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Meat and egg production with dual-purpose poultry: biological background, feed requirements and efficiency, meat and egg quality

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Unsere Leidenschaften sind nicht zufällig,
sie sind unsere Berufung.

Fabienne Frederickson

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Abbreviations

a*	Redness
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADFom	Acid detergent fiber, expressed exclusive of residual ash
ADG	Average daily gain
aNDFom	Neutral detergent fiber assayed with a heat stable amylase, expressed exclusive of residual ash
b*	Yellowness
BM	Belgian Malines
BMY	Breast meat yield
BW	Body weight
CH	Schweizerhuhn
CP	Crude protein
DM	Dry matter
FAME	Fatty acid methyl ester
HU	Hubbard
IMF	Intramuscular fat
L*	Lightness
LB	Lohmann Brown
LD	Lohmann Dual
ME	Metabolizable energy
MUFA	Monounsaturated fatty acid
ND	Novogen Dual
NDF	Neutral detergent fiber
PSE	Pale, soft, exudative
PUFA	Polyunsaturated fatty acid
SE	Standard error
SEM	Standard error of the mean
SFA	Saturated fatty acid

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Summary

Globally, there has been an intensive specialization in the commercial poultry sector during the last 60 years, which was associated with a complete decoupling of the egg and the meat production. This system optimization led to the culling of laying type cockerels immediately after hatch, as their growth is far too slow for an economic fattening. This practice is of increasing public concern as a large number of healthy day-old chicks are sacrificed (> 300 million in the EU27). Different possible solutions are commonly discussed to stop chick culling: the use of dual-purpose types, where the males are used for meat and the females for egg production, the fattening of male layers and the *in ovo* sex-determination. For the present doctoral thesis, the objective was to identify the biological background, feed requirements and efficiency and carcass, meat and egg quality of dual-purpose poultry, but also the fattening the layer cockerels was considered. Additionally, a special focus was placed on to the conflict between animal welfare and food-feed competition in order to contribute to a sustainable agriculture and food security. It was especially investigated to which extent the expected lower feed efficiency, characteristic for dual-purpose systems, can be counteracted by the possibility to feed these poultry types with food industry by-products instead of food that is also suitable for humans and what were the effects on the products.

In a first small-scale fattening experiment, Lohmann Dual, a modern dual-purpose type, and two traditional dual-purpose types (Belgian Malines and Schweizerhuhn) were compared with a fast-growing (Ross PM3) and a slow-growing broiler (Sasso 51) as well as a layer type (Lohmann Brown Plus) feeding a standard intensive broiler diet. The modern dual-purpose type performed at a similar level as the slow-growing broiler regarding growth and many of the major quality traits for carcass and meat. Traditional dual-purpose types, however, performed clearly less and similar to the layer type cockerels. Out of the results of the first experiment, a large-scale practice-oriented fattening experiment was conducted with two modern dual-purpose types (Lohmann Dual and Novogen Dual), a slow-growing broiler (Hubbard JA 757) and males from a layer type (Lohmann Brown) feeding an organic diet. Additionally, two different fattening periods (67 and 84 days) were tested in order to identify an optimal slaughter weight for dual-purpose chicken. The two dual-purpose types showed a very similar growth performance to the slow-growing broiler during both fattening periods, which indicated a high suitability for the organic production, whereas a longer fattening period did not increase competitiveness of the latter. A drawback of the dual-purpose types was the smaller breast meat proportion compared to the slow-growing broiler regardless of the fattening period. A further fattening experiment focused on growth and slaughter performance as well as in-depth meat quality analyses when fed a diet with less soybean-based ingredients and therefore less crude protein. It showed that the dual-purpose chickens were slightly less susceptible to this diet, allowing the use of components, which can be produced in a more environmentally friendly way. In addition, the alteration of the fatty acid profile in the meat through the diet could be an advantage regarding the consumers' health, when specific agrifood industry by-products with a favorable fatty acid profile are chosen. Soy cake was partially replaced with rapeseed cake, which contains a beneficial amount of omega-3 fatty acids.

Simultaneously with the first fattening experiment, laying hens of the same dual-purpose and layer types were tested regarding hen performance and egg quality. During the late laying period (weeks 36 to 52 of lay) they were fed either a common laying hen diet or an experimental diet, which was composed to a large extent of agrifood industry by-products, ingredients which do not compete with the human food production, and without soy. This diet contained less energy and less methionine, the first limiting amino acid in poultry feed. Following the feeding experiment, the hens were used to determine the carcass and meat quality. The applied feeding measures led to a clearly decreased feed intake along with an impaired performance in specialized layers and in the modern dual-purpose type, but not in the traditional dual-purpose types. However, this indicated a too severe change of the diet composition and therefore it was difficult to make an exact prediction about the use of food industry by-products for such types.

In conclusion, modern dual-purpose types are a genuine alternative to chick culling but only for organic production. The drawback is the smaller breast meat proportion in the males compared to slow-growing broilers on the meat side, the poorer laying persistence on the egg side and the more unfavorable feed efficiency on both sides compared to specialized types. The fattening of layer cockerels with their very slow growth does not seem to be an option, unless a special emphasis on promotion and marketing strategies would be done. Traditional dual-purpose types, as represented by Belgian Malines and Schweizerhuhn, are obviously not a valid alternative due to the lack of a sufficient growth performance or egg production.

Zusammenfassung

Weltweit fand in den letzten 60 Jahren im Wirtschaftsgeflügelsektor eine intensive Spezialisierung statt, welche zu der heutzutage vollständigen Entkopplung der Eier- von der Fleischproduktion führte. Diese Systemoptimierung brachte es mit sich, dass die männlichen Legeküken direkt nach dem Schlupf getötet werden, da ihr Wachstum für eine wirtschaftliche Mast viel zu langsam ist. Diese Praxis löst in der Öffentlichkeit zunehmend Bedenken aus, weil damit eine grosse Anzahl gesunder Eintagsküken eliminiert wird (> 300 Millionen in der EU27). Verschiedene mögliche Lösungen werden diskutiert, um das Kükentöten zu vermeiden: die Verwendung von Zweinutzungstypen, bei denen die Männchen für die Fleisch- und die Weibchen für die Eierproduktion verwendet werden, die Mast von männlichen Legetypen sowie die *in ovo* Geschlechtsbestimmung. Das Ziel der vorliegenden Doktorarbeit war es, den biologischen Hintergrund darzustellen, den Futterbedarf und die Futterverwertung sowie die Schlachtkörper-, Fleisch- und Eiqualität von Zweinutzungsgeflügel zu ermitteln und die Mast von Legehähnen zu untersuchen. Darüber hinaus wurde ein besonderes Augenmerk auf den Konflikt zwischen Tierschutzanliegen und dem Wettbewerb um Nahrungs- und Futtermittel gelegt, um einen Beitrag an eine nachhaltige Landwirtschaft und Ernährungssicherheit zu leisten bei gleichzeitig bedarfsgerechter Fütterung der Tiere. Insbesondere wurde untersucht, inwieweit die schlechtere Futterverwertung von Zweinutzungsgeflügel durch einen vermehrten Einsatz von Nebenprodukten aus der Lebensmittelindustrie kompensiert werden kann und wie sich dies auf die Fleisch- und Eiqualität auswirkt.

In einem ersten Mastversuch wurden der moderne Zweinutzungstyp Lohmann Dual, und zwei traditionelle Zweinutzungstypen (Mechelner Huhn und Schweizerhuhn) mit einem schnell wachsenden (Ross PM3) und einem langsam wachsenden Broiler (Sasso 51) sowie einem männlichen Legehybrid (Lohmann Brown Plus) verglichen. Alle Tiere wurden mit demselben Standard-Mastfutter gefüttert. Der moderne Zweinutzungstyp konnte mit dem langsam wachsenden Broiler in der Wachstumsleistung und in vielen wichtigen Qualitätsmerkmalen für Schlachtkörper und Fleisch mithalten. Traditionelle Zweinutzungstypen erbrachten jedoch eine deutlich geringere und dadurch ähnliche Leistung wie die männlichen Legetypen. Aufgrund der Ergebnisse aus dem ersten Experiment wurde ein grösser angelegter Mastversuch mit zwei modernen Zweinutzungstypen (Lohmann Dual und Novogen Dual), einem langsam wachsenden Broiler (Hubbard JA 757) und einem männlichen Legehybrid (Lohmann Brown) unter praxisnahen Bedingungen und Biofütterung durchgeführt. Zusätzlich wurden zwei verschieden lange Mastperioden (67 und 84 Tage) getestet, um ein optimales Schlachtgewicht

für Zweinutzungstypen zu ermitteln. Die beiden Zweinutzungstypen entwickelten sich während beider Mastperioden sehr ähnlich wie der langsam wachsende Broiler, was auf deren Eignung für die Bioproduktion hindeutet. Die längere Mastperiode erhöhte die Wettbewerbsfähigkeit der Zweinutzungstypen nicht. Ein Nachteil der Zweinutzungstypen war der geringere Brustfleischanteil im Vergleich zum langsam wachsenden Masthähnchen unabhängig von der Mastzeit. Ein weiterer Mastversuch fokussierte auf die Wachstums- und die Schlachtleistung sowie die Fleischqualität beim Einsatz eines Futters mit reduziertem Soja- und Rohproteingehalt. Es konnte gezeigt werden, dass Zweinutzungstypen etwas weniger anfällig auf eine derartige Fütterung waren, was die Verwendung von Futtermitteln mit geringerer Qualität und umweltfreundlicherer Herstellung ermöglichen könnte. Darüber hinaus konnte gezeigt werden, dass das Fettsäurenprofil im Fleisch mit dem Futter variiert werden kann, was für die Gesundheit der Konsumenten von Vorteil sein könnte, wenn bei der Auswahl bestimmter Nebenprodukte der Lebensmittelindustrie auf ein günstiges Fettsäureprofil geachtet wird. Im beschriebenen Experiment wurde Sojakuchen teilweise durch Rapskuchen ersetzt, der einen vorteilhaften Gehalt an Omega-3-Fettsäuren aufweist.

Zeitgleich mit dem ersten Mastversuch wurden Legehennen derselben Zweinutzungstypen und desselben Legehybrids eingestallt und deren Leistung sowie die Eiqualität untersucht. In der späten Legephase (Wochen 36 bis 52 der Legetätigkeit) wurden sie entweder mit einem praxisüblichen Legehennenfutter oder mit einem Futter, welches zu grossen Teilen aus Nebenprodukten der Lebensmittelindustrie bestand und kein Soja enthielt, gefüttert. Damit wurden jene Futterkomponenten, die mit Lebensmitteln konkurrieren minimiert. Das Versuchsfutter war im Vergleich zur Kontrolle energieärmer und enthielt weniger Methionin - die erstlimitierende Aminosäure beim Geflügel. Am Versuchsende wurden die Hennen geschlachtet und die Qualität der Schlachtkörper sowie die Qualität des Fleisches untersucht. Dieses Versuchsfutter führte zu einer deutlich verminderten Futteraufnahme und damit zu einer Leistungseinbusse sowohl beim Legetyp als auch beim modernen Zweinutzungstyp, nicht aber bei den traditionellen Zweinutzungstypen. Trotzdem scheint es, dass der gänzliche Verzicht auf Soja und dessen Ersatz durch die gewählten Nebenprodukte zu einschneidend war, und somit eine genaue Aussage über die Verwendung von Nebenprodukten aus der Lebensmittelindustrie für solche Typen unter den gewählten Bedingungen nicht möglich ist.

Zusammenfassend lässt sich sagen, dass moderne Zweinutzungstypen eine echte Alternative zum Kükentöten darstellen, jedoch nur für die biologische Produktion. Der Nachteil ist der geringere Brustfleischanteil bei den männlichen Zweinutzungstypen im Vergleich zu langsam wachsenden Masthähnchen, die schlechtere Legepersistenz der Hennen und die ungünstigere Futtereffizienz auf beiden Seiten im Vergleich zu spezialisierten Hybriden. Die Mast von Legehähnen mit sehr langsamem Wachstum scheint keine Option zu sein, ausser es wird besonderes Gewicht auf die Werbe- und Marketingstrategien gelegt. Traditionelle Zweinutzungstypen, wie beispielsweise das Mechelner Huhn und das Schweizerhuhn, sind offensichtlich auch keine Alternative. Sowohl die Wachstumsleistung als auch die Legeleistung waren nicht zufriedenstellend.

Chapter 1

General introduction

During the past decade the per capita consumption of poultry increased worldwide (+16%), and still, an ongoing increase by 5.5% is expected for the next decade (OECD/FAO, 2018). The egg production will grow at similarly robust levels (OECD/FAO, 2018). The reasons for this are various. On the one hand, production costs can be maintained on a low level due to the favorable feed efficiency of the poultry and therefore, the resulting products are sold at a comparatively low price. On the other hand, poultry meat is considered healthy, due to low fat content and greater proportions of polyunsaturated fatty acids than meat derived from other animals (Swiss Food Composition Database, 2018). Another important consideration refers to poultry meat not being associated with potential religious or cultural constraints. To meet increasing demands for poultry products, the global commercial poultry industry underwent a tremendous specialization during the last 60 years. Specifically, meat and egg production was completely decoupled and poultry is no longer reared and bred on farm, but is provided by a few breeding companies. This was realized by breeding specialized hybrids, which grow fast and have therefore a great meat accretion reaching 2.3 kg in 5 weeks (Table 1.1), or lay more than 300 eggs per year, respectively (Figure 1.1). Together with the selection for a better growth or laying performance, the feed efficiency, i.e. the amount of feed consumed to produce 1 kg of meat or egg, decreased (Table 1.1 and Figure 1.2).

Table 1.1 Body weight and cumulative feed efficiency after 42 days of fattening for different broiler types originated from year 1957, 1978, 2001 and 2014

Broiler from year	1957[1]	1978[2]	2001[1]	2014[3]
Body weight (kg)	0.54	1.21	2.67	2.81
Feed efficiency (g feed:g body weight gain)	2.34	1.90	1.63	1.69

[1]Havenstein et al. (2003)
[2]Zuidhof et al. (2014)
[3]Aviagen (2014)

However, muscle development and laying performance are antagonistic traits and accordingly differential metabolism results in very poor growth of layer males (Gerken et al., 2003; Koenig et al., 2012; Lichovníková et al., 2009). Thus, in western countries they are usually culled immediately after hatch. This practice raises more and more ethical concerns in public and political discussions (Bruijnis et al., 2015; Krautwald-Junghanns et al., 2018). Therefore, there is a need for alternatives to conform to productivity goals as well as ethical issues in modern times.

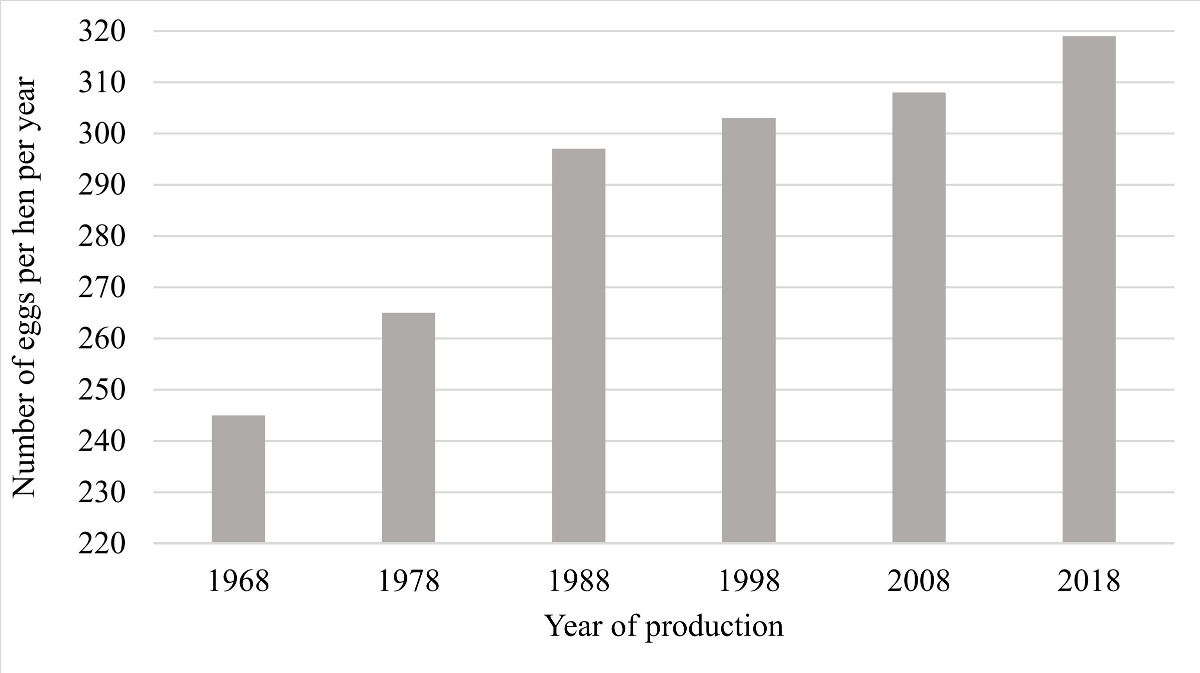

Figure 1.1 Development of the laying performance (egg per hen per year) since 1968 (Damme and Hildebrand, 2011; Damme et al., 2018).

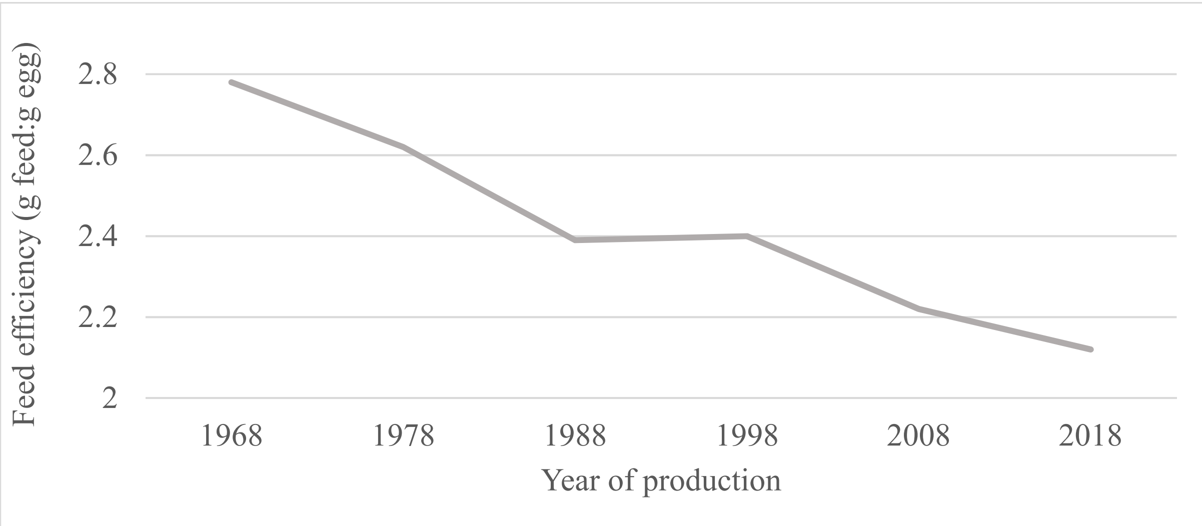

Figure 1.2 Development of the feed efficiency (g feed:g egg) of laying hens since 1968 (Damme and Hildebrand, 2011; Damme et al., 2018).

