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S. Mueller,*[,1] M. Kreuzer,* M. Siegrist,† K. Mannale,* R. E. Messikommer,* and I. D. M. Gangnat*

*ETH Zurich, Institute of Agricultural Sciences, Universitaetstrasse 2, 8092 Zurich, Switzerland; and †ETH Zurich, Institute for Environmental Decisions, Consumer Behavior, Universitaetstrasse 22, 8092 Zurich, Switzerland

ABSTRACT Currently, there is an intensive ethical discussion about the practice of culling day-old layer cockerels. One solution to avoid this practice could be using dual-purpose types, where males are fattened for meat and females used for egg production. The aim of the present study was to compare fattening performance, carcass conformation, and composition as well as meat quality of Lohmann Dual, a novel dual-purpose type, and 2 traditional dual-purpose types (Belgian Malines and Schweizerhuhn) with 2 broiler types and 1 layer type (Lohmann Brown Plus). Broilers included a conventional line (Ross PM3) and a slower-growing line (Sasso 51) fulfilling requirements of organic farming. Nine birds of each type were fed on a conventional broiler diet. Feed intake and metabolizability of nitrogen and energy were recorded per pen (n = 3), the latter through excreta sampling. For each bird, carcass conformation was assessed, and weights of body, carcass, breast meat, legs, wings, and inner organs were determined. Additionally, breast angle, an indicator for carcass appeal, and skin color were recorded. Meat quality assessment included determinations of thaw and cooking loss, shear force, meat color, and proximate composition of the breast meat. None of the dual-purpose types (20 to 30 g ADG) performed as well in growth as the intensively growing broiler line (68 g ADG). However, Lohmann Dual could compete with the slower-growing broiler line (slower growth but better feed efficiency, similar in carcass weight and breast proportion). Also breast angle was quite similar between Lohmann Dual (100°) and the extensive broiler type (115°C) compared to the intensive broiler line (180°). Meat quality was most favorable in the intensive broilers with the smallest shear force and thawing loss, whereas meat quality was not different between the other types. The Schweizerhuhn performed only at the level of the layer hybrid, and the Belgian Malines was ranked only slightly better.

Key words: carcass conformation, chicken type, culling, dual-purpose, growth performance

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INTRODUCTION

In the last decades, poultry meat and egg consumption increased strongly worldwide (Magdelaine et al., 2008; Kearney, 2010). The reasons for this increase are manifold but the main factor for the increasing poultry meat demand is that it represents a cheap animal protein source (Magdelaine et al., 2008). Although, in the past, poultry were bred and reared at the farm level, today a few globally operating breeding companies provide the birds to specialized farms. This was associated with a tremendous specialization in the poultry sector, which resulted in the 2 decoupled branches of production, egg and meat, with correspondingly specialized breeding lines. As a consequence, every year billions (Poultry Site, 2015) of healthy layer-type males are culled immediately after hatch worldwide due to their inability to lay eggs and their poor growth performance (Damme and Ristic, 2003; Gerken et al., 2003; Leenstra et al., 2011). This practice is controversially debated in the public for ethical reasons. Krautwald-Junghanns et al. (2018) recently reviewed approaches to avoid the culling of day-old male chicks which consist of 3 different options. The fattening of male layer chickens is not economical due to the great costs resulting from the long fattening period and an unfavorable feed efficiency (Murawska et al., 2005; Schäublin, 2005), and the low price due to the poor meatiness and the non-appealing appearance of the products. Indeed, the carcasses of male layer chickens have a prominent keel bone (Damme and Ristic, 2003) and the breast meat cuts are very flat. Possible future alternatives to killing of day-old male layer chickens include *in ovo*-sex determination (Weissmann et al., 2013), but this option is not yet ready for use in poultry practice (Vizzier Thaxton et al., 2016; Schulze Pals, 2017; Krautwald-Junghanns et al., 2018).

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[1]Corresponding author: sabine.mueller@usys.ethz.ch

Another solution to cope with this dilemma, which could be introduced immediately, consists in establishing production systems based on dual-purpose chicken types (Krautwald-Junghanns et al., 2018). In this case, the females are used to produce eggs whereas the males are fattened. This approach is facilitated by new commercial dual-purpose chicken types including Lohmann Dual (Lohmann Tierzucht GmbH, Cuxhaven, Germany; cf. Icken and Schmutz, 2013), Walesby Specials (Gefluegelzucht Hoelzl, Moosburg, Germany; cf. Urselmans and Damme, 2014), Dominant Red Barred D 459 (Dominant CZ, Lazne Bohdanec, Czech Republic; cf. Urselmans and Damme, 2014), and Novogen Dual (Groupe Grimaud, Quintin, France). In addition, there is a pool of less specialized but long established traditional poultry breeds, which are intended to serve the same dual purpose. Compared to the specialized layer and broiler lines, a limited performance in both laying and fattening is to be expected with dual-purpose types (Damme et al., 2015). Fattening will have to be extended beyond the standard 5 wk and even then it is unclear if the carcasses get competitive in terms of meatiness, appearance, and meat quality. Gangnat et al. (2018) showed that Swiss consumers are preferring this type of production over chick culling and would be willing to pay more for such foods but linking it to organic production could be a factor needed for success in the market. Studies comparing poultry-type breeds with different purpose are scarce (e.g., male layer types vs. broilers: Gerken et al., 2003; Koenig et al., 2012; spent hens: Loetscher et al., 2015).

Therefore, the aim of the present study was to experimentally test novel and traditional dual-purpose types for their performance, carcass characteristics, and meat quality. This was done in comparison to commercial fast-growing and slow-growing (organic) broiler types as well as males from a commercial layer hybrid. Using the latter type also provided data helpful to clarify the feasibility of the option of fattening the male layer chickens. A particularly extensive set of carcass and meat quality characteristics was determined under controlled conditions to facilitate a comprehensive comparison of these very different types of chickens.

