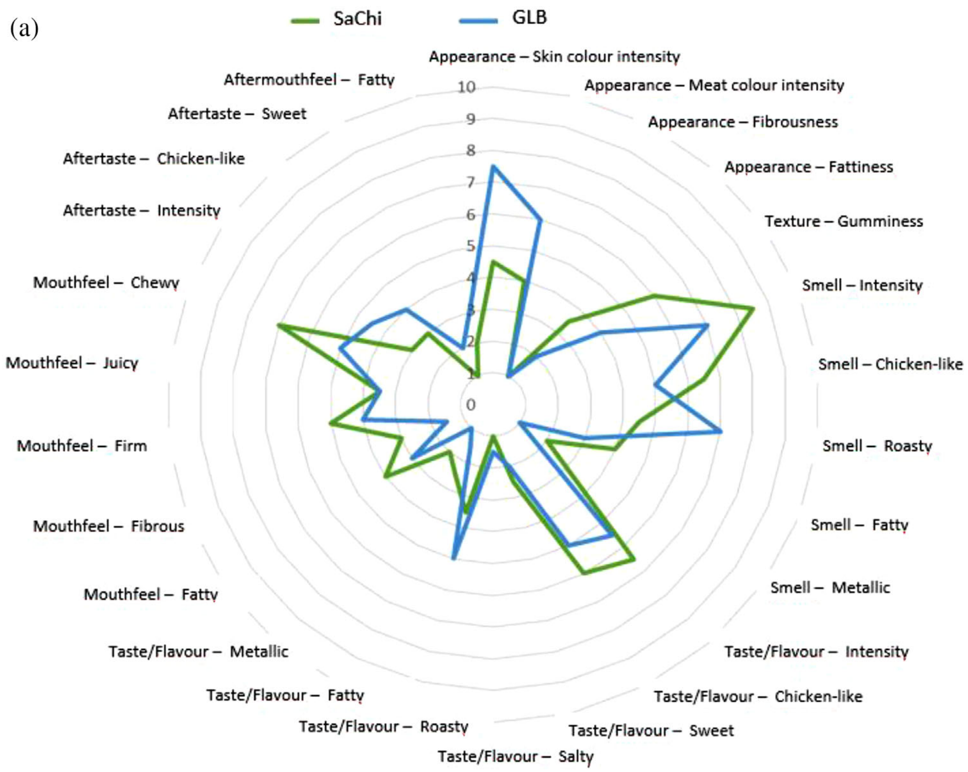



**FIGURE 4** Effect of breed on plumage condition (a) and skin injuries (b) during the rearing period in the local German chicken breeds Saxonian Chickens (SaChi) and German Langshan bantams (GLB). In (a), the proportion per score represents to the arithmetic mean of the four plumage regions assessed (back, belly, dorsal neck and wing feathers). The *p* values refer to the analysis of the total plumage score, which was calculated on individual animal level by adding the individual scores of the regions

slow-growing broilers, which reach 2235 g by week 6 (Damme et al., 2015); and dual-purpose hybrids, which reach 2161 g by week 9 (Müller et al., 2018). In comparison with other fancy chicken breeds, the body masses of SaChi chickens were lower than those of Bresse Gauloise (Nolte et al., 2020), Rhinelander (Tiemann et al., 2020), Malines and Swiss chickens (Müller et al., 2018) and at a similar level to the body masses of Vorwerk chickens (Nolte et al., 2020), but higher than the body masses of Augsburg chickens (Damme & Schreiter, 2020). However, it should be noted that in our own study, roosters and hens were fed a diet intended for layers; higher body mass gains are likely to be achieved when fattening diets are used. As expected, the inflection point in the growth curve of the roosters occurred later among the SaChi than the GLB chickens (10.5 vs. 9.2 weeks of age), as GLB chickens are a bantam breed with lower mature body weights. The three Italian chicken breeds studied by Rizzi et al. (2013) showed later inflection points (at 12.0–12.6 weeks). Slaughtering closer to the inflection points of the Gompertz model would likely result in a better feed conversion in the breeds. However, the lower carcass weights at this time would hamper successful marketing to consumers.