1.1 Possible alternatives to chick culling

Over the past years, an intensive search to avoid the culling of day-old male layer chicken has taken place, and is still ongoing. More and less promising solutions are considered but not all of them are immediately feasible. Moreover, a combination of two approaches may be even better than a single one.

1.1.1 Dual-purpose poultry

Globally operating breeding companies, e.g. Lohmann from Germany or Novogen from France, recently developed dual-purpose poultry to face the problem. Additionally, there are smaller and local hatcheries, e.g. Hölzl Hatchery or Dominant CZ, which provide dual-purpose types as Walesby Special or Dominant Red Barred, respectively, to the market. Dual-purpose types are a cross of meat and layer hybrids (Damme et al., 2015b). The males of such types should yield a high amount of meat and the females should show an acceptable laying performance. In order to obtain hens with a low body weight and a slower growth than the males, a sex-linked dwarf gene was used (Damme et al., 2015b). This is important from an animal welfare perspective and a world nutrition point of view, as the laying hens should be fed *ad libitum*. For instance, broiler breeder hens until they start to lay need to be feed restricted, and as a consequence they show improper behavior. Such misconduct should not occur in laying hen flocks. The dwarf gene therefore, reduces the body weight of dual-purpose hens by about 25% and at the same time the feed intake. However, to combine egg and meat production in one type is a challenge. It is inevitable that with the negative genetic correlation between the two traits a longer fattening period or a lower laying performance results (Icken and Schmutz, 2013). Therefore, it is suggested to use these types in organic production (Kaufmann et al., 2016), where lower performances are aimed at (Bio Suisse, 2018) resulting in a more favorable health status and hence in a lower mortality (Keppler et al., 2011). However, also traditional dual-purpose breeds gained renewed interest. They could also be used for such dual-purpose systems, although they performed inefficient in former studies (Hörning et al., 2011; Lambertz et al., 2018; Rizzi and Chiericato, 2010).

1.1.2 Fattening the male layer cockerels

An immediately feasible way to avoid chick culling is to fatten the male layer cockerels as already implemented in the Austrian organic poultry production (Leithner, 2016). In Austria, the laying cockerels are fattened for about 9 weeks until they reach a live weight of 1 kg, which is equal to a carcass weight of 650 g (Hürner, 2016). Marketing these cockerels at a lower slaughter weight (650 g) than common for broilers has been investigated also in other studies (Koenig et al., 2012). Additionally, different feeding regimes have been tested with a special focus on economy, management factors, duration of the fattening period and product quality (Koenig et al., 2012; Lichovníková et al., 2009).

1.1.3 *In ovo* sex determination

Over the past few years, various noninvasive and invasive techniques to determine the sex *in ovo* have been established. Yet, none of them is suitable for a practical use in hatcheries (Krautwald-Junghanns et al., 2018). Completely noninvasive methods base on egg shape (Imohlt, 2010; Yilmaz-Dikmen and Dikmen, 2013) and odor (Webster et al., 2015) but for both methods, the differences found could not be sufficiently correlated to the sex of the chicken post-hatching. An invasive method as the measurement of hormones require sample extractions from eggs and can be applied only after 9 days of incubation (Weissmann et al., 2013) which is a disadvantage. Near-infrared Raman and fluorescence spectroscopy can be performed after 3.5 days of incubation and are minimally invasive as the egg has to be windowed while leaving the inner egg shell membrane intact (Galli et al., 2018). Recently, the Technical University of Munich presented another promising contact-free and therefore noninvasive method, which determines the sex with the help of magnetic resonance imaging and thus, there is no need to open the eggshell (Letz, 2018). The installation of such a prototype in a hatchery for testing under field conditions will be expected within the next two years (Letz, 2018).

1.1.4 Altering the secondary sex ratio

Very few literature is available about altering the gender ratio at birth (secondary sex ratio) using different temperature regimes during the last days of incubation (Elmehdawi et al., 2016). Additionally, it was tested especially for broiler lines (Elmehdawi et al., 2016; Tzschentke and Halle, 2009) not always with success to alter the secondary sex ratio at birth. Due to the fact that no article about this topic is existing for laying hens, it is suggested that this option is not at all a solution to avoid chick culling.

1.2 The situation in Switzerland

Since January 2014, dual-purpose eggs and dual-purpose chicken meat have been marketed seasonally in a pilot project by one Swiss supermarket chain. Since January 2016, dual-purpose eggs are permanently available and dual-purpose chicken meat remains therefore seasonally available in several stores in this supermarket (Gangnat et al., 2018). Additionally, these products are available only in organic quality. Currently, there are five flocks of dual-purpose laying hens producing eggs (Nüssli, 2018), which equals 10’000 male laying chicks not being culled. In order to generate enough dual-purpose products and to omit the import of day-old chickens, the first parent stock was established in October 2017 in the Emmental (Pfeiffer, 2017). In addition to the dual-purpose approach, there is the practice of fattening the layer cockerels with the “Henne & Hahn” project launched by Hosberg AG at the beginning of 2016 (Hosberg, 2018) and more commercially since the beginning of February 2018 in collaboration with Roman Clavadetscher (Nüssli, 2018). “Hahn im Glück” is the fattening program of layer cockerels from Demeter Switzerland (Demeter Schweiz, 2018). From 2019 onwards, Demeter Switzerland will resign from chick culling (Demeter Schweiz, 2018).

The discussion about an early ban of day-old chick culling is taking place almost only in the organic production with the goal that Bio Suisse resign from chick culling at the beginning of 2019. Still, there are different positions among Bio Suisse producers about this practice (Nüssli, 2018). The commercial production is waiting for a more economical solution as may be the case with *in ovo* sex determination.

1.3 Dual-purpose poultry and the feed no food concept

Constraints encountered concerning the use of dual-purpose types or the fattening of layer cockerels include the lower laying performance and the greater proportion of smaller eggs in females as well as the slower growth and the unfavorable carcass conformation in males and on both sides the unsatisfactory feed efficiency (Damme et al., 2015b). Especially the unfavorable feed efficiency of these types is not only an economic but also an ethical problem, because poultry diets contain to a large extent potential human foods. It might be possible to feed the dual-purpose types or the male layers with lower quality diets, as they also have a lower performance. Therefore, agrifood industry by-products from cereal and oilseed milling or from industries producing starch, sugar or biofuel could be used instead of cereals, which compete with human nutrition. Possible alternative energy and protein sources are presented in Table 1.2.

Despite the good characteristics of soy, its feeding is controversially discussed in public mostly because of environmental issues (Semino et al., 2009). Soybean components are valuable poultry feed components, which represent about one third of the diet (Baur, 2011). They contain a lot of crude protein and essential amino acids (especially lysine), and have a low fat and fiber content (Swiss Feed Database, 2018). However, the lysine:methionine ratio is not optimal for poultry. Methionine is the first limiting amino acid for poultry (Toride, 2004). A disadvantage of most plant protein sources is the low methionine content. In addition, the use of such alternative ingredients is often limited because of their anti-nutritional effects. Flaxseed for instance contains several of these substances as cyanogenic glycosides, trypsin inhibitors and mucilages (Jeroch et al., 2013). Molasses contains a lot of non-protein-nitrogen (Jeroch et al., 2013), which does not contribute to the protein supply for monogastric animals but enriches the excreta with nitrogen, an undesirable effect from an ecological point of view. Additionally, the great potassium content could lead to a greater moisture content in the excreta.

Finally, meal from insect larvae, mostly from the black soldier fly (*Hermetia illucens*), are in discussion to replace soybean-based components in poultry diets (Cullere et al., 2018; Leiber et al., 2017; Maurer et al., 2016; Mwaniki et al., 2018). Yet, there is no legal basis to use insect meal in livestock diets (EC 2013; EFSA 2015; Zimmerli, 2017).

The feasibility of the objective to replace such components and the extent, to which the requirements for nutrient density of dual-purpose types are low enough, still has to be investigated. A study conducted by Urban et al. (2018) did not show an effect of reducing the protein content in the diet on performance and whole body composition of Lohmann Dual broilers. However, the metabolizable energy of the diet used by these authors was as great as in a standard broiler diet and no food industry by-products have been used (Urban et al., 2018).

Table 1.2 Alternative protein and energy sources and their nutrient profile (Jeroch et al., 2013; Swiss Feed Database, 2018) with soybean meal and cake as references

Component	Source for		Metabolizable energy (MJ /kg fresh matter)	Crude protein (g/kg fresh matter)	Methionine	Lysine:methionine ratio	Limitation of use[1] (%)	
	Protein	Energy					H	B
Brewer's yeast	×	×	12.3	467	7.3	4.3	5	5
Brewer's grains	×		9.3	230	4.5	2.0	-[2]	-
Buckwheat, dehulled		×	13.8	116	2.1	3.1	25	20
Cottonseed meal, partly dehulled	×		6.6	401	6.4	2.6	7.5	10
Distillers dried grains with solubles	×		-	312	4.8	1.1	15	5
Field bean	×	×	10.2	258	2.1	7.3	10	5
Field pea	×	×	11.2	187	1.7	7.7	10	5
Flaxseed cake	×		-	330	6.1	2.1	10	5
Flaxseed meal	×		5.8	295	5.4	2.1	10	5
Lucerne meal, dried	×		5.8	188	2.1	3.5	5	0
Mill by-products		×	8.1	149	2.2	2.5	10	5
Molasses		×	8.5	108	-	-	2	2
Rapeseed cake	×		9.6	315	5.8	3.2	5	5
Rapeseed meal	×		7.2	344	6.0	3.1	10	5
Rice, broken		×	14.6	80	2.2	1.2	20	10
Sunflower cake	×		7.6	253	5.5	1.8	10	5
Sunflower meal	×		6.5	371	8.4	1.7	10	5
Sweet lupine (*L. albus*)	×		8.4	320	2.2	6.9	20	15
Sweet lupine (*L. angustifolius*)	×		7.3	304	1.9	7.3	20	15
Soybean cake	×		9.8	436	6.1	4.3	25	30
Soybean meal	×		9.4	496	6.9	4.4	25	30
Hermetia illucens meal[3]	×		-	590	9.8	3.2	-	-

[1]Recommended maximal quantity in the respective diet for hens (H) and broilers (B) according Futtermittelkatalog, (2016) and Jeroch et al. (2013)
[2]Values not available
[3]based on Maurer et al. (2016)

1.4 Product quality

For a comprehensive assessment of the use of these birds, the quality of their products such as carcasses, meat and eggs has also to be taken in account. Urselmans et al. (2015) and Schmidt et al. (2016) described carcass conformation and egg size of different dual-purpose types. As expected, the antagonism between the meat accretion and the laying performance was evident. Dual-purpose males developed a noticeably smaller breast meat proportion than the specialized broiler lines, which led to a more visible keel bone (Schmidt et al., 2016) and laying hens had a greater proportion of small eggs compared to layer hybrids (Urselmans et al., 2015). However, in-depth analyses of meat and egg quality of dual-purpose types are scarce.

Carcass composition and meat quality of layer cockerels were investigated in some experiments and with different male layer types (Gerken et al., 2003; Koenig et al., 2012; Lichovníková et al., 2009; Murawska et al., 2005). All of them reported an unfavorable carcass confirmation and a very low meat yield.

Regarding meat quality, it is well known that chicken meat has a very low fat content (Swiss Food Composition Database, 2018) and is therefore classified as healthy. Additionally, the fatty acid profile in chicken meat, but also in eggs, exclusively the egg yolk, can be modified by the diets fed to the animals (Ghasemi et al., 2016; Poureslami et al., 2012). This phenomenon is important when changing feed ingredients with industry by-products or local protein and energy sources as proposed above.

1.5 Thesis outline and aim of the project

The present doctoral project aimed at identifying the biological background, feed requirements and efficiency and carcass, meat and egg quality of dual-purpose poultry. Further, the fattening of male layer cockerels was investigated. It was of interest whether diets with a lower energy and protein content and composed of agrifood industry by-products have an effect on the performance of the animals and the respective products, especially carcass, meat and egg quality. The following hypotheses were tested:

Hypothesis 1. Promising dual-purpose poultry systems could include types recently developed by global operating companies, but also traditional dual-purpose types.

Hypothesis 2. Male layer cockerels are inferior in growth and slaughter performance compared with dual-purpose types.

Hypothesis 3. For the fattening of dual-purpose or layer types, as well as for the egg production with dual-purpose types, the use of food industry by-products is possible without negative effects on performance and the product quality.

Hypothesis 4. The meat quality of dual-purpose and male layer types is comparable to meat of broiler types.

Hypothesis 5. The egg quality of dual-purpose females is similar to that of specialized hybrids.

1.6 Design of the project

To test these hypotheses, initially a dual-purpose type (Lohmann Dual), recently developed by an international breeding company and two available traditional dual-purpose types (Schweizerhuhn and Belgian Malines) were chosen. In a fattening experiment, these types were compared with an intensive and a slow-growing broiler as well as a layer type. Out of the results of the first fattening experiment, where the traditional dual-purpose types performed at a similar level to the layer cockerels, two modern dual-purpose types were selected for a practice-oriented up-scaling experiment with a special emphasis on an optimal fattening period. For an in-depth analysis of the chicken meat quality, a further experiment was conducted over two runs where three types (slow-growing, dual-purpose, layer) and two different diets (common broiler diet vs. low-protein diet) were tested. To investigate the performance of dual-purpose laying hens, the same types as in the first fattening experiment types were compared with the laying hybrid Lohmann Brown Plus. The hens stayed in the experiment for one laying turnover, i.e. one year. In the late laying phase until slaughter, the suitability of a diet composed to a large extent of food industry by-products was investigated with the focus on laying performance, feed efficiency and egg quality. After slaughter, the carcass and meat quality was assessed.

Chapter 2

Carcass and meat quality of dual-purpose chickens (Lohmann Dual, Belgian Malines, Schweizerhuhn) in comparison to broiler and layer chicken types

This chapter is based on Mueller S., Kreuzer M., Siegrist M., Mannale K., Messikommer R.E., and Gangnat I.D.M. 2018: Poultry Science, 97: 3325-3336.

2.1 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). In addition, 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 were ranked only slightly better.

2.2 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). While, 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 three 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).

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., 2015a). 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.

2.3 Materials and methods

2.3.1 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 2.1). 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 m2. After 7 d 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

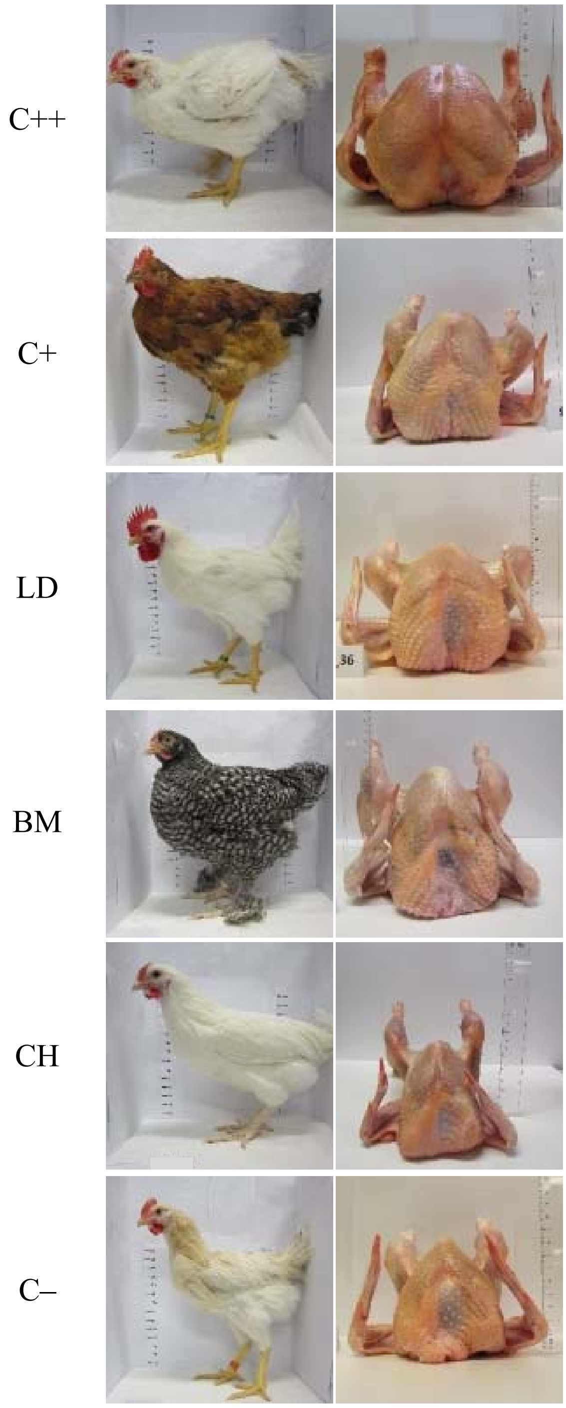

Figure 2.1 Appearance of the 6 chicken types short before slaughter and as carcasses. C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus, where C++ were 35 days of age and all others were 63 days of age. The corresponding breast angles 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 ($P < 0.05$).

boxes in groups of 3. From regrouping onwards, all birds received the same diet with 13.0 MJ/kg ME and 198 g/kg CP (Table 2.1) composed as required by fast-growing broiler types (GfE, 1999).

Table 2.1 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 & 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 (wk 3, 5 and 9)
[4]As indicator, values are means of 6 determinations (wk 3, 5 and 9)

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 wk 1 (when additionally heating lamps were installed) to 20°C in wk 6 and then remained at 20°C until wk 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.

2.3.2 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 wk 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, USA) 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.

2.3.3 Feed and excreta analysis

Diet and excreta samples were analyzed by standard procedures (AOAC, 1997). For DM a thermo-gravimetric 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).

2.3.4 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 were 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., Basle, Switzerland).

2.3.5 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, Surrey, UK) 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).

2.3.6 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, USA) 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.

2.4 Results

2.4.1 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 2.2).

