Animal 20 (2026) 101800

Contents lists available at ScienceDirect

Animal
The international journal of animal biosciences

Potentials of newly selected chicken genotypes for dual-purpose under organic conditions

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ARTICLE INFO

Article history:
Received 8 September 2025
Revised 3 March 2026
Accepted 5 March 2026
Available online 13 March 2026

Keywords:
Alternative systems
Chick culling
Organic poultry
Free-range
Animal welfare-focused production

ABSTRACT

Motivated by consumer concerns for animal welfare, several European countries have recently banned the culling of day-old male chicks from layer lines. Germany and France were the first countries to enact this binding prohibition, and in Germany, Article 1 § 4c of the Tierschutzgesetz (TierSchG) makes it a punishable offence to kill a vertebrate animal without reasonable cause. Economic unprofitability, which is the key reason for killing day-old male chicks from layer lines, whose genetically determined productivity is insufficient for commercial meat production, is explicitly excluded as a sufficient justification for the taking of animal life. Consequently, alternative systems such as dual-purpose poultry, in which both males and females are reared for commercial use, have gained importance. However, knowledge on the management and productivity of dual-purpose chickens is still limited. This study assessed the potential of selected dual-purpose chicken genotypes as an alternative to single-purpose poultry in organic production systems. Three genotypes with different performance profiles were reared and compared to commercial layer and broiler types as controls under organic husbandry guidelines. Due to biosecurity measures for avian influenza, males had access only to a covered outdoor run, while females were restricted to covered areas from 18 to 28 and 60–72 weeks, with full pasture access between 28 and 60 weeks of age. In the fattening trial, dual-purpose males required 37–50% longer to reach a target weight of 2.1 kg compared to the control, but exhibited more balanced growth of valuable cuts, whereas the control showed disproportionately high breast meat yield. Meat quality in dual-purpose males was not compromised relative to the control. Laying performance in dual-purpose hens was 19–25% lower than the control, with feed conversion ratios of 2.62–3.43 vs 2.14 in the control. However, due to their dual-purpose nature, the meat yield in these hens was 17–27% higher. While significant differences were observed in performance, egg quality remained similar across genotypes, and meat quality varied slightly. Economic evaluations indicated scenarios of short-, medium-, and long-term profitability depending on production goals and market context. Overall, dual-purpose poultry may represent a promising alternative for farming systems prioritising ethical considerations and product quality.

Implications

The study highlights the potential of dual-purpose poultry to support diversified, welfare-oriented and value-driven production systems, in which ethical considerations and product differentiation may justify reduced biological efficiency. Overall, the results suggest that the performance profiles of dual-purpose genotypes can contribute to more ethical poultry supply chains and a wider

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https://doi.org/10.1016/j.animal.2026.101800
1751-7311/

range of farm structures, if production systems are adapted accordingly. The study provides a basis for the development of an expressive Dual-Purpose-Index and for further multifarm and multiyear evaluations, essential in refining management strategies, strengthening economic resilience, and supporting broader implementation of dual-purpose poultry in organic and alternative production systems.

Introduction

The poultry industry has long relied on highly specialised genotypes selected for either egg or meat production. In commercial layer lines, intensive selection for high laying performance has resulted in poor growth characteristics in males, rendering them economically unviable for meat production (Preisinger, 2018; Haas et al., 2021). Consequently, the culling of day-old male chicks has been a standard industry practice, with an estimated 330 million male chicks culled annually in Europe alone, regardless of the production system (EC 1099/2009; Vinci, 2022). However, growing societal concern regarding animal welfare and the intrinsic value of animals has led to increasing ethical scrutiny of this practice (Brümmer et al., 2018; Wadiwel, 2018), resulting in legal prohibitions in several European countries (Di Concetto et al., 2023). Among the proposed alternatives, the use of dual-purpose chicken genotypes–breeds capable of both egg and meat production–has gained attraction, particularly within organic production systems, which emphasise ethical animal husbandry (Gremmen et al., 2018; Haas et al., 2021). Dual-purpose poultry offers a compromise by rendering meat from males and eggs from females, thereby aligning production with societal values around sustainability and animal welfare (Bruijnis et al., 2015; Prache et al., 2022).

Beyond addressing ethical concerns, the unbalanced genetic selection for either egg or meat production has led to health and welfare issues in highly specialised, high-output poultry genotypes (Korver, 2023). Dual-purpose genotypes, with a more balanced performance profile for both eggs and meat, are promising in this regard. They have demonstrated improved animal welfare indicators (Tiemann et al., 2020; Baldinger and Bussemas, 2021) and greater robustness (Reddy et al., 2002; Stehr et al., 2019; Ajayi et al., 2020; Daş et al., 2021) under organic conditions. Additionally, dual-purpose poultry show lower amino acid requirements and better adaptability compared to high-performing genotypes (Urban et al., 2018; Kreuzer et al., 2020; Röhe et al., 2019; Baldinger and Bussemas, 2020; Müller et al., 2023). This is particularly beneficial in organic husbandry systems where access to high-quality protein sources is limited, and the use of synthetic amino acids is prohibited. Thus, dual-purpose poultry seems suitable for extensive and organic production systems, where flocks are exposed to high levels of external stimuli and environmental variability when compared to conventional floor-housing systems (Früh et al., 2015; Urban et al., 2018; Kreuzer et al., 2020; Röhe et al., 2019; Baldinger and Bussemas, 2020; Müller et al., 2023). However, performance of this type of poultry varies widely across genotypes, and, particularly under organic conditions, remains insufficiently studied (Leenstra et al., 2010; Lambertz et al., 2018; Muth et al., 2018; Werner et al., 2023). Most existing data are derived from conventional settings and focus either on laying or fattening performance in isolation (Bamidele et al., 2020; Müller et al., 2020; Torres et al., 2019; Muth et al., 2018). Few studies provide a comprehensive evaluation of both male and female performance, or assess economic feasibility at the farm level (Blandford and Harvey, 2014; Damme et al., 2015; Lambertz et al., 2018; Gemechu and Abiy, 2019; Hammershøj et al., 2021).

The present study aims to evaluate production performance, product quality, and economic potential of the males and females from three newly selected dual-purpose genotypes under organic conditions, in order to gain knowledge to improve and develop the management of this type of poultry. A commercial layer and broiler have been used as benchmarks in the evaluation. By assessing the performance of both sexes, this study provides a comprehensive assessment of dual-purpose poultry genotypes and their potential to support more ethical and sustainable poultry systems, making the intentional culling of male chicks evitable.

Material and methods

Trials comparing three dual-purpose genotypes were conducted with male and female birds from the same hatch. Therefore, both the fattening trial of the males and the laying trial of the females started simultaneously in October 2020. While the fattening trial of the males ended in March 2021, the laying trial of the females continued until March 2022. Both trials were carried out at the research station of the Thünen Institute of Organic Farming (Westerau, DE), in compliance with organic farming standards (EU Regulation 2018/848).

Origin of the birds and rearing conditions during the starter phase

The dual-purpose genotypes (**GTs**) were selected by the French Poultry and Aquaculture Breeding Technical Center (SYSAAF, FR) in collaboration with the breeding companies Hendrix Genetics ISA (Ploufragan, FR) and Novogen (Plédran, FR). The genotypes were chosen based on their specific performance profiles, as described below:

- **DualMeat**: An experimental cross of a ‘label-rouge’ broiler-type male and an egg-layer female, focused on meat production
- **DualBalance**: A rustic, pure–breed with a balanced dual-purpose profile, though not specifically selected for any particular trait
- **DualEgg**: An experimental crossbreed of a layer, focused on egg production

Widely available, high-performing commercial genotypes commonly used on organic farms in Germany were chosen as the control for fattening and laying

- Mixed-sex control for the males (**CONM**): JA757, a broiler (M77xJA57 cross) considered to be slow-growing according to the German interpretation of EU regulation 2018/848 (Annex ll, Part ll, point 1.9.4.1.)
- Control for the females (**CONF**): Lohmann Brown+, a layer hybrid selected from Rhode Island and White Rock breeds, suitable for alternative housing systems

The CONM and CONF chicks were sourced from two commercial hatcheries (CONM from Overmeyer, Hopsten-Halverde; CONF from Hockenberger, Eppingen-Elsenz, both DE). Sexed day-old chicks of the dual-purpose genotypes were provided by a commercial hatchery (Hubert SAS, Bourgvallées, FR). In total, 627 male chicks (DualMeat = 160, DualBalance = 160, DualEgg = 52 + 95 = 147, CONM = 160) and 316 female chicks (DualMeat = 80, DualBalance = 84, DualEgg = 52, CONF = 100) arrived at the research farm. Due to low hatchability for DualEgg, male chicks were delivered in two batches within 1 week, resulting in the two male batches DualEgg1 (n = 52) and DualEgg2 (n = 95, 1 week after DualEgg1). Sexing was performed by cloacal inspection at hatch for all genotypes except CONM, which was reared mixed-sex.

All chicks were vaccinated at the hatcheries against Marek, Newcastle (ND) and Gumboro disease, infectious bronchitis (IB), coccidiosis, and infectious laryngotracheitis (ILT). During the rearing period, the birds received further vaccinations for IB, ND, Gumboro, ILT and Salmonella. Each chick was individually weighed and tagged with a wing band for further bird-based data collection.

The chicks were allocated to pens based on genotype and sex, resulting in a total of eight pens. Until the age of 4 weeks, all chicks were housed under identical conditions, in floor pens of 6 m^2 each. Each pen was equipped with a brooding circle, containing feed troughs and bell drinkers, with wood shavings used as bedding. Perches were introduced during the first week. Heating plates and lamps provided shelter and warmth. The temperature in the barn was 34 °C at arrival and was gradually decreased to 19 °C by week 6, and to the outdoor ambient temperature after that. Upon arrival, the birds were exposed to 24 h of light for 2 days and then adapted to a 16 h:8 h light:dark cycle over 4 weeks. Details regarding weather conditions during the trial period are presented in Fig. 1. A few mis-sexed chicks were identified during the starter phase and relocated to the correct pens, ensuring that the male groups only consisted of males when their fattening trial started.

Both pelleted feed and water (bell drinkers) were provided *ad libitum*. To support gut health, a probiotic lacto-fermented liquid (Kanne Brottrunk®, DE) was mixed in a 1:10 ratio with drinking water and lightly sprayed over the pelleted feed in the first weeks. From day 4, maize silage was offered as enrichment in a separate trough. Dust baths with a mineral powder (Cumbasil®, DE) and pecking stones (Pickstein fresh®, DK) were provided in the pens.

Experimental design and housing conditions during fattening trial

After the starter phase, the fattening trial of the males followed (Fig. 2a). At 4 weeks of age, the males were divided into groups of 40 birds each, with the term "group" indicating the replicate within genotype. The chicks were allocated to the groups by first applying the Excel choose (randbetween) function and then, if necessary, manual adjustments to ensure similar mean BW of groups. Outliers weighing less or more than the mean BW ± 1.5 SD were removed. A total of four groups (4 × 20 = 80 birds in total) of the genotypes DualMeat, DualBalance and CONM, and three groups (3 × 20 = 60 birds in total) of DualEgg entered the fattening trial. DualMeat and CONM males were immediately transferred to the mobile barns (Fig. 3a). Due to slower plumage development, DualBalance and DualEgg birds remained in indoor pens for two additional weeks to ensure sufficient plumage, necessary for thermoregulation. Because CONM chicks could not be sexed at the hatchery, females and males were reared together until their sex could be determined based on comb growth and body size at the age of 6 weeks. Then, the CONM birds were divided into 2 purely male and 2 purely female groups.

A total of eight mobile barns on permanent pasture were available for the fattening trial, with each barn being divided into two pens of 4 m^2 each. The 15 groups of birds were allocated to the 16 pens in a rotational way to ensure that each barn housed two genotypes, and that the genotypes were equally distributed over the whole housing facility. One pen remained empty. The equipment of each pen consisted of chopped straw as bedding, a nipple drinker with eight nipples, two feeders, and perches. The outdoor runs of 160 m^2 per pen could not be used because of measures to prevent the spread of avian influenza (**AI**). Therefore, 12 m^2 greenhouses were attached to each pen for added foraging space and enrichment (Fig. 3b). The maximum stocking density during fattening was 21 kg/m^2 indoor space.

Slaughter age was determined based on the breeders' recommendations, with a target BW of 2.1 kg. The CONM and DualMeat males were expected to reach this after 55–64 and 65–80 days, respectively. DualEgg males were expected to reach the target BW after 110 days, and no prior information was available for DualBalance. Because animal numbers were limited, two slaughter dates were possible for each genotype, and week 12 was chosen as the common slaughter age to compare all genotypes. In addition, CONM and DualMeat were slaughtered at 10 weeks of age, and DualBalance and DualEgg at 16 weeks. The two heavier groups of each genotype were slaughtered at the respective first slaughter date. In the case of mixed-sex CONM, males were slaughtered at 10 weeks of age, while females, due to their slower growth, were slaughtered at 12 weeks.

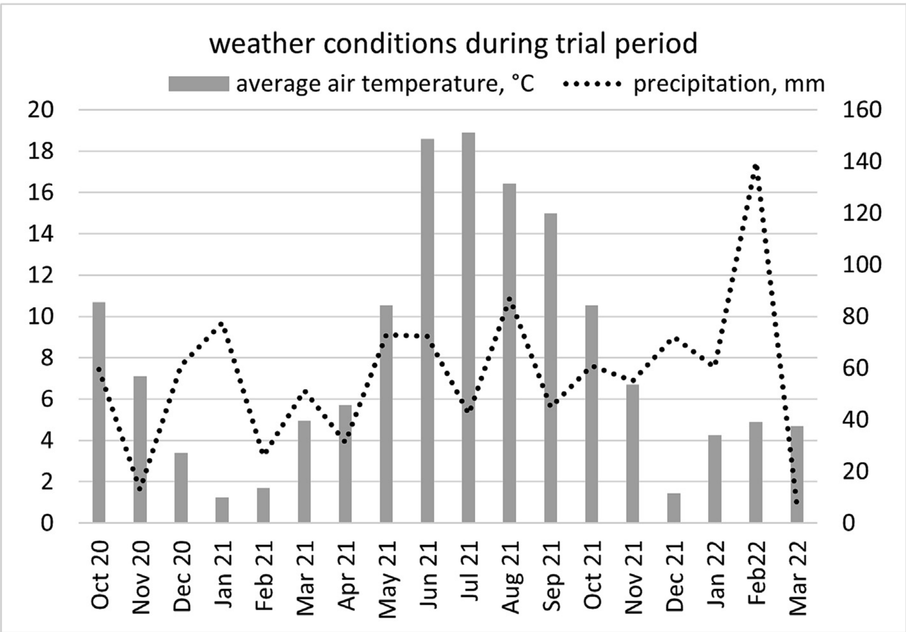


Fig. 1. Mean temperature (°C) and precipitation (mm) during fattening and laying trial period of tested chicken genotypes from October 2020 to March 2022 in Wulmenau, Northern Germany.