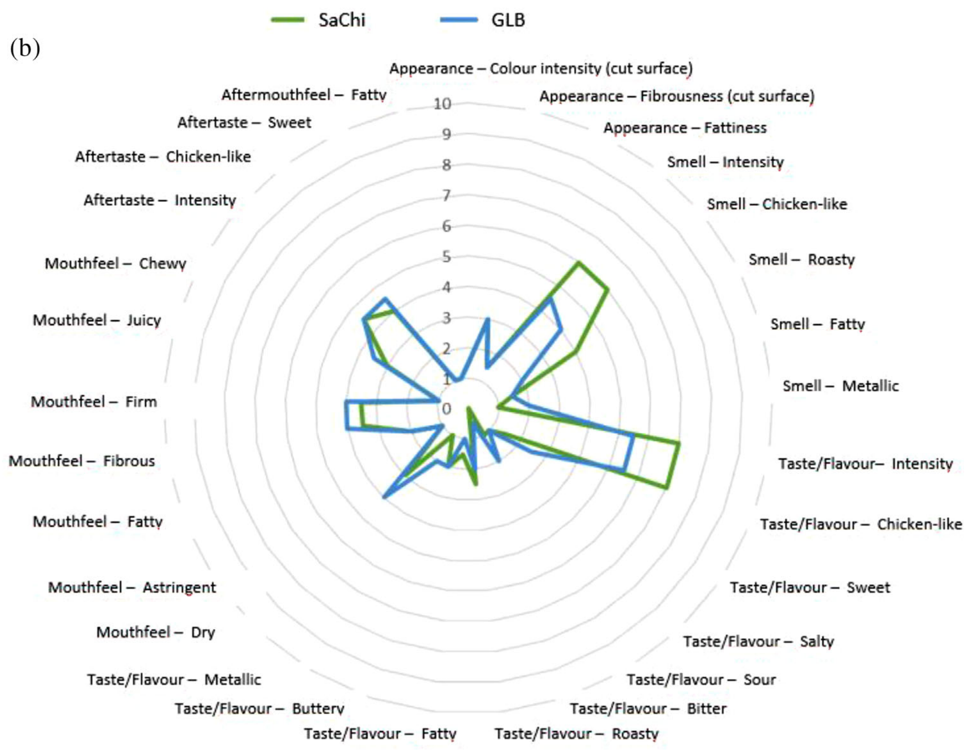




**FIGURE 5** Spider plots visualising sensory differences in (a) legs and (b) breast fillets between the local German chicken breeds Saxonian Chickens (SaChi) and German Langshan bantams (GLB) within the dimensions appearance, texture, smell, taste/flavour, mouthfeel, aftertaste and after mouthfeel

**TABLE 3** Results of logistic regression models of the effect of breed, age and sex across all animals of the local German chicken breeds Saxonian Chickens (SaChi) and German Langshan bantams (GLB) included in this study as well as the effect of plumage colour, age and sex within the breed SaChi on the occurrence of plumage damage

| Trait | Score 1 (%) | Coefficients (SE) | Odds ratio (95% CI) | Individual *p* value | Overall *p* value |
|---|---|---|---|---|---|
| Both breeds | | | | | |
| *Breed* | | | | | <0.001 |
| SaChi | 13.6 | Reference | Baseline | | |
| GLB | 7.5 | −2.93 (0.43) | 0.0 (0.02–0.12) | <0.001 | |
| *Age* | | | | | <0.001 |
| Day 18 | 5.8 | Reference | Baseline | | |
| Day 35 | 13.6 | 3.43 (0.73) | 30.80 (7.34–129.25) | <0.001 | |
| Day 53 | 13.4 | 3.41 (0.73) | 30.22 (7.19–126.91) | 0.012 | |
| Day 70 | 3.6 | 1.97 (0.78) | 7.17 (1.55–33.34) | <0.001 | |
| Day 105 | 13.3 | 3.43 (0.75) | 30.99 (7.20–133.41) | <0.001 | |
| Day 140 | 0.0 | −15.84 (2570.59) | 0.00 (0.00–0.00) | 0.995 | |
| *Sex* | | | | | <0.001 |
| Female | 4.6 | Reference | Baseline | | |
| Male | 13.0 | 0.77 (0.21) | 2.17 (1.45–3.24) | <0.001 | |
| Intercept | | −5.00 (0.73) | | | |
| Saxonian Chicken | | | | | |
| *Plumage colour* | | | | | 0.001 |
| Black | 16.0 | Reference | Baseline | | |
| White | 4.6 | −4.00 (1.02) | 0.02 (0.01–0.13) | <0.001 | |
| Cuckoo | 20.9 | 0.30 (0.22) | 1.35 (0.87–2.10) | 0.179 | |
| *Age* | | | | | <0.001 |
| Day 18 | 1.1 | Reference | Baseline | | |
| Day 35 | 25.7 | 3.59 (0.74) | 36.11 (8.51–153.15) | <0.001 | |
| Day 53 | 24.7 | 3.53 (0.73) | 34.15 (8.04–144.99) | <0.001 | |
| Day 70 | 4.2 | 1.39 (0.83) | 4.05 (0.79–20.56) | 0.095 | |
| Day 105 | 22.5 | 3.44 (0.75) | 32.02 (7.30–140.44) | <0.001 | |
| Day 140 | 0.0 | −16.52 (3524.65) | 0.00 (0.00–0.00) | 0.996 | |
| *Sex* | | | | | <0.001 |
| Female | 10.1 | Reference | Baseline | | |
| Male | 17.7 | 0.71 (0.22) | 2.03 (1.32–3.14) | 0.001 | 0.001 |
| Intercept | | −4.75 (0.74) | | | |