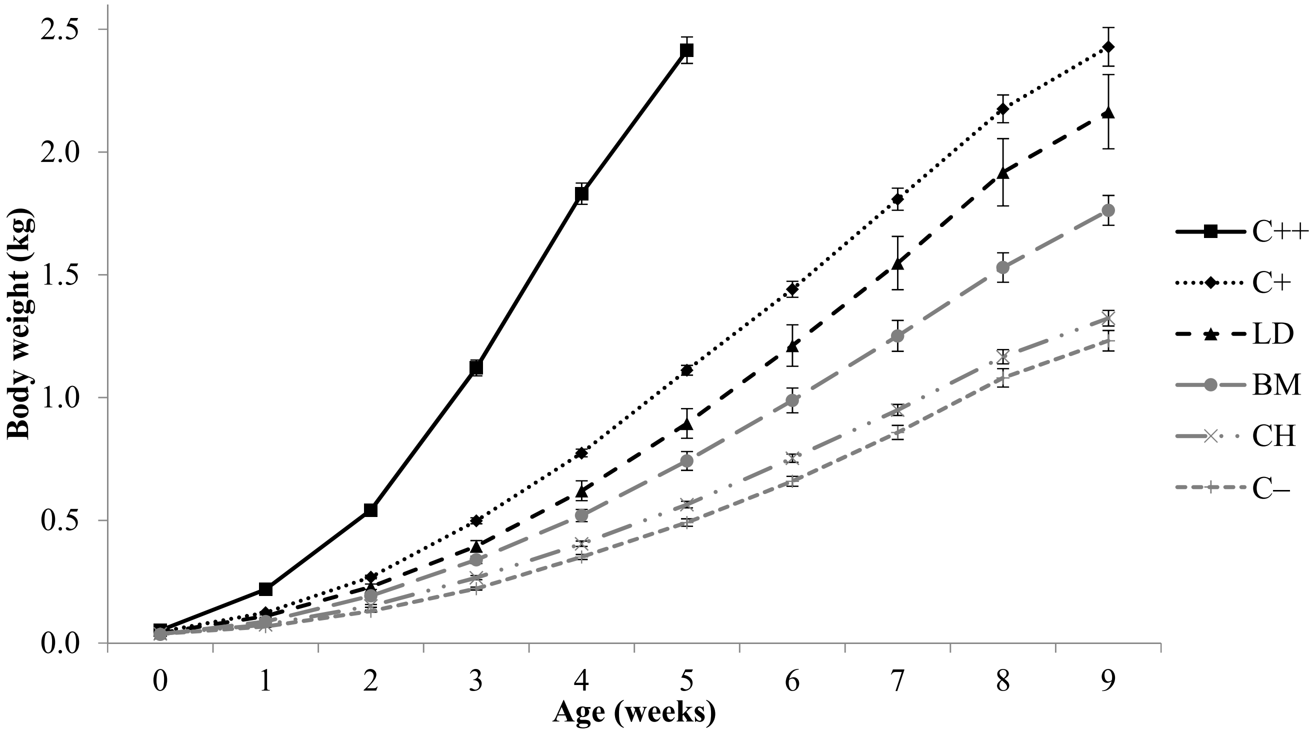

Figure 2.2 Weight development of the 6 chicken types (means ± SE) during the experiment with n = 9 per chicken type. C++ = Ross PM3; C+ = Sasso 51; LD = Lohmann Dual; BM = Belgian Malines; CH = Schweizerhuhn; C– = Lohmann Brown Plus.

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 2.2). 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 wk 3 and 5 and around 12 % in wk 9 (data not shown). The chicken type did not significantly affect fiber digestibility. In wk 3, but not in wk 5 and 9, energy metabolizability was greater ($P < 0.05$) with C+ than with C++, and intermediate in all other types. In wk 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 wk 9, but differences between individual types were not significant. In wk 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 wk 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 wk 5.

Table 2.2 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[bc]	46.3[a]	41.3[b]	36.0[d]	38.3[bcd]	37.2[cd]	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[bc]	69[c]	52[d]	48[d]	1.6	<0.001
Feed efficiency (g of feed/g of ADG)[3]	1.52[d]	2.43[bc]	2.22[c]	2.55[ab]	2.73[a]	2.46[abc]	0.059	<0.001
Metabolizability of nitrogen (%)								
Wk 3	68.2[a]	62.6[ab]	61.3[b]	59.0[b]	58.7[b]	61.6[b]	1.33	0.003
Wk 5	65.9[a]	55.6[b]	60.8[ab]	55.5[b]	56.7[b]	56.9[b]	1.62	0.004
Wk 9	–	35.4	38.5	46.4	45.2	47.8	2.73	0.037
Metabolizability of energy (%)								
Wk 3	77.3[b]	79.7[a]	78.2[ab]	78.4[ab]	79.4[ab]	78.8[ab]	0.46	0.035
Wk 5	77.4	77.6	77.8	78.6	78.7	77.6	0.45	0.27
Wk 9	–	77.8	77.2	77.0	78.0	78.0	0.72	0.78
Excreta DM (g/kg)								
Wk 3	457[b]	537[ab]	480[b]	625[a]	608[a]	588[a]	22.8	0.001
Wk 5	317	376	329	414	415	395	27.3	0.097
Wk 9	–	392[ab]	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

2.4.2 Carcass characteristics

Carcass composition was strongly influenced by chicken type (Table 2.3). 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 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+.

Table 2.3 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^{ab}	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^{cd}	126^{bc}	130^{b}	139^{a}	2.0	<0.001
Abdominal fat	14.0^{bc}	40.8^{a}	24.5^{b}	19.0^{bc}	17.2^{bc}	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^{bc}	26.2^{abc}	24.8^{bc}	34.6^{ab}	42.3^{a}	3.90	<0.001
Heart	6.50^{c}	6.37^{c}	6.86^{bc}	7.47^{abc}	7.83^{ab}	8.48^{a}	0.269	<0.001
Spleen	0.96^{e}	1.73^{cd}	2.79^{b}	1.37^{de}	2.37^{bc}	4.11^{a}	0.162	<0.001
Pancreas	2.06^{c}	2.09^{c}	2.44^{bc}	2.35^{bc}	2.73^{ab}	3.14^{a}	0.112	<0.001
Leg parts (g/kg leg)								
Meat[3]	687^{ab}	687^{ab}	703^{a}	691^{ab}	672^{bc}	661^{c}	5.3	<0.001
Bone (tibia & femur)	126^{cd}	125^{d}	142^{bc}	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 days of age, all others were 63 days of age
[2]Proventriculus and gizzard
[3]Without skin, cartilage and fat tissue

The only carcasses in which no keel bone was apparent (breast angle > 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 2.4). 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*) was most prominent in C++ (P < 0.05).

2.4.3 Bone characteristics

Overall C++, C+, LD and BM had heavier and thicker tibias than CH and C– (P < 0.05). Tibia length differed by 26 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 were 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.

Table 2.4 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^{bc}	25.7^{b}	20.6^{cd}	18.1^{d}	18.8^{d}	1.06	<0.001
Length (mm)	159^{bc}	186^{a}	177^{a}	164^{b}	157^{bc}	148^{c}	3.1	<0.001
Leg, maximal thickness (mm)	41.7^{a}	38.7^{a}	39.2^{a}	34.6^{ab}	23.7^{c}	29.4^{bc}	1.89	<0.001
Skin color at slaughter								
Lightness (L*)	62.6^{cd}	64.4^{bc}	66.3^{ab}	67.7^{a}	61.1^{d}	64.6^{bc}	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^{ab}	128^{ab}	125^{b}	118^{c}	1.7	<0.001
Thickness (mm)	8.09^{ab}	8.11^{ab}	8.38^{a}	8.31^{a}	7.19^{bc}	7.00^{c}	0.243	<0.001
Maximal breaking force (N)	497^{a}	391^{b}	396^{b}	322^{bc}	289^{c}	279^{c}	22.0	<0.001
Composition (g/kg)								
Total ash	181^{c}	213^{a}	198^{b}	201^{ab}	199^{ab}	203^{ab}	3.6	<0.001
Calcium	72.6^{b}	90.6^{a}	82.2^{ab}	81.7^{ab}	82.7^{ab}	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 days of age, all others were 63 days of age

2.4.4 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 2.5). Drip loss was not affected by chicken type. The breast meat of C++ had 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 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.

Table 2.5 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^{bc}	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^{bc}	3.90^{abc}	3.54^{bc}	5.04^{a}	4.38^{ab}	0.319	<0.001
Cooking loss (%)	16.1^{a}	12.2^{b}	11.3^{bc}	10.9^{bc}	8.3^{c}	9.4^{bc}	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^{bc}	54.3^{ab}	56.0^{a}	50.6^{bc}	54.6^{ab}	1.09	<0.001
a*	3.58^{a}	1.82^{bc}	1.26^{c}	1.58^{bc}	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^{bc}	7.9^{bc}	7.9^{bc}	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^{ab}	0.49^{ab}	0.10^{ab}	0.72^{ab}	0.305	0.04
Proximate composition (g/kg)								
Moisture	746^{ab}	741^{b}	745^{ab}	754^{a}	744^{b}	748^{ab}	2.1	0.002
Protein	192^{c}	202^{b}	206^{ab}	202^{b}	204^{ab}	208^{a}	1.2	<0.001
Fat	39.8^{a}	40.0^{a}	35.4^{ab}	31.5^{ab}	35.7^{ab}	26.7^{b}	2.23	<0.001

$^{a–b}$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 days of age, all others were 63 days of age
[2]As determined by the Volodkevich device

2.5 Discussion

2.5.1 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, this 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 d 63 vs. 2.2 kg at d 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+ which does not contribute to egg production. The novel dual-purpose type can, however, not 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+. 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.

2.5.2 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, which 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, which 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) which made up a correspondingly small proportion in C++ than in the other types. The greater liver proportion of the whole carcass in C++ suggest 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 C– and 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, which 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.

2.5.3 Meat Quality

Concerning meat quality, the results found with C++ deviated most from that of the other chicken types, which 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 years 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 (Chueachuaychoo et al., 2011; Fletcher, 2002; McCormick, 1994). The small shear force found in the intensive broiler type may even be perceived as too unstructured and soft; this especially in countries where meat from traditional poultry types is still available and consumed (Jaturasitha et al., 2017).

The drip loss was very small, similar in 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 weeks 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 which 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 towards 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.

2.5.4 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.

2.6 Conclusion

The present study demonstrated that novel dual-purpose types, here represented by Lohmann Dual, might 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.

Chapter 3

Growth, carcass and meat quality of two dual-purpose chicken types and a layer type fattened for 67 or 84 days compared with a slow-growing broiler

This chapter is based on Mueller S., Taddei L., Albiker D., Kreuzer M., Siegrist M., Messikommer R.E., and Gangnat I.D.M. Submitted to Animal, under review.

3.1 Abstract

To avoid chick culling, fattening could be performed with either dual-purpose types, where both males and females are used in production, or layer males. It remains unclear how far the dual-purpose types can compete with slow-growing broiler types, typically used in organic farming, and the extent to which layer males are inferior to these types. Therefore, growth and slaughter performance, and meat quality of males of two competing dual-purpose types from globally operating companies (Lohmann Dual, LD; Novogen Dual, ND) and layers (Lohmann Brown, LB) were compared with non-sexed slow-growing broilers (Hubbard S 757, HU). Fattening periods tested were either standard (67 days) or prolonged to 84 and 126 days (LB only). Per type 1350 birds were tested and kept in five compartments of 20 m2. Growth data were recorded weekly per compartment. Carcass and meat quality were analyzed in detail in respectively 24 and 10 birds per type and fattening period. Type, age at slaughter and their interaction were tested as fixed effects by ANOVA. Final body weight, average daily gains and feed intake did mostly not differ between ND, LD and HU and were lower in LB irrespective of fattening period. Across 67 days, HU had a more favorable feed efficiency (2.62 kg feed/kg gain) than ND (2.81) and LD (2.83) whereas differences vanished during prolonged fattening. The LB were always inferior in this trait (3.61). Carcass weights of HU, ND and LD were about 1.1 and 1.5 kg after 67 and 84 days, respectively. Breast angle, as an indicator for keel bone prominence, was largest with HU, similar with ND and LD and smallest with LB. Breast meat proportions were always greater for HU than ND and LD with 21, 18 and 17%, respectively, and lowest for LB (15%). Larger leg proportions partially compensated this in the dual-purpose types vs. HU. Breast meat from dual-purpose types was similar or slightly superior to HU in water-holding capacity and shear force and slightly inferior in intramuscular fat content. The LB meat did not differ much from that of the others. Fattening for 126 days improved carcass quality in LB without impairing meat quality. In conclusion, the dual-purpose types were competitive to the slow-growing broilers except for the substantially smaller breast meat proportion and breast angle. The layer cockerels were inferior in growth and carcass quality, but delivered meat of the same quality.

3.2 Implications

Currently, there is an intensive ethical discussion about the practice of culling day-old male layer chicks. This could be omitted by introducing dual-purpose types for egg and meat production or fattening of the male layers. The study demonstrated that Novogen Dual and

Lohmann Dual are competitive to slow-growing broilers in growth, carcass and meat quality when fattened for 67 or 84 days, except for breast meat proportion and keel bone prominence. The meat quality of Lohmann Brown males was also comparably high, but growth and carcass quality were poor. Prolonged fattening for 126 days slightly improved their carcass quality.

3.3 Introduction

In the global poultry sector, the production of meat and eggs is extremely specialized and specific types are used. Different from meat production, where birds of both genders are fattened, males are useless in egg production. As laying performance and meat accretion are antagonistic traits, the productivity of male laying cockerels is low (Gerken et al., 2003; Lichovníková et al., 2009; Mueller et al., 2018). Thus, they are culled immediately after hatch with very few exceptions. This causes ethical debates in the public and in politics (Vizzier Thaxton et al., 2016). Although there is no legal ban, different solutions to avoid chick culling are intensively discussed. Besides in ovo sexing, which is not ready yet for the use in poultry production (Krautwald-Junghanns et al., 2018), the most promising alternatives are the introduction of dual-purpose systems, where females are designated for egg and males for meat production (Schmidt et al., 2016) or fattening of male layers as practiced in organic poultry production in Austria (Leithner, 2016). As these types are expected to be incapable to compete with specialized broiler types, both alternatives are primarily attractive for organic poultry meat production, where birds are deliberately fattened at a much slower growth rate realized by using different broiler types (Bio Suisse, 2018). First performance tests of dual-purpose types, recently developed by globally operating companies in response to the public demand, focused on general fattening performance and carcass quality (e.g., Schmidt et al., 2016), others investigated crossbreds obtained from small-scale breeders (Lambertz et al., 2018). A controlled study (Mueller et al., 2018) with birds kept in pairs in large cages under optimal housing conditions showed that indeed birds of the dual-purpose type Lohmann Dual (LD) were competitive to slow-growing broilers in some, but not all, growth and carcass performance traits. In addition, it remained unclear if the results would be similar when scaling up to large herds kept under common floor housing. Information about whether or not traits improve when prolonging the fattening period is also missing.

Therefore, the aim of the present study was to investigate growth performance, carcass and meat quality in two competitive dual-purpose types and in layer type cockerels as opposed to slow-growing broilers at different ages at slaughter.

3.4 Material and methods

3.4.1 Birds, housing and experimental conditions

A total of 5400 birds of four different types were investigated (4 × 1350). Types were males of two dual-purpose types, Novogen Dual (ND) and LD, males of the layer type Lohmann Brown (LB) and unsexed birds of the slow-growing broiler type Hubbard S 757 (HU). The latter is among the accepted types for Swiss organic poultry meat production (Bio Suisse, 2018). The day-old birds of HU, LB and LD were purchased from Animalco AG (Staufen, Switzerland), and those of ND from Novogen (Le Fœil, France). They were kept in an experimental barn of the Foundation Aviforum (Zollikofen, Switzerland) in 20 compartments of 20 m^2 each with unrestricted access to protected outdoor areas of 4 m2 during daylight from day 21 onwards. Birds per type were randomly distributed to five compartments of 270 birds each. The compartments were equipped with an elevated surface as well as feeding pans and nipples, both variable in height. Straw meal pellets were used as litter material. A crumbled starter diet was followed, after 278 g/bird had been spent, by a pelleted fattening diet (Table 3.1; for ingredient composition see Table S1, Supplementary Material). The birds had unrestricted access to feed and water. Body weight (BW) and average daily feed intake (ADFI) were determined at the end of each experimental week per compartment. For BW, balances with attached metal plates freely hanging short above the floor were installed per compartment. Plates were frequently entered by the birds. The averages of the BW obtained on the measurement day were calculated with a software excluding data obtained with more than one bird staying on the plate. Feed intake was measured by the difference between amounts of feed put into the feeders and those recovered from the feeders after 1 week. During the first 3 days, the chicken had light for 24 h. Afterwards, the photoperiod was limited to natural daylight (about 15 h/day at the time of the experiment). The initial temperature of 33°C was gradually reduced to 20 to 25°C until day 21, and remained unchanged thereafter. The health status of the flock was controlled daily and mortality was assessed.

Table 3.1 Composition of the experimental diets

	Starter diet	Fattening diet
Analyzed feed composition (g/kg of feed)		
DM	902	901
Organic matter	839	850
CP	195	210
Ether extract	70	80
Calculated feed composition (per kg of feed)		
Metabolizable energy (MJ)	12.4	12.8
Lysine (g)	10.7	10.9
Methionine (g)	4.2	4.2
Methionine & cysteine (g)	8.4	8.5
Tryptophan (g)	2.6	2.7
Threonine (g)	8.7	8.6
Ca (g)	9.5	8.0
P (g)	6.8	5.8

3.4.2 Fattening and slaughter

Two fattening periods of different length were tested for all types. These were either standard (here: 67 days, fulfilling the ≥ 9-week limit as stated in the Swiss guidelines for organic production; Bio Suisse, 2018) or prolonged to 84 days (further on called 'prolonged fattening'). One group of the male layer cockerels was even fattened for 126 days as done by Gerken et al. (2003). Shortly before slaughter, the final BW was recorded after 11 h of fasting. Slaughter was accomplished in a small-scale commercial abattoir (Kopp, Heimisbach, Switzerland). On day 67, birds from two of the five compartments per type were slaughtered, on day 84 birds from the remaining three compartments and on day 126 the remaining male layers. At slaughter, birds were eviscerated. Head, neck, feet and abdominal fat were removed. After slaughter, carcasses were stored at 4°C for 24 h when carcass weight was measured.