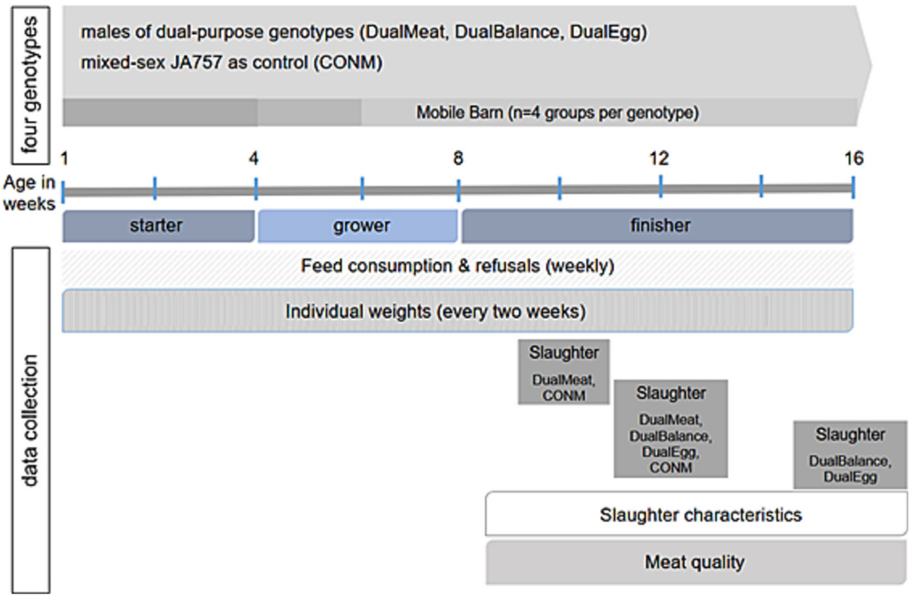


Fig. 2. Data collection in fattening (a) and laying (b) trial of tested chicken genotypes (DualMeat, DualBalance, DualEgg, CONM, CONF).

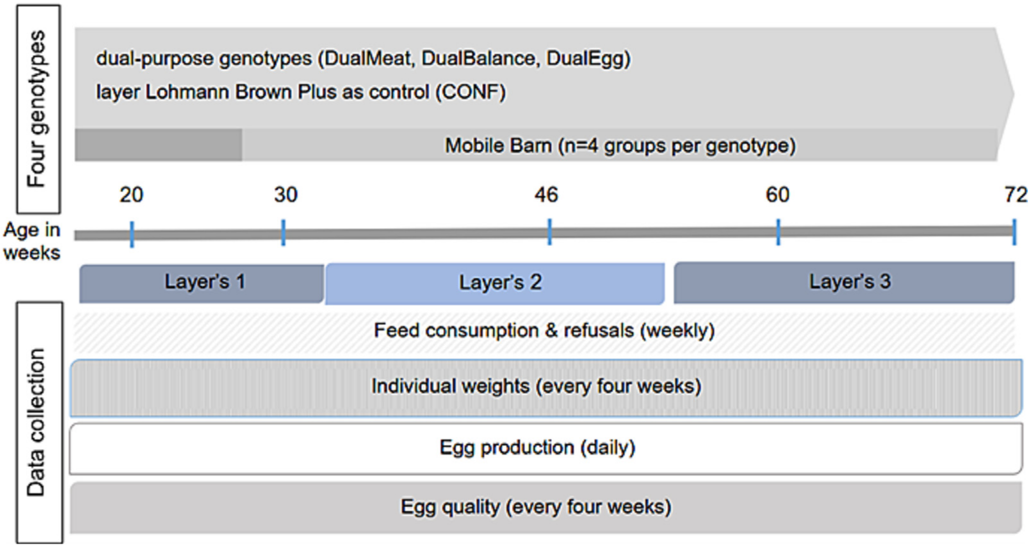


Fig. 2 (*continued*)

Feeding regimen during fattening trial

All genotypes were fed the same feed mixtures, and feed was supplied *ad libitum*. The feed components were 99% organic, with 1% of a conventional yeast mixture added to ensure an optimal supply of B vitamins. The pelleted feed (3 mm) was produced at the farm's own feed mill. The feeding regimen consisted of three phases: starter (weeks 1–4), grower (weeks 4–8), and finisher (week 9 onward). For the composition and analysed nutrient contents, see Table 1a. The chicks were offered maize silage starting from day 4, with the amount gradually increased up to 10 g/d per bird (Table 1b).

Data collection during the fattening and slaughter of the males

Throughout the fattening trial, feed refusals were weighed weekly to calculate feed intake (**FI**), which was adjusted daily for the number of birds alive. BW was measured individually every 2 weeks (Fig. 2a). The feed conversion ratio (**FCR**) was calculated per group as FI divided by weight gain over the fattening period of 10, 12 and 16 weeks of age. Mortality was recorded continuously.

At each slaughter date, two groups per GT (n = 40) with the highest BW were selected for slaughter, in order to represent the usual practice on organic farms. The birds were fasted overnight before slaughter at a commercial abattoir. Each bird was individually stunned using electric tongs, and after evisceration, the giblets, head, neck, and legs (thighs and drumsticks) were removed. Carcasses were chilled overnight at 4 °C and weighed the following day to calculate dressing percentages by dividing chilled carcass weight (**CW**) by BW. A total of 20 birds per genotype falling within the mean BW ± three SD were selected for further analysis. For these sample birds, the weights of breast (*pectoralis major* and *minor* without skin) and leg meat were recorded and used to calculate the yield as a proportion of valuable cuts relative to BW. The pH values were measured 15 min, 24 h, and 72 h *postmortem* (p.m.),

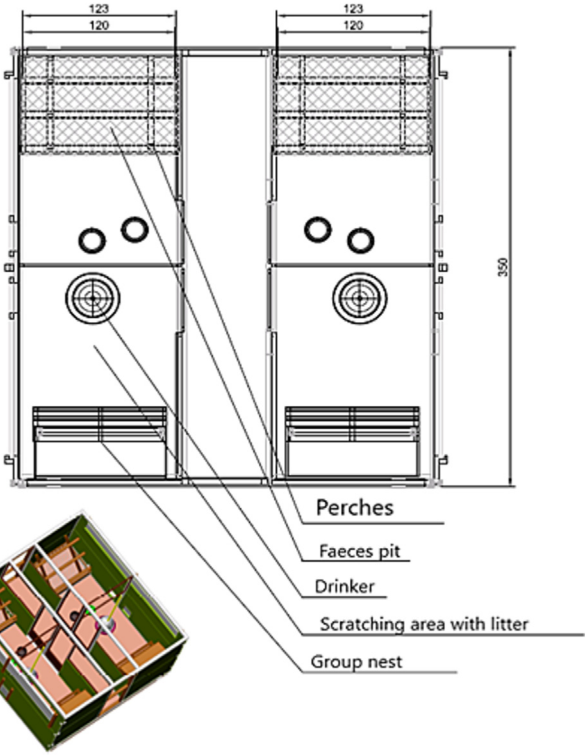


Fig. 3. (a) Floor plan of the mobile barn interior; exterior view of the mobile barn during the period of precautionary biosecurity measures due to avian influenza, shown with (b) an attached greenhouse during the fattening trial, and (c) an attached aviary during the laying trial of tested chicken genotypes.

using a glass injection probe at a depth of 1 cm on three anteroventral points of the *p. major*. The colour of breast meat was measured 15 min and 24 h p.m., using a portable colorimeter (Chroma Meter CR-400, Konica Minolta, JP) and expressed according to the CIE L*a*b* system (L*: 0 black, 100 white; a*: –100 green, 100 red; b*: –100 blue, 100 yellow; Commission Internationale de l'Éclairage). Colour values were obtained as the arithmetic mean of three measurements per sample. The left breast muscles, *p. major* and *minor*, were used to determine drip loss with the bag method (Le Bihan-Duval et al., 1999). For this purpose, meat hangers were pierced through the muscles, immersed in a 3 L plastic bag and sealed with a clothespin. Samples were hung freely on racks in a cold store at 5 °C. They were weighed 24 h and 72 h p.m., and the total percentage of drip loss was calculated (drip loss = weight$_{24hp.m.}$–weight$_{72hp.m.}$/weight$_{24hp.m.}$ × 100).

Rearing of the pullets

After the starter phase, the females were reared until the onset of lay, after which the laying period followed. From weeks 5 to 18, the females stayed in their pens, but rearing conditions were gradually adapted: artificial light was reduced to a 12 h:12 h schedule, wood shavings were replaced with chopped straw, and bell drinkers with hanging nipple drinkers. Heating ceased after week 6. Starting in week 8, pullets gained access to a roofed 15 m^2 outdoor area with wood chip bedding (permanently open from week 8). Enrichment included straw bales, hay nets, shelters, dustbaths, and daily maize silage (10 g/d per bird, Table 1b) in separate troughs. Group nests with spelt husks were introduced in week 17, and from week 18, limestone grit (Rakonit®, DE) was provided as an additional calcium source. After the starter phase (weeks 1–3), the feeding regimen during rearing consisted of a grower (weeks 4–8) and a prelay (weeks 9–18) feed. Starting from week 7, wheat grains were distributed in the bedding daily, making up 5% of the FI. The transfer to the mobile barns for the laying period was originally scheduled for week 17 but had to be postponed until week 28 due to mandatory AI prevention measures enforced by regional veterinary authorities. The females were individually weighed four times during rearing, at 6, 10, 14, and 18 weeks of age.

Experimental design and housing conditions during laying trial

At the age of 28 weeks, the DualMeat, DualBalance, and CONF females were randomly divided into four groups of 20 birds per genotype using the same method as for the males, see there. The 52 DualEgg females were divided into two groups of 20 and one group of 12. In total, 15 groups (=292 birds) were moved to the same eight mobile barns that were previously used for the fattening trial, which were set up at a different location on permanent pasture. The allocation of the groups to the barns was done as described for the males. Each barn contained two 4 m^2 pens, each housing a group of 20 hens (indoor stocking density: 5 birds/m^2). Both groups had access to a total of 160 m^2 of netted outdoor runs, divided into two 80 m^2 sections for rotational use, providing 4 m^2

Fig. 3 (*continued*)

Fig. 3 (*continued*)

per hen. Each pen included a group nest (400 cm^2), one hanging drinker with eight nipples, two feeding troughs, perches, a pecking stone, and chopped straw bedding. The natural light was supplemented by artificial lighting, guaranteeing 16 h daily. Hens had outdoor access from 0900 h until dusk, except during mandatory AI restrictions (weeks 60–72), when covered foraging space was provided via attached wire mesh houses (6 × 3 × 2 m, Wiltec Aviary, DE; Fig. 3c).

Feeding regimen during laying trial

All female groups were fed the same pelleted feed mixtures of 99% organic origin. The feeding regimen during the laying period consisted of three phases: layer 1 (weeks 19–32), layer 2 (weeks 33–52), and layer 3 (weeks 53–72). Wheat grains were distributed in the bedding daily, making up 10% of total FI. Feed samples were sent to a commercial laboratory and analysed for nutrients according to the EU Regulation 152/2009 (Table 1c).

Data collection during laying trial

The feed intake of the females consisted of consumed pellets and whole wheat grains. Throughout the laying period, pellet refusals were weighed weekly and adjusted according to the number of birds alive each day, serving as the basis for calculating weekly FI. BW was measured individually every 4 weeks (Fig. 2b).

The following data regarding laying performance were recorded daily: number of eggs, egg weight (g), egg size distribution according to EC Regulation No. 589/2008 (S 40–52 g, M 53–62 g, L 63–73 g, XL > 73 g), and the number of discarded eggs. Discarded eggs were classified as non-marketable and included floor eggs, cracked, dirty, and shell-less eggs. Laying performance was calculated as the weekly mean per group and corrected for mortality. Every 4 weeks, five marketable eggs per group were selected for egg quality assessment. The day after collection, eggs were weighed, and any irregularities were noted. At the broad side of the egg, shell colour was measured at three points, using a colorimeter (Chroma Meter CR-400, Konica Minolta, JP) with CIE L*a*b* values. Egg diameter and length were measured with an electronic calliper to calculate the shape index (SI = diameter/length × 100). After cracking, shells were wiped clean and their weight in DM was recorded after drying at 60 °C for ≥ 18 h.

The feed conversion ratio for laying (FCR$_{lay}$) was calculated as total FI per total egg mass. To evaluate overall dual-purpose performance, a total FCR (FCR$_{total}$) was also calculated, incorporating both total egg mass and CW of the females as marketable outputs, relative to total FI across rearing and laying phases.

At 72 weeks of age, the fasted females were electrically stunned with tongs and slaughtered in a mobile slaughtering unit on-site. A sample of 20 hens per GT was randomly selected for measuring CW after overnight cooling, and the weight of breast meat (*pectoralis major* and *minor*) and legs. The pH values of the breast meat, the colour of the meat on the right *p. major* muscle and the drip loss of the left *pectoralis* muscles were determined as described for the males.

Statistical analysis

The experimental unit for FI, FCR and egg quality traits was the group, while the experimental unit for BW, daily weight gain (**DWG**) and carcass characteristics was the individual bird. The model for FI, FCR and egg quality traits included the fixed factors GT, the age of the birds and their interaction (GT*age), with group nested within genotype as a random effect. The model for BW, DWG and carcass characteristics included the fixed factors GT and age in weeks. The individual bird (wing band) nested within GT and age was used as a random effect. The model for carcass characteristics included GT, age, and GT*age as fixed effects for the males and only GT for females due to one slaughter date only. Laying performance and FCR$_{lay}$ were evaluated from 18 while egg quality traits were evaluated from 21 weeks of hen age. The total egg number per female (marketable and non-marketable) was calculated as the group means up to week 72. Analyses were performed with SAS 9.4 (SAS Institute Inc., USA) using generalised linear mixed models (GLIMMIX), with P-values < 0.05 indicating significant differences. The results are reported as least square means and SEM. Multiple comparisons were made using Tukey's test. Further details and statistical codes are provided in Supplementary Material S1.

Dual-purpose index

A dual-purpose index (**DPI**) was calculated for each dual-purpose genotype to assess combined male and female performance. The DPI can be used as exploratory tool to identify each genotype's suitability for dual-purpose use and practical farm implementation. It was calculated following the method proposed by Hörning (2023): Female laying performance was expressed as a

Table 1
Feed ingredients (%) and analysed nutrient composition (g kg^{-1} (as fed) unless stated otherwise) of diets in fattening (a) and laying (b) trials of tested chicken genotypes, and analysed nutrient composition of maize silage (% of DM) (c).