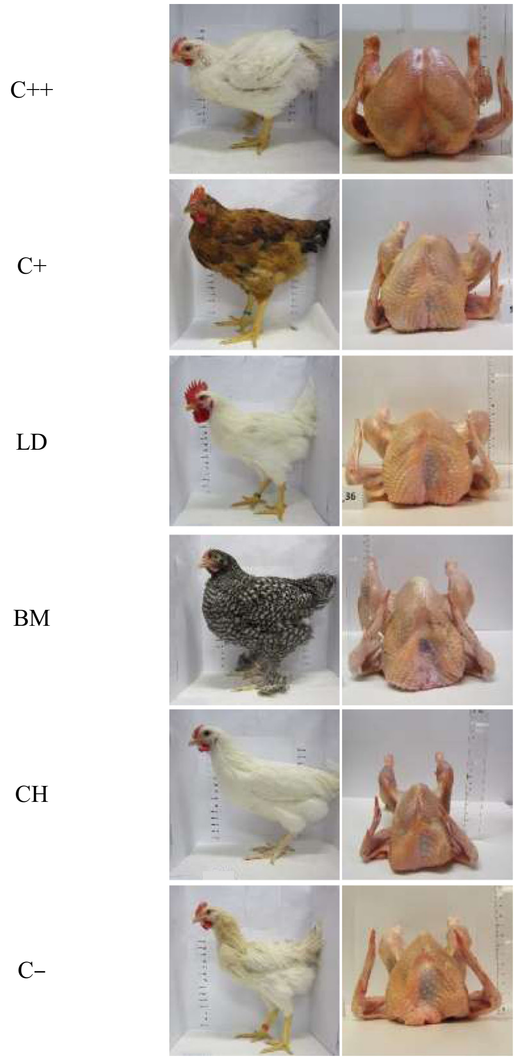

Figure 1. Appearance of the 6 chicken types short before slaughter and as carcasses. C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus, where C++ were 35 d of age and all others were 63 d of age. The corresponding breast angles on average of all representatives per type (n = 9) were $180^{\circ a}$, $115^{\circ b}$, $100^{\circ c}$, $72^{\circ d}$, $72^{\circ d}$, and $77^{\circ d}$, respectively. Breast angle means with different superscript are significantly different ($P < 0.05$).

MATERIALS AND METHODS

Experimental design, animals, and housing

An experiment, approved by the Cantonal Veterinary Office of Zurich, Switzerland (license no. 267/14), was conducted with a total of 54 birds from 6 different chicken types (n = 9; Figure 1). The comparison included 3 dual-purpose types. One was Lohmann Dual (**LD**), a representative of the available novel breeding lines, the 2 other were traditional dual-purpose breeds, the Belgian Malines (**BM**) and the Swiss breed Schweizerhuhn (**CH**). The negative control (commercial layer type) selected was Lohmann Brown Plus (**C–**). The 2 positive controls included Ross PM3 (**C++**), a fast-growing commercial broiler line, and Sasso 51 (**C+**), a slower-growing commercial broiler line suitable to be fattened for longer periods. As both slower-growing broilers and dual-purpose chicken types are currently predominantly used in organic farming in Switzerland and Austria, the C+ can be considered as a representative of the chicken type which is especially in competition with establishing dual-purpose production systems. In order to reflect fattening practices, in C+ both genders (4 males and 5 females) were included in the experiment as commonly no sexing is performed in broiler types. Despite this practice, in the present experiment only males were selected from C++ in order to simulate the maximum performance that can be obtained under the given experimental conditions. The birds were purchased from local hatcheries. In detail, C++ and C+ came from

Erb Brueterei AG (Aeschlen b. Oberdiessbach, Switzerland), C– and LD from Animalco AG (Staufen, Switzerland), BM from Gefluegelzucht Winnen (Langenbruck, Switzerland), and CH from Dario Filisetti (Esslingen, Switzerland) and Gefluegelzucht Winnen.

After purchase, all birds were reared for either 7 d (C++) or 14 d (all other types) on a commercial starter diet (UFA 636, UFA, Herzogenbuchsee, Switzerland) with 12.6 MJ/kg ME and 220 g/kg CP. In that period, all birds were kept on wood shavings in wooden boxes with a floor size of 1.7 m^2. After 7 and 14 d, respectively, 6 birds per type were moved in pairs to pens (80 × 80 × 80 cm). The pens were equipped with mesh floors, perches for seating, feeding troughs variable in height, nipples providing water from a container where consumption could be recorded, and containers for excreta collection. Another 3 birds per type remained in the 6 boxes in groups of 3. From regrouping onward, all birds received the same diet with 13.0 MJ/kg ME and 198 g/kg CP (Table 1) composed as required by fast-growing broiler types (GfE, 1999). This was done in order to allow exhibiting the maximum chicken type differences making the compromise that the likely smaller requirements for dietary nutrient and energy density of the slower-growing chicken types were not considered. The diet was supplemented with 15 g celite/kg, an indigestible indicator used to determine apparent digestibility and metabolizability from sampled excreta. The experimental diet was mixed and steam pelleted in a laboratory pelleting press (model DFPL, Buehler AG, Uzwil, Switzerland) to particles with 2.5 mm diameter. Birds always had access to feed and water. The room temperature was continuously reduced from 28°C in week 1 (when additionally heating lamps were installed) to 20°C in week 6 and then remained at 20°C until week 9. Light was provided for 16 h/d. The C++ were fattened for 35 d as is common, all other types were fattened for 63 d as is prescribed for organic poultry farming in Switzerland.

Table 1. Composition of the broiler-type fattening diet

Item	Proportion
Components (g/kg as fed)	g/kg
Maize	325
Wheat	310
Soybean meal	221
Soybean oil	47
Potato protein	30
Wheat bran	17.8
Celite[1]	15.0
Dicalcium phosphate	14.0
Calcium carbonate	7.8
Sodium bicarbonate	3.3
Vitamin-mineral premix[2]	3.0
DL-methionine	2.5
L-lysine	2.4
NaCl	1.2
Calculated nutrient contents per kg diet	
ME (MJ)	13
CP (g)	198
Linoleic acid (g)	34.8
Lysine (g)	11.8
Methionine and cysteine (g)	8.6
Threonine (g)	7.5
Tryptophan (g)	2.3
Analyzed nutrient contents per kg diet	
DM[3] (g)	903
Organic matter[3] (g)	838
CP[3] (g)	191
Ether extract (g)[3]	65.2
Neutral detergent fiber[3] (g)	125.7
Acid detergent fiber[3] (g)	53.2
HCl insoluble ash[4] (g)	16.4

[1]No. 545, acid-washed diatomaceous earth (Schneider Dämmtechnik, Winterthur, Switzerland).