3.4.3 Carcass and meat quality analysis

For carcass quality, 24 birds per type and fattening period were used. Dressing percentage was calculated as the ratio of cold carcass weight to BW. However, as birds lost their foot ring during scalding, carcass weights could not be related to BW, and thus dressing percentage could only be estimated from the mean carcass and body weights. At 24 h post mortem, skin color was measured on top of the left breast at three places using a chromameter (CR-300, Minolta, Ramsey, NJ, USA) operating with the L* (lightness) a* (redness) b* (yellowness) system. Breast angle, describing the visual keel bone appearance on the carcass (illustrated in Mueller et al., 2018), was determined by a protractor in the middle of the keel bone. Carcasses were dissected by always the same person into breast meat (without skin and adherent fat), whole legs and wings. The different body parts were individually weighed. Maximal thickness of the left breast meat and the right leg as well as breast meat length were measured. Meat quality was determined in a random sample of 10 out of the 24 chickens per type and fattening period. For that, pH24 h (model testo 205, Rausser, Ebmatingen, Switzerland) and color (determined like skin color) were analyzed in the left breast meat. The left leg was further dissected into meat, bones and the remainder (skin, cartilage, fat tissue). Breast and leg meat (both left side) were separately homogenized with a mix chopper (La Moulinette, Moulinex, Alençon, France) and homogenates as well as the entire right breast were stored at –20°C. Thaw loss was determined by weighing the breast meat before freezing and after thawing overnight at 4°C. The thawed samples were cooked to a core temperature of 74°C in a water bath (model SW 22 Shaking Water Bath, Julabo, Seelbach, Germany). After cooling in cold tap water for 5 min, samples were weighed again to calculate cooking loss. Four to 11 strips (depending on breast meat size) of 10 × 10 mm were cut with a double knife in the direction of the fibers. On those, maximal shear force was determined with a Volodkevich device mounted on a texture analyzer (model ProLine table-top machine Z005) using the software testXpertII V3.61 (both Zwick Roell, Ulm, Germany). Homogenized meat and diets were analyzed for proximate contents. Dry matter (DM) was evaluated with an automatic thermo-gravimetric device (model TGA-701, Leco, St. Joseph, MI, USA). Crude protein was determined as 6.25 × N obtained by a C/N analyzer (model TruMac®CN, Leco, St.Joseph, MI, USA) following the guidelines of AOAC (1997; index no. 968.06). To obtain the intramuscular fat (IMF) content of meat, homogenized samples were hydrolyzed with a Hydrolysis Unit B-425 (Büchi Labortechnik AG, Flawil, Switzerland). For that, 5 g sample and Celite 545 each were put together with 100 ml of 4 M HCl into a digestion vessel. After 30 min of boiling, the samples were filtered with the help of hot distilled water through a quartz glass crucible with quartz sand (0.5 to 0.7mm) and Celite 545. The crucible was dried in a microwave oven. Subsequently, ether extract was determined using a Soxhlet extraction system (model Extraktionsapparatur B-811, Büchi, Flawil, Switzerland; AOAC index no. 963.15).

3.4.4 Statistical analysis

Data were subjected to ANOVA using the General Linear Model procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC, USA). Type, age and their interaction were considered as fixed effects. A second model, including only the data of the male layers, comprised only age. Results and discussion about this evaluation are given in the Supplementary Material. Growth performance data were available only for entire compartments (n = 5 compartments per type for 67 days and n = 3 for 84 days). Carcass characteristics and meat quality traits were based on n = 24 and n = 10 birds per type per fattening period, respectively. Comparisons among Least Square Means were performed by the Tukey-Kramer option considering $P < 0.05$ as significant.

3.5 Results

3.5.1 Growth performance

Irrespective of the length of the fattening period, the LB had the smallest ($P < 0.05$) final BW of all chicken types (Table 3.2). This type also had the smallest ($P < 0.05$) average daily gains (ADG) which were lower by 40 and 32 % than the average of all other types after 67 and 84 days, respectively. Feed intake was also smallest ($P < 0.05$) but the difference to the other types was smaller. Therefore, they utilized the feed less efficiently ($P < 0.05$) than the other types. The other three types had a similar final BW at either fattening period. The ND had smaller ($P < 0.05$) ADG compared to LD within 67 days but not within 84 days of fattening. The ADG were similar in HU and LD for both fattening periods. Feed intake during 67 days was about 68 g/day for HU, ND and LD, and increased to an average of 80 g/day during 84 days. The HU birds needed least ($P < 0.05$) feed per unit of gain. The mortality was 0.9% on average irrespective of the fattening period and did not differ between chicken types.

Table 3.2 Effect of chicken type and fattening period on performance (average of the compartments; n = 5 for 67 days and n = 3 for 84 days of fattening)

Type (T)	Hubbard S 757		Novogen Dual		Lohmann Dual		Lohmann Brown			P-values		
Fattening period (F; days)	67	84	67	84	67	84	67	84	SEM	T	F	T × F
Final BW (g)	1727^{b}	2105^{a}	1674^{b}	2175^{a}	1740^{b}	2184^{a}	1061^{d}	1470^{c}	18.8	<0.001	<0.001	0.01
Average daily gains (g/bird)	24.8^{ab}	24.6^{ab}	24.0^{b}	25.4^{a}	25.0^{a}	25.5^{a}	15.0^{d}	17.0^{c}	0.26	<0.001	<0.001	<0.001
Average daily feed intake (g/bird)	65^{d}	76^{b}	68^{cd}	79^{b}	71^{c}	84^{a}	56^{f}	60^{e}	0.9	<0.001	<0.001	<0.001
Feed efficiency (g feed/g weight gain)	2.62^{d}	2.68^{cd}	2.81^{bc}	2.99^{b}	2.83^{bc}	2.92^{bc}	3.66^{a}	3.55^{a}	0.052	<0.001	0.09	0.02
Mortality (%)	0.8	0.6	1.6	1.3	0.8	0.7	0.4	0.7	0.46	0.14	0.84	0.80

$^{a-f}$Values within a row with different superscripts differ significantly at $P < 0.05$

3.5.2 Carcass characteristics

Carcass weights were similar in HU, ND and LD within fattening period and were clearly lighter ($P < 0.05$) in LB (Table 3.3). Carcasses were about 40 % heavier ($P < 0.05$) with prolonged fattening. Calculated from the averages of BW and carcass weight, dressing percentage was 72% in HU, 66 and 67% in ND and LD, and 56% in LB. It increased with prolonged vs. standard fattening from 62 to 68% across all types. Regardless of the fattening period, breast angle was greatest ($P < 0.05$) in HU, followed by ND and LD, and was smallest for LB (123, 102/101 and 81°, respectively). Prolonged fattening increased ($P < 0.05$) the breast angle in all types by 7° on average. There was a similar gradient between types ($P < 0.05$) in thickness, length and weight of the breast meat. Despite the greater ($P < 0.05$) leg weight and thickness with prolonged fattening, LB had still smaller ($P < 0.05$) legs than the other types already after 67 days of fattening. Leg weight and thickness was greater ($P < 0.05$) after 84 days in all types but to a different extent (interaction $P < 0.01$). The LB had the lightest ($P < 0.05$) wings even after 84 days of fattening, whereas there were no differences between the other types. In all types, wings got heavier ($P < 0.05$) by prolonged fattening. Breast meat proportion (g/kg carcass) was greatest ($P < 0.05$) in HU (21%), followed by ND (18%), LD (17%) and LB (15%) ($P < 0.05$) and did not change with age. Leg proportion was smallest ($P < 0.05$) in HU, followed by LB, ND and then LD. Leg proportion increased ($P < 0.05$) in all types by 3% on average with prolonged fattening. The greatest ($P < 0.05$) wing proportion was found in LB after 67 days of fattening. It decreased ($P < 0.05$) at 84 days but it always made up the greatest ($P < 0.05$) proportion of all types. With prolonged fattening, the greater size of the leg and breast meat corresponded with the increase in carcass weight. The LB had the lightest ($P < 0.05$) skin (i.e., highest L^*) after 67 days of fattening, followed by a decrease ($P < 0.05$) in L^* with prolonged fattening to a level similar to HU and LD. The LD had the reddest ($P < 0.05$) skin compared to all other types (2.5 vs. 2.0). The HU and ND birds had a more ($P < 0.05$) yellow skin than LD, and LB had the least ($P < 0.05$) yellow skin. For HU, LD and ND, prolonged fattening resulted in a less ($P < 0.05$) red and yellow skin whereas for LB it resulted in a redder skin ($P < 0.05$).

3.5.3 Meat quality

The pH24 h of the breast meat was not affected by chicken type but increased ($P < 0.05$) with prolonged fattening (Table 3.4). Thaw loss was not affected by either type or fattening period. At 67 days, breast meat of HU showed the greatest ($P < 0.05$) cooking loss and LB the smallest, ND and LD were in between. Cooking loss increased (P < 0.05) with prolonged fattening, but the chicken type differences (P < 0.05) were restricted to those between LB (low) and HU (high). Overall, shear force was highest (P < 0.05) in LB (11.4 N), lowest in LD (9.8) and intermediate in HU and ND (10.4 and 10.2, respectively). Prolonged fattening increased (P < 0.05) shear force of HU breast meat but not that of the other types. The lightest (P < 0.05) breast meat was found in LB after 67 days of fattening which decreased to a value similar to that of all other types after 84 days (interaction, P < 0.001). After 67 days of fattening the LB birds had the least (P < 0.05) red meat which got redder after 84 days (interaction, P < 0.001). Breast meat of LB was more (P < 0.05) yellow than that of HU, ND and LD, which were similar. Prolonged fattening decreased (P < 0.05) the yellowness of the breast meat. None of the factors tested affected moisture content of the breast meat. For LB breast meat, prolonged fattening resulted in a greater (P < 0.05) protein content whereas it was smallest (P < 0.05) after 67 days of fattening. The protein content in ND breast meat was in between, and the breast meat of all other types had a similar protein content. The IMF content of the breast meat was lower (P < 0.05) in LD than in HU and LB with ND in between. There was a decrease (P < 0.05) in IMF content with prolonged fattening in LB but not in the other types (interaction, P < 0.001). Moisture content of the leg meat was greatest (P < 0.05) in LB and similar in all others. The greatest (P < 0.05) protein content in the leg meat was found in LD after 67 days of fattening. The protein content of LD and LB leg meat decreased with prolonged fattening, that of ND increased and that of HU was low and remained unchanged (interaction, P < 0.001). The IMF content of the leg meat was greatest with HU, followed by ND. The LD and LB had the smallest (P < 0.05) IMF content. Prolonged fattening increased IMF of leg meat in HU and remained similar in the other types (interaction, P < 0.001).

Table 3.3 Effect of chicken type and fattening period on carcass characteristics (n = 24 per type and fattening period)

Type (T)	Hubbard S 757		Novogen Dual		Lohmann Dual		Lohmann Brown			P-values		
Fattening period (F; days)	67	84	67	84	67	84	67	84	SEM	T	F	T × F
Carcass weight (g)	1169^{b}	1585^{a}	1054^{b}	1486^{a}	1094^{b}	1552^{a}	579^{d}	842^{c}	30.1	<0.001	<0.001	0.01
Breast angle (°)	120^{a}	125^{a}	98^{bc}	105^{b}	96^{c}	105^{b}	78^{d}	84^{d}	1.6	<0.001	<0.001	0.81
Breast muscle												
Maximal thickness (mm)	22.5^{bc}	26.3^{a}	19.7^{d}	23.2^{b}	20.4^{cd}	21.0^{bcd}	14.7^{e}	16.4^{e}	0.54	<0.001	<0.001	0.01
Length (mm)	167^{b}	188^{a}	154^{cd}	167^{b}	164^{bc}	181^{a}	132^{e}	150^{d}	2.7	<0.001	<0.001	0.60
Leg, maximal thickness (mm)	31.5^{b}	35.1^{a}	31.7^{b}	35.9^{a}	32.9^{b}	36.1^{a}	25.8^{d}	27.5^{c}	0.038	<0.001	<0.001	0.01
Body parts (g)												
Breast muscles	242^{b}	332^{a}	191^{c}	263^{b}	188^{c}	260^{b}	86^{e}	125^{d}	6.2	<0.001	<0.001	<0.001
Legs	383^{b}	526^{a}	372^{b}	536^{a}	391^{b}	575^{a}	200^{d}	300^{c}	11.9	<0.001	<0.001	0.004
Wings	153^{b}	195^{a}	136^{c}	185^{a}	138^{bc}	191^{a}	84^{e}	116^{d}	3.6	<0.001	<0.001	0.01
Body parts (g/kg carcass)												
Breast muscles	209^{a}	210^{a}	182^{b}	177^{bc}	170^{c}	167^{c}	148^{d}	148^{d}	2.5	<0.001	0.39	0.53
Legs	326^{d}	330^{d}	353^{bc}	361^{ab}	357^{b}	371^{a}	345^{c}	356^{b}	2.5	<0.001	<0.001	0.25
Wings	131^{c}	123^{e}	129^{cd}	125^{e}	126^{de}	123^{e}	146^{a}	138^{b}	0.9	<0.001	<0.001	0.002
Skin color (24 h post mortem)												
L* (lightness)	54.8^{cd}	56.0^{c}	53.2^{d}	58.9^{b}	52.7^{d}	56.0^{c}	61.6^{a}	55.6^{c}	0.50	<0.001	0.003	<0.001
a* (redness)	2.30^{bc}	1.44^{e}	2.77^{ab}	1.30^{e}	2.94^{a}	2.01^{cd}	1.64^{de}	2.50^{abc}	0.126	<0.001	<0.001	<0.001
b* (yellowness)	0.77^{bc}	-0.21^{c}	3.60^{a}	-3.46^{d}	1.73^{b}	-4.63^{d}	-0.58^{c}	-4.31^{d}	0.323	<0.001	<0.001	<0.001

$^{a-e}$Values within a row with different superscripts differ significantly at $P < 0.05$

Table 3.4 Effect of chicken type and fattening period on meat quality (n = 10 per type and fattening period)

Type (T)	Hubbard S 757		Novogen Dual		Lohmann Dual		Lohmann Brown			P-values		
Fattening period (F; days)	67	84	67	84	67	84	67	84	SEM	T	F	T × F
Breast meat												
pH (24 h post mortem)	5.28^{b}	5.80^{a}	5.51^{ab}	5.81^{a}	5.53^{ab}	5.81^{a}	5.65^{ab}	5.76^{a}	0.107	0.40	<0.001	0.32
Thaw loss (%)	4.00	4.12	5.18	4.07	2.97	8.04	6.54	4.66	1.337	0.61	0.56	0.05
Cooking loss (%)	10.7^{ab}	11.8^{a}	8.1^{cd}	11.1^{a}	8.6^{bcd}	9.9^{abc}	7.0^{d}	8.3^{bcd}	0.55	<0.001	<0.001	0.29
Maximal shear force (N)[1]	9.0^{b}	11.4^{a}	9.9^{ab}	10.4^{ab}	9.9^{ab}	9.7^{ab}	11.2^{a}	11.6^{a}	0.42	0.01	0.02	0.01
Color (24 h post mortem)												
L* (lightness)	52.0^{b}	50.6^{b}	52.4^{b}	51.1^{b}	49.7^{b}	49.1^{b}	58.5^{a}	49.0^{b}	0.80	<0.001	<0.001	<0.001
a* (redness)	1.69^{bc}	1.69^{bc}	2.12^{ab}	1.87^{abc}	2.60^{a}	2.58^{a}	1.11^{c}	2.63^{a}	0.196	<0.001	0.03	<0.001
b* (yellowness)	-0.22^{abc}	-1.31^{cde}	0.22^{ab}	-1.63^{de}	-0.34^{bc}	-2.01^{e}	1.06^{a}	-0.67^{bcd}	0.291	<0.001	<0.001	0.58
Proximate composition (g/kg)												
Moisture	720	716	718	723	719	719	722	718	1.7	0.47	0.51	0.03
Protein	250^{ab}	250^{ab}	249^{b}	248^{b}	250^{ab}	248^{b}	243^{c}	254^{a}	1.1	0.42	0.01	<0.001
Fat	4.1^{bc}	5.0^{ab}	4.3^{abc}	3.9^{c}	3.4^{c}	3.5^{c}	5.4^{a}	3.5^{c}	0.24	<0.001	0.05	<0.001
Leg meat												
Proximate composition (g/kg)												
Moisture	749^{ab}	743^{b}	745^{ab}	749^{ab}	743^{b}	745^{ab}	752^{ab}	753^{a}	2.1	<0.001	0.60	0.11
Protein	204^{d}	203^{d}	202^{d}	214^{bc}	221^{a}	211^{c}	219^{ab}	211^{c}	1.4	<0.001	<0.001	<0.001
Fat	17.9^{b}	24.0^{a}	18.4^{b}	16.8^{b}	15.8^{b}	14.1^{bc}	15.0^{bc}	11.1^{c}	1.00	<0.001	0.71	<0.001

$^{a-e}$Values within a row with different superscripts differ significantly at $P < 0.05$

[1]Determined with the Volodkevich device

3.6 Discussion

3.6.1 Competitiveness of dual-purpose types with slow-growing broilers depending on fattening period

When fattened for the standard period of 9 weeks, the two dual-purpose types (ND and LD) and the slow-growing broilers (HU) remained slightly below the threshold of 27.5 g in ADG as defined by the Swiss organic regulations (Bio Suisse, 2018). This indicates that all three types are highly suitable for this production system. In a previous study (Mueller et al., 2018), slow-growing broilers (Sasso 51) and LD exceeded 27.5 g ADG: This may have been owed to the optimal and space-restricted housing conditions and points towards a major effect of the growing environment. Organic regulations (Bio Suisse, 2018) prescribe access of poultry to a protected outdoor area and a pasture. Fanatico et al. (2008) described that final BW of slow-growing broilers reared indoors or with outdoor access did not differ. The birds of the present study had no access to pasture. However, the effect of this is considered small compared with changing from housing in separate groups of two (Mueller et al., 2018) to large groups competing for space and feed as is the case in the way of housing used in the present study and also in farm practice. Different from growth, the dual-purpose types were not fully competitive to HU in feed efficiency. The low mortality in the present experiment is likely the result of the slow growth and the resulting more favorable health status (Keppler et al., 2011). After 67 days of fattening, BW and carcass weights were in the range suitable for selling entire carcasses (1530 g; Hoffmann et al., 2013). Prolonged vs. standard fattening did not cause new differences between dual-purpose types and HU, but the extra time of fattening elevated BW and carcass weight to levels of birds commonly used for dissection and selling the valuable cuts separately (Hoffmann et al., 2013). Therefore, varying slaughter age would allow to respond to demands by retailers if these standards are given also for organic chickens.