Item	Starter Week 1–4	Grower Week 4–8	Finisher Week 9+
(a) Fattening trial			
Wheat	19	16	10
Maize	18	16	16
Triticale	10	8	14
Barley	5	8	10
Wheat Bran	1.6	2.4	0
Soya cake, toast	22	14	14
Peas	8.5	16.5	12.5
Rapeseed cake	5	7.5	10
Sunflower cake	5	7.5	10
Potato protein	1.2	0	0
Yeast mixture*	1	1	1
Minerals	2	2	2
Monocalcium phosphate	1	0.5	0.4
Calcium carbonate	0.5	0.5	0
Salt	0.2	0.1	0.1
DM, %	88.15	83.40	89.80
Ash	6.65	6.15	5.70
CP	22.0	21.70	21.75
Ether extracts	4.90	5.05	5.60
Crude fibre	5.75	6.25	7.10
MJ AME_N/kg	11.47	10.87	11.70
Lysine	1.09	1.15	1.06
Methionine	0.27	0.30	0.28
Cysteine	0.36	0.37	0.34
g methionine MJ^{-1} AME_N	0.24	0.26	0.24
Phosphorous	0.96	0.83	0.79
Calcium	1.12	1.05	0.83
Sodium	0.18	0.14	0.13

Item	Starter Week 1–3	Grower I Week 4–8	Prelay Week 16–18	Layer 1 Week 19–32	Layer 2 Week 33–52	Layer 3 Week 53–72
(b) Laying trial						
Wheat	19	17.5	12.3	11	10	10
Maize	18	17	14	11	13.5	12.5
Triticale	7	10	13	12	11.5	14.5
Barley	6	7	8	7	9	9
Wheat bran	0	0	5	0	2	2
Soya cake, toast	21.5	17.5	12.5	17	16	12.5
Peas	8.5	10	11.5	11	9.5	10
Rapeseed cake	5	6.4	8.5	9.4	8.5	8.5
Sunflower cake	5	6.5	10.5	10.5	10	10
Potato protein	5	3.2	1	0	0	0
Yeast mixture*	1	1	1	1	1	1
Minerals	2	2	1.2	2	2	2
Monocalcium phosphate	0.9	0.6	0	0	0	0
Calcium carbonate	1.1	1.2	1.4	5	3.9	4.9
Rakonit				3	3	3
Salt	0.1	0.1	0.1	0.1	0.1	0.1
DM, %	87.05	89.35	89.70	89.60	89.70	88.70
Ash	6.75	6.00	6.20	11.50	10.30	11.30
CP	23.75	22.10	22.00	22.00	22.10	20.30
Ether extracts	4.90	5.00	5.60	5.80	6.00	5.10
Crude fibre	5.90	6.20	8.10	8.80	8.20	7.20
MJ AMEN/kg	11.27	11.66	11.48	10.71	10.97	10.78
Lysine	1.25	1.11	1.05	1.10	1.09	1.02
Methionine	0.28	0.28	0.29	0.28	0.29	0.28
Cysteine	0.38	0.32	0.37	0.32	0.34	0.31
g methionine MJ^{-1} AME_N	0.24	0.24	0.25	0.26	0.27	0.26
Phosphorous	0.88	0.83	0.73	0.85	0.86	0.87
Calcium	1.13	1.03	0.99	2.94	2.40	2.80
Sodium	0.17	0.14	0.16	0.24	0.23	0.25

Table 1 (*continued*)

Item	Value
(c) Maize silage	
DM, %	29.10
Crude ash	4.30
CP	6.10
Crude fat	3.50
Crude fibre	22.30
MJ AME_N/kg	3.1
Lysine	0.28
Methionine	0.11
Phosphorous	0.31
Calcium	0.20
Sodium	<0.1

Abbreviations: *non-organic origin, AME_N = nitrogen-corrected apparent metabolisable energy.

proportion of a standard layer's output (CONF), and male DWG required to reach ≥ 2.1 kg was expressed relative to a standard broiler (CONM). DPI was calculated by dividing proportional laying performance by proportional fattening performance (DPI= (laying performance$_\text{Dual}$ / laying performance$_\text{Layer}$) / (DWG$_\text{Dual}$/DWG$_\text{Broiler}$)). Laying performance data for CONM females and fattening performance data for CONF males were not available from this trial. Thus, CONM laying data up to week 40 were taken from the Breeder Management Guide (Hubbard, 2023), and CONF male DWG (19.3 g) up to 10 weeks were taken from Kreuzer et al. (2020). Higher DPI values indicate greater egg-type suitability; lower values reflect stronger meat-type performance.

Economic evaluation

Excel-based models were used to analyse both the fattening and laying trials. For the fattening trial, the Technology Impact Policy Impact Calculations (TIPI-CAL) model, as described by Chibanda et al. (2020), was applied. For the laying trial, a simplified Excel tool was used, as a specific laying hen module had not yet been integrated into TIPI-CAL (Isermeyer and Thobe, 2018). Both models followed the principle of full cost accounting, assessing the total cost of production per unit. In the fattening trial, TIPI-CAL categorised costs into cash and non-cash costs, as well as factor and non-factor costs, over the 12-week fattening period. Cash costs included direct payments for inputs such as chicks, feed, and veterinary services, while noncash costs comprised depreciation and opportunity costs. Factor costs were associated with land, labour, and capital, whereas non-factor costs encompassed other expenses such as feed, maintenance, energy, and taxes (Chibanda et al., 2020). Table 2 shows the base price assumptions for the fattening trial (a), which were subsequently modified to model the following scenarios. (1) identical selling price assumptions (3.60 €/kg BW), (2) premium selling price (5.90 €/kg BW) for dual-purpose chicken meat reflecting regional marketing conditions, (3) premium selling price (5.90 €/kg BW) combined with a 15% reduction in feed costs for dual-purpose males while price assumptions for CONM remain unchanged, and (4) no premium price (3.60 €/kg BW) with a 15% reduction in feed costs for dual-purpose males.

For the laying trial, the simplified Excel tool organised costs into three categories: variable, non-cash, and fixed costs. Variable costs covered direct expenses for inputs such as pullets, feed, and veterinary care. Non-cash costs included depreciation and opportunity costs, while fixed costs—covering buildings, machinery, and labour—were derived from standard reference values for Germany (Thobe and Isermeyer, 2019). Feed costs reflected regional valua-

Table 2
Regional market conditions and price assumptions (net €) for the economic evaluation of fattening (a) and laying (b) trials of tested chicken genotypes (DualMeat DualBalance, DualEgg, Control).

		Genotype			
Cost item	Unit	DualMeat	DualBalance	DualEgg	*Control
(a) Fattening trial					
Chicks	€/bird	0.50	0.50	0.50	1.03
Starter feed	€/t	753	753	753	753
Grower feed	€/t	663	663	663	663
Finisher feed	€/t	634	634	634	634
Labour	€/hour	15.35	15.35	15.35	15.35
Energy	€/cycle	741	741	741	741
Veterinary costs	€/cycle	494	494	494	494
Selling price	€/kg BW	5.90	5.90	5.90	3.60
(b) Laying trial					
Feed	€/t	560	560	560	560
Pullets	€/bird	11	11	11	11
A-eggs raw loose, fix barn	€/egg	0.34	0.34	0.34	0.34
A-eggs raw loose, mobile barn	€/egg	0.38	0.38	0.38	0.38
B-eggs raw loose	€/egg	0.05	0.05	0.05	0.05
Slaughter hen	€/bird	8.00	8.00	8.00	8.00

* Control refers to control males (CONM) and control females (CONF) in respective trials.

tion prices at the time of purchase and included processing charges. Depreciation captured the loss in value of long-term assets, and opportunity costs represented forgone alternatives, particularly unpaid family labour. The base price assumptions used in the laying trial (b) are presented in Table 2. A second scenario was modelled in which feed costs for the female dual-purpose chicken were reduced by 15%.

Results

Feed intake and fattening performance of the males

The mean FI of the males up to the different ages of slaughter differed between the genotypes, as shown in Table 3. The FI of CONM was already higher than that of DualEgg1 and DualEgg2 at slaughter at week 10, and higher than all other genotypes until slaughter at 12 weeks. There was no difference in FI of the dual-purpose genotypes until slaughter at 10 weeks (53–78 g/d; P = 0.060–1.000, Supplementary Figure S1), but DualMeat consumed more feed than DualEgg1 until slaughter at week 12 (89 vs 63 g/d; P = 0.036, Supplementary Figure S1).

Regarding BW, there was a significant interaction of GT*age, with CONM being significantly heavier than all other genotypes from week 6 onwards ($P < 0.05$; Supplementary Figure S2). Also, CONM always had a higher DWG than the dual-purpose genotypes, also reflected in the FCR given in Table 3. Among the dual-purpose genotypes, DualMeat males had the highest BW and DWG at every weighing date, followed by DualBalance and DualEgg, which did not differ from each other (Supplementary Figure S2). From week 8 on, BW of DualMeat males was higher than the slower-growing genotypes DualEgg1 and DualBalance ($P < 0.05$). While CONM reached the target weight of 2.1 kg at 8 weeks of age, DualMeat exceeded this weight in 12 weeks of age. FCR until slaughter at 12 weeks of age differed between genotypes, with CONM showing

Table 3
BW, feed intake (FI), daily weight gain (DWG), feed conversion ratio (FCR), cumulative mortality, dual-purpose index (DPI) of tested chicken genotypes (DualMeat, DualBalance, DualEgg1/2, CONM) during the fattening trial.

	Genotype								
Item	DualMeat	DualBalance	DualEgg1	DualEgg2	CONM	SEM	GT	age	GT*age
10 weeks									
BW, g	1 770^{b}	1 369^{c}	1 248^{d}		3 147^{a}	12.1–23.0	<0.05	<0.05	<0.05
FI, g	78.3^{ab}	61.0^{b}	53.4^{b}		102^{a}	5.5–6.5	<0.05	<0.05	<0.05
DWG, g	24.7^{b}	18.9^{c}	17.2^{c}		43.0^{a}	0.3–0.5	<0.05	<0.05	<0.05
FCR	3.12^{b}	3.20^{b}	3.70^{b}		2.33^{a}	0.1–0.2	<0.05	<0.05	<0.05
12 weeks									
BW, g	2 187^{b}	1 763^{c}	1 652^{d}	1 644^{c}	3 851^{a}	12.1–23.0	<0.05	<0.05	<0.05
FI, g	88.6^{b}	72.1^{bc}	62.9^{c}	65.1^{c}	122^{a}	5.0–6.0	<0.05	<0.05	<0.05
DWG, g	25.7^{b}	20.4^{c}	19.0^{c}	19.2^{c}	44.6^{a}	0.3–0.5	<0.05	<0.05	<0.05
FCR	3.36^{b}	3.53^{b}	3.92^{b}	3.66^{b}	2.52^{a}	0.1–0.2	<0.05	<0.05	<0.05
16 weeks									
BW, g		2 483^{a}		2 367^{b}		16.0–16.1	<0.05	<0.05	<0.05
FI, g		92.2		87.9		4.8–5.4	0.565	<0.05	0.933
DWG, g		21.7^{a}		20.6^{b}		0.20–0.22	<0.05	<0.05	0.790
FCR		4.17^{b}		4.61^{a}		0.12–0.15	<0.05	<0.05	<0.05
Mortality, %	1.11	1.11	5.22	4.20	1.67				
DPI	1.30	1.77		1.86	0.70*/2.36^{+}				

Abbreviation: GT = genotype.
*Laying performance data for control females (CONM) and $^{+}$fattening performance data for control males (CONF) were not available from this trial. For DPI calculations, CONM laying data up to week 40 were obtained from the Breeder Management Guide (Hubbard, 2023), and CONF male growth data up to 10 weeks were sourced from Kreuzer et al. (2020).
Values within row with different superscripts differ significantly ($P \leq 0.05$).

the overall lowest FCR, followed by DualMeat ($P < 0.05$). There was no difference in FCR between DualBalance and DualEgg1 in week 12 ($P = 0.991$) nor between DualBalance and DualEgg2 in week 16 ($P = 0.417$). Animal losses occurred only in the first few weeks of rearing and were highest in DualEgg males (Table 3).

Carcass and meat quality of the males

Analysis of sample birds at week 10 showed that the CW of CONM was about twice as high as in DualMeat and dressing percentage was over 9% points higher ($P < 0.05$, Table 4). At 12 weeks of age, CONM also had the overall highest CW and dressing percentage while DualMeat had the highest CW and dressing percentage among the dual-purpose genotypes ($P < 0.05$). From weeks 10 to 12, CW of DualMeat and CONM increased by 29 and 25%, respectively. The extended fattening period of DualBalance and DualEgg2 resulted in an increase of CW from week 12 to week 16 by 51 and 56%, respectively.

With regard to valuable cuts, breast meat yield (**BMY**) of CONM was 8 percentage points higher than that of DualMeat in week 10, and more than twice as high as of DualMeat and DualBalance in week 12, where all four genotypes were included in meat quality measurements ($P < 0.05$, Table 4). Comparing the tested dual-purpose genotypes, the males of DualBalance had the lowest BMY ($P < 0.05$) compared to DualMeat and DualEgg. The DualEgg males increased BMY from 10.5% in week 12 to 11.7% at slaughter age at week 16, being significantly heavier than DualBalance ($P < 0.05$). The overall level of leg percentage was 20.1–21.6% (Table 4). Genotype and age but not their interaction had a significant effect on the percentage of legs, but none of the pairwise comparisons were. Wings in relation to BW were not significantly different between genotypes and ranged from 7.4 to 8.4%. At the second slaughter date, the overall weight of valuable cuts increased by 17 and 21% for CONM and DualMeat, respectively, and by 46 and 55% for DualBalance and DualEgg.

The breast skin colour for genotypes DualMeat and CONM in week 10 did not vary in its lightness (L*), but DualMeat was a deeper red (a*) and more yellow (b*) than CONM. In week 12, skin colour was only measured in genotypes DualMeat, DualBalance and DualEgg1. They did not vary in lightness of the skin, but DualEgg1 was deeper yellow ($P < 0.05$, Table 4).

In week 10, colour measurements of the breast meat without skin showed that DualMeat was deeper red in colour than the overall darker CONM, while there was no substantial difference in the degree of yellowness. In week 12, DualBalance had the lowest L* values, and therefore, darkest meat and meat from DualMeat had the deepest yellow, closely followed by DualEgg1.

There were no significant differences between pH values at 10 weeks of age between DualMeat and CONM. At week 12, pH_{15min} was highest in DualMeat and CONM, closely followed by DualBalance and lowest in DualEgg1 ($P < 0.05$). After overnight chilling, the pH_{24h} decreased in all genotypes, except DualEgg1, whose pH_{24h} was 6.71 (Table 4). The pH_{72h} remained at levels of pH_{24h} for DualMeat, DualBalance and CONM while it decreased for DualEgg1 to a similar value.