CI, confidence interval; SE, standard error; score 0, intact plumage; score 1, plumage damage.

Assessing the integument condition aimed to indirectly identify severe feather pecking and cannibalism. Although feather pecking occurs to a lesser extent during rearing than during the laying period, the plumage condition during rearing is a crucial factor to ensure intact plumage during the laying period (Janczak & Riber, 2015). Since improved animal welfare seems to be necessary in the marketing of products using regional breeds (Escobedo del Bosque et al., 2021), plumage condition that is readily visible to consumers is of particular interest. In the present study, which showed generally good integument condition, plumage damage and skin lesions were most pronounced at days 35, 53 and 105 of age. These ages are also considered critical in laying hybrids, as these are the times at which the largest number of preferentially pecked and blood-filled feather follicles are present during moulting (Keppler, 2017; Schreiter et al., 2020a). Plumage damage during rearing in White Plymouth Rock, Bresse and New Hampshire chicken breeds was observed by Hörning et al. (2020) to occur primarily in the wing feathers (in up to 60% of birds) and less commonly in the back and belly plumage. However, as in this study, the roosters examined by Hörning et al. (2020) showed greater plumage loss than the hens during rearing. The moderate foot pad dermatitis observed by Tiemann et al. (2020) in 20% of Rhineland chickens from week 15 onwards was not found in our study, which,

**TABLE 4** Carcass characteristics and meat quality in 140-days old male Saxonian Chickens and German Langshan bantams (mean ± standard deviation)

| Trait | Saxonian Chickens | German Langshan bantams | *p* Value |
|---|---|---|---|
| Carcass weight (g) | 1448.8 ± 196.5 | 717.3 ± 79.1 | <0.001 |
| Breast fillet yield[a] (%) | 10.4 ± 1.3 | 10.2 ± 1.3 | 0.524 |
| Leg yield[a] (%) | 33.4 ± 1.6 | 32.9 ± 3.3 | 0.496 |
| pH 24 h p.m.[b] | 5.83 ± 0.15 | 5.88 ± 0.12 | 0.265 |
| pH 6 d p.m.[b] | 5.69 ± 0.08 | 5.75 ± 0.08 | 0.015 |
| $L^*$ 24 h p.m.[b] | 56.5 ± 2.4 | 57.6 ± 3.4 | 0.212 |
| $a^*$ 24 h p.m.[b] | 2.0 ± 1.0 | 3.7 ± 1.1 | <0.001 |
| $b^*$ 24 h p.m.[b] | 14.2 ± 1.9 | 17.0 ± 1.5 | <0.001 |
| Cooking loss (%)[b] | 28.9 ± 3.5 | 30.1 ± 3.4 | 0.294 |
| Shear force (N)[b] | 8.6 ± 1.1 | 7.8 ± 1.1 | 0.019 |

p.m., post mortem; $L^*$, lightness; $a^*$, redness; $b^*$, yellowness.
[a]Calculated as the percentage of carcass weight.
[b]*Musculus pectoralis superficialis*.

in addition to the housing conditions, may be due to the lower body masses of the SaChi and GLB chickens and, thus, the lower mechanical pressure on the foot pads of the animals. The remarkable differences in plumage and skin damage between SaChi and GLB chickens indicated the presence of breed effects in the occurrence of feather pecking and cannibalism in indigenous chicken breeds; these effects are also known to occur among laying hybrid strains (Schreiter et al., 2020b).