[2]Provided per kg of diet: Ca, 925 mg; Cu, 10 mg; Mn, 100 mg; J, 1 mg; Zn, 80 mg; Fe, 80 mg; Se, 0.30 mg; retinol, 3.44 mg; cholecalciferol, 81 μg; menadione, 3.25 mg; riboflavin, 6 mg; thiamine, 2.5 mg; pyridoxine, 5 mg; cyanocobalamin, 15 μg; biotin, 150 μg; folic acid, 1.5 mg; niacin, 60 mg; pantothenic acid, 15 mg.

[3]Values are means of 6 determinations (week 3, 5, and 9).

[4]As indicator, values are means of 6 determinations (week 3, 5, and 9).

Measurements and sampling

Weekly, the individuals' health status was recorded and their BW was measured. In the subset of 6 penned birds per type, feed intake and water expenditure were measured weekly and daily, respectively (n = 3 observations per type). In addition, excreta and diet samples were collected per pen during 5-d periods in week 3, 5, and 9 for the determination of fiber digestibility, energy and nitrogen metabolizability, and excreta DM content. The excreta were first frozen at −20°C and then lyophilized (model Beta 1–16, Christ, Osterode am Harz, Germany). Dried excreta and diet samples were milled through 0.50 and 0.75 mm screens, respectively, with a centrifugal mill (model ZM1, Retsch GmbH, Haan, Germany).

After 11 h of fasting, the final BW was determined and the animals were slaughtered by stunning with a blow on the head followed by exsanguination. Liver, stomach (proventriculus and gizzard together), heart, spleen, and pancreas were weighed. The color of the skin on top of the left breast was determined immediately after removal of the feathers at 3 places with a chromameter CR-300 (Minolta, Ramsey, NJ) applying the $L^* a^* b^*$ color space. After evisceration and removal of abdominal fat, feathers, feet, head, and neck, the carcasses were stored at 4°C for 24 h and then weighed. Dressing percentage was defined as the ratio of cold carcass weight to BW. The breast angle was recorded with a protractor. The carcasses were dissected into breast meat (without skin and adherent fat), whole legs, and whole wings. Maximal thickness and length of the left breast meat as well as the maximal thickness of the left leg were measured. The left leg was further dissected into meat, bones, and the remainder consisting of skin, cartilage, and fat tissue. All body parts were weighed. Breast meat samples from the left carcass side were subjected to drip loss measurement. Subsequently, these samples and the dissected meat from the left leg were homogenized separately with a mix chopper (La Moulinette, Moulinex, Alençon, France) and frozen at −20°C. Breast meat (right carcass side), leg meat, and tibia were immediately frozen at −20°C for further analysis.

Feed and excreta analysis

Diet and excreta samples were analyzed by standard procedures (AOAC, 1997). For DM a thermogravimetric device (model TGA-701, Leco, St. Joseph, MI) was used. Nitrogen (**N**) was assessed using a C/N analyzer (model TruMac CN, Leco, St. Joseph, MI) with CP = 6.25 × N. Neutral detergent fiber (**NDF**) and acid detergent fiber (**ADF**), corrected for ash content, were determined on a Fibertec System M (Tecator, 1020 Hot Extraction, Flawil, Switzerland) according to AOAC (1997; method #973.18). For NDF determination, 100 μL of α-amylase (Sigma-Aldrich, St. Louis, USA) was added. Combustion energy was measured in a bomb calorimeter (Calorimeter System C700 with Cooler C7002, IKA, Staufen, Germany). The 4 M-HCl insoluble ash was determined according to Vogtmann et al. (1975). Ether extract (diet only) was determined on a Soxhlet extraction system (model Extraktionsapparatur B-811, Büchi, Flawil, Switzerland).

Bone analysis

Weight and length of the dissected and cleaned left tibia were measured. In the middle of the bone the diameter was assessed. Maximal breaking strength was measured using a bending device mounted on a texture analyzer (Stable Micro Systems Ltd TA-HD, Surrey, UK). This 3-point device consisted of 2 V-shaped metal holders positioning the bone over a free hanging distance of 20 mm and a central vertically moving indenter. The total ash content of the bones was determined by heating at 550°C for 48 h in a muffle furnace. The remainder was ground in a mortar whereof 200 mg was incubated in 50 mL of 80 mL/L (v/v) HCl for 1 d. In this solution, calcium, phosphorus, and magnesium were analyzed with a COBAS MIRA Autoanalyzer (F. Hoffmann-La Roche Ltd, Basel, Switzerland).

Meat analysis

Color traits were measured in breast and leg meat directly after dissection on the day after slaughter with the same method as applied for skin color. The pH was determined with a pH meter (testo 205, Rausser, Ebmatingen, Switzerland) in the left breast muscle. Drip loss was assessed by positioning the whole left breast muscle freely hanging in a net placed into a sealed plastic bag at 4°C for 24 h. For determining thaw and cooking loss, the right breast muscle was weighed prior to freezing, after being thawed overnight and after being cooked to a core temperature of 74°C in a water bath in sealed bags, respectively. Maximal shear force was measured with a Volodkevich device mounted on a texture analyzer (Stable Micro Systems Ltd TA-HD) as applied previously in spent hen meat (Loetscher et al., 2014). With this device 2 wedges are moved until they have contact and thus shear the meat. The device simulates the action of the molars. It was applied instead of the more commonly applied Warner–Bratzler shear blade because the breast meat of the layer type chickens was too thin to obtain suitably large meat cores along the muscle fiber direction. The shear force was assessed perpendicular to the muscle fiber direction in 5 to 10 cube-shaped stripes of breast muscle per bird of a size of 10 × 10 mm which had been obtained by using a double knife along with the muscle fiber in the cooked meat after cooling to ambient temperature. Contents of moisture, protein, and intramuscular fat (**IMF**) were determined in the homogenized breast and leg meat samples. The same methods as for diet analysis were applied except for IMF, where ether extract was determined after hydrolyzation in 4 M HCl (BAG, 1999).