At 10 weeks of age, no difference in drip loss was observed between DualMeat and CONM (Table 4). At 12 weeks, a significant difference was found only between DualBalance and CONM, with the highest drip loss measured in DualBalance meat. Moreover, age had a significant effect on the drip loss of DualBalance and DualEgg, which decreased by 23 and 47% from week 12 to week 16, respectively ($P < 0.05$). For all four genotypes, drip loss decreased with increasing age ($P < 0.05$).

Table 4

Carcass weight (CW), slaughter and postmortem (p.m.) meat characteristics of tested chicken genotypes (CONM, DualMeat, DualBalance, DualEgg1/2) at 10, 12 and 16 weeks of age during the fattening trial (n = 20 per genotype).

	Genotype											
	CONM		DualMeat		DualBalance		DualEgg1	DualEgg2		*P*-value		
Fattening period in weeks	10	12	10	12	12	16	12	16	SEM	GT	age	GT*age
CW (g)	2 075^{a}	2 613^{a}	1 007^{b}	1 307^{b}	954^{c}	1 436	922^{c}	1 436	37.2–118.6	<0.05	<0.05	0.027
Dressing (%)	65.6^{a}	67.4^{a}	56.3	61.0	54.6	58.0	56.5	59.1	0.47–0.60	<0.05	<0.05	0.015
Valuable cuts (g)												
Breast meat	557^{a,B}	738^{a,A}	169	211^{b,A}	163^{c,B}	249^{b,A}	170^{bc,B}	282^{a,A}	9.3–12.3	<0.05	<0.05	<0.05
Legs	668	695^{a}	377	454^{b}	354^{bc,B}	525^{A}	331^{c,B}	503^{A}	19.1–23.4	<0.05	<0.05	0.502
Wings	252^{B}	309^{a,A}	147	169^{b}	142^{b,B}	187^{A}	150^{b,B}	210^{A}	7.9–18.4	<0.05	<0.05	0.018
Valuable cuts (%)												
Breast meat	17.6^{a,B}	19.1^{a,A}	9.3^{b}	9.8^{b}	9.3^{b}	10.1^{b}	10.5^{b,B}	11.7^{a,A}	0.25–0.31	<0.05	<0.05	0.128
Legs	21.1	21.6	20.9	21.0	20.1	21.2	20.3	20.9	0.30–0.48	0.032	0.039	0.699
Wings	7.5	7.4	8.0	7.8	8.0	7.6^{b}	8.2	8.4^{a}	0.19–0.28	0.005	0.487	0.387
Skin colour (24 h p.m.)												
L*	63.1		64.4^{A}	54.9^{B}	55.4		55.3		0.56–0.95	0.437	<0.05	
a*	6.5^{b}		8.0^{a,A}	1.9^{b,B}	2.0^{b}		5.5^{a}		0.27–0.45	<0.05	<0.05	
b*	11.6^{b}		13.6^{a,A}	6.9^{aB}	8.9^{a}		2.6^{b}		0.38–0.65	<0.05	<0.05	
Breast meat colour												
L*	56.5^{b}		64.0^{a,A}	54.2^{B}	50.9	51.1	52.2	51.5	1.0–1.8	<0.05	<0.05	0.714
a*	1.0		2.0^{B}	9.5^{A}	8.6^{A}	3.5^{B}	10.7^{A}	3.3^{B}	0.46–0.80	0.178	<0.05	0.058
b*	0.3^{b}		3.6^{a,B}	7.2^{a,A}	5.0^{b}	6.5	7.0	5.9	0.32–0.55	<0.05	<0.05	0.002
pH values												
15 min p.m.	6.70	6.71^{a}	6.62	6.67^{a}	6.37^{b}	6.28	6.47^{b}	6.41	0.04–0.05	<0.05	0.207	0.837
24 h p.m.	5.58	5.57^{b}	5.62	5.50^{b}	5.41^{b}	5.50	6.71^{a,A}	5.65^{B}	0.07–0.09	<0.05	<0.05	<0.05
72 h p.m.		5.54^{ab}		5.46^{b}	5.48^{ab,B}	5.61^{A}	5.54^{a,B}	5.63^{A}	0.01–0.02	0.003	<0.05	0.178
Drip loss (%)	0.82	0.73	0.90	0.75	1.13	0.88^{a}	0.95^{A}	0.51^{b,B}	0.08–0.14	0.015	<0.05	0.443

Abbreviations: GT = genotype, L* = lightness, a* = redness, b* = yellowness; values within row with different superscripts differ significantly ($P \leq 0.05$), small letters indicate significant differences between genotypes at same age, capital letters indicate significant differences between age within GT.

Feed intake and BW development of the females

Feed intake of the females differed significantly between the genotypes in the rearing and laying period, with highest in DualMeat and lowest in CONF and DualBalance and DualEgg in between, not differing from each other (Table 5). The total feed consumption from hatching till slaughter was the lowest in CONF at 54.9 kg, followed by DualEgg at 57.8 kg, DualBalance at 58.0 kg and DualMeat at 60.3 kg.

BW of the females differed significantly at each weighing, with DualMeat consistently being the heaviest, followed by DualEgg and DualBalance, and CONF with the lowest BW ($P < 0.05$, Table 5). At the age of 18 weeks, females of DualMeat weighed 2 305 g and were 36% heavier than CONF at 1 696 g, while females of DualBalance and DualEgg were in between with 1 881 and 1 924 g, respectively, and did not differ from each other. The highest BW of DualBalance was recorded in week 58 (2 604 g), and in week 63 for all other genotypes (DualMeat 2807, DualEgg 2534, CONF 2 200 g; Supplementary Figure S3). After the peak, BW slightly decreased across all genotypes, until in week 72, DualMeat females weighed 2 766 g and were 32% heavier than CONF at 2 093 g, while DualBalance and DualEgg weighed 2 523 g and 2 478 g, respectively.

Laying performance, egg quality and carcass quality of the females

The genotypes DualMeat and CONF started laying in week 17, followed by DualBalance and DualEgg in week 18. DualBalance and DualEgg reached peak production in week 24 and 26 (89.7 and 96.8%), respectively, followed by DualMeat in week 38 (81.5%) and finally CONF in week 48 (95.2%; Fig. 4a). Most of the time (except weeks 24–28, 31–33 and 37), the laying performance of DualBalance and DualEgg hens was very similar and always between DualMeat and CONF hens. At the end of the laying period (weeks 60–72), DualEgg exhibited the highest persistency among the dual-purpose genotypes. Genotype and age but not their interaction had a significant effect on overall laying performance, with CONF achieving the highest, and DualEgg, DualBalance and DualMeat being 11, 12 and 21 percentage points lower, respectively (Table 5). The total egg mass produced by an average hen was 15.2 kg in DualMeat, 17.5 kg in DualBalance, 18.2 kg in DualEgg and 21.4 kg in CONF hens, respectively. While the significantly highest FCR_{lay} was recorded for DualMeat and the lowest for CONF, DualBalance and DualEgg were in between. The FCR_{total}, which considers egg mass, meat yield and total feed consumption, followed the same order as FCR_{lay}.

The egg weight was significantly influenced by the interaction of GT*age ($P < 0.05$). The steepest egg weight increase was recorded for CONF (Fig. 4b), and this genotype also produced the highest egg weight overall ($P < 0.05$). Eggs of DualMeat, DualBalance and DualEgg were 2.8 to 4.3% lighter than CONF, and did not differ from each other. During the laying period, egg weight increased in all genotypes, from 49.4-51.3 g in week 21 to 67.4–68.9 g in week 72. The proportion of M and L eggs ranged from 82% (CONF) to 85% (DualMeat), with DualMeat having the highest proportion of S eggs and CONF having the highest proportion of XL eggs (Fig. 4c). The share of non-marketable eggs was lowest for CONF and highest for DualMeat ($P < 0.05$, Table 5).

A total of 280 eggs from DualMeat, DualBalance, and CONF, and 270 eggs from DualEgg were analysed for selected egg quality traits. Egg shape was influenced by both genotype and age

Table 5

Feed intake (FI), BW, laying performance, feed conversion ratio (FCR), cumulative mortality from weeks 21–72 and postmortem (p.m.) carcass characteristics (n = 20 per genotype) of tested female chicken genotypes (DualMeat, DualBalance, DualEgg, CONF).

	Genotypes							
Item	DualMeat	DualBalance	DualEgg	CONF	SEM	GT	age	GT*age
FI, g feed d^{-1}								
Week 1–17	84.6^{a}	73.1^{bc}	82.7^{ab}	70.1^{c}	2.7	<0.05	<0.05	
Week 18–72	130.5^{a}	127.2^{ab}	125.3^{ab}	121.1^{b}	1.7–2.4	0.022	<0.05	0.893
BW, g								
Week 18	$2\ 305^{a}$	$1\ 881^{b}$	$1\ 924^{b}$	$1\ 696^{c}$	17.1–24.4	<0.05	<0.05	<0.05
Week 38	$2\ 578^{a}$	$2\ 299^{b}$	$2\ 364^{b}$	$2\ 015^{c}$	18.3–24.5	<0.05	<0.05	<0.05
Week 72	$2\ 766^{a}$	$2\ 523^{b}$	$2\ 478^{b}$	$2\ 093^{c}$	18.2–25.0	<0.05	<0.05	<0.05
Laying performance per hen alive								
Laying performance, %	61.8^{b}	71.2^{b}	72.3^{ab}	82.9^{a}	2.5–3.4	<0.05	<0.05	0.070
Egg weight, g	61.9^{b}	63.2^{b}	62.9^{b}	64.7^{a}	0.4–0.6	<0.05	<0.05	<0.05
Number of eggs	242	270	279	312				
Non-marketable eggs, %	24.02	23.65	17.89	20.98	2.0–2.3	0.215	<0.05	<0.05
FCR_{lay}	3.43^{a}	2.86^{b}	2.62^{bc}	2.14^{c}	0.09–0.12	<0.05	<0.05	0.599
FCR_{total}	3.57	3.05	2.95	2.43				
Mortality, %	11.0	7.0	12.0	12.0				
Carcass characteristics								
CW, g	$1\ 642^{a}$	$1\ 443^{b}$	$1\ 430^{b}$	$1\ 194^{c}$	22.3–30.1	<0.05		
Dressing, %	55.2^{a}	55.2^{a}	54.6^{a}	51.8^{b}	0.32	<0.05		
Drip loss, %	0.90^{a}	0.53^{b}	0.67^{a}	0.51^{b}	0.1	<0.05		
Legs, g	543^{a}	470^{b}	472^{b}	382^{c}	6.4	<0.05		
Legs, %	35.5^{b}	34.5^{b}	34.3^{b}	38.3^{a}	0.42	<0.05		
Breast, g	348^{a}	271^{b}	275^{b}	211^{c}	5.3	<0.05		
Breast, %	22.7^{a}	19.9^{b}	19.8^{b}	19.2^{b}	0.27	<0.05		
Wings, g	182^{a}	163^{b}	167^{b}	140^{c}	2.06	<0.05		
Wings, %	11.8^{a}	12.1^{a}	12.1^{a}	12.9^{b}	0.13	<0.05		
pH_{15min}	6.5^{a}	6.4^{a}	6.4^{a}	6.3^{b}	0.03	<0.05		
pH_{24h}	5.8^{b}	5.8^{b}	5.8^{b}	5.9^{a}	0.02	<0.05		
L*, 24 h p.m. breast	53.8	51.9	52.3	51.7	0.65–0.67	0.103		
a*, 24 h p.m. breast	1.1	1.2	1.4	0.8	0.15	0.058		
b*, 24 h p.m. breast	2.8^{a}	3.2^{a}	3.1^{a}	1.7^{b}	0.23–0.24	<0.05		

Abbreviations: GT = genotype, CW = Carcass weight, L* = lightness, a* = redness, b* = yellowness; values within row with different superscripts differ significantly ($P \leq 0.05$).

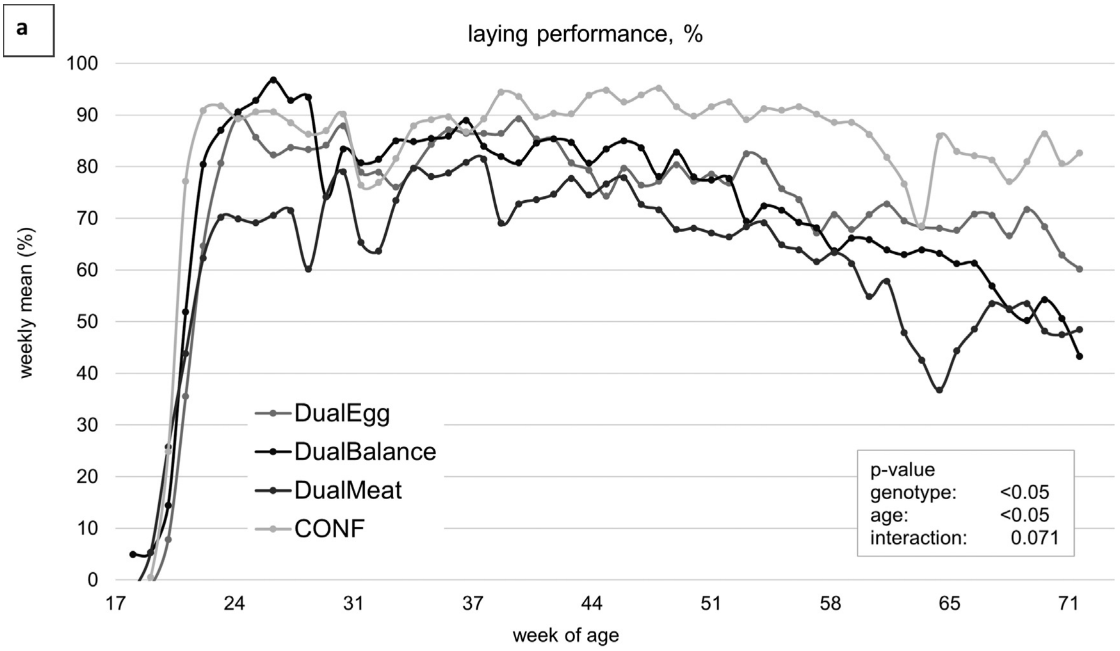


Fig. 4. Performance and quality traits of tested chicken genotypes (DualMeat, DualBalance, DualEgg, CONF) as differentiated by hen age between 18–72 weeks of age for a-c and from 21–72 weeks of age for d-g. (a) weekly laying performance, %; (b) egg weight, g; (c) egg size distribution (small (S) <53 g, medium (M) ≥53 g to <63 g, large (L) ≥63 to <73 g, extra-large (XL) ≥73 g), %; (d) egg shape index (SI); e) shell colour, L*; (f) shell weight, g DM; global *P*–values of the fixed effects of genotype, age and their interaction.