Carcass appearance, breast meat size and its proportion of the carcass are further important marketing criteria, especially in Europe, as breast meat is the most valuable cut (Leenstra et al., 2010). Both dual-purpose types were not competitive to HU in this aspect. Also when sold as entire carcasses, a smaller breast proportion is disadvantageous as it results in an even more visible keel bone and thus less attractive carcasses (Mueller et al., 2018). Compared to conventional broilers, slow-growing broilers as such are already characterized by smaller carcass and breast meat weights in combination with higher leg yields (Zhao et al., 2009; Mikulski et al., 2011; Mueller et al., 2018) and thus are not competitive outside of programs like organic farming. Fattening for 84 days clearly increased breast meat and leg weights in HU and dual-purpose types in the present study indicating that this might be a good strategy to improve the yield and acceptance of the valuable cuts. These findings are consistent with Murawska and Bochno (2007) who found increasing leg yields with increasing age. Skin color is another important trait for purchase decision and is affected by various factors including genetics (Lichovníková et al., 2009; Batkowska et al., 2014). European consumers prefer a pale, slightly reddish chicken skin (Kennedy et al., 2005), which was given for the birds of the present study. Prolonged fattening led to paler and less reddish skins in dual-purpose types and HU. A yellow skin is considered unnatural (Kennedy et al., 2005), but this was not a problem in the chicken types investigated. Different from the large variability, which had been found under commercial conditions (Sirri et al., 2010), skin color was actually quite homogenous among birds in the present study, and no visible differences between dual-purpose types and slow-growing broilers existed.

Dual-purpose types were similar to HU in physicochemical meat quality criteria. The pH of the breast muscle measured 24 h post mortem was quite low according to the classification of Carvalho et al. (2017). Especially the meat of HU fattened for 67 days seems to have expressed a pale, soft and exudative (PSE) condition where water-holding capacity could be impaired. However, thaw and cooking losses in HU and the dual-purpose types remained far below the acceptable losses of 10 and 26%, respectively (Galobart and Moran, 2004). A possible reason for the differences in cooking loss between types and ages could be the different breast meat dimensions. Larger breast meat needs a longer cooking time and, consequently, more moisture is loosed during cooking (Fanatico et al., 2007). Color measurements are also often taken into account as descriptors of PSE meat (Barbut et al., 2008; Kralik et al., 2014) because paleness can be attributed to the denaturation of sarcoplasmic proteins, which increase light scattering in the muscle (Barbut et al., 2008). Most of the L* values obtained in the present study ranged between 48 and 53, which is considered as normal (Qiao et al., 2001). Together with the traits discussed before, there is no indication that meat with PSE condition occurred. Shear force, which is used to describe meat tenderness, was on average similar between the dual-purpose types and HU but increased for the latter with prolonged fattening. Therefore, the adequate time for slaughter to obtain larger body parts at concomitantly satisfactory meat tenderness could be chicken type specific. Dual-purpose types seem to have the advantage of a more flexible time point of slaughter in this respect. There are contradictory findings about age effects on meat tenderness. Accordingly, Janisch et al., (2011) and Poltowitz and Doktor (2012) found higher shear force values for older compared to younger birds, whereas Poole et al. (1999) did not find age-related differences. In addition, it remains to be identified if the differences in shear force in the HU were great enough at all to be recognized by the consumers (Sonaiya et al., 1990). Swiss raw breast meat without skin is expected to contain, per 100 g, 24.6 g protein, 72.7 g water and 1.0 g total fat (Swiss Food Composition Database, 2018). The values obtained in the present study were similar, with the exception of the smaller IMF content. Due to more activity, it is expected to find a smaller IMF content in meat from free-range or organic production systems (Fanatico et al., 2007). In addition, the slower growing chicken types recommended for organic production are likely to accrete less fat in the body. Consistent with the present findings, Mikulski et al. (2011) and Castellini et al. (2002) also found less than 10 g IMF/kg breast meat in slow-growing broilers kept with outdoor access or under organic production conditions, respectively.

3.6.2 Differences between the two dual-purpose types slaughtered at 67 or 84 days

There are very few studies comparing dual-purpose types among each so far. In the study of Schmidt et al. (2016), ND had a lower growth performance than LD and both could not compete with extensive broilers in this respect. This was not the case in the present study where these three types were similar. The growth performance of LD was lower than reported by Schmidt et al. (2016), and they performed similarly to LDex investigated by Kaufmann et al. (2016). A reason for a decreasing growth performance of the LD type could be a selection by the producer towards egg production in the time between our study and the one of Schmidt et al. (2016). In the present study, both dual-purpose types were extraordinarily similar in almost all carcass and meat quality criteria. Mueller et al. (2018) compared LD with two traditional dual-purpose types, Belgian Malines and Schweizerhuhn, where LD outcompeted the two others by far in performance and carcass quality.

3.6.3 Competitiveness of the male layer type in growth, carcass and meat quality

Compared to the three other types investigated in the present study, the performance of the LB was as poor as described in former studies (Gerken et al., 2003; Lichovníková et al., 2009; Murawska and Bochno, 2007; Mueller et al., 2018). This was associated with an inferior feed efficiency, which is of concern when the diet is mainly composed of food-grade components. Additionally, in the first weeks of the experiment, the LB were observed to exhibit a particular feed waste behavior. Therefore, values for ADFI and feed-to-gain ratios might have been overestimated for LB in the standard fattening period. This indicates that the standard feeders used in farm practice might have to be adapted when LB are fattened. Koenig et al. (2012) investigated the economic feasibility of fattening male layer cockerels and found that it is reasonable to end fattening after 49 days. The dilemma of a shorter fattening period is then that the products cannot be sold under the organic label and another sales channel has to be found. The LB birds had the most prominent keel bone of all types (see also Mueller et al., 2018), which is consistent with the smallest breast meat of these birds. The LB meat had a lower cooking loss, a slightly higher shear force, and it was lighter and less red after 67 days of fattening than the HU meat. Consistent with Lichovníková et al. (2009), the IMF content of LB breast meat was < 10 g/kg. Effects of prolonging the fattening period from the standard period to 84 days or even to 126 days on carcass and meat quality of the LB are discussed in the Supplementary Material.

3.7 Conclusions

Both dual-purpose types performed at a same level as the slow-growing broiler type. A certain drawback was, however, the smaller breast meat proportion and, along with that, the more prominent keel bone of LD and ND compared to these broilers. Although these differences seemed to decline when the animals were fattened longer for about 3 weeks, this does not seem necessary to improve competitiveness, because there is a segment of consumers willing to buy such meat and to pay a premium price for it (Gangnat et al., 2018). In a system approach including egg production, dual-purpose systems could be more sustainable anyway than using separate broiler and layer types in organic farming. Differences between the two dual-purpose types were very small and, therefore, they should be considered equivalent. The layer males were clearly inferior in growth performance and carcass quality to all other types, whereas meat quality was similar. Carcass quality can be improved by doubling the 9-week fattening period (cf. Supplementary Material), but the economic inefficiency may be limiting. In order to minimize requiring food as feed, the suitability of dual-purpose and layer types for fattening on diets mostly composed of food-industry waste has to be tested.

3.8 Supplementary material

3.8.1 Materials and Methods

Table 3.S1 gives the complete ingredient composition of the experimental diets fed to all four chicken types. All ingredients were of organic origin.

Table 3.S1 Ingredient composition of the experimental diets (g/kg feed)

	Starter diet	Fattening diet
Corn	346.9	244.7
Wheat	133.0	120.0
Corn flour		100.0
Wheat bran	20.0	
Corn gluten meal	43.0	46.0
Rapeseed cake	20.0	
Soybean cake	312.0	348.0
Sunflower cake	69.0	88.0
Soybean oil	14.0	20.0
Calcium carbonate	15.4	11.8
Monocalcium phosphate	8.5	3.7
Sodium bicarbonate	3.4	2.9
Sodium chloride	1.8	1.9
Vitamin-mineral premix[1]	5.0	5.0
Formic acid and propionic acid mixture[2]	5.0	5.0
Fermented wheat bran[3]	3.0	3.0

[1]Provided per kg of diet: vitamin A, 10000 IU; vitamin D_3, 2000 IU; vitamin E, 40 IU; vitamin K, 3.5 mg; vitamin B_1, 1.8 mg; vitamin B_2, 4 mg; vitamin B_6, 3.5 mg; vitamin B_{12}, 18 µg; biotin, 0.2 mg; folic acid, 0.95 mg; nicotinic acid, 37.5 mg; pantothenic acid, 10 mg; Zn, 60 mg; Fe, 42 mg; Mn, 58 mg; Cu, 6 mg; I, 0.8 mg; Se, 0.2 mg
[2]Lupro-Cid®, BASF SE, Ludwigshafen, Germany
[3]Synergen®, Alltech, Nicholasville, Kentucky, US

3.9 Results and Discussion

3.9.1 Effects of extending the fattening period of the layer type to 126 days

The further prolongation of fattening of the Lohmann Brown (LB) layer males to a total of 126 days increased final BW to 2-fold values and carcass weight to 2.4-fold values ($P < 0.05$) compared to 67 days of fattening (Table 3.S2). With that, they finally exceeded the targets for the BW of specialized broilers (1530 g) and carcasses may be used for dissection (Hoffmann et al., 2013). Gerken et al. (2003) fattened two layer strains (LB and White Leghorns) also for 18 weeks and compared them with conventional broilers (Lohmann Meat hybrids). At this age, the LB birds were able to reach about 2 kg BW whereas the White Leghorns, an especially light and common layer hybrid, did not reach it yet. In the present study, the calculated dressing percentage (54.6, 57.3 and 63.4% at 67, 84 and 126 days, respectively) indicated a gradual improvement in this important trait. Although breast meat proportion and breast meat thickness increased ($P < 0.05$), carcass conformation was still unfavorable, as breast angle declined again ($P < 0.05$) compared to the level reached with 84 days. No or a low visibility of the keel bone has been shown to be an important reason for consumers preferring carcasses (Damme and

Ristic, 2003), and this was not given at any of the fattening periods tested in the LB. Apart from breast proportion, also leg proportion further increased (P < 0.05) with prolonged fattening. The proportion of valuable cuts (breast meat and legs) relative to the whole carcass was greatest (P < 0.05) after 126 days of fattening. This was probably due to the smaller (P < 0.05) wing proportion and the decrease in bone content with particularly long fattening in breast and leg parts (Murawska et al., 2005). With fattening to 126 days, the skin got darker (P < 0.05) and redder (P < 0.05) than at 67 days of fattening and was similarly yellow.

Table 3.S2 Effect of fattening period[1] on carcass characteristics of Lohmann Brown layer males

Fattening period (days)	67	84	126	SEM	P-value
Final BW[2] (g)	1061^{c}	1470^{b}	2146^{a}	22.8	<0.001
Carcass weight (g)	579^{c}	842^{b}	1370^{a}	14.6	<0.001
Breast angle (°)	78^{b}	84^{a}	80^{b}	1.0	0.003
Breast meat					
Maximal thickness (mm)	14.7^{c}	16.4^{b}	20.7^{a}	0.43	<0.001
Length (mm)	132^{c}	150^{b}	171^{a}	3.1	<0.001
Leg, maximal thickness (mm)	25.8^{c}	27.5^{b}	33.9^{a}	0.30	<0.001
Body parts (g)					
Breast meat	86^{c}	125^{b}	218^{a}	3.3	<0.001
Legs	200^{c}	300^{b}	513^{a}	6.1	<0.001
Wings	84^{c}	116^{b}	172^{a}	1.8	<0.001
Body parts (g/kg carcass)					
Breast meat	148^{b}	148^{b}	159^{a}	1.8	<0.001
Legs	345^{c}	356^{b}	374^{a}	1.9	<0.001
Wings	146^{a}	138^{b}	126^{c}	0.8	<0.001
Skin color (24 h post mortem)					
L* (lightness)	61.6^{a}	55.6^{b}	48.4^{c}	1.17	<0.001
a* (redness)	1.64^{c}	2.50^{b}	3.78^{a}	0.134	<0.001
b* (yellowness)	-0.58^{a}	-4.31^{b}	-0.85^{a}	0.282	<0.001

$^{a-c}$Values within a row with different superscripts differ significantly at $P < 0.05$
[1]The values described for periods with 67 and 84 days are taken from the main manuscript
[2]4 × 5/3 compartments for 67/84 days of fattening; 4 × 24 randomly selected birds for 126 days

The ultimate pH of the meat increased and thaw loss decreased with prolongation of fattening (P < 0.05) whereas cooking loss remained unchanged (Table 3.S3). In addition, shear force was lowest (P < 0.05) with the LB birds fattened for 126 days (-20% from 84 to 126 days). This was contradictory to the expectations as a greater shear force is often set into the context of older birds (Poltowicz and Doktor, 2012) based on the observation that with animal age meat typically tends to become less tender due to the forming of cross-links between the collagen molecules in the connective tissue (Chueachuaychoo et al., 2011). These cross-links increase the resistance to be sheared (and to be tender) even in the cooked meat due to the cooking resistance of the crosslinks (Owens and Meullenet, 2010). Therefore, with an age of 18 weeks birds still appear to be young enough for their muscles having not developed a detrimental crosslink formation. Like the skin, the meat was darker and redder, but it also was less yellow with prolonged fattening. The age on its own is one important factor that affects meat color. It needs to be determined if the comparably small extents of changes in color really would cause acceptance problems, though. Meat composition changes with age, but to a limited degree and in a non-systematic way with respect to an increasing age of the LB birds at slaughter.

Table 3.S3 Effect of fattening period[1] on meat quality[2] of Lohmann Brown layer males

Fattening period (days)	67	84	126	SEM	P-value
Breast meat					
pH (24 h post mortem)	5.65^{c}	5.76^{b}	5.99^{a}	0.027	<0.001
Thaw loss (%)	6.54^{a}	4.66^{b}	4.42^{c}	0.489	0.003
Cooking loss (%)	7.0	8.3	7.0	0.54	0.117
Maximal shear force (N)[3]	11.2^{ab}	11.6^{a}	9.3^{b}	0.79	0.020
Color (24 h post mortem)					
L* (lightness)	58.5^{a}	49.0^{b}	47.0^{b}	0.78	<0.001
a* (redness)	1.11^{b}	2.63^{a}	3.33^{a}	0.239	<0.001
b* (yellowness)	1.06^{a}	-0.67^{b}	-2.21^{c}	0.361	<0.001
Proximate composition (g/kg)					
Moisture	722^{a}	718^{a}	708^{b}	2.2	<0.001
Protein	243^{b}	254^{a}	255^{a}	1.5	<0.001
Fat	5.4^{a}	3.5^{b}	3.9^{b}	0.30	<0.001
Leg meat					
Proximate composition (g/kg)					
Moisture	752^{a}	753^{a}	741^{b}	2.7	<0.001
Protein	219^{a}	211^{b}	219^{a}	2.2	0.015
Fat	15.0^{a}	11.1^{b}	14.9^{a}	0.72	<0.001

$^{a-c}$Values within a row with different superscripts differ significantly at $P < 0.05$
[1]The values described for periods with 67 and 84 days are taken from the main manuscript
[2]n = 10 per type and fattening period
[3]Determined with the Volodkevich device

In conclusion, difficulties are to be expected when slaughtering 18 weeks old male layer types in a commercial abattoir and in marketing the carcasses of LB males. Additionally, the economic feasibility of LB is problematic. Carcass and meat quality of the layer males fattened for 18 weeks are improved, but a period this long is unlikely to be adapted by farmers. This should be clarified in an economic feasibility study opposing growth to feed and energy costs. In addition, fattening up to this age can already be critical and further extension is not realistic because cockerels then will reach puberty, spend time and energy for fighting and might get injured (Habig et al., 2016). However, in the present study we could not observe any severe injuries or death as a consequence of cockfights.

Chapter 4

Do dual-purpose and male layer chickens have a greater resilience against a low-protein-low-soybean diet than slow-growing broilers?

This chapter is based on Mueller S., Mazzolini L., Siegrist M., Messikommer R.E., Kreuzer M., and Gangnat I.D.M. British Poultry Science (in preparation for submission).

4.1 Abstract

1. The common practice of culling day-old male layer chicks raises ethical discussions. Fattening either dual-purpose types or male layer hybrid chickens has been proposed as alternatives especially for organic farming. This practice would, however, only be sustainable, if feed components competing with human food production can be at least partially replaced by other diet ingredients.

2. Lohmann Dual (LD), a novel dual-purpose type, Lohmann Brown (LB), a male layer hybrid, and Hubbard JA 957 (HU), a slow-growing broiler were fattened for 9 weeks on two diets (control and 20% reduced crude protein) (n=6×12 birds). Growth, carcass and meat quality were analysed in detail. Data were evaluated considering chicken type, diet and their interaction as fixed effects.

3. Growth performance of HU exceeded that of LD and especially of LB. The growth depression caused by the low-protein diet in LD (numerically -7% final body weight) was only half of that found in HU (-14%; significant). The LD fed the control diet had the same feed efficiency as the HU fed the low-protein diet. Even the LB suffered from the low-protein diet and had an inferior feed efficiency. There was a gradient in carcass quality (weight, dressing percentage, breast meat yield, breast proportion and breast angle) from HU to LD to LB, with some additional adverse effects of the low-protein diet especially in HU. Physicochemical meat quality was superior in LD and LB compared to HU. There were some chicken type differences in fatty acid profile of the intramuscular fat.

4. In conclusion, the dual-purpose type used was complying with regulations for Swiss organic poultry systems in growth and turned out to be less susceptible to a low-protein diet than the slow-growing broiler. The LB males were inferior in all traits besides meat quality. Future studies should determine the exact protein and amino acid requirements of dual-purpose and layer hybrid chickens and the economic feasibility of the systems for organic farming.

4.2 Introduction

The poultry sector has remarkably changed during the last decades in order to be as efficient as possible with regard to meat and egg production (Bruijnis et al., 2015). As only females produce eggs, male chicks from layer hybrids are currently mostly culled due to the very slow growth and low meat yield (Leenstra et al., 2011) and less appealing carcasses (Mueller et al., 2018). From an ethical point of view, this practice is questionable and currently leads to controversial discussions. Several alternatives to chick culling have been proposed during the last years, but many of these generated new dilemmas (Bruijnis et al., 2015). There is an intensive search for suitable methods of sex determination in eggs (Krautwald-Junghanns et al., 2018) but none of the methods is yet practicable for a large-scale use. From technical and socio-ethical perspective, two other alternatives seem to have potential for solving this issue. The first option is to fatten male layer hybrids to produce meat (Koenig et al., 2012). A more appealing solution builds on the use of dual-purpose chicken types, recently developed by breeding companies, where hens produce a sufficient amount of eggs and the males are clearly superior in growth to male layer hybrids (Damme et al., 2015b). Inevitably, this compromise results in a reduction of performance on both sides compared to specialized hybrids (Mueller et al., 2018). Especially in middle Europe, where dual-purpose poultry is used for egg or meat production, this happens in organic farming where a smaller level of performance is aimed at.