Calculations and statistical analysis

The digestibility coefficients of NDF and ADF as well as the metabolizability of N and gross energy were calculated as outlined by Vukić Vranješ et al. (1994) considering the known intake of acid-insoluble ash. Data were subjected to ANOVA using the GLM procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC) with type as fixed effect and either bird or pen as the experimental unit. For multiple comparisons of the least square means, the Tukey–Kramer option was used considering $P < 0.05$ as significant.

RESULTS

Growth performance

During the experiment, no animal died and no health problems were recorded. After 7 d of rearing, the C++ already differed ($P < 0.05$) from all other types in their BW development (Figure 2). At the end of the fattening period (35 d for C++, 63 d for all others), C++, C+, and LD had reached a similar BW followed by BM, whereas CH and C− had the poorest performance ($P < 0.05$) (Table 2). Differences in ADG were the same except for C++ where ADG was greatest ($P < 0.05$). The FCR was smallest ($P < 0.05$) with C++, followed by LD, intermediate with C+, BM, and C−, and most unfavorable with CH. The NDF digestibility ranged between 25 and 30% in all 3 periods measured, whereas that of ADF was around 19% in week 3 and 5 and around 12% in week 9 (data not shown). The chicken type did not significantly affect fiber digestibility. In week 3, but not in week 5 and 9, energy metabolizability was greater ($P < 0.05$) with C+ than with C++, and intermediate

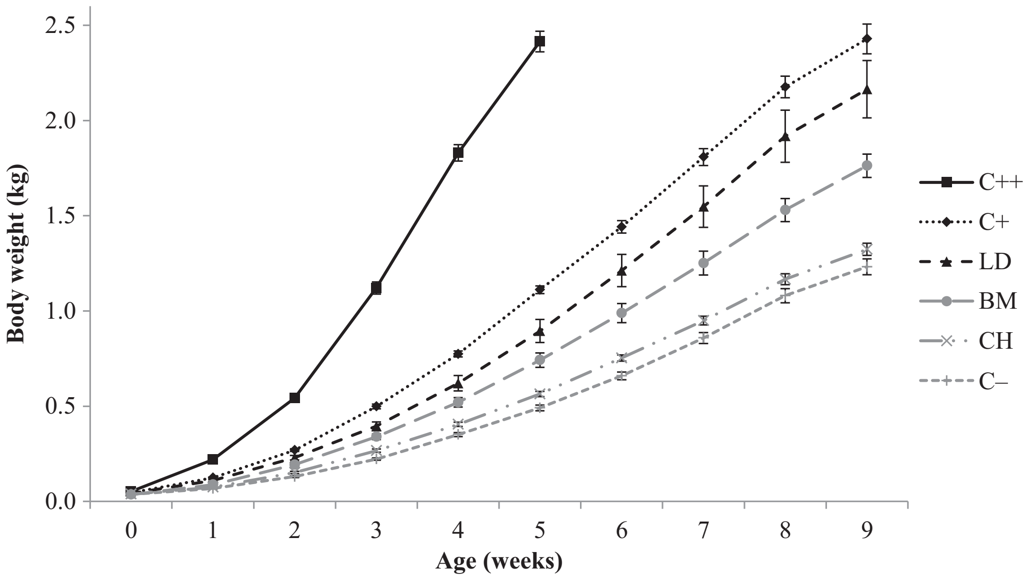

Figure 2. Weight development of the 6 chicken types (means ± SE) during the experiment with n = 9 per chicken type. C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus.

Table 2. Effect of chicken type on performance (n = 3 pens per treatment with 2 animals each except BW and ADG where data are based on n = 9 per type)

Type[1]	C++	C+	LD	BM	CH	C–	SEM	*P*-value
BW (g)								
After hatch	40.7[b,c]	46.3[a]	41.3[b]	36.0[d]	38.3[b-d]	37.2[c,d]	0.87	<0.001
At slaughter	2415[a]	2423[a]	2161[a]	1758[b]	1317[c]	1227[c]	80.3	<0.001
ADG (g/head)	67.8[a]	37.7[b]	33.6[b]	27.3[c]	20.3[d]	18.9[d]	1.38	<0.001
ADFI[2] (g/head)	102[a]	87[b]	80[b,c]	69[c]	52[d]	48[d]	1.6	<0.001
Feed efficiency (g of feed/g of ADG)[3]	1.52[d]	2.43[b,c]	2.22[c]	2.55[a,b]	2.73[a]	2.46[a,b,c]	0.059	<0.001
Metabolizability of nitrogen (%)								
Week 3	68.2[a]	62.6[a,b]	61.3[b]	59.0[b]	58.7[b]	61.6[b]	1.33	0.003
Week 5	65.9[a]	55.6[b]	60.8[a,b]	55.5[b]	56.7[b]	56.9[b]	1.62	0.004
Week 9	–	35.4	38.5	46.4	45.2	47.8	2.73	0.037
Metabolizability of energy (%)								
Week 3	77.3[b]	79.7[a]	78.2[a,b]	78.4[a,b]	79.4[a,b]	78.8[a,b]	0.46	0.035
Week 5	77.4	77.6	77.8	78.6	78.7	77.6	0.45	0.27
Week 9	–	77.8	77.2	77.0	78.0	78.0	0.72	0.78
Excreta DM (g/kg)								
Week 3	457[b]	537[a,b]	480[b]	625[a]	608[a]	588[a]	22.8	0.001
Week 5	317	376	329	414	415	395	27.3	0.097
Week 9	–	392[a,b]	353[b]	384[b]	458[a]	379[b]	15.4	0.008

[a–d]Values in the same row with different superscript are significantly different ($P < 0.05$).
[1]C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus.
[2]As fed.
[3]35 d for C++, 63 d for all others.

in all other types. In week 3 and 5, the greatest ($P < 0.05$) N metabolizability was found with C++, followed by C+ and LD, respectively, and small with all other types. There were type effects in N metabolizability also in week 9, but differences between individual types were not significant. In week 3, the DM content of the excreta of BM, CH, and C– was greater ($P < 0.05$) than of those of C++ and LD. In week 9, the excreta DM content was greatest ($P < 0.05$) in CH and smallest in BM, C–, and LD. No differences in this variable occurred in week 5.