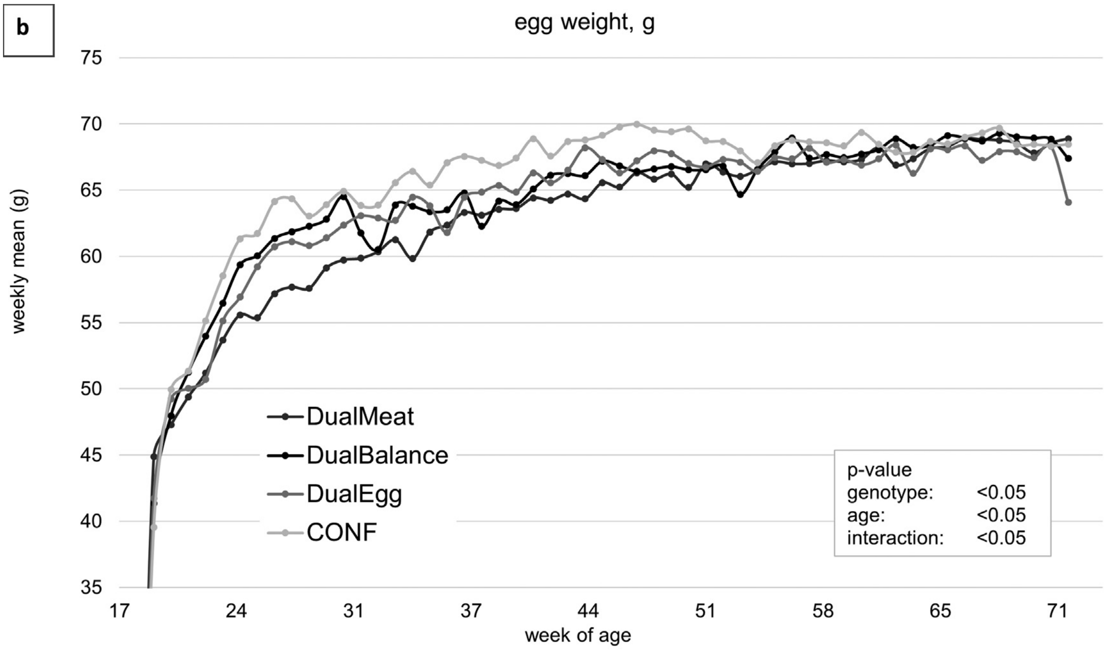


Fig. 4 (*continued*)

(Fig. 4d), with all genotypes starting with a high SI that decreased over time ($P < 0.05$). Both DualMeat and DualBalance laid elongated, pointed eggs (mean SI 75.4 and 75.9), while DualEgg and CONF laid rounder eggs (mean SI 77.0 and 77.6, Fig. 4d).

The eggshell colour of DualMeat, DualEgg and CONF was cream to light brown, with DualMeat and DualEgg eggs being the lightest and CONF eggs being darker in colour. The eggs of DualBalance were dark brown and partly spotted (Fig. 4e). Eggshell mass was highest in CONF at 6.5 g, followed by DualMeat (6.3 g), DualEgg (6.1 g), and DualBalance (5.9 g) (Fig. 4g). This corresponded to 14% of total egg mass in DualMeat, DualEgg, and CONF, and 13% in DualBalance.

Regarding the carcass quality of the hens slaughtered at the age of 72 weeks, CW was the highest in DualMeat and the lowest in CONF, with DualBalance and DualEgg presenting intermediate CW values ($P < 0.05$, Table 5). Expressed in relation to BW, CONF had the highest proportion of leg meat (38.3%), whereas DualMeat had the highest proportion of breast meat (22.7%; $P < 0.05$). The

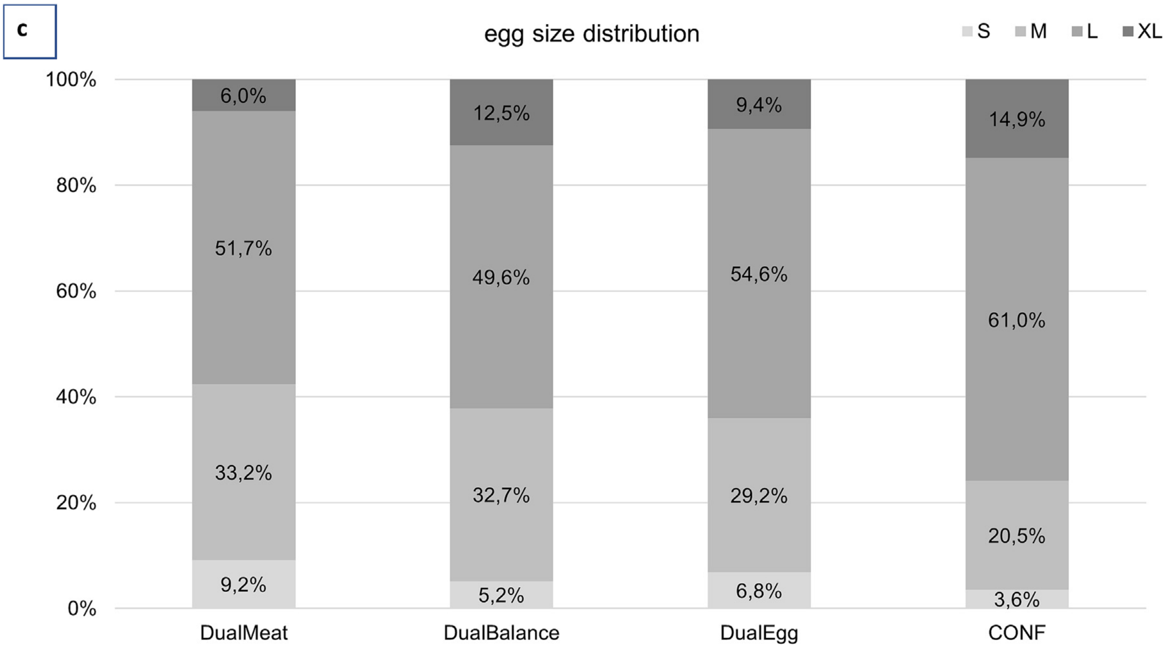


Fig. 4 (*continued*)

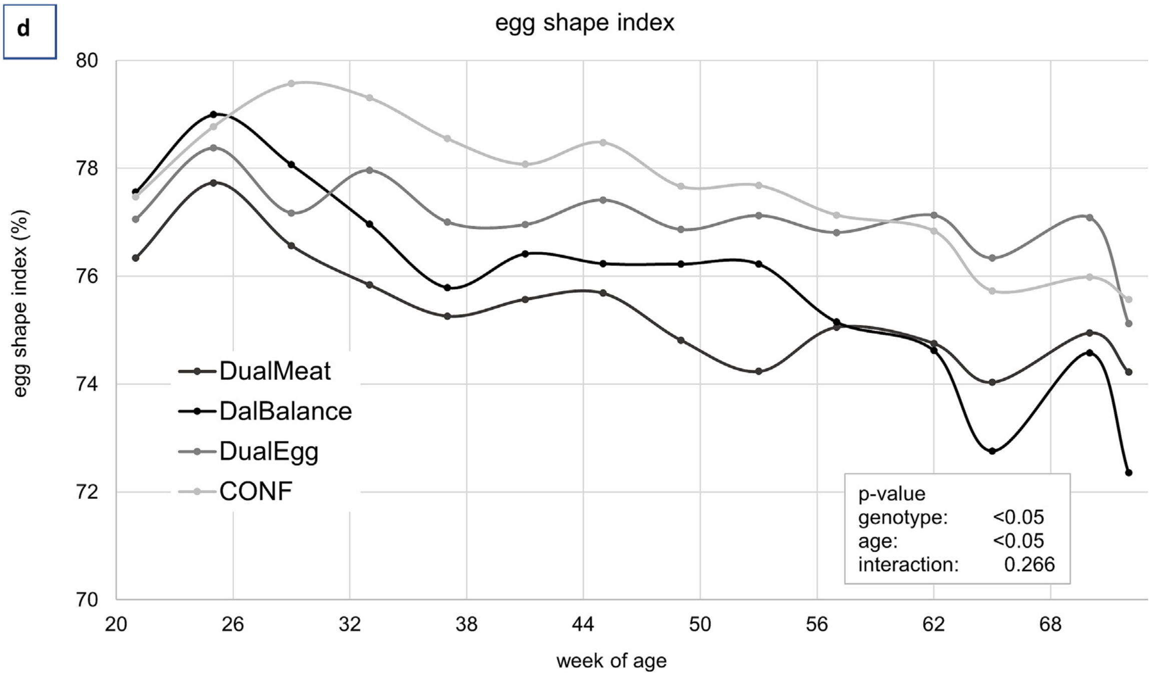


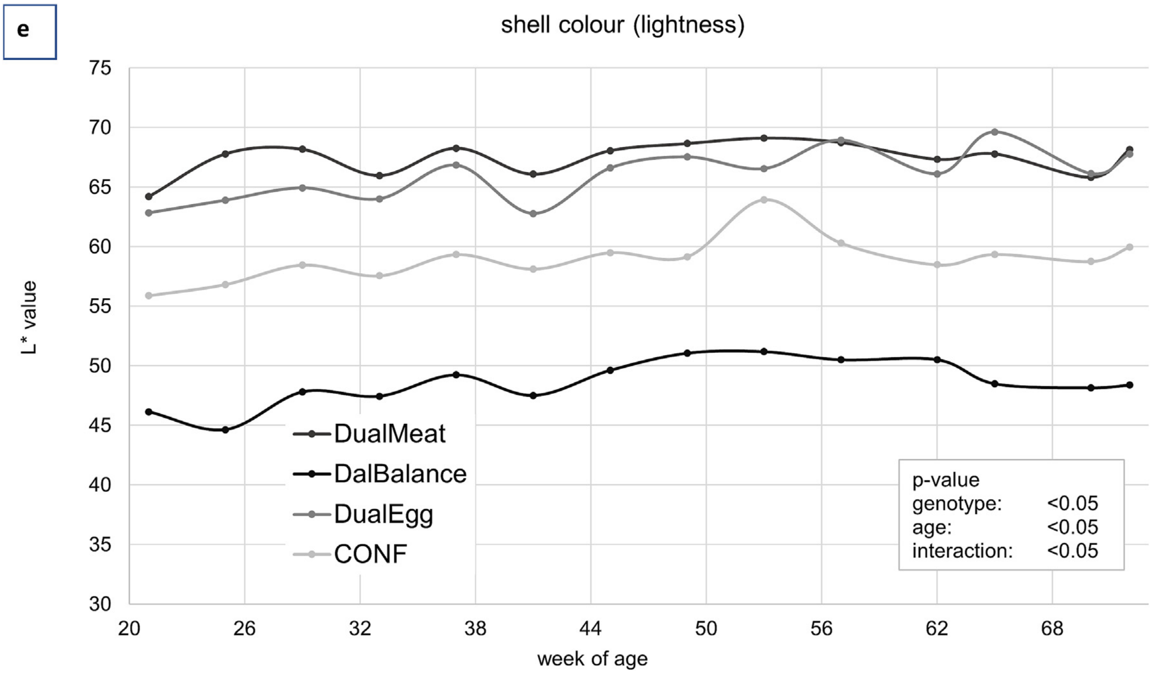
Fig. 4 (*continued*)

highest drip loss of breast meat was recorded for DualMeat and the lowest for CONF ($P < 0.05$). No significant differences were found in breast meat lightness or redness between genotypes. Although the lowest redness value was recorded for CON, it was not statistically different from the values for the other genotypes, while its yellowness was significantly lower than in the other genotypes (Table 5).

The DPI was highest in the specialised high-output genotype CONF and lowest in CONM (2.36 vs 0.70). Among the tested dual-purpose genotypes, DPI values ranged in between, with the highest in DualEgg (1.86), followed by DualBalance (1.77) and DualMeat (1.30; Table 3).

Economic feasibility of the males and females

In terms of meat production under regional marketing conditions and price assumptions (Table 2), DualMeat males were the most cost-effective among the dual-purpose genotypes (332 €/100 kg BW), followed by DualEgg (360 €/100 kg BW) and DualBalance (369 €/100 kg BW), as illustrated in Scenario 1 (Fig. 5). As expected, CONM achieved the lowest overall production costs at 255 €/100 kg BW. A 15% reduction in feed costs in Scenario 2 further decreased the total production costs of fattening DualMeat, DualBalance, and DualEgg males by 9–10% (Fig. 5).



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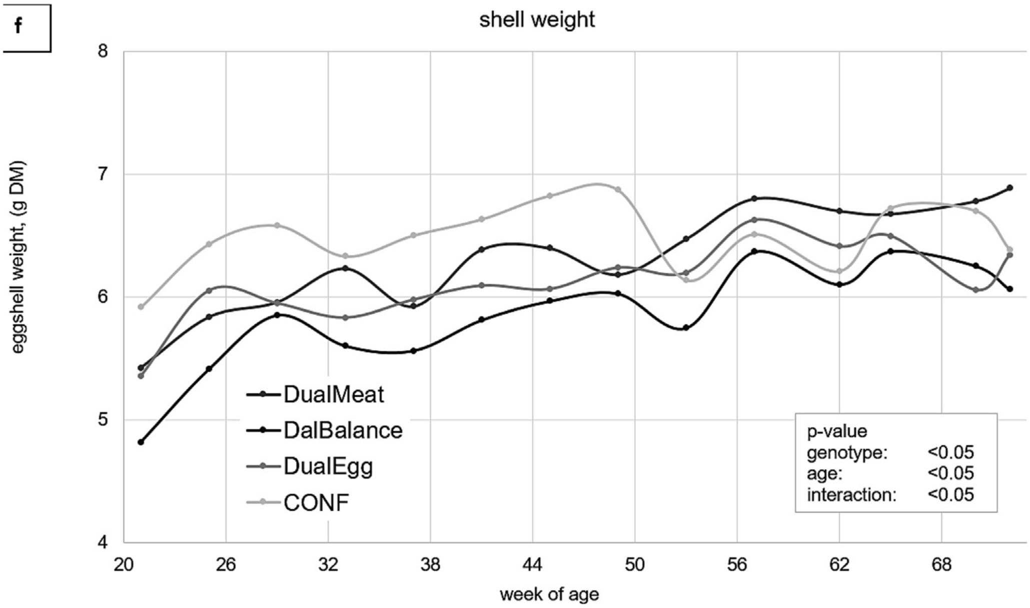

Fig. 4 (*continued*)

Regarding profitability, Scenarios 2, 3, and 4 were profitable in the short, medium, and long term, with revenues exceeding cash, depreciation, and opportunity costs (Fig. 6). Under the identical selling price assumption in Scenario 1, none of the dual-purpose genotypes were profitable, generating 100–109% lower net income compared with CONM. In Scenario 3, which represents the most favourable conditions for dual-purpose meat production, the net income of the dual-purpose genotypes was 145–179% higher than CONM. Under Scenario 4, dual-purpose meat production remained profitable; however, net income was 41–79% lower than CONM.