The most serious remaining constraint in replacing broilers by dual-purpose or layer types is that, due to the inferior efficiency, the demand for resources, including feeds being in competition with human food production, is greater per unit of meat and egg (Damme et al., 2015b). However, it can be anticipated that dual-purpose types and especially male layer hybrids could perform similarly on diets of lesser quality as their requirements for nutrient amount and density in the diet should be smaller. This would for instance offer the opportunity to reduce dietary protein content and, with that, specifically the use of soybean-based ingredients, the cultivation of which is controversially debated (Semino et al., 2009). The soy dependence is even more pronounced in organic farming, since the ban of synthetic amino acids (Regulation (EU), 2018; Bio Suisse, 2018) does not allow a reduction of soy currently accounting for about 1/3 in organic diets (Baur, 2011). However, in case protein (amino acid) requirements would not be covered, along with a depressed growth, a smaller muscularity and a smaller proportion of valuable cuts would results. First such studies showed that protein reduction causes only a weak growth impairment of a dual-purpose type (LD) (Urban et al. 2018) and of male layer hybrids (Ammer et al., 2017), but comparisons between these types and, in case of the LD, with slow-growing broilers were not made. Apart from carcass quality, this measure could also affect physicochemical meat quality traits. Finally, the exchange of feeds would often result in changes of ingredients with different dietary fatty acid profile and thus affecting the final product.

Based on these considerations and in order to obtain more information about the requirements of dual-purpose and layer types, three hypotheses were tested. (1) Dual-purpose types are less impaired in growth and carcass quality to slow-growing broilers fed a low-protein

(LP) diet. (2) Different from such broilers, layer hybrids tolerate a LP diet without growth depression. (3) Both, LP diet and chicken type affect meat quality, and the two factors interact in this respect.

4.3 Material and methods

4.3.1 Experimental design, animals and diets

The experiment, based on a 3 × 2-factorial design (chicken type × diet), was approved by the cantonal veterinary office of Zurich, Switzerland (licence no. 267/14). The LD (n = 21) and the LB (n=24) were purchased from the hatchery Animalco AG (Staufen, Switzerland), the HU (n = 24) from Wüthrich Brüterei AG (Belp, Switzerland). All LD and LB birds were males, because the hens were selected for egg production. Following common practice for broiler fattening, the HU remained unsexed, with 11 males and 13 females being studied. Chicks per type were randomly allocated to either a control (C) diet, covering requirements of broilers (GfE, 1999) or a LP diet (Table 4.1). The LP contained 20% less crude protein (CP) than C and less soybean-based ingredients. Rapeseed cake and sunflower cake partially replaced soybean cake. Further, cereals replaced the maize gluten and some soybean cake. These substitutions were made at unchanged calculated proportions of methionine and lysine (45 and 17 g/kg CP, respectively). The content of metabolisable energy (ME) was also kept similar in both diets. The indigestible indicator celite was mixed into the diets to be able to determine metabolisability out of the excreta samples. Ingredients were ground, mixed and pelleted with a diameter of 3 mm (Kahl 40PS, Amandus Kahl GmbH & Co, Reinbek, Germany) with the use of steam (about 60°C; Installation Bühler AG, Uzwil, Switzerland).

For the first 14 days of life, the birds were reared by type in 1.7 m^2 sized open wood boxes on wood shavings. During that time, a commercial starter diet (UFA 636, UFA, Herzogenbuchsee, Switzerland) was fed to all birds. Afterwards, the two experimental diets were fed at ad libitum access for another 7 weeks until the birds were slaughtered at 9 weeks of age. This was equivalent to the minimum fattening period prescribed by the Swiss organic regulations (Bio Suisse, 2018). During the 7 weeks of fattening, the chicks were kept in pairs in pens (80 × 77 × 79.5 cm) on mesh floor. The pens were equipped with troughs and nipples variable in height, perches for sitting and containers for excreta collection. Room temperature was continuously reduced from 30°C in the first week of life, where additionally heating lamps were installed, to 20°C from week 5 onwards. Light was provided for 16 h/day. Before slaughter, the animals were fasted overnight. At slaughter, the chickens were stunned with a blow on the head, exsanguinated, eviscerated and plucked. The experiment was carried out in two subsequent runs, each with six chickens per each of the six treatments.

4.3.2 Data and sample collection as well as laboratory analyses

Diet and excreta samples were collected in weeks 4 and 9 of the experiment. Excreta was collected per pen within 5 days each, frozen at -20°C and lyophilised (model Beta 1-16, Christ, Oserode am Harz, Germany). The dried excreta and diet samples were milled through a 0.50 mm screen with a centrifugal mill (model ZM1, Retsch GmbH, Haan, Germany). Individual body weight (BW) and feed consumption per pen were measured weekly. Following slaughter and immediately after plucking, skin colour was analysed on top of the left breast at three places. For that, a chromameter CR-300 (Minolta, Ramsey, NJ, USA) was used and the L* a* b* colour space was applied. Subsequently, the weight of different inner organs was determined.

After 1 day of storage at 4°C, the weights of the carcass and of the excised abdominal fat were recorded. Carcass weight was defined as the eviscerated body without feathers, feet, head, neck and abdominal fat. Dressing percentage was calculated as the ratio of carcass weight to final BW. To quantify the prominence of the keel bone, the breast angle was recorded with a protractor in the middle of the sternum. Both breast muscles were dissected and trimmed of skin, superficial tendons and adherent fat, and then weighed. Breast meat yield (BMY) was calculated as the ratio of breast weight to carcass weight. Breast meat colour was determined directly afterwards applying the same equipment as used for skin colour. The pH was measured with a pH-Meter (testo 205, Rausser, Ebmatingen, Switzerland) and drip loss was assessed by positioning the whole left breast meat freely hanging in a net placed into a sealed plastic bag at 4°C for 24 h. Afterwards, the meat was homogenised with a mix chopper (model La Moulinette, Moulinex, Aleçon, France), vacuum packaged and stored at -20°C like the entire right breast meat. The entire legs and wings were dissected from the carcasses and weighed. The left leg was dissected into meat, bones and the remainder. The tibia was frozen. The sum of breast and leg meat was defined as valuable cuts.

All further meat quality traits and the fatty acid composition of the breast meat were determined in 10 randomly selected birds per treatment. Thaw and cooking loss were assessed by weighing the right breast meat after being thawed overnight at 4°C and after cooking followed by chilling under cold running water for 5 min. Cooking was accomplished in a water bath until a meat core temperature of 74°C was reached. Shear force was assessed on the cooked breast meat perpendicular to the muscle fibre direction with a Volodkevich device mounted on a texture analyser (model ProLine table-top machine Z005, Zwick GmbH & Co. KG, Ulm, Germany) with the testing software testXpertII V3.61 (Zwick Roell, Ulm, Germany). Per bird, at least five 1 × 1 cm cube-shaped stripes of cooked meat were sheared. The stripes had been prepared with a double knife and cut along the fibres' orientation.

Standard methods were applied for proximate analysis of the samples of diets, excreta and homogenised breast meat. An automatic thermo-gravimetric device (model TGA-701, Leco, St. Joseph, MI) was used to assess moisture/dry matter content. Nitrogen (CP = 6.25 × N) was analysed using a C/N analyser (model TruMac® CN, Leco, St. Joseph, MI; AOAC index #968.06). In diets and excreta, neutral and acid detergent fibre contents, corrected for ash, were determined on a Fibertec System M (Tecator, 1020 Hot Extraction, Foss Hillerød, Denmark) according to Mertens et al. (2002) and AOAC (index #973.18), respectively. In case of neutral detergent fibre, 100 µL of α-amylase (Sigma-Aldrich, St. Luis, USA) was added. The method of Vogtmann et al. (1975) was applied to determine 4 M-HCl insoluble ash. Combustion energy was determined on a bomb calorimeter (Calorimeter System C700 with Cooler C7002, IKA, Staufen, Germany). In breast meat, ether extract was determined using a Soxhlet extraction system (model Extraktionsapparatur B-811, Büchi, Flawil, Switzerland; AOAC (2006) index #963.15). For that, the homogenized samples were hydrolysed with a Hydrolysis Unit B-425 (Büchi Labortechnik AG, Flawil, Switzerland) putting 5 g of each sample and Celite 545 into a digestion vessel. After adding 100 ml of 4 M HCl, samples were boiled for 30 min and filtered with hot distilled water through a quartz glass crucible with quartz sand (0.5 to 0.7mm) and Celite 545. The crucible was dried in a microwave oven for 12 min at 600 W then for 12 min at 450 W.

Fatty acid profiles of diet and breast meat lipids were determined according to IUPAC (1991) method 2.301. For that, lipids were extracted with hexan:isopropanol in a ratio 3:2 (vol/vol) for the diets using an Accelerated Solvent Extractor (model ASE 200, Dionex Corp., Sunnyvale, CA, USA). Triundecanoin (C11:0, Fulka) and butylated hydroxytoluene (BHT) were added as internal standards. For the meat, the internal standard was added, then mixed for 2 min at 15,000 rpm with a rotor-stator homogenizer (Polytron, PT 6000, Kinematica AG, Lucerne, Switzerland) and centrifuged at 3200 g for 6 min for a faster phase separation. The upper phase from the diets and the solvent from the meat samples were then removed under N_2 stream at 50°C until dryness was achieved with the help of an evaporator (model Turbo Vap LV, Zymark Center, Hopkinton, Massachusetts, USA). The fatty acids were converted into fatty acid methyl esters (FAME) (IUPAC, 1991) by using a boron trifluoride-methanol solution and hexane (Fluka Chemie, Buchs, Switzerland). In the extracts from the diets, the organic phase containing the FAME was purified on a silica gel (Wettstein et al., 2001). The FAME was injected into a gas chromatograph (model HP 6890, Hewlett-Packard, Wilmington, PA, USA) equipped with a Supelcowax-10 column (30 m × 0.32 mm × 0.25 µm, Supelco Inc., Bellefonte, PA, USA). The injection volume was set to 1 µl (split ratio of 1:20 for diets, 1:30 for meat). Hydrogen served as carrier gas at a flow rate of 2.1 (diets) and 2.2 (meat) ml/min, respectively. Oven temperature was programmed as follows: initial temperature 160°C for 0.5 min; increase by 20°C/min to 190°C, increase by 7°C/min to 230°C, isotherm at 230°C for 5.3 min; increase by 20°C/min to 250°C and isotherm at 250°C for 6 min. Detector temperature was 270°C. Chromatograms were evaluated on a HP ChemStation software (Agilent, Palo Alto, CA, USA), where the individual FAME peaks were identified by comparison with the retention times of a standard FAME mixture (37 component FAME Mix, Supelco Inc). The response factors were calculated using sunflower oil (diet) and pork fat (meat).

Tibias were weighed, and length and diameter were determined in the middle of the bone. Maximal breaking strength was assessed on the same texture analyser as used for shear force measurements. On that apparatus, a three-point device consisting of two V-shaped metal holders positioning the bone over a free hanging distance of 20 mm and a central vertically moving indenter were mounted. Bones were ashed at 550 °C for 48 h in a muffle furnace and ground in a mortar. Thereof 200 mg were incubated in 50 ml of 80 ml/l (v/v) HCl for 24 h. In the solution Ca, P and Mg were assessed with a COBAS MIRA® Autoanalyser (F. Hoffmann-La Roche Ltd., Basle, Switzerland).

4.3.3 Calculations and statistical analysis

For statistical analysis of skin and meat colour, as well as shear force of the meat, averages obtained per bird were used. The metabolisability of gross energy and of nitrogen was calculated from intake and excretion of the indigestibly 4-M HCl insoluble ash (Vukić Vranješ et al., 1994). Data were subjected to analysis of variance using the Mixed procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC, USA) considering chicken type, diet and their interaction as fixed effects. The experimental run was considered as random factor. In addition, either bird or pen served as the experimental units. For multiple comparisons of the Least Square Means, the Tukey-Kramer option was used with $P < 0.05$ considered statistically significant.

4.4 Results

4.4.1 Experimental diets

According to the analyses, the realised difference in CP between the two diets was 44 g/kg (-20%), whereas the analysed contents of organic matter and fibre were quite similar (Table 4.1). The partial replacement of the soybean-based components by other ingredients in diet LP compared to diet C resulted in some changes in ether extract and fatty acid composition of the dietary lipids. The partial exchange of soybean cake with maize and rapeseed cake and oil shifted fatty acids especially towards less C18:2 n-6 and more C18:1 n-9, a consequence of the inclusion of rapeseed cake and oil in diet LP, components not used in diet C.

4.4.2 Growth performance

During the experiment, no health problems occurred and no chicken died. There were clear differences ($P < 0.05$) in feed intake between chicken types, whereas no diet effect and no interaction were found (Table 4.2). Feed intake (g/day and bird) declined ($P < 0.05$) from HU (95.6) to LD (71.6) and LB (46.5). In the same order, final BW and ADG were greatest ($P < 0.05$) in HU, followed by LD and LB. In both traits, there was a diet effect ($P < 0.001$) with 13% smaller values for birds fed diet LP compared with diet C. Feeding LP caused numerical declines in final BW and ADG in every chicken type, but in multiple comparisons, this decline was only significant for HU. On average, feeding LP reduced ADG by 14, 8 and 23% in HU, LD and LB, respectively. Differences in chicken type appeared already at 7 days of age and diet differences seemed to occur from 21 days of age onwards, i.e. 1 week after starting the use of the experimental diets (Figure 4.1). These differences got larger until slaughter except for the diet effect in LD in the last weeks. Feed efficiency was most favourable in HU, followed by LD and LB ($P < 0.05$). It was less favourable ($P < 0.01$) with diet LP than C (0.40 vs. 0.45 g gain/g feed). Feeding LP to HU reduced feed efficiency to the level of the LD fed C, and the same was true for LP-fed LD compared to C-fed LB. Chicken types differed ($P < 0.05$) in metabolisability of energy (week 4 only) and N. The latter was greater ($P < 0.001$) in chickens fed LP compared to those fed C, but diet did not affect energy metabolisability. Diet LP resulted in a smaller ($P < 0.01$) excreta dry matter content (287 vs. 321 g/kg in C).

Table 4.1 Composition of the control and the protein-reduced diet

Diet	Control (C)	Reduced protein (LP)
Ingredients (g/kg as fed)		
Soybean cake	295	150
Maize gluten	45	–
Sunflower cake	65	80
Rapeseed cake	–	100
Soybean oil	20	–
Rapeseed oil	–	20
Maize	340	454
Wheat	194.7	157.8
Calcium carbonate	11.0	11.5
Dicalcium phosphate	6.5	3.9
Sodium bicarbonate	3.2	3.0
Vitamin-mineral premix[1]	3.0	3.0
NaCl	1.6	1.8
Celite[2]	15.0	15.0
Analysed (g/kg as fed)		
Organic matter	938	941
Crude protein	215	171
Neutral detergent fibre	152	154
Acid detergent fibre	71	81
Ether extract	93	85
Calculated (per kg as fed)		
Lysine (g)	9.7	7.9
Methionine (+ cysteine) (g)	3.6 (7.9)	3.0 (6.7)
Threonine (g)	8.3	6.6
Tryptophan (g)	2.5	2.0
Metabolisable energy (MJ)	12.7	12.6
Fatty acid composition (g/kg of total dietary fatty acids)[3]		
C14:0	1.3	1.2
C16:0	181	135
C16:1	2.2	3.0
C18:0	62.4	50.3
C18:1 n-9	355	462
C18:1 n-7	15.6	23.3
C18:2 n-6	313	262
C18:3 n-3	31.7	26.6
C20:0	6.7	6.5
C20:1 n-9	4.3	7.1
C22:0	8.3	6.6
C24:0	3.8	3.3
Saturated fatty acids	269	207
Monunsaturated fatty acids	381	500
Polyunsaturated fatty acids	350	293
n-3	32	27
n-6	314	263
n-6:n-3	10.7	11.8

[1]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
[2]No. 545, acid-washed diatomaceous earth (Schneider Dämmtechnik, Winterthur, Switzerland)
[3]Determined as fatty acid methyl esters

Table 4.2 Effect of chicken type and diet on growth performance

Chicken type	Hubbard		Lohmann Dual		Lohmann Brown			*P*-value		
Diet	C	LP	C	LP	C	LP	SEM	Type	Diet	Type × Diet
Birds (*n*)	12	12	10	11	12	12				
Feed intake (g/day)[1]	97.3[a]	93.8[a]	70.0[b]	73.2[b]	47.4[c]	45.5[c]	2.79	<0.001	0.760	0.461
Final body weight (kg)	3.05[a]	2.63[b]	2.16[c]	2.00[c]	1.26[d]	1.03[d]	0.088	<0.001	<0.001	0.270
Average daily gains (g)	47.9[a]	41.2[b]	33.7[c]	31.1[c]	20.3[d]	15.7[d]	1.40	<0.001	<0.001	0.272
Feed efficiency (g gain/g feed)[1]	0.491[a]	0.444[ab]	0.442[ab]	0.413[b]	0.406[b]	0.346[c]	0.0243	<0.001	0.003	0.651
Metabolisability of energy[1]										
4 weeks of age	0.764[b]	0.757[b]	0.779[a]	0.779[a]	0.772[a]	0.769[a]	0.0043	<0.001	0.288	0.778
9 weeks of age	0.761	0.752	0.770	0.763	0.773	0.762	0.0126	0.132	0.092	0.953
Metabolisability of nitrogen[1]										
4 weeks of age	0.530[bc]	0.584[a]	0.528[c]	0.597[a]	0.485[d]	0.557[ab]	0.0330	0.016	<0.001	0.793
9 weeks of age	0.447[c]	0.545[a]	0.411[d]	0.495[b]	0.405[d]	0.531[ab]	0.0134	0.009	<0.001	0.307
Excreta dry matter (g/kg)[1]										
4 weeks of age	373	381	401	396	381	367	72.7	0.440	0.790	0.861
9 weeks of age	305[ab]	286[bc]	339[a]	305[bc]	319[ab]	286[c]	14.4	0.099	0.006	0.551

C: control diet; LP: protein reduced diet; SEM: standard error of the mean
[a-d]Values in the same row with different superscript are significantly different ($P < 0.05$)
[1]Data from $n = 5$ or 6 compartments per type and diet