Carcass characteristics

Carcass composition was strongly influenced by chicken type (Table 3). The differences in carcass weight and in dressing percentage were similar to the ones found in final BW. Most remarkable were the differences in breast muscle proportion and in organ weights. Breast muscles were heaviest ($P < 0.05$) in C++, followed by C+ and LD, then BM, CH, and C–. When relating breast muscle weight to carcass weight, the same order of difference was found as that in absolute weight. Leg weight was similar in C++, C+, and LD, followed

Table 3. Effect of chicken type on carcass weight and body composition (n = 9 birds per type)

Type[1]	C++	C+	LD	BM	CH	C–	SEM	P-value
Carcass weight (g)	1760[a]	1677[a,b]	1455[b]	1163[c]	866[d]	776[d]	58.4	<0.001
Dressing percentage	72.9[a]	69.0[b]	67.0[c]	66.0[c]	65.4[c]	62.9[d]	0.45	<0.001
Body parts (g)								
Breast muscles	521[a]	335[b]	287[b]	192[c]	143[c]	130[c]	16.1	<0.001
Legs	535[a]	551[a]	521[a]	416[b]	292[c]	274[c]	21.9	<0.001
Body parts (g/kg carcass)								
Breast muscles	296[a]	200[b]	194[b]	165[c]	165[c]	167[c]	4.4	<0.001
Legs	304[c]	327[b]	358[a]	357[a]	338[b]	353[a]	3.1	<0.001
Wings	99[e]	117[d]	121[c,d]	126[b,c]	130[b]	139[a]	2.0	<0.001
Abdominal fat	14.0[b,c]	40.8[a]	24.5[b]	19.0[b,c]	17.2[b,c]	7.5[c]	2.79	<0.001
Liver	24.7[a]	19.4[b]	19.2[b]	22.7[a]	23.0[a]	24.1[a]	0.61	<0.001
Stomach[2]	16.8[c]	20.7[b,c]	26.2[a,b,c]	24.8[b,c]	34.6[a,b]	42.3[a]	3.90	<0.001
Heart	6.50[c]	6.37[c]	6.86[b,c]	7.47[a,b,c]	7.83[a,b]	8.48[a]	0.269	<0.001
Spleen	0.96[e]	1.73[c,d]	2.79[b]	1.37[d,e]	2.37[b,c]	4.11[a]	0.162	<0.001
Pancreas	2.06[c]	2.09[c]	2.44[b,c]	2.35[b,c]	2.73[a,b]	3.14[a]	0.112	<0.001
Leg parts (g/kg leg)								
Meat[3]	687[a,b]	687[a,b]	703[a]	691[a,b]	672[b,c]	661[c]	5.3	<0.001
Bone (tibia and femur)	126[c,d]	125[d]	142[b,c]	155[b]	171[a]	171[a]	3.8	<0.001

[a–e]Values in the same row with different superscript are significantly different ($P < 0.05$).
[1]C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus; C++ were 35 d of age, all others were 63 d of age.
[2]Proventriculus and gizzard.
[3]Without skin, cartilage, and fat tissue.

by BM, and smallest ($P < 0.05$) in CH and C–. The differences between types in leg and wing proportions were opposite. The C+ showed the greatest ($P < 0.05$) abdominal fat proportion, being almost twice as large as in next largest one (LD) and 5 times greater than in C–, with intermediate values for the other types. Liver proportion was greater ($P < 0.05$) in C++, C–, CH, and BM than in C+ and LD. The C– and CH had the greatest, C++ the smallest stomach proportion. The chicken type order was the same in heart proportion. Proportions of spleen and pancreas were greatest ($P < 0.05$) in C– and smallest in C++ or C+, respectively, with all others ranging in between. The meat proportion of the legs was greater in LD compared to CH and C–, with intermediate values for BM, C++, and C+. Bone proportion was greatest ($P < 0.05$) in CH and C–, followed by BM and LD then C++ and C+.

The only carcasses in which no keel bone was apparent (breast angle $\geq 180°$) were those from C++ (Figure 1; SEM 2.4, type effect $P < 0.001$). In C+ and LD, there was a visible keel bone, but not as prominent as in BM, CH, and C–. Consistent with this, large differences in breast muscle thickness were measured. The smallest and flattest ($P < 0.05$) breast muscles were found in C– and CH (Table 4). The thickest breast muscles (C++) were 2 times thicker than the ones of C+ and LD ($P < 0.05$). Breast muscles were longest ($P < 0.05$) in C+ and LD. The thickest ($P < 0.05$) legs were found in C++, C+, and LD and the thinnest in CH, with BM and C– ranging in between.

Skin color also differed between types. The BM showed the palest skin (greatest L*-value, $P < 0.05$), whereas redness (a*) and yellowness (b*) were most prominent in C++ ($P < 0.05$).

Bone characteristics

Overall C++, C+, LD, and BM had heavier and thicker tibias than CH and C– ($P < 0.05$). Tibia length differed by 40 mm between the longest (C+) and the shortest (C–) bones ($P < 0.05$). Breaking strength of the tibia was greatest in C++ with almost 500 N, followed by LD and C+, BM and CH and C–. Total ash, Ca, and P content was greatest ($P < 0.05$) in C+ bones and smallest in C++, with all other values in between. Bone Mg content was not affected by chicken type.