In the laying trial under Scenario 1, DualEgg showed the lowest production costs among the dual-purpose genotypes, at +4.8 cents per egg relative to CONF, followed by DualBalance (+5.3 cents). DualMeat incurred the largest cost increase (+11.3 cents) (Fig. 7). As expected, CONF hens maintained the lowest egg production costs, while DualMeat hens had the highest. Overall, egg production costs for the dual-purpose hens were 18–43% higher than for CONF, with feed contributing 30–32% of total costs. Despite these higher costs, the economic analysis under Scenario 1 indicated that egg production from DualEgg, DualBalance, and DualMeat hens remained economically viable across the short, medium, and long term. Total revenues covered both fixed and variable costs, resulting in a positive net return (Fig. 7). Under Scenario 2, a 15% reduction in feed costs increased total returns for eggs from the dual-purpose layers by 14–36% compared with Scenario 1, with the strongest impact observed for DualMeat (Fig. 7).

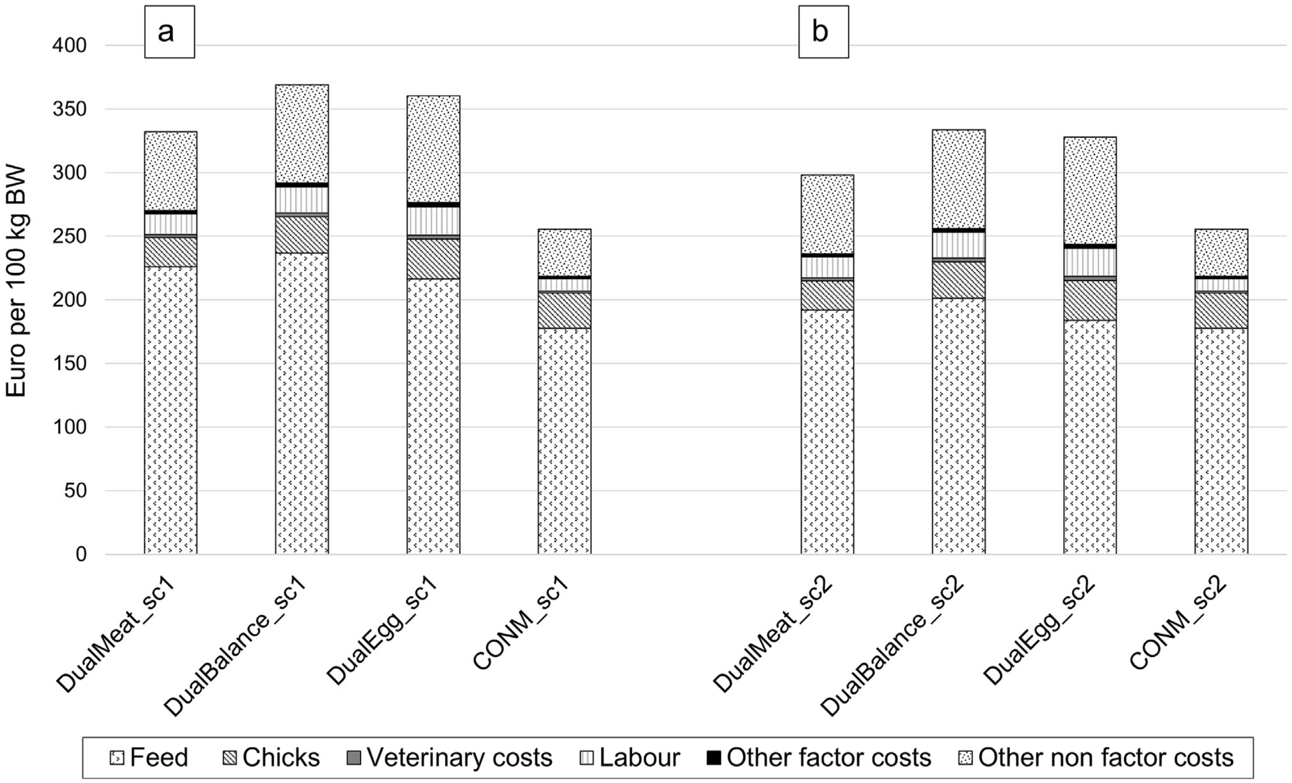

Fig. 5. Comparison of production costs for four tested chicken genotypes (DualMeat, DualBalance, DualEgg, CONM) in the fattening trial up to 12 weeks of age under two different scenarios: (a) identical feed costs for all genotypes; (b) 15% feed-cost reduction for dual-purpose genotypes.

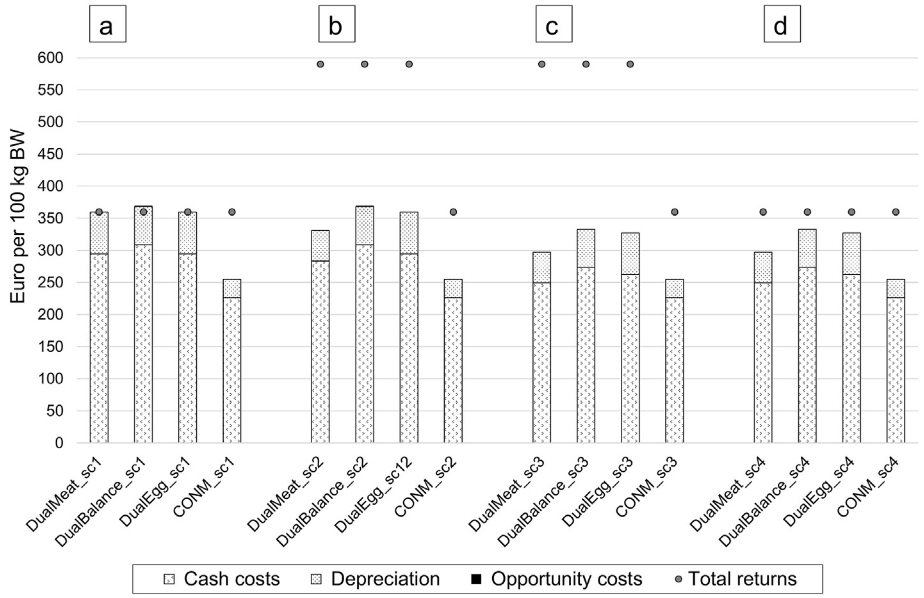

Fig. 6. Profitability of four tested chicken genotypes in the fattening trial (DualMeat, DualBalance, DualEgg, CONM), evaluated across four scenarios: (1) same meat price for all genotypes; (2) premium pricing for dual-purpose meat; (3) premium pricing combined with a 15% feed-cost reduction for dual-purpose genotypes; and (4) identical meat price combined with a 15% feed-cost reduction for dual-purpose genotypes.

Consequently, net income increased by 1–2 cents per egg across the dual-purpose genotypes relative to CONF.

Discussion

Specialised layer and broiler lines are intensively selected for quantitative and qualitative traits of meat or eggs. In dual-purpose poultry, production performance cannot be expected at the same high level since both fattening and laying are combined in one genotype. To successfully implement dual-purpose genotypes in commercial production, it is necessary to identify genotypes that show good performance with an optimised resource consumption, as well as high product quality and ability to generate higher consumer prices. This study aimed to evaluate the performance, product quality traits and economic feasibility of hens and males of three novel dual-purpose genotypes in relation to a

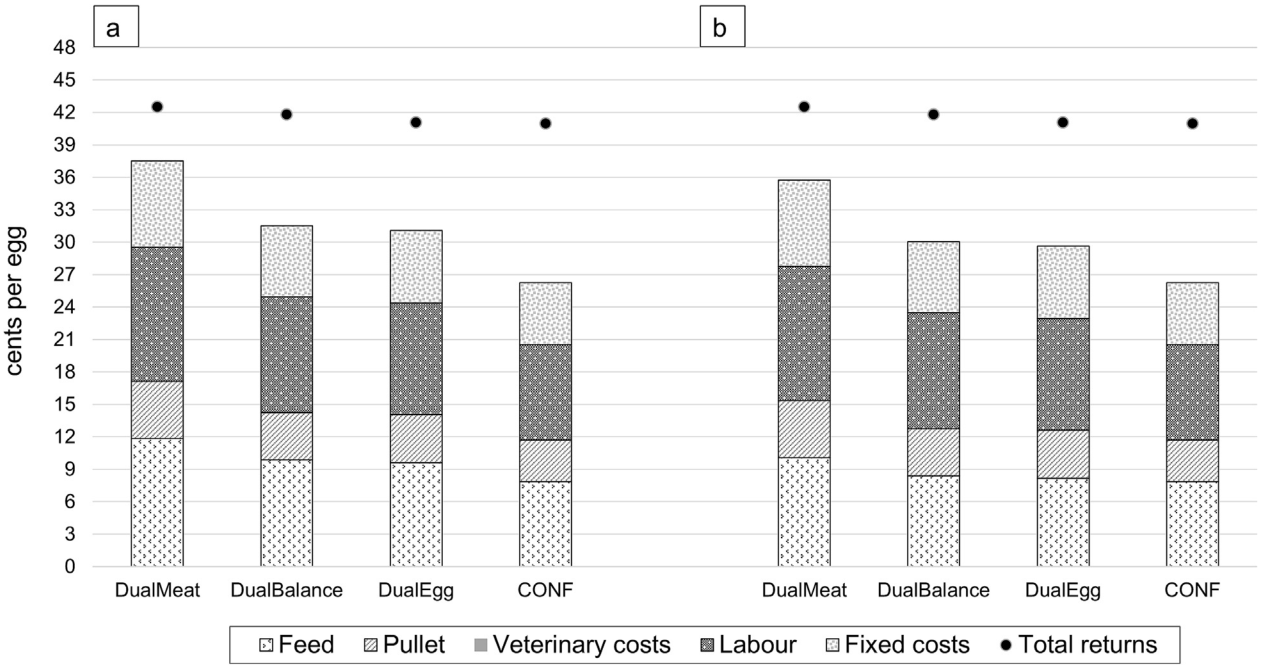

Fig. 7. Production costs, returns, and profitability of the laying trial for the tested chicken genotypes (DualMeat, DualBalance, DualEgg, CONF) evaluated under two economic scenarios: (a) based on the price assumptions listed in Table 2, and (b) incorporating a 15% feed-cost reduction for dual-purpose layers.

commercial layer and broiler under organic husbandry conditions. Due to restrictions to prevent the spread of AI, access to an uncovered outdoor run was not allowed for the males and only from week 28 to week 60 for the females. As a substitute, all birds had access to covered outdoor runs. Environmental and management factors, such as weather variation, confinement, and delayed outdoor access, may have differentially affected genotype performance, potentially confounding comparisons. The presented results do not account for these deviations, which were implemented due to biosecurity measures.

Feed intake and fattening performance of the males

Throughout the fattening period, CONM always had the highest FI compared to the dual-purpose genotypes, with the difference ranging from 23 to 48% up to week 10, and by 27 to 48% up to week 12. This range of FI translated into an equally high variation of fattening performance between the tested genotypes, highlighting their differing genetic profiles. The mixed-sex rearing of CONM up to 6 weeks of age may have affected early growth and feed intake patterns, thereby potentially constraining direct comparisons with dual-purpose males. Among the dual-purpose genotypes, the fact that DualMeat had a 21 to 26% higher DWG compared to DualBalance and DualEgg1 at 12 weeks confirms the meat-focused genetic selection of this genotype. In order to represent the usual practice on organic farms, for the first slaughter date of each genotype, the heaviest groups were chosen. This means that the DualMeat males slaughtered at 12 weeks represent the lower-performing groups of this genotype and still had a higher CW and dressing percentage than the best-performing groups of DualBalance and DualEgg, which also underlines their superior fattening performance.

The BW development of DualMeat is comparable to that of Lohmann Dual males fed similar diets (Urban et al., 2018; Müller et al., 2020). Considering that the birds in these studies were reared under conditions comparable to a conventional indoor floor system (no outdoor range), the fattening performance of DualMeat males is competitive with other dual-purpose genotypes.

The growth curves of DualBalance and DualEgg1 males up to 12 weeks were flatter than in DualMeat, with DualEgg1 having the lowest DWG of the dual-purpose genotypes. In a study on dual-purpose breed improvement, Bamidele et al. (2020) illustrated that the genetic gain towards higher laying performance comes at the expense of fattening ability. This effect can also be seen in DualEgg, which had the highest laying performance and a lower fattening performance as compared to DualMeat and DualBalance. Nevertheless, growth of DualEgg1 males until 12 weeks was still faster than in dual-purpose crosses from German traditional breeds reared under organic conditions, for which Baldinger and Bussemas (2020) reported a DWG of 19.2–20.6 g until 11 weeks of age. Although DualBalance was not subject to intensive selection (personal communication, Maïlys Faure, Hendrix Genetics), the BW of DualBalance males did not differ from that of DualEgg2 in week 16. The DWG achieved by DualBalance and DualEgg2 was only slightly lower than the DWG of 21.7–22.3 g reported by Lambertz et al. (2018) for free-range males of purebred Bresse-Gauloise and their crosses with New Hampshire. All dual-purpose genotype males exceeded that of males of layer lines, for which a BW of 1 243 g after 10 weeks (Damme and Ristic, 2003), 1 705 g after 15 weeks (Baldinger and Bussemas, 2021) and 1 597 g after 16 weeks (Murawska et al., 2019) have been reported. This comparison emphasises the competitiveness of the males of dual-purpose genotypes to the rearing of males of layer lines, achieving optimised FCRs with higher BW in the same fattening period.

When discussing the fattening performance of novel chicken genotypes, the type of feed offered to the birds must be considered: most studies, including the present one, have used broiler diets with high energy and protein contents (Torres et al., 2019; Tiemann et al., 2020; Baldinger and Bussemas, 2021). Few studies have used a pullet feed or diets with lower energy and protein content (Kreuzer et al., 2020; Freick et al., 2022; Becker et al., 2023). The FCR of dual-purpose chicken is higher than that of specialised broilers, as demonstrated both in our study and the one by Leenstra et al. (2010). It should be noted, however, that AI restrictions active during our study prevented the birds from feeding in the outdoor range, which could have slightly reduced their intake of concentrate feed. Moreover, the precise nutritional requirements of dual-purpose chicken have yet to be validated. Due to their lower growth performance, dual-purpose males have lower nutritional requirements than broiler chickens, which experience greater growth depression when dietary protein content is reduced (Ammer et al., 2017; Urban et al., 2018; Kreuzer et al., 2020). Although providing all genotypes with the same diet - designed for optimal weight gain - ensured comparability in our study, it may have constrained the expression of genotype-specific performance. Adapting feeds to match the lower nutrient requirements of dual-purpose poultry could make feeding more economical than for high-performance genotypes. This not only improves overall cost-effectiveness but may also enhance nutrient efficiency by reducing the proportion of nutrients excreted. Such improvements have implications beyond feed cost, contributing to greater environmental sustainability. Further research, including the analysis of droppings and classical dose–response studies, is needed to more precisely evaluate nutrient utilisation of dual-purpose poultry.