We observed inferior slaughter performance among our chickens compared with that of commercial broiler hybrids in terms of carcass yield, analogous to the results for other fancy chickens (Müller et al., 2018; Nolte et al., 2020). Remarkably, the roosters of the investigated breeds reached the level of commercial dual-purpose chickens (Müller et al., 2018), with a carcass yield of ~69% for SaChi chickens and ~70% for GLB chickens. In relation to the total carcass weight, the valuable leg-cut weights (~33%) were higher than the breast fillet weights (~10%). With the legs being more than three times heavier than breast fillets, the whole carcass had a different appearance compared with conventional carcasses from fast- and slow-growing broilers, whose leg and breast proportions are ~30% and ~26%, respectively (Damme et al., 2015). In terms of sensory characteristics, the meat samples of the two chicken breeds were shown to have a higher intensity of flavour and odour and a significantly firmer texture compared with broiler hybrids (Siekmann et al., 2018).

Some limitations in the study design must be considered in terms of the generalisability of the results. Not separating the breeds by sex and plumage colour provided a good representation of the common rearing conditions among fancy poultry breeders, as well as potential small-scale niche production. However, this methodology did not enable us to draw conclusions on feed consumption and conversion among the sexes, or the tendency to engage in feather pecking between chickens with different plumage colours. Future studies should include a commercial hybrid strain as a control group and several groups per genotype (e.g., compartments per breed and plumage colour).

## 5 | CONCLUSIONS

This study provides insights into the performance traits and welfare indicators for two endangered German chicken breeds – SaChi and GLB. Compared with slow-growing broiler genetics, the growth rate of both SaChi and GLB is comparatively low during rearing. Therefore, if these breeds are to be used for chicken meat production, a reference to the additional benefit of preservation of animal genetic resources and regional cultural heritage should be made in marketing to achieve higher product prices. In addition, farmers should be made aware of the possible occurrence of plumage damage during rearing due to severe feather pecking, that appropriate countermeasures can be taken in time. These results could help fill knowledge gaps about their productive potential, in combination with an evaluation of the first laying period of reared pullets, provide a basis for assessing the suitability of both breeds in niche production.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## CONFLICT OF INTEREST

None.

## ETHICAL STATEMENT

The animals were kept in accordance with the legal requirements of the EU (Council Directive 1999/74/EC, minimum standards for the protection of laying hens) (Council Directive 1999/74/EC of 19 July 1999) and Germany (Animal Welfare Act; Animal Protection Keeping of Production Animals Order). In particular, the principles and specific guidelines of the Guide for the Care and Use of Agricultural Animals in Research and Teaching (American Dairy Science Association 2010) were implemented. In accordance with Directive 2010/63/EU of the European Parliament and the Council on the protection of animals used for scientific purposes (Council Directive 2010/63/EU), no invasive treatment of the hens was performed. The roosters were slaughtered for human consumption as part of the normal agricultural use after completion of rearing at the age of 20 weeks. The following legal requirements were met during slaughter: Regulations EC No. 853/2004, EC No. 1099/2009, and the German Ordinance on the Protection of Animals at Slaughter or killing and on the implementation of Council Regulation (EC) No. 1099/2009.

## AUTHOR CONTRIBUTION

*Conceptualisation, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, supervision, validation, writing – original draft, writing – review & editing* : M. F. *Data curation, formal analysis, writing – review & editing*: M. H. *Data curation, formal analysis, writing – review & editing*: S. R. *Data curation, formal analysis, visualisation, writing – review & editing*: I. V. *Data curation, formal analysis, visualisation, writing – review & editing*: J. W. *Conceptualisation, funding acquisition, supervision, writing – review & editing*: W. J. *Conceptualisation, data curation, formal analysis, methodology, supervision, writing – review & editing*: R. S.

## DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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