Meat quality

The greatest ($P < 0.05$) ultimate breast meat pH was measured in C++ followed by C+, BM, and C–, and then CH (Table 5). Drip loss was not affected by chicken type. The breast meat of C++ had not only the smallest thaw loss, but also the greatest cooking loss ($P < 0.05$). For CH it was the opposite, and thaw and cooking losses ranged in between with all other types. The smallest ($P < 0.05$) shear force was found in C++ breast meat, whereas it was similar in all other types. The BM had a paler and less red ($P < 0.05$) breast meat than the C++, with intermediate values for the other types. The yellowness was not affected by the chicken type. Moisture and IMF content of C++ breast meat was greatest, whereas its protein content and that of the leg meat was

Table 4. Effect of chicken type on carcass conformation, skin color, and bone quality traits (n = 9 birds per type)

Type[1]	C++	C+	LD	BM	CH	C–	SEM	*P*-value
Breast muscle								
Maximal thickness (mm)	41.0[a]	23.4[b,c]	25.7[b]	20.6[c,d]	18.1[d]	18.8[d]	1.06	<0.001
Length (mm)	159[b,c]	186[a]	177[a]	164[b]	157[b,c]	148[c]	3.1	<0.001
Leg, maximal thickness (mm)	41.7[a]	38.7[a]	39.2[a]	34.6[a,b]	23.7[c]	29.4[b,c]	1.89	<0.001
Skin color at slaughter								
Luminosity (L*)	62.6[c,d]	64.4[b,c]	66.3[a,b]	67.7[a]	61.1[d]	64.6[b,c]	0.70	<0.001
Redness (a*)	3.02[a]	0.25[b]	0.67[b]	0.36[b]	1.11[b]	0.64[b]	0.247	<0.001
Yellowness (b*)	1.65[a]	–1.64[b]	–1.40[b]	–2.13[b]	–2.96[b]	–2.87[b]	0.579	<0.001
Tibia properties								
Size								
Weight (g)	19.6[a]	20.0[a]	21.1[a]	18.8[a]	14.8[b]	13.5[b]	0.90	<0.001
Length (mm)	108[d]	134[a]	132[a,b]	128[a,b]	125[b]	118[c]	1.7	<0.001
Thickness (mm)	8.09[a,b]	8.11[a,b]	8.38[a]	8.31[a]	7.19[b,c]	7.00[c]	0.243	<0.001
Maximal breaking force (N)	497[a]	391[b]	396[b]	322[b,c]	289[c]	279[c]	22.0	<0.001
Composition (g/kg)								
Total ash	181[c]	213[a]	198[b]	201[a,b]	199[a,b]	203[a,b]	3.6	<0.001
Calcium	72.6[b]	90.6[a]	82.2[a,b]	81.7[a,b]	82.7[a,b]	84.3[a]	2.56	<0.001
Phosphorus	31.7[b]	39.8[a]	36.8[a]	36.4[a]	36.8[a]	37.4[a]	0.98	<0.001
Magnesium	1.38	1.56	1.47	1.56	1.48	1.47	0.071	0.52

[a–d]Values in the same row with different superscript are significantly different ($P < 0.05$).
[1]C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus; C++ were 35 d of age, all others were 63 d of age.

smallest ($P < 0.05$) compared to the other types. The IMF content in breast and leg meat was numerically smallest in C–. The leg meat of C++, C+, and CH was darker ($P < 0.05$) than that of LD, BM, and C–. The redness of the leg meat was greatest ($P < 0.05$) in CH compared to all other types. Yellowness was greater ($P < 0.05$) in C++ than in C+, with all others ranging in between. The skin of the BM was characterized by black dots at the points where the black feathers had been rooted.

DISCUSSION

Growth performance and feed efficiency

When considering strategic changes in poultry production in terms of new hybrids, it is crucial to know the fattening and slaughter performance as well as the meat quality to satisfy the expectations of all stakeholders. As anticipated, there were large differences between the types in almost all traits measured. The BW at slaughter achieved in C+ in the present study was greater than the breeding company's reference value (Sasso, 2017). This could have been the results of the housing system where birds had to move only minimally and of the diet which was too dense in energy for this chicken type. Therefore, these birds had an extraordinarily great proportion of abdominal fat. The diet was even less appropriate for the layer hybrid males but they did not invest in abdominal fat consistent with the studies by Gerken et al. (2003) and Murawska and Bochno (2007). This illustrates the extreme genetic programming of this type to allocate energy to egg production and not to body tissue accretion, even though the males do not produce eggs. Despite the great diet quality, the LD birds were lighter than the reference value given by the breeding company (2.2 kg at day 63 vs. 2.2 kg at day 56; Icken et al., 2013), but ADG were still larger than the maximal 27.5 g set as target by the Swiss organic farming guidelines (Bio-Suisse, 2017). As it is confirmed by Kaufmann et al. (2016), in a free range system ADG are smaller compared to the results of the present study and therefore, the LD could be a good alternative to the slow-growing organic broiler type C+ that does not contribute to egg production. The novel dual-purpose type cannot, however, compete with a modern fast-growing broiler type as in the underlying crossing efforts both sides, meat and egg production, had to be considered. From the traditional dual-purpose types investigated, almost no literature is available but, as our study revealed, their performance has to be classified to be in the range of the male layer chickens (CH) or only slightly better (BM). Considering these results and that the traditional dual-purpose types also cannot compete with layer types in egg yield, fattening these chicken types is, therefore, no real alternative to sacrificing day-old male layers. The performance of the latter was as poor as in former studies (Damme and Ristic, 2003; Gerken et al., 2003; Koenig, 2012) even though in the present study a comparably heavy hybrid type (Lohmann Brown Plus) has been used.

Specialized meat type broilers are bred for maximal feed conversion efficiency, whereas for organic broilers a longer fattening period is required by the regulations, which in turn impairs feed conversion efficiency. This also gets apparent when comparing C++ and C+.