Carcass characteristics and meat quality of the males

While dressing percentage and the proportion of valuable cuts increased with age across all genotypes, dual-purpose males consistently differed from CONM in carcass characteristics at all slaughter ages. The results reflect the breeding success of recent decades in fast growth, as demonstrated by the superior performance of CONM. In contrast, all three tested dual-purpose genotypes exhibited slower growth and consequently lower CW. This is largely due to their genetic selection not only for meat growth but also for the laying performance of their female siblings.

At 10 weeks, DualMeat and CONM reared organically had higher BMY than conventionally reared ISA Dual and JA757 (Chodová et al., 2021). At the second slaughter date, CONM and DualMeat showed 17 and 21% higher yields of valuable cuts, respectively. The smaller gain observed in CONM suggests that this genotype had already reached its growth peak, with a subsequent slowdown in growth rate. This indicates that the first slaughter date was optimal under the trial conditions, both in terms of feed efficiency and achieving the target weight. By 12 weeks, CONM matched fast-growing genotype Cobb 700 (20.7% BMY), while DualMeat, DualBalance, and DualEgg1 aligned with medium grower Naked Neck Kabir (10.1%) under organic conditions (Sirri et al., 2011). At this age, DualMeat and DualEgg1 carcasses appeared rounder and fleshier, while DualBalance remained leaner (Fig. 8). By 16 weeks, DualMeat and DualEgg2 exhibited improved body conformation. While DualBalance and DualEgg2 showed similar dressing percentages and leg meat yields, DualEgg2 achieved a notably higher BMY. Overall, at 16 weeks, DualBalance and DualEgg2 produced 46 and 55% more valuable cuts, respectively—supporting the recommendation to extend the fattening period for these slower-growing genotypes to optimise the yield of attractive, high-value portions.

While BW increased with slaughter age across all genotypes, growth allocation differed. In CONM, breast weight rose by 32% from week 10 to week 12, while leg weight increased by just 4%, reflecting selective breeding for breast muscle growth that has changed muscle fibre characteristics (Chodová et al., 2021; Weng et al., 2021). In contrast, DualMeat showed more balanced gain, consistent with prior findings that dual-purpose chickens allocate more growth to leg muscles, while breast development relative to BW is prioritised in broilers (Almasi et al., 2015; Becker et al., 2023). The harmonised development of all valuable cuts is a marketing advantage: each cut—including giblets— offers a distinct nutritional and culinary value, supporting the “nose-to-tail” concept and the valorisation of the whole animal (Seong et al., 2015; European Commission, 2020). For instance, leg muscles contain more intramuscular fat than breast muscle, primarily due to differences in muscle fibre composition. Chicken breast muscle is composed predominantly of type IIB fibres, whereas leg muscles contain higher proportions of type I and type IIA fibres, which are associated with greater intramuscular fat deposition (Kim et al., 2008; Hwang et al., 2010). Intramuscular fat content is a key component for high palatability of meat, making this cut an undervalued yet distinguished culinary asset. Balanced muscle and organ development supports overall bird health and helps prevent metabolic disorders (Julian, 1998; Angel, 2007; Huber, 2024). In contrast, rapid, disproportionate growth in poultry can impair physiological and metabolic functions, ultimately compromising meat quality.

Fig. 8. Carcass conformation of males of tested dual-purpose chicken genotypes at 12 weeks of age after overnight chilling (from left to right: DualMeat, DualBalance, DualEgg).

When marketing whole carcass, visual traits such as skin colour, as well as the presence of feather residues, are crucial to consumer perceptions of quality and freshness (Escobedo del Bosque et al., 2021). Although DualBalance and DualEgg had dark plumage, the plucking machine effectively removed pinfeathers, leaving no visible traces—an important processing advantage, since dark-feathered poultry often presents plucking challenges (Müller, 2018).

In our study, DualEgg exhibited the highest breast skin redness, while DualBalance had the highest yellowness among the tested dual-purpose genotypes. Both values exceeded those reported for the dual-purpose Bresse Gauloise, a breed renowned for its meat quality and consumer appeal (Muth et al., 2018). Skin and meat colour are largely genetically determined (Fletcher et al., 2000), but access to pasture and increased locomotor activity also contribute to darker, more deeply pigmented meat due to higher myoglobin content (Fanatico and Born, 2010; Tong et al., 2015). Moreover, foraging chickens tend to produce meat with lower total cholesterol, higher levels of vitamins A and E, increased n-3 fatty acids, and a more favourable n-3-to-n-6 ratio (Dal Bosco et al., 2016). At 12 weeks of age, the breast meat redness of the tested dual-purpose genotypes exceeded the values reported for purebred Bresse Gauloise and its cross with New Hampshire (Lambertz et al., 2018). As outdoor access was temporarily restricted due to AI regulations, the pronounced red coloration observed may reflect a genetically determined trait in these genotypes. Multiple studies reported that dual-purpose birds tend to have darker and more yellow skin and meat than broilers, with these traits influenced by genotype, diet, and rearing conditions (Almasi et al., 2015; Muth et al., 2018; Torres et al., 2019). Meat colour also tends to deepen with age (Baeza et al., 2013), which was reflected in both DualMeat and CONM genotypes, showing lighter meat colour at the first slaughter date compared to the second. The breast meat yellowness of DualMeat and DualEgg1 was higher than reported for other dual-purpose breeds (Lambertz et al., 2018; Fiorilla et al., 2024). This may indicate higher intramuscular fat deposition, as b* values are positively correlated with fat content (Chen et al., 2016; Popova et al., 2023). Since tenderness, a key trait for meat quality, is associated with fat content (Castellini et al., 2002), the elevated b* values observed may indicate superior culinary quality. Altogether, these findings suggest that the dual-purpose genotypes tested, especially when given access to pasture, exhibit desirable traits, which align with consumer expectations for organic and free-range poultry—specifically, darker and more yellow meat coloration (Castellini et al., 2008).

The pH_{24h} value is an important indicator of muscle-to-meat conversion and influences tenderness, water-holding capacity, and drip loss. A pH above 6.1 is associated with firm, dry meat with reduced shelf life, while a pH_{24h} below 5.5 results in pale, soft, acidic meat with increased drip loss (Fletcher et al., 2000). Except for DualEgg1 at 12 weeks, all measured pH_{24h} values were in the normal range. After slaughter at 10 weeks, the pH_{24h} value of DualMeat matched values reported by Chodová et al. (2021) for ISA Dual, while CONM exhibited slightly lower values compared to JA757 in the same study. At 12 and 16 weeks, pH_{24h} values remained within the recommended range of 5.5–5.9 for chilled carcasses and were consistent with previous reports on dual-purpose genotypes (Englmaierová et al., 2020; Fiorilla et al., 2024). As mentioned above, the only exception was DualEgg1 at 12 weeks, for which a temporarily elevated pH_{24h} was recorded, although the final pH_{72h} normalise drip loss was low for all genotypes at all slaughter ages. This indicates good water-holding capacity of the muscular fibres, which has a positive effect on shelf-life and a strong impact on sensory parameters (Ahmad et al. 2019). The values were similar to 0.68–1.05% of organically reared broilers at 10 weeks, reported by Müller (2018).

In summary, while the dual-purpose genotypes yielded lower CW and valuable cuts compared to specialised broiler genotype, their functional meat qualities were comparable. The dual-purpose males showed a more balanced distribution of valuable cuts. Harmonised proportionate growth favours the sale of dual-purpose males as whole carcass, offering superior quality when compared to the rather lean, less desirable carcasses of males of layer breeds (Müller, 2018). This favourable conformation, coupled with reports of higher palatability and a higher nutritional quality (Sirri et al., 2011; Sarsenbek et al., 2013; Torres et al., 2019; Pérez et al., 2021) of dual-purpose chicken meat, represents an opportunity—rather than an obstacle—for marketing this alternative product.

Feed intake and BW development of the females

During rearing, FI of DualMeat and DualEgg was higher than that of CONF due to their faster growth. During the laying period, FI of DualMeat was still higher than that of CONF, while DualBalance and DualEgg did not differ anymore (Table 5). No significant differences in FI were observed among the dual-purpose genotypes during the laying period. However, the greater difference in FI between the dual-purpose genotypes and CONF during the rearing period, as compared to the laying period, highlights the potential for genotype-specific feeding strategies during rearing to improve the overall sustainability and efficiency of dual-purpose poultry systems. (Müller et al., 2023; Ito, 2023). During the laying period, the FI of CONF was similar to the range of 117–126 g/d found for the same genotype in organic husbandry in a study by Giersberg et al. (2019). While the higher FI of DualMeat compared to CONF presents an economic disadvantage, there might be improvement options for the future, namely reducing the costly protein concentration in the diet, which can reduce body fat content and increase egg production of dual-purpose hens (Röhe et al., 2019; Hu et al., 2024). Also, the design of the outdoor run in free-range systems can help reduce feed costs by 15% without compromising the yield (Meng et al., 2016). This option was only available to a limited extent during the course of our study, because access to an uncovered outdoor run was only possible from weeks 28–60 due to AI restrictions.

BW and flock uniformity at the onset of lay are important indicators of optimal body development during rearing, and they significantly impact productivity, health, and welfare during the laying period (Janczak and Riber, 2015; Jongman, 2021). At 18 weeks of age, uniformity (BW within ± 10% GT mean) was similar across the tested genotypes, ranging from 75% in DualMeat, 83% in CONF, 85% in DualEgg, to the highest 86% in DualBalance. While the dual-purpose genotypes were selected for differing performance profiles, all were heavier than CONF. The BW of CONF was 10% higher than the breedeŕs recommendation in alternative systems (1 565 g), with hens reaching adult BW around 30 weeks of age (Lohmann, 2021). For the dual-purpose genotypes, no breedeŕs recommendations are currently available, but their BW at the onset of lay aligned with that of traditional breeds such as the Vanaraja or Bresse chicken (Kumaresan et al., 2008; Baldinger and Bussemas, 2020). Throughout the laying period, all genotypes showed a 22–38% increase in BW, reaching peak values between 58 and 63 weeks of age (Supplementary Figure S3). Hens housed in mobile barns had full outdoor access from 28-60 weeks of age, after which access was restricted due to AI control measures. During the following final 14 weeks, BW stagnated or slightly declined by 1–4%, likely due to limited space and associated stress, as well as broodiness observed in some individual hens.

Mortality rates over the laying period were 7% (DualBalance), 11% (DualMeat), and 12% (DualEgg and CONF), lower than or comparable to values (9–26%) reported for organic dual-purpose crosses (Baldinger and Bussemas, 2020). Notably, low mortality and sustained laying performance suggest that DualBalance performed well under the given conditions. Free-range systems are more prone to elevated mortality rates due to predator exposure, underscoring the importance of protective infrastructure and landscape-adapted management to safeguard flocks. Mortality prior to 28 weeks of age was lowest in CONF (2.0%), followed by DualBalance (2.4%) and DualMeat (2.5%), and highest in DualEgg (9.6%). Thus, the majority of casualties occurred when the birds were housed in the mobile barns.

Egg productivity

The dual-purpose genotypes began laying in week 18, similar to CONF, contradicting earlier reports of delayed sexual maturity in traditional and dual-purpose breeds (Hocking et al., 2003; Bekele et al., 2010; Rizzi, 2020). Overall laying performance of the dual-purpose genotypes ranged from 62 to 72%, comparable to dual-purpose genotypes such as Lohmann Dual and Novogen experimental lines under organic conditions (Kaufmann et al., 2018; Schmidt and Damme, 2017). DualMeat, which maintained the highest BW, exhibited the lowest egg production, while CONF, with the lowest BW, achieved the highest. Nonetheless, DualMeat outperformed values reported for meat-type Bresse hens (55%) and Italian dual-purpose breeds (53–56%) (Baldinger and Bussemas, 2020; Rizzi, 2020). The laying rates of DualBalance and DualEgg were intermediate and aligned with dual-purpose crossbreeds reared under organic conditions (Baldinger and Bussemas, 2020).

The DualBalance hens exhibited a steeper rise in egg production but lower persistency compared to DualEgg hens, resulting in no significant difference in total output between the two. The laying performance of CONF was 83%, slightly lower than the 89% reported by Giersberg et al. (2019) under semi-commercial aviary conditions. The laying performance of CONF was lower than expected, highlighting the challenge for high-performing genotypes, such as the control in this trial, to reach their genetic potential under organic feed and husbandry conditions. This underlines the need for breeding objectives and genotypes adapted to extensive and organic systems (Castellini et al., 2016).

In addition to laying performance, egg size as defined by weight is a critical economic parameter for producers, with the highest demand for sizes M and L. CONF showed a rapid increase in egg weight (70% by week 54), reflecting its breeding focus and history (Hocking et al., 2003). In contrast, egg weight increased more gradually in DualMeat (48%), DualBalance (61%), and DualEgg (59%) over the same period. Selection for rapid weight gain modulates energy metabolism, growth and body composition as well as endocrine regulation and may also affect the reproductive system. These physiological changes may impair ovarian and oviduct immune responses, disrupting egg quality, yolk and albumen synthesis, and shell calcification, thereby increasing the likelihood of blood spots, meat spots, double yolks, and compromised shell quality (Hammershøj and Steenfeldt, 2005; Honkatukia et al., 2011; Wu et al., 2025). A breeding strategy promoting a gradual weight increase towards size L eggs may enhance laying persistency and eggshell integrity (Bain et al., 2016; Gautron et al., 2021). DualMeat produced the heaviest first eggs and maintained the highest proportion of preferred-size eggs (M, L) throughout the laying period. DualBalance and CONF exhibited the highest percentage of large (L, XL) eggs and the lowest proportion of small (S) eggs. Overall, dual-purpose genotypes achieved favourable egg size distributions (83–85% M and L), exceeding those reported for traditional breed crosses (75–81%) and the control in this study (Baldinger and Bussemas, 2020; Fig. 4c). Creative marketing strategies, such as pricing eggs by weight, or offering a mix of egg sizes in 1 kg cartons, could make the retailing of varying egg sizes more convenient. These strategies would also give these alternative products a unique attribute and clear identification at the point of sale.

BW is linked to egg weight (Di Masso et al., 1998; Ahmad et al., 2019), as also seen here: heavier genotypes (DualMeat, DualBalance) tended to lay smaller eggs than lighter ones (CONF, DualEgg). Both genotype and hen age significantly affected egg weight, which is known to increase with age. Overall egg weights were higher than in a Danish study with the same tested genotypes (Hammershøj et al., 2021), likely due to the shorter trial period studied (only 54 weeks); rankings also differed, with DualBalance highest, while DualEgg and DualMeat did not differ.