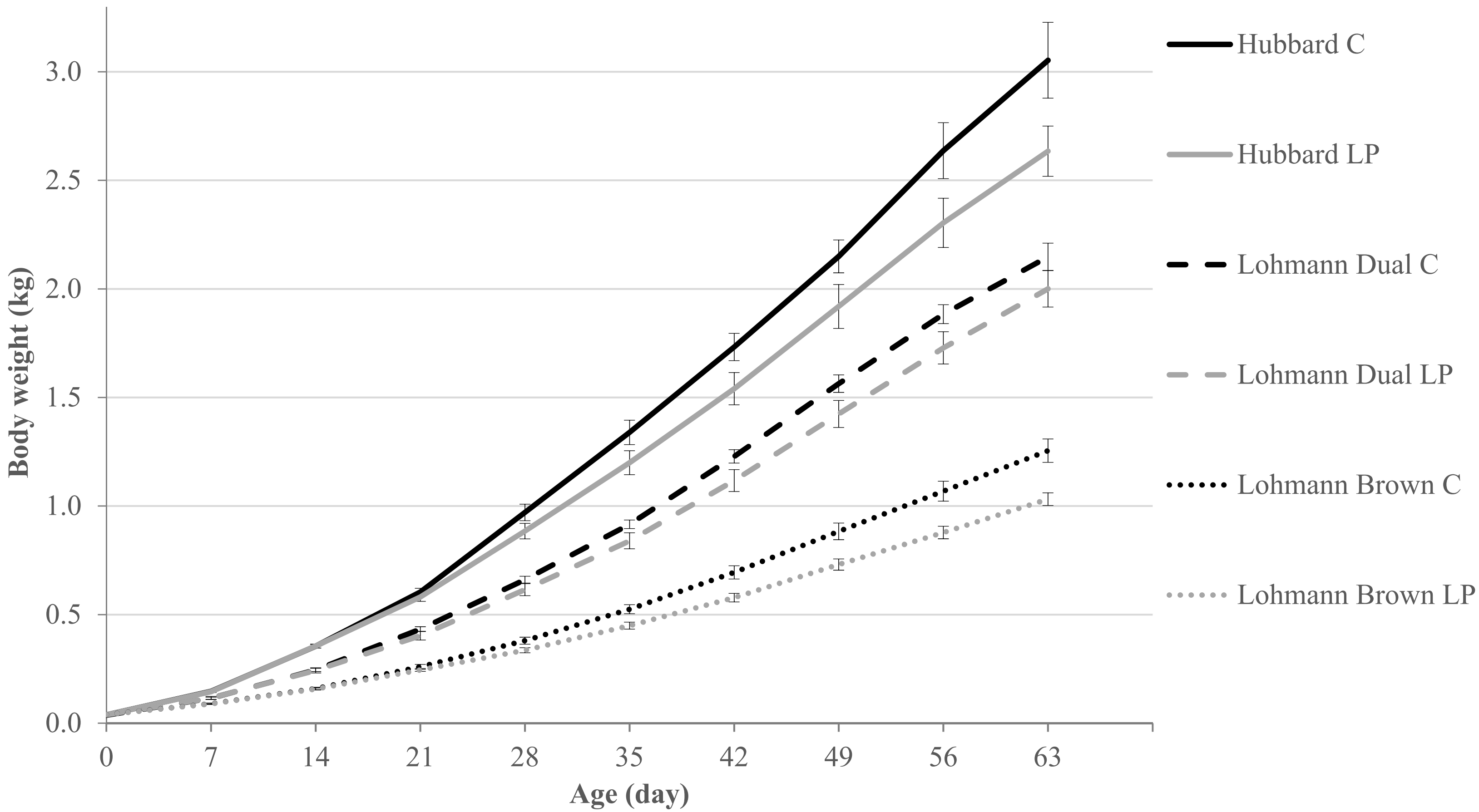

Figure 4.1 Body weight gain (± se) of the three chicken types fed one of the two diets (C, control; LP, reduced in protein and soybean) (means of 10 to 12 chickens for each of the six groups).

4.4.3 Carcass quality

Dressing percentage was greatest in HU (69.1), smaller in LD (63.5) and smallest in LB (59.8) ($P < 0.05$; Table 4.3). According to this clear gradient, the differences between chicken types in carcass weight were even more pronounced than those in final BW. Feeding LP was adverse ($P < 0.001$) for carcass weight compared to C and, overall, for dressing percentage ($P < 0.01$) although this decrease ($P < 0.05$) was only found in HU and LB, and not in LD. The yields of valuable cuts (breast and leg meat) and of breast meat were similarly different among groups as carcass weight, and there was an interaction for breast meat yield ($P < 0.05$). The breast angle differed ($P < 0.001$) between chicken types, whereas diet only caused differences within HU but not within LD and LB. Breast meat proportion (g/kg carcass) was greatest in HU (252), followed by LD (193) and smallest in LB (164) ($P < 0.05$). This was compensated by the opposite relationships in almost all other body parts and organs in LB (except wings and abdominal fat) and mainly in legs and wings in LD. Abdominal fat proportion was similar in HU and LD, and about four times greater than in LB. There were some diet effects ($P < 0.05$) on the proportion of inner organs (liver, stomach, heart and pancreas; greater with LP) and on breast proportion (smaller with LP), but the magnitude of the differences was small. In the proportions of the stomach and pancreas, there was an interaction ($P < 0.05$). Skin colour was lightest ($P < 0.05$) in LD, and HU skin was most red ($P < 0.05$). Feeding LP reduced ($P < 0.05$) skin yellowness. Tibia characteristics of HU and LD were quite similar with the exception that tibias were shorter ($P < 0.05$) in HU than LD. By contrast, the tibias of the LB were lighter, shorter and thinner and were breaking easier than in the other chicken types ($P < 0.05$). Diet LP resulted in lighter and shorter bones ($P < 0.05$) at the same breaking strength. Chicken types and diets did not affect bone mineral composition.

4.4.4 Meat quality

A number of the physicochemical meat quality traits analysed were influenced ($P < 0.05$) by chicken type (Table 4.4). Ultimate pH (24 h p.m.) and drip loss were smaller ($P < 0.05$) in HU than LD and LB meat, whereas the opposite was found for thaw loss and cooking loss. In HU, thaw loss was greater ($P < 0.05$) when chickens were fed LP than C. The LB breast meat was most yellow ($P < 0.05$). The HU breast meat contained more moisture and ash and less protein than that of LD and LB, whereas the intramuscular fat content of the LD meat was smallest (all $P < 0.05$). There was a small but significant decline in meat protein content with LP, especially caused by differences in HU meat.

There were chicken type differences ($P < 0.05$) in the proportions of a number of individual fatty acids and major groups of fatty acids, but not in total saturated fatty acids (SFA) and n-3 fatty acids (Table 4.5). Especially HU differed from LD and LB ($P < 0.05$) by greater proportions of C14:0, C16:0, C16:1 n-7, C20:1 n-9, C20:2 n-6 and monounsaturated fatty acids (MUFA), and smaller proportions of C20:0, C18:2 n-6, C20:4 n-6 and C22:6 n-3 and polyunsaturated fatty acids (PUFA). In most individual fatty acids and groups of fatty acids there were diet effects ($P < 0.05$), with the profile of the intramuscular fat being richer in MUFA with LP vs. C and poorer in PUFA and SFA ($P < 0.05$). Such effects were only absent in the proportions of n-3 fatty acids, C14:0, C18:0 and C20:0. In two minor MUFA (C14:1 and C20:1 n-9) there was an interaction ($P < 0.05$), otherwise, the majority of the diet effects were found in all chicken types though not always to the same degree.

Table 4.3 Effect of chicken type and diet on carcass properties and composition

Chicken type	Hubbard		Lohmann Dual		Lohmann Brown			*P*-value		
Diet	C	LP	C	LP	C	LP	SEM	Type	Diet	Type × Diet
Birds (*n*)	12	12	10	11	12	12				
Carcass weight (g)	2132^{a}	1806^{b}	1374^{c}	1265^{c}	757^{d}	611^{d}	61.8	<0.001	<0.001	0.139
Dressing percentage	69.8^{a}	68.5^{b}	63.6^{c}	63.3^{c}	60.4^{d}	59.2^{e}	0.38	<0.001	0.002	0.283
Valuable cut yield[1] (g)	896^{a}	795^{b}	654^{c}	618^{c}	498^{d}	469^{e}	27.3	<0.001	<0.001	0.059
Breast meat yield (g)	551^{a}	441^{b}	276^{c}	235^{c}	126^{d}	101^{d}	34.3	<0.001	<0.001	0.010
Breast angle (°)	154^{a}	142^{b}	104^{c}	103^{c}	81^{d}	80^{d}	5.0	<0.001	0.089	0.167
Carcass composition (g/kg)										
Breast meat	260^{a}	245^{a}	201^{b}	186^{b}	166^{c}	164^{c}	19.4	<0.001	0.029	0.426
Legs	347^{b}	353^{b}	377^{a}	383^{a}	372^{a}	369^{a}	10.9	<0.001	0.478	0.585
Wings	121^{c}	126^{c}	139^{b}	136^{b}	160^{a}	167^{a}	8.6	<0.001	0.261	0.376
Abdominal fat	30.3^{a}	27.4^{a}	30.2^{a}	28.4^{a}	8.0^{b}	6.0^{b}	4.34	<0.001	0.264	0.972
Liver	22.5^{c}	23.1^{c}	22.6^{c}	23.7^{c}	30.5^{b}	33.5^{a}	0.79	<0.001	0.009	0.216
Stomach[2]	15.4^{d}	16.5^{d}	22.7^{c}	25.9^{c}	32.6^{b}	41.0^{a}	1.26	<0.001	<0.001	0.007
Heart	5.92^{e}	6.68^{d}	7.49^{c}	8.04^{c}	9.10^{b}	9.73^{a}	0.325	<0.001	0.001	0.904
Pancreas	2.33^{c}	2.10^{c}	2.98^{b}	3.26^{b}	3.36^{b}	3.91^{a}	0.162	<0.001	0.070	0.014
Spleen	2.23^{b}	2.14^{b}	2.52^{b}	2.55^{b}	4.55^{a}	4.36^{a}	0.209	<0.001	0.601	0.857
Skin colour										
Lightness (L*)	61.6^{b}	61.9^{b}	67.2^{a}	67.7^{a}	62.6^{b}	62.9^{b}	0.78	<0.001	0.501	0.987
Redness (a*)	0.75^{ab}	1.15^{a}	-0.09^{c}	0.13^{c}	0.41^{bc}	0.12^{bc}	0.249	<0.001	0.566	0.294
Yellowness (b*)	0.32^{ab}	0.13^{b}	1.72^{a}	0.17^{ab}	-0.01^{b}	-0.97^{b}	0.616	0.032	0.041	0.444
Bone characteristics										
Weight (g)	22.4^{a}	20.7^{ab}	20.6^{ab}	19.2^{b}	13.4^{c}	11.0^{c}	1.03	<0.001	0.024	0.883
Length (mm)	134^{a}	130^{ab}	130^{ab}	125^{b}	118^{c}	111^{c}	1.9	<0.001	<0.001	0.641
Diameter (mm)	10.1^{a}	9.7^{a}	10.4^{a}	10.3^{a}	8.2^{b}	7.5^{b}	0.29	<0.001	0.080	0.547
Breaking strength (N)	364^{a}	357^{a}	320^{a}	316^{a}	264^{b}	235^{b}	23.1	<0.001	0.466	0.826
Mineral composition (g/kg)										
Calcium	65.0	62.9	64.2	62.0	65.0	65.7	1.45	0.257	0.289	0.479
Phosphorus	32.5	30.2	32.2	31.6	33.1	32.7	0.76	0.084	0.062	0.345
Magnesium	1.07	1.00	1.08	0.99	1.09	1.06	0.037	0.361	0.026	0.756

C: control diet; LP: protein reduced diet; SEM: standard error of the mean

$^{a\text{-}e}$Values in the same row with different superscript are significantly different ($P < 0.05$)

[1]Sum of breast meat and legs

[2]Including proventriculus and gizzard

Table 4.4 Effect of chicken type and on meat quality measured in the left breast meat (*n*= 6 × 10 birds).

Chicken type	Hubbard		Lohmann Dual		Lohmann Brown			*P*-value		
Diet	C	LP	C	LP	C	LP	SEM	Type	Diet	Type × Diet
pH (24 h)	5.57^{b}	5.58^{b}	5.82^{a}	5.82^{a}	5.80^{a}	5.85^{a}	0.040	<0.001	0.335	0.603
Drip loss (%)	0.91^{b}	0.68^{b}	2.52^{a}	2.52^{a}	3.50^{a}	2.55^{a}	1.262	<0.001	0.279	0.522
Thaw loss (%)	7.43^{b}	10.74^{a}	5.95^{c}	6.78^{c}	6.73^{c}	7.18^{bc}	1.410	0.010	0.043	0.236
Cooking loss (%)	15.0^{a}	14.0^{ab}	10.8^{bc}	10.7^{bc}	10.3^{bc}	7.2^{c}	1.40	<0.001	0.213	0.524
Shear force (N)	11.6	10.8	9.9	10.7	10.7	10.6	0.57	0.283	0.905	0.386
Colour										
Lightness (L*)	51.6^{ab}	52.7^{a}	50.1^{b}	53.2^{a}	51.8^{ab}	52.1^{ab}	1.11	0.824	0.033	0.264
Redness (a*)	1.96	2.25	1.88	1.74	1.94	1.91	0.284	0.499	0.853	0.673
Yellowness (b*)	3.75^{b}	3.17^{b}	4.04^{ab}	2.98^{b}	5.01^{a}	3.98^{b}	0.397	0.008	0.005	0.766
Chemical composition (g/kg)										
Moisture	731^{a}	737^{a}	717^{b}	721^{b}	718^{b}	718^{b}	4.8	<0.001	0.152	0.642
Ash	15.0	14.4	13.4	13.9	14.1	13.6	0.49	0.100	0.603	0.449
Protein	236^{b}	231^{c}	249^{a}	246^{a}	248^{a}	245^{a}	3.7	<0.001	0.011	0.775
Fat (ether extract)	9.20^{ab}	9.89^{ab}	7.24^{b}	6.93^{b}	9.14^{ab}	10.71^{a}	0.957	0.014	0.687	0.530

C: control diet; LP: protein reduced diet; SEM: standard error of the mean

$^{a\text{-}c}$Values in the same row with different superscript are significantly different ($P < 0.05$)

Table 4.5 Effect of chicken type and diet on the fatty acid composition (g/kg of total fatty acids determined as fatty acid methyl esters[1]) and the ratio of n-6 to n-3 fatty acids in the intramuscular fat of the left breast meat (*n*= 6 × 10 birds)

Chicken type	Hubbard		Lohmann Dual		Lohmann Brown			*P*-value		
Diet	C	LP	C	LP	C	LP	SEM	Type	Diet	Type × Diet
C14:0	2.84^{a}	2.68^{a}	2.33^{b}	2.24^{b}	1.93^{c}	2.05^{bc}	0.107	<0.001	0.617	0.385
C14:1	0.433^{a}	0.307^{b}	0.276^{b}	0.254^{b}	0.150^{c}	0.158^{c}	0.0369	<0.001	0.040	0.042
C16:0	174^{a}	168^{b}	166^{b}	161^{bc}	160^{c}	149^{d}	5.5	<0.001	<0.001	0.365
C18:0	82.2	83.6	88.2	86.1	93.0	84.7	3.15	0.760	0.246	0.304
C20:0	0.681^{b}	0.695^{b}	0.768^{b}	0.761^{b}	0.933^{a}	1.051^{a}	0.0863	<0.001	0.537	0.729
C16:1 n-7	13.35^{a}	10.35^{b}	9.56^{b}	8.67^{b}	5.57^{b}	6.69^{b}	1.076	<0.001	0.205	0.080
C18:1 n-9	250^{b}	297^{a}	230^{bc}	282^{a}	226^{c}	300^{a}	18.8	0.072	<0.001	0.193
C18:1 n-7	19.7^{b}	25.4^{a}	18.2^{b}	25.2^{a}	18.6^{b}	24.7^{a}	0.64	0.232	<0.001	0.519
C20:1 n-9	2.27^{c}	2.99^{a}	1.81^{d}	2.67^{b}	1.96^{d}	3.17^{a}	0.208	0.003	<0.001	0.034
C18:2 n-6	305^{a}	254^{b}	312^{a}	258^{b}	322^{a}	273^{b}	6.8	0.040	<0.001	0.917
C18:3 n-3	24.3	21.9	22.5	20.5	20.1	20.3	1.48	0.044	0.130	0.465
C20:2 n-6	5.68^{a}	4.17^{b}	4.78^{b}	3.81^{c}	4.70^{b}	3.23^{c}	0.414	0.007	<0.001	0.598
C20:4 n-6	54.7^{b}	59.8^{ab}	69.6^{ab}	72.7^{a}	71.5^{a}	64.0^{ab}	7.07	0.048	0.962	0.501
C22:4 n-6	12.9^{a}	10.9^{ab}	13.2^{a}	12.5^{ab}	12.3^{ab}	9.8^{b}	0.99	0.200	0.034	0.655
C22:5 n-3	11.4	14.2	13.8	16.4	12.7	13.3	2.10	0.144	0.064	0.636
C22:6 n-3	9.7^{c}	11.6^{bc}	14.7^{ab}	15.3^{ab}	16.3^{a}	14.8^{ab}	1.72	0.005	<0.815	0.564
Saturated fatty acids	273^{a}	269^{a}	274^{a}	265^{ab}	274^{a}	252^{b}	9.1	0.222	0.007	0.212
Monounsaturated fatty acids	292^{b}	345^{a}	266^{c}	326^{a}	259^{c}	342^{a}	17.7	0.014	<0.001	0.139
Polyunsaturated fatty acids	435^{b}	387^{d}	460^{a}	409^{c}	468^{a}	407^{c}	9.4	<0.001	<0.001	0.355
n-6 fatty acids	384^{b}	334^{d}	404^{a}	352^{c}	415^{a}	355^{c}	5.4	<0.001	<0.001	0.330
n-3 fatty acids	47.6	50.0	53.2	54.6	50.8	50.0	4.49	0.053	0.567	0.736
n-6:n-3 fatty acids	8.09^{ab}	6.83^{bc}	7.83^{ab}	6.45^{c}	8.54^{a}	7.22^{abc}	0.581	0.077	<0.001	0.982

C: control diet; LP: protein reduced diet; SEM: standard error of the mean

$^{a\text{-}d}$Values in the same row with different superscript are significantly different ($P < 0.05$)

[1]Minor fatty acids are not presented but considered in the total sum of fatty acids

4.5 Discussion

4.5.1 Differences among dual-purpose, layer hybrids and slow-growing broiler types

The dual-purpose type chosen for the present study, Lohmann Dual (LD), had an ADG slightly exceeding those complying with the Swiss regulations for organic poultry fattening (max. 27.5 g; Bio Suisse, 2018). It may be owed to the optimised, controlled and confined conditions applied in the experiment like keeping in pairs with large space, few feed competition and small need for movement. Unexpectedly, the final BW of LD was smaller with 2 kg on day 63 than what was expected from the producer' statement (2.2 and 3 kg on day 56 and 70, respectively; Icken and Schmutz, 2013). Lohmann Brown (LB) has a slightly greater muscularity than other layer hybrids and therefore a greater BW than for instance Lohmann Selected Leghorn (Koenig et al., 2012; Ammer et al., 2017). The slow-growing broiler Hubbard JA 957 (HU), chosen as an example for a positive control, did not belong to the recommended Hubbard types for organic farming (Bio Suisse, 2018) and thus did not comply with the Swiss organic regulations with an ADG of 47.9 g/d. Still the performance gap between HU and common intensive broilers would be huge (Mueller et al., 2018).