Table 5. Effect of chicken type on meat quality (n = 9 birds per type)

Type[1]	C++	C+	LD	BM	CH	C–	SEM	*P*-value
Breast meat								
pH (24 h post mortem)	6.25[a]	5.92[b]	5.82[b,c]	5.91[b]	5.73[c]	5.90[b]	0.029	<0.001
Drip loss (%)	0.68	0.92	0.86	0.78	1.05	1.09	0.111	0.10
Thaw loss (%)	2.75[c]	3.28[b,c]	3.90[a-c]	3.54[b,c]	5.04[a]	4.38[a,b]	0.319	<0.001
Cooking loss (%)	16.1[a]	12.2[b]	11.3[b,c]	10.9[b,c]	8.3[c]	9.4[b,c]	0.87	<0.001
Maximal shear force (N)[2]	8.7[b]	10.8[a]	11.8[a]	11.8[a]	11.7[a]	12.1[a]	0.39	<0.001
Color								
L*	49.0[c]	50.2[b,c]	54.3[a,b]	56.0[a]	50.6[b,c]	54.6[a,b]	1.09	<0.001
a*	3.58[a]	1.82[b,c]	1.26[c]	1.58[b,c]	2.51[b]	1.35[c]	0.222	<0.001
b*	0.09	0.48	0.52	0.72	0.57	0.72	0.356	0.83
Proximate composition (g/kg)								
Moisture	737[a]	711[b]	710[b]	714[b]	712[b]	711[b]	2.5	<0.001
Protein	224[b]	246[a]	250[a]	247[a]	248[a]	251[a]	1.8	<0.001
Fat	14.5[a]	10.8[b]	8.4[b,c]	7.9[b,c]	7.9[b,c]	6.8[c]	0.78	<0.001
Leg meat								
Color								
L*	48.3[b]	48.6[b]	51.9[a]	53.1[a]	48.8[b]	53.1[a]	0.71	<0.001
a*	4.37[b]	4.03[b]	4.54[b]	4.16[b]	6.54[a]	4.56[b]	0.372	<0.001
b*	1.10[a]	–0.28[b]	0.62[a,b]	0.49[a,b]	0.10[a,b]	0.72[a,b]	0.305	0.04
Proximate composition (g/kg)								
Moisture	746[a,b]	741[b]	745[a,b]	754[a]	744[b]	748[a,b]	2.1	0.002
Protein	192[c]	202[b]	206[a,b]	202[b]	204[a,b]	208[a]	1.2	<0.001
Fat	39.8[a]	40.0[a]	35.4[a,b]	31.5[a,b]	35.7[a,b]	26.7[b]	2.23	<0.001

[a–c]Values in the same row with different superscript are significantly different ($P < 0.05$).

[1]C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus; C++ were 35 d of age, all others were 63 d of age.

[2]As determined by the Volodkevich device.

Aiming at the best feed efficiency is of economic, environmental, and social concern (Godfray et al., 2010). To be sustainable also from this point of view, dual-purpose types should match the performance of the C+ in that regard. This was fully achieved with LD. Subsequent studies upscaling this comparison under farm conditions would be necessary to confirm this competiveness. The reasons for the type differences observed in nitrogen and energy metabolizability between C++ and the other types (greater for nitrogen, smaller for energy in C++ vs. others) are unclear.

Carcass quality

Besides the carcass weight, attractiveness of carcass appearance as well as size and shape of the breast meat are important marketing criteria. In Europe, breast meat is the most valuable cut and is often marketed as such (Leenstra et al., 2010), which makes breast meat proportion a major success criterion for marketing dual-purpose chickens. Selective breeding towards breast meat resulted in thick breast muscles (Flock, 2004) as those found in C++. Consumers are used to this shape. Therefore, they prefer well-developed breast meat (Damme and Ristic, 2003). At a similar BW at slaughter, the extensive broilers C+ exhibited clearly less breast meat in absolute and relative terms than the C++, and the novel dual-purpose type LD achieved almost the same level as the C+. The 2 types were therefore closer in these traits than reported by Icken et al. (2013). Breast meat weights and proportions were unfavorably small in the traditional dual-purpose types and almost at the same level as the cuts from the male layers for which the small levels are known (Gerken et al., 2003). These type differences were also manifested in the shape of the breast meat (especially thickness) where, in comparison with C++, all types were inferior and differences among types were not very large. The appeal for consumers of the entire carcass is also closely related to the size of the breast muscle. Carcasses with small breast muscles exhibit a very prominent keel bone that is not attractive (Damme and Ristic, 2003). We used the breast angle as an easy-to-measure estimate of carcass attractiveness and thus breast meat proportion. Although in C+ and LD, different from C++, there was a visible keel bone (breast angles between 115 and 100°), it gets obvious from Figure 1 that this is clearly less impairing the appeal of the carcass than a further reduction in breast angles to 70 to 80° as found with BM, CH, and C–.

Dressing percentage is a further economic criterion for marketing carcasses. Despite similar slaughter weights, dressing percentage of C++ was greater than that of C+ and LD that is likely the result of the greater meatiness of the C++ carcasses. The small dressing percentage found in the male layers was consistent with the results of Gerken et al. (2003). The second most valuable poultry cuts are the legs. Leg weight, thickness, and meat proportions were quite similar between C++, C+, and LD and even BM birds were almost at the same level. This was different for the second traditional dual-purpose type and the layer type males suggesting that other, less valuable, body parts like wings (Murawska et al., 2005) and skeleton were compensating the smaller breast and leg meat proportion. Other compensating body parts were inner organs (except the liver) that made up a correspondingly small proportion in C++ than in the other types. The greater liver proportion of the whole carcass in C++ suggests a more important function of the liver during growth compared to the other organs in these fast-growing chicken types. Compared to carcass weight, the spleen weights were greatest in LB and also greater in most of the dual-purpose types than in C++. As the weight of lymphoid organs like the spleen is indicative of the capacity of the immune system in poultry (Pope, 1991), this finding could reflect an advantage of these chicken types in providing lymphoid cells during an immune response. These were all types that are bred for a longer life the immune system of which would be stressed repeatedly. The higher proportionate pancreas weight found in C− and CH compared to C++ and C+ indicates a higher pancreatic activity of the former, because Engberg et al. (2002) found higher activities of pancreatic enzymes (amylase, lipase, and chymotrypsin), when the relative pancreas weight was higher.

Another important trait of the appeal of carcasses to consumers is skin color, which is influenced by the diet, but also genetics may have an effect (Batkowska et al., 2014). Consumers' preference for skin color varies worldwide based on traditions and local feeding strategies (Fletcher, 2002). In Europe, consumers prefer less pigmented poultry skins than customers in the United States (Fletcher, 1999). Irish consumers (Kennedy et al., 2005) consider a pale or reddish skin color as fresh, whereas a yellow skin color is perceived as unnatural. In the present study, the skin was always pale and slightly reddish but no yellow was apparent, besides in Sasso (C+), where the carcasses were slightly yellow. Carcasses of BM were palest and also least red. However, black points of the pinfeathers remained at the roots of the blackish feathers after plucking. Unless this is communicated well, together with the advantages of keeping traditional dual-purpose types, this is likely a major constraint in marketing meat and carcasses of these birds.