Broodiness was observed across all genotypes during the laying period, particularly between weeks 39 and45. This intrinsic behaviour, previously reported from 20 weeks postlay in dual-purpose breeds (Jiang et al., 2010; Lambertz et al., 2018), was most pronounced in DualMeat hens, affecting 14% during this period. Although rare in high-producing layers (Basheer et al., 2015), broodiness was also seen in two CONF hens around week 40. While detrimental to productivity, broodiness remains valuable for small-scale systems without artificial incubation (Thieme et al., 2014). Extended laying cycles may help offset lower overall egg output in dual-purpose hens (Lambertz et al., 2018), though this strategy needs further study.

After AI regulations were reinstated in week 60, production declined in DualMeat and CONF earlier (after week 64) than in DualBalance and DualEgg (after week 68). During restricted outdoor access, production dropped more sharply in DualMeat (21%) and DualBalance (22%) compared to DualEgg (12%) and CONF (8%), suggesting greater resilience of the latter genotypes under confinement stress. This stress may have also triggered increased broodiness/moulting in DualMeat and DualBalance hens at the end, causing a rapid decline in egg production.

The values of FCR_{lay} and FCR_{total} were higher in all dual-purpose hens relative to CONF, which consumed less feed and laid more eggs overall. DualMeat was the least efficient due to its higher FI and lower laying rate. CONF outperformed breeder data (FCR 2.3–2.4; Lohmann, 2021) due to their higher egg weight and showed comparable efficiency to Lohmann Brown Classic hens under organic conditions (FCR 2.2, Schmidt et al., 2016). The dual-purpose genotypes tested here showed FCR values consistent with previous reports, ranging from 2.8 to 3.4 (Lambertz et al., 2018; Baldinger and Bussemas, 2021).

Quality of eggs and meat

The proportion of non-marketable eggs ranged from 18% in DualEgg to 24% in DualMeat and DualBalance, and 21% in CONF. These values fall within the previously reported range of 16–36% for purebred dual-purpose genotypes (Rizzi, 2020). Although no significant differences were observed in egg weight or laying performance between DualBalance and DualEgg, the lower proportion of non-marketable eggs in DualEgg suggests a clear advantage for this genotype. Despite identical nest designs across all genotypes, differences in marketable egg proportions may be attributed to genotype-specific prelaying behaviour, such as nest-searching, as previously described by Kruschwitz et al. (2008). Notably, DualBalance hens appeared to differ in this behaviour, leading to the highest incidence of cracked (3.47%) and floor (6.41%) eggs ($P = 0.029$). Additionally, the presence of feathered toes in DualBalance, combined with higher humidity during winter, may have contributed to increased egg soiling in the bedded nest, reducing marketability.

From the consumer's perspective, eggshell colour, along with egg shape and size, is a key visual cue influencing purchasing decisions. Therefore, distinct traits in dual-purpose poultry, such as the genotype-specific dark brown colour observed in DualBalance, offer valuable marketing potential for alternative genotypes. In terms of shape, all genotypes showed a decrease in shape index over time, consistent with previous findings (Lambertz et al., 2018). Egg shape is an important factor for packing, transport, and processing (Zeidler, 2002), as elongated eggs can pose challenges in standard packaging systems, increasing the risk of breakage due to poor fit and pressure. As such, egg shape should be considered a breeding objective to enhance packing efficiency and reduce food loss. Eggs with an SI between 72 and 76% are considered standard ovoid; values below this range indicate more elongated or pointed shapes, while higher values reflect rounder eggs. In this study, eggs from DualMeat and DualBalance fell within the standard ovoid range, while those from DualEgg and CONF were classified as round.

The eggshell weight of CONF was generally higher than that of the dual-purpose genotypes but declined after week 50, reaching levels comparable to the dual-purpose hens. Typically, eggshell quality declines towards the end of the laying period, often leading to a greater proportion of non-marketable eggs due to reduced eggshell strength. Interestingly, eggshell weight increased steadily over time in the dual-purpose genotypes, with DualMeat reaching the highest values by the end of the laying period. These results align with Hammershøj et al. (2021), who reported consistently high eggshell quality in DualMeat eggs throughout the laying cycle. The maintenance and even improvement of eggshell weight in later stages suggest promising egg quality in these dual-purpose lines. Notably, the eggshell weights observed here were slightly higher than those previously reported by Hammershøj et al. (2021) for the same genotypes and followed a similar ranking:

highest in DualMeat, followed by DualEgg and DualBalance. Organic and free-range systems positively influence egg quality traits—such as increased shell thickness—compared to confined housing systems. The greater environmental stimuli in these systems encourage physical activity, strengthen bones, and support calcium resorption (Rizzi et al., 2006; Hammershøj, 2011). Genetic background and selection also play critical roles in eggshell quality, with marked differences observed between traditional breeds and modern commercial layers (Hocking et al., 2003). Consequently, the genetic composition of the crossbred strains used for dual-purpose genotypes significantly affects egg quality (Tůmová et al., 2007; Singh et al., 2009; Ahmad et al., 2019) and should manifest as a key focus in the breeding of dual-purpose poultry lines.

In this study, egg size distribution and the tested product quality parameters in dual-purpose genotypes were comparable to those observed in the control, indicating that genotype differences do not compromise egg marketability. However, housing and management practices should be adapted to reduce the number of floor and dirty eggs, thereby increasing the share of marketable eggs. Furthermore, the broader diversity in external egg characteristics, such as eggshell colour and size, could serve as a distinctive marketing feature, enhancing consumer recognition and appeal of alternative poultry products.

Due to their balanced performance profile for both egg and meat production, dual-purpose hens exhibit greater meat yields than conventional layers. Rizzi et al. (2007) reported preslaughter BW of 1.7 kg in layers and 2.3 kg in dual-purpose hens, with corresponding dressing percentages of 56 and 66%, respectively. The present study supports these findings: the tested dual-purpose genotypes exhibited 19.8–37.5% higher CW and 2.8–3.4% higher dressing percentages compared to CONF. BMY ranged from 19.8 to 22.7% in dual-purpose hens, surpassing values reported for Belgian Malines females at 52 weeks (16.5%; Müller, 2018) and Bresse layers at 75 weeks (18.4%; Lambertz et al., 2018). While CONF showed a higher leg proportion, leg yields in dual-purpose genotypes (34.3–35.5%) were comparable to those of Bresse hens (33%; Nolte et al., 2020). These findings confirm that, both in absolute and relative terms, dual-purpose hens produce more meat than commercial layers. From a marketing perspective, carcasses can be sold whole, as valuable cuts or further processed into value-added products such as sausages and ready-to-eat meals. The latter has been shown to generate higher economic returns for farmers (Loetscher et al., 2015; Arya et al., 2017). Meat from spent layers is characterised by a high collagen content (Chueachuaychoo et al., 2011), which contributes to a firmer texture—making it more suitable for soups and processed dishes rather than as a centrepiece meat. Although limited, sensory studies on meat from dual-purpose hens have not shown statistically inferior quality compared to meat from spent layers. In fact, more intense aroma and superior flavour have been noted (Rizzi et al., 2007; Puchała et al., 2015; Siekmann et al., 2018; Siebenmorgen et al., 2024). These preliminary findings warrant further investigation to validate the sensory qualities of meat from dual-purpose hens and support the potential for establishing a price premium over conventional spent layer meat. Nevertheless, further investigation using a larger sample size, including evaluation of sensory properties and consumer acceptance, is needed.

Dual-purpose-index

A 237% difference in the DPI between CONF and CONM highlights the striking divergence in performance driven by specialised breeding for either laying or fattening. Moreover, as demonstrated in this study, the performance of dual-purpose genotypes varies depending on the applied selection criteria. This variability underscores the need for a more precise definition of "dual-purpose poultry" to distinguish it from single-purpose types (Hörning, 2023; Gebhardt et al., 2023). The DPI provides a valuable exploratory framework for classifying performance profiles and helps identify genotypes best suited to specific farming systems and marketing strategies. Since both internal and external data were used, the DPI serves as a preliminary, integrative tool and represents an important step towards assessing the dual-purpose potential of different genotypes. Notably, since the DWG of dual-purpose males was 39–50% lower than that of commercial broilers, laying performance had a disproportionately strong influence on DPI values. Based on the DPI, DualMeat appears well-suited for farms focused on meat production and processing, with eggs marketed as a complementary product. DualBalance is a robust backyard genotype ideal for farms with small-sized flocks that have the capacity and facilities to rear both pullets and cockerels on-site. Both genotypes are particularly attractive for farms engaged in direct marketing, especially those with on-site customer traffic, where the birds' unique appearance and curious behaviour can enhance customer experience. DualEgg, by contrast, is best suited to farms that specialise in egg production and purchase pullets, outsourcing the fattening of males. The diversity of performance profiles allows farmers to select the genotype that best aligns with their production and marketing systems, supporting the realisation of price premiums. Abbasi et al. (2024) explored the potential and importance of integrating alternative poultry into farming systems based on circular economy principles, aiming to enhance food security and promote sustainable agricultural practices. Identifying the most suitable genotype for such systems, using tools like the DPI, is essential for the development of sustainable farming practices, as not all genotypes are equally well-adapted to extensive or organic conditions (Castellini et al., 2016; Mancinelli et al., 2020; Cartoni Mancinelli et al., 2021).

Economic evaluation

Under regional market conditions, the observed performance differences among the tested genotypes were clearly reflected in their respective production costs for both eggs and meat. Egg production costs were 18–43% higher for dual-purpose females compared with CONF, while meat production costs were 29–44% higher for dual-purpose males relative to CONM. Within the dual-purpose group, DualMeat males exhibited the best fattening performance, resulting in the smallest cost difference compared with CONM. Likewise, DualEgg females showed the highest laying performance, leading to a smaller cost gap relative to CONF than observed for the other dual-purpose genotypes. While these cost differences were consistent with the known performance profiles of the genotypes, several important nuances emerged. Raising dual-purpose males for meat up to 12 weeks of age was profitable in Scenarios 2, 3, and 4 (Fig. 6). Profitability in these scenarios was primarily driven by either sufficiently high selling prices or reduced feed costs, both of which produced positive returns across all three dual-purpose genotypes. In contrast, under uniform selling prices and identical feed costs in Scenario 1, only CONM was profitable (Fig. 6). In Scenario 2, profitability was enabled by a high market price (5.90 €/kg BW), which provided adequate margins to offset elevated production costs and generated positive returns for all dual-purpose males.

Conversely, DualMeat females had the highest egg production costs among the dual-purpose groups due to lower laying performance and higher mortality rates. A comparison between DualBalance and DualEgg hens further showed that the latter's slightly higher mortality resulted in marginally lower net income per egg. This highlights the disproportionate influence of even small mortality differences on economic outcomes, emphasising the importance of robust, well-adapted genotypes regardless of performance level. It is important to note that the analysis did not include potential price premiums for dual-purpose products or for mobile housing systems, both of which could help offset higher production costs. Successful market examples—such as organic or specialty label systems (e.g., Label Rouge, Beter Leven)—demonstrate that price premiums can be justified by added value related to genotype choice, animal welfare, and husbandry practices.

Across all genotypes and both sexes, feed represented the largest cost component, accounting for 30–32% of total egg production costs and 60–70% of total meat production costs. This underscores the critical role of feed efficiency and the potential advantage of dual-purpose genotypes, which have lower nutrient requirements than high-performance genotypes. Although this study applied standardised feeding strategies to ensure comparability, future reductions in feed costs could be achieved through the valorisation of regional agricultural by-products or side streams, a strategy particularly relevant in organic systems, where feed costs are typically 35–40% higher than in conventional systems (Cobanoglu et al., 2014; Kowalski and Makara, 2021; Boumans et al., 2022). This potential was reflected in Scenarios 3 and 4 of the fattening trial and Scenario 2 of the laying trial, demonstrating that reducing feed costs can substantially enhance the profitability of dual-purpose chickens.

Conclusion

The use of dual-purpose poultry seeks to balance meat and egg production and may offer a practical and ethical alternative to chick culling in the egg industry. These birds may be well-suited to organic farming systems, providing a holistic and consistent solution for operations aiming to meet the growing demand for sustainable and ethical poultry production. In this study, the selected dual-purpose genotypes represented a spectrum of performance profiles—egg-type, meat-type, and balanced. This diversity was reflected in the outcomes of the on-station trial, which provided insight into their responses under a standardised organic baseline. Although their growth was 37–50% slower and egg productivity 19–25% lower than that of specialised high-performing genotypes, no major compromises in the assessed quality traits were detected. Yet sensory and consumer acceptance requires further investigation. Additionally, their distinctive appearance supports direct marketing, especially for farms with on-site customer engagement. A first-step integrative index was explored to describe dual-purpose performance, requiring further validation. From an economic perspective, dual-purpose poultry offers a promising route to address ethical concerns by emphasising both the integrity of the production process and the quality of the final products. While this added value is not yet fully captured in current retail pricing, coordinated marketing efforts across the production chain are crucial to communicate these benefits and offset higher production costs. Further research is needed to refine feeding strategies for dual-purpose genotypes, with the aim of better aligning with their actual nutritional needs while improving cost efficiency and sustainability. Lastly, multifarm and multiyear validation of organic dual-purpose poultry would assist further in optimising its implementation and management.

Supplementary material

Supplementary Material for this article (https://doi.org/10.1016/j.animal.2026.101800) can be found at the foot of the online page, in the Appendix section.

Ethics approval

The study is in accordance with German legal and ethical requirements of appropriate animal procedures. Experiments were approved under the considerations of the 3Rs by the Schleswig-Holstein Ministry of Energy Transition, Agriculture, Environment and Rural Areas on June 24, 2020, acknowledged on July 20, 2020 (V 244 – 42781/2020).

Data and model availability statement

Once this article has been published, the data on performance and product quality will be deposited in the OpenAgrar repository (https://www.openagrar.de) and available to the public. Information is available from the authors upon request.

Declaration of generative AI and AI-assisted technologies in the writing process

Artificial intelligence–assisted technologies were used to enhance the readability and language of this work. All edits were conducted under thorough human oversight, and the authors took full responsibility for the content of this publication.

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Declaration of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgments

The authors would like to express their sincere gratitude to their colleagues at the research facilities in Wulmenau and the team of the PPILOW project, especially Sanna Steenfeldt, Sarah

Lombard, Antoine Roinsard and Olivia Tavares. They would also like to express thanks to Camille Raoult, Claire Bonnefous, Catherine Hurtaud and Sophie Réhault-Godbert for their support.

Financial support statement

We thank our partners SYSAAF, Novogen, Hendrix Genetics and ITAB for supplying the birds and providing valuable support. This study is part of the PPILOW project that has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement N°816172.

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