Meat quality

Concerning meat quality, the results found with C++ deviated most from that of the other chicken types that were more similar to each other. This included texture, water-holding capacity, color, and IMF content. Accordingly, C++ birds exhibited the smallest shear force of the breast meat, which can be translated into the greatest tenderness (Lyon and Lyon, 1990). Castellini et al. (2002) and Poltowicz and Doktor (2012) reported a greater shear force with a prolonged fattening period, suggesting that the present findings on shear force may be more linked to the age of the birds (35 vs. 63 d) than to the type. The present shear force values were less than half of that found with the same device in breast meat from spent hens slaughtered at about 1.5 yr of age (Loetscher et al., 2014). Age effects in shear force are often resulting from alterations of collagen characteristics such as the increased collagen cross-linking in the muscle (McCormick, 1994; Fletcher, 2002; Chueachuaychoo et al., 2011). The small shear force found in the intensive broiler type may even be perceived as too unstructured and soft; this is especially in countries where meat from traditional poultry types is still available and consumed (Jaturasitha et al., 2017).

The drip loss was very small and similar for all types and analog to the values reported by Berri et al. (2008). It is known that an increasing storage time may cause more thaw exudate (Miller et al., 1980). Still, the breast meat of C++ exhibited the smallest thawing loss although this meat had been stored 4 wk longer at −20°C. In contrast, the cooking loss was greatest for C++. This may have resulted from the large size of the C++ breast meat pieces that needed a longer time to reach the target core temperature of 74°C which was likely associated with a greater loss of water. Another possible explanation of the greater cooking loss could be the greater moisture content of the C++ meat. Water-holding capacity is most compromised in case pale soft and exudative (**PSE**) meat is occurring. Most indicative for this is the early postmortem pH, but this was not measured in the present study. However even the ultimate pH values ranged above the thresholds applied for classification of meat as PSE (Ristic and Damme, 2013). The greatest ultimate pH was found in the meat of the C++ consistent with the findings of Glamoclija et al., (2015) were meat pH was found to be smaller in broilers fattened for a longer time. An L^*-value of breast meat of >53 to 54 is considered as light (Qiao et al., 2001), and points toward PSE (Woelfel et al., 2002). Such meat was found on average in LD, BM, and C−, whereas the C++ meat was darkest. The latter may, however, have also been a result of a more reddish breast meat (great a^*-value), which was not the case in the leg meat. Yet the statistically significant differences would possibly be too small for the consumer's eye to detect any difference in color. Considering all quality traits described, we consider the breast meat of all chicken types to be in a normal range.

Even though the amount of abdominal fat had been largest in C+, the IMF content was lesser in breast meat and similar in leg meat compared to C++. These findings coincide with those of Zhao et al. (2007), where a smaller IMF content led to a decreased tenderness of the meat. Indeed, the smaller IMF content of the breast meat of all types compared to C++ may negatively affect meat flavor and juiciness (Chizzolini et al., 1999). No sensory analysis had been conducted in the present experiment to confirm this. Reference values for raw breast meat without skin sold in Switzerland are 1% fat, 24.6% protein, and 72.7% water (Federal Food Safety and Veterinary Office, 2017). The corresponding values for the leg meat without skin are 6.2%, 19.7%, and 72.9%. These values were very similar to the proximate composition of the meat found in the present study, with some differences for the different types. Across all relevant meat quality traits, the differences between the extensive broiler line C+ and the dual-purpose types were small showing their competitiveness to C+ in this respect. Also the meat of the layer males did not differ much despite the great differences in growth and carcass quality.

Bone characteristics

Strong bones of fattened chickens are favored in order to prevent for instance tibia dyschondroplasia, a common cause of deformity, lameness, and mortality in broilers (Fleming, 2008). Bones resistant against breaking are also preferred for the processing after slaughter to minimize the risk of undesired bone fragments in the meat. The greatest resistance to breaking was found for the tibias of the C++ type. It is known that the carcasses of slow-growing broilers are elongated including the legs, whereas the body of fast-growing chickens is more compact with shorter legs (Batkowska et al., 2014). This is consistent with the present results with longer tibias of C+ and of the dual-purpose types and, less so, with the layer type, although the latter was given the same life time for growing bones. Longer bones, at the same or even a smaller bone weight, could compromise breaking strength, a combination that was found especially in the layer type chickens. This was unexpected because the females of this type have to produce eggs with strong shell and therefore should have developed mechanisms for effective Ca and P resorption as well as storage mobilization metabolism (Etches, 1987). It seems that in the early growing period these mechanisms are not fully developed yet. Broilers bred for a fast growth need an especially great level of Ca and P in metabolism in the early stage of growth for their skeletal development, and a large supply prevents tibia dyschondroplasia (Fleming, 2008). The smaller Ca and P contents of the bones of the C++ compared to the other types might indicate that the supply was limiting in this chicken type, but in the present study this was no cause of an impairment of breaking strength. Overall, bone properties of LD and BM were similar to that of the extensive broiler line, whereas the traditional dual-purpose type CH resembled more the layer type.

CONCLUSION

The present study demonstrated that novel dual-purpose types, here represented by Lohmann Dual, may compete with slow-growing broilers in many of the major quality criteria for carcass and meat. The difference to the product quality of the male layer types was large. This shows that, at least in organic production systems currently using slow-growing broilers, novel dual-purpose types are a genuine alternative, whereas male layer types are not. Traditional dual-purpose types, as represented by Belgian Malines and Schweizerhuhn in the present study, obviously are not even a valid alternative to male layer types due to similar quality levels in carcass and meat and the lack of a satisfactory egg yield on the female side. Given the limited growth performance of the novel dual-purpose type compared with fast-growing broiler types, it seems unlikely that they are a commercially viable alternative to the existing system. Therefore, it seems not realistic to attempt to completely abandon the current practice of culling day-old layer type males from egg producing hybrids by utilizing dual-purpose chickens unless there is a ban of this practice by law as has been discussed in 1 German state recently.

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