Concerning carcass quality, HU also were superior to LD, and LD were more favourable than LB in carcass weight, dressing percentage, BMY, breast meat proportion of the carcass and breast angle. Accordingly, breast meat formation was more than proportionate to ADG in the broiler chickens compared to dual-purpose or egg-type chickens as also expected from data by Icken et al. (2013). This also led to less appealing carcass shapes with more pronounced keel bones in LD and especially LB vs. HU (cf. illustrations by Mueller et al., 2018). The combination of smaller final BW and less pronounced breast development together caused LD being inferior to HU as the breast meat is considered as the most valuable cut and the compensation by proportionately more leg meat is not very helpful in this respect. Therefore, meat obtained by dual-purpose or layer types has to be considered as a niche product for specialised markets (Leenstra et al., 2010; Koenig et al., 2012) that does not aim at large economic profit as production costs per unit of meat are great (Leenstra et al., 2010). Additionally, the special circumstances of the production of this meat should be clearly communicated (Gangnat et al., 2018). Obvious changes in skin and meat colour could represent another unfavourable criterion for marketing. However, the chicken type differences on the colour of skin and meat were quite weak and thus likely not relevant.

Bone health is not only of an economic but also of an animal welfare interest and therefore still an issue in the layer and the broiler industry (Andersson, 2018; Harvey et al., 2015). The bone parameters indicated that, along with increasing growth rate and body size, bones got larger, thicker and stronger without changes in their mineral composition as was found previously (Mueller et al., 2018). The breaking strength found does not seem to be of concern for a fattening period of 9 weeks in any of the types.

Important physical properties of the breast meat is tenderness for which shear force is an indicator (Lyon and Lyon, 1990). A greater shear force is often set into the context of older birds (Poltowicz and Doktor, 2012) which is most likely a result of increased cross-linking of the collagen, the main protein of the connective tissue (Chueachuaychoo et al., 2011). Accordingly, shear force was similar in all types investigated in the present study, since all birds were slaughtered after 63 days of fattening. Another meat quality problem would consist in pale, soft and exudative (PSE) poultry meat. Based on the pH and L* values, the breast meat obtained in this study can be classified as normal, with HU being closest to the PSE conditions but only when regarding pH (Zhuang and Savage, 2010). Should the HU meat have been PSE-like, a greater drip loss compared to LD and LB meat would have been expected but was not found. Still, thaw and cooking loss were more favourable for LD and LB than HU meat. Overall, the thaw and cooking losses measured in the present study were below the acceptable thresholds of 10 and 26 %, respectively (Galobart and Moran, 2004). As the HU breast meat had a greater size as that of LD, the longer cooking time needed to reach the same internal temperature might have caused moisture loss to increase (Fanatico et al., 2007). As cooking losses did not differ between LD and LB despite largely different cut sizes, there seems to be a genetic component, too.

The breast meat of LD was similar in moisture and protein content to LB whereas breast meat of HU contained less protein and more moisture. In the study of Mueller et al. (2018), this difference was only found between LD and the common broiler, but not the slow-growing broiler (Sasso 51). The intramuscular fat content of the breast meat was low and similar in LB and HU, and even lower in LD. Different from that, Lichovníková et al. (2009) and Mueller et al. (2018) found a greater intramuscular fat content in broilers than in layer males. This might have resulted from the different genetic background of the chicken types. Indeed, from the present results it became apparent that layers have a different way of distributing fat in the body compared to broilers as they intend to maintain only a minimal level of functional lipids in the muscles, and put all other energy available into the egg and not into storage tissues. The latter is also obvious from the very small proportion of abdominal fat. In the latter respect, the LD (a cross of layer and broiler; Damme et al., 2015b) resembled more the broilers.

There is a certain genetic component determining the fatty acid profile of the intramuscular fat in poultry (Dal Bosco et al., 2012; Boschetti et al., 2015; Puchala et al., 2015). Indeed, also in the present study significant type differences were found in a number of fatty acids. These differences particularly occurred in the group of the n-6 fatty acids and, with that, in total PUFA proportion, which was smaller in HU than LD and LB (compensated by opposite relationships for MUFA proportion). However, there was no systematic gradient in the profiles from HU to LD and LB, and the chicken-type caused differences in profile were smaller than those caused by the diet.

4.5.2 Effects of a reduction in dietary protein content

Methionine and lysine are generally considered as the first and second limiting amino acids in poultry diets (Toride, 2004). One reason for the wide-spread use of soybean-based ingredients is the great content of protein and essential amino acids (especially lysine) and, at the same time, the low fat and fibre content. However, its lysine:methionine ratio is not optimal for poultry. In order to avoid a bias in the present study, the exchange of the soybean-based components was performed in a way that the calculated proportions of the three limiting amino acids methionine, lysine and threonine remained similar. For this reason, and because of the similar energy content in the diets, dietary effects can be predominantly associated to the reduction in dietary protein. However, an effect of specific components other than protein in the feeds exchanged cannot be fully excluded. The average growth depression caused by feeding LP instead of C was 13% in ADG, 5% in breast meat proportion, 19% in BMY (equivalent to a more than proportionate decline of breast meat in carcass), this at almost unchanged feed (energy) intake and body fat accretion (abdominal fat proportion). This also excludes confounding by a different palatability of the feeds exchanged. The increased N metabolisability with LP could be a result of smaller excreta N losses as with C the CP content may exceeded the chickens' requirement. The reduction in bone size with the low-protein diet was probably due to the smaller final BW, an assumption supported by the unchanged breaking strength and bone mineral composition.

Consistent with Bogosavljevic-Boskovic et al. (2010) the meat protein content was smaller with LP. This further confirms the presence of a selective protein (amino acid) deficiency. Additionally, Bregendhal et al. (2002) and Jariyahatthakij et al. (2018) reported that decreasing dietary CP, for example by reducing the amount of soy components in the feed of chickens, results in a decrease of growth rate and feed efficiency. Exchanging part of the soybean cake by insect protein, by contrast, had no effect on performance on organic broiler when maintaining the dietary CP content (Leiber et al., 2017). Otherwise, effects of decreasing protein supply on physicochemical meat quality traits were small. The decline of meat and skin yellowness found with LP was probably due to the change in dietary ingredients and not because of the change in protein supply as such. There was no maize gluten in LP and therefore this diet contained less colorants (carotenoids). Concerning fatty acid profile, diet effects were pronounced, because poultry meat reflects the fatty acid composition of the diet (Soriano Santos, 2009; Ghasemi et al., 2016). It could have been expected that the exchange of the ingredients and subsequent the protein in LP was associated with a certain increase in dietary starch content and therefore could have facilitated the de novo synthesis of SFA. However, this effect was not observed, probably because the lipids in LP contained less SFA. Soybean cake and sunflower cake are quite similar in fatty acid profile, although the first has a greater proportion of C18:3 n-3 (Sauvant et al., 2004). Therefore, the greater C18:1 n-9 (and total MUFA) and smaller C18:2 n-6 (and total and n-6 PUFA) proportions with LP are likely due to the use of rapeseed based ingredients (Sauvant et al., 2004). The same qualitative changes were found by Kirchgessner et al. (1993) in the body fat, although in that study differences were more pronounced in body fat because pure fatty acids had been used. The present results show that by choosing appropriate oil seed cakes and oils in exchange of soybean-based feeds a desired fatty acid profile may be generated. In this sense, the n-6:n-3 ratio declined with the LP diet, but it was still greater than the desirable ratio of 4:1 to 6:1 (Gerster, 1998) but at least clearly smaller than the estimated value of the Western diets with 10-20:1 (Molendi-Coste et al., 2011).

4.5.3 Response of the different chicken types to a low-protein diet

The main aim of the present study was to determine whether dual-purpose and layer male chickens with a slower growth are less susceptible to a diet, which is deficient in protein. Possibly these types have smaller requirements as the slow-growing broilers. Indications are either apparent from significant interactions between chicken types and diet or by significance of protein effects in some but not in other types. Indeed, growth performance was impaired significantly by the deficient protein supply, but on a closer look, this was significant only in HU. Also numerically the decline by LP was only about half in LD compared to HU. Ammer et al. (2017) also described a larger growth depression in HU compared to LB when replacing part of soybean-based feeds and lowering dietary protein content. In addition, LD only weakly responded to two levels of dietary protein reduction in the study of Urban et al. (2018), but dietary protein contents (especially in the grower phase) were greater and levels of reduction were smaller than those in the present study indicating that there was no protein deficiency or no susceptibility to it in that study. A differentiated response of the chicken types was also obvious in carcass quality. The BMY of HU decreased by 20% when fed LP, whereas for LD and LB there were only numerical decreases. The smaller carcass weight and the smaller breast meat proportion were thus particularly detrimental in HU. The interaction found in the stomach proportion can be attributed to the changes in gizzard size (data not shown). Gizzard development is promoted by a greater dietary fibre content (Sacranie et al., 2012) or coarse particles (Kheravii et al., 2017) but diets did not differ much in fibre content. A well-developed gizzard also would assist in the digestion of nutrients. If so, the LB were the only chicken type, which tried to compensate the small nutrient content with a greater gizzard proportion, but this did not result in a greater energy metabolisability with LP. Pancreas was the other organ responding in size to LP only in the LB. A greater relative pancreas weight could indicate an enhanced activity of protein degrading enzymes (chymotrypsin) (Engberg et al., 2002). As the LB chickens, different from HU and LD, are from a layer strain, a well-developed reproductive tract is of importance. Therefore, it seems that LB chickens fed LP tried to compensate the lower crude protein content with a more developed digestive system.

4.6 Conclusions

The present results illustrate that dual-purpose chickens may be a valid alternative to broiler types but this only in competition to slow-growing broilers. Due to the great growth rate of HU, they did not fit to Swiss organic regulations, whereas dual-purpose type would fit quite well. However, there was a genuine disadvantage for LD in breast meat yield. A competitive advantage of the dual-purpose chickens, and thus partly confirming the first hypothesis, was their slightly smaller susceptibility to the low-protein-low-soybean diet, allowing the use of diets with smaller proportions of ingredients competing with human food production. In addition, meat quality of the dual-purpose type exceeded that of the slow-growing broilers. Different from that, the performance of male layer hybrids was too small and the carcass quality was so unfavourable that their fattening may result in problems of marketing. Meat quality of the male layers was equal to that of the dual-purpose type and slightly superior to that of the slow-growing broiler. Protein reduction impaired growth performance and carcass quality, but also type differences were found. Therefore, the third hypothesis can be verified. The male layer hybrid seem to have developed some coping mechanisms to protein deficiency in the internal organs, but this did not prevent an adverse response which was not much smaller than that found in the slow-growing broilers (not confirming hypothesis 2). Further studies are necessary to quantify the exact protein and amino acid requirements of dual-purpose chickens and male layer hybrids to be able to design optimised diets.

Chapter 5

Egg yield and quality, carcass and meat quality of late-laying hens from three dual-purpose types vs. a layer type fed a by-product based diet

This chapter is based on Mueller S., Messikommer R.E., Kreuzer M., Siegrist M., and Gangnat I.D.M. Animal Feed Science and Technology (in preparation for submission).

5.1 Abstract

In laying hen nutrition, most of the diet is typically composed of potential foods. The use of alternative protein and energy sources is limited by their availability and nutritional content. This could be different in less demanding hen types. Therefore, it was investigated whether dual-purpose types, the use of which avoids culling of male chicks, would better tolerate a diet composed of agrifood industry by-products than layer hybrids. Hen types were Lohmann Brown Plus (LB, layer hybrid; n=10), Lohmann Dual (LD, modern dual-purpose type; n=10), Belgian Malines (BM) and Schweizerhuhn (CH) (both traditional dual-purpose types; n=9). In a cross-over design, each animal received for 4 weeks a common layer diet (control diet; 11.5 MJ/kg ME and 4.3 g methionine/kg) or a by-product diet (10.4 MJ/kg ME and 2.4 g methionine/kg). Subsequently, they stayed for 8 weeks on the same diet until slaughter. Effects of type, diet and interaction where statistically evaluated. There were hen type effects in various performance and egg quality traits. The by-product diet affected most performance and carcass parameters, but not egg quality. Body and carcass weights were greatest in BM, followed by CH, and were similar in LB and LD. Interactions occurred in feed intake, which did not change between diets in BM and CH but declined from the control diet in LB and LD (101 to 121 g/d) to the by-product diet (80 and 65 g/d, respectively). Also laying performance which was already moderate (37 to 54 %) for BM and CH and remained on the same level with both diets. In LB and LD, it declined from the control (92 and 68 %, respectively) to the by-product diet (53 and 50 %, respectively). Overall, feed efficiency (g feed/g egg) was better in LB and LD (both 2.8) than in CH (5.2) and BM (5.9) and more favorable with the control than with the by-product diet. The average egg weights were similar for all types, but were greater with the control (63 g) than with the by-product diet (59 g). The traditional dual-purpose types had more valuable carcasses than LB, with LD in between. Meat quality differences were small and in favor of LD. Overall, the performance of the traditional dual-purpose types was small allowing them to tolerate the diet based on by-products, whereas especially the layer hybrids but also the modern dual-purpose type experienced serious impairments with this diet.

5.2 Introduction

Commercial laying hen diets are characterized by large proportions of cereals and soybean products. Due to the concept of ‘feed no food’ and environmental concerns in soybean production (Semino et al., 2009), alternative plant energy and protein sources are sought. However, the use of such alternative ingredients is often limited by their availability or by antrinutritive compounds. Another drawback of most plant protein sources is the low methionine content, the first limiting amino acid for poultry. In order to cover the animals' requirements, a supplementation of synthetic amino acids would be required, which is not permitted in organic farming (Bio Suisse, 2018; Regulation (EU), 2018). The use of rapeseed cake is not yet established for layers, although it represents an important protein source and hens with the gene for the inability to metabolize trimethylamine were eliminated and therefore no “fishy taint” eggs occur anymore from 2007 onwards (Pottgüter, 2006). The presence of glucosinolate and sinapine was reduced to a minimum in the 00-type cultivars but still the fiber content is much greater than that of soybean meal or cake (Swiss Feed Database, 2018). Further alternative protein sources include lupines and field beans. Recent cultivars are largely alkaloid free (Kaczmarek et al., 2014; Nalle et al., 2011) or condensed tannin free (Crépon et al., 2010), compounds which negatively affected feed intake, nutrient utilization and protein digestibility. Brewer's grains with a favorable amino acid profile (Swiss Feed Database, 2018), could help to replace soybean products. Brewer's yeast represents both, an alternative protein and energy source (Swiss Feed Database, 2018). Considering the limitations of these individual sources, it seems advantageous to substitute soybean ingredients with a selection of other protein sources together.

As a new development, modern dual-purpose poultry (crossbreds of meat and layer lines; Damme et al., 2015b), used for egg and meat production, are discussed as alternatives for specialized lines in order to avoid the culling of newly hatched male layer cockerels (Urselmans et al., 2015). Also traditional dual-purpose hen types gained renewed interest for this reason. The gap in performance of dual-purpose types to the specialized lines (Halle, 2017) could also translate into smaller requirements for energy, protein and methionine. In addition, the use of such diets might be less adverse to performance when fed in the late period of lay, a time where nutrient requirements could be smaller due to the declining performance. Therefore, dual-purpose types might better tolerate diets based on by-products of the food industry. A further advantage of dual-purpose types could be their greater meat yield as spent hens. This might help to turn the current inclination to discard these birds for instance in biogas plants. The tasty and low-fat meat (Lee et al., 2003) would be harvested from the carcasses and processed to sausages or convenience food (Arya et al., 2017; Lee et al., 2003; Loetscher et al., 2015). However, research on dual-purpose poultry is still in its infancy and responses to by-product diets in laying and slaughter performance as well as egg and meat quality have to be further investigated.

The hypotheses tested in the present study were (1) to which extent dual-purpose poultry types would respond not or less severe to exchanging a common layer diet by one based exclusively on agrifood industry by-products in laying performance and meat yield, (2) that there are differences in performance response between modern and traditional dual-purpose types, and (3) that these diets do not impair egg and meat quality.

5.3 Material and methods

5.3.1 Experimental diets

Two different diets were tested. One represented a common diet designed for layer hybrids (control diet, C) widely based on cereals and soybean meal. In the second diet, cereals and soybean-based feeds had been replaced with by-products of the agrifood industry (by-product diet, B) (Table 5.1). In addition, diet C was supplemented with methionine to cover the hens' requirements according to GfE (1999), whereas this supplementation was omitted in diet B in order to simulate organic production conditions. With these changes, diet B was calculated to have a 1 MJ/kg lower ME content and a 44% lower methionine content at a slightly greater crude protein (CP) content than diet C. It had been shown in earlier periods of lay on the same hens that the omission of synthetic methionine (Mueller et al., 2016a) and both reduction of methionine and ME by 1 MJ/kg (Mueller et al., 2016b) had been without effect on performance. Both diets contained the indigestible marker celite in order to allow determinations of digestibility and metabolisability of the feed (Vukić Vranješ et al., 1994). All components were ground through a 2 mm sieve before mixing and diets were then stored at room temperature.

Table 5.1 Composition (g/kg as fed) of the experimental diets

Item	Control diet (C)	By-product diet (B)
Ingredients		
Corn	380	0
Wheat	135	0
Soybean meal	180	0
Sunflower cake	40.0	0
Potato protein	20.0	0
DL-methionine	1.6	0
Broken rice	56.3	180
Wheat bran	28.0	120
Sunflower oil	30.0	50.9
Sweet lupine (*Lupinus angustifolius*)	0	150
Field bean (*Vicia faba*)	0	100
Brewer's grains	0	100
Rapeseed cake	0	70.0
Molasses	0	50.0
Brewer's yeast	0	45.0
Limestone grit	65.0	69.2
Calcium carbonate	24.0	26.0
Celite[1]	16.3	16.3
Dicalcium phosphate	10.0	9.7
Monocalcium phosphate	5.0	5.0
Sodium bicarbonate	2.6	1.3
NaCl	1.6	2.0
Choline chloride	0.8	0.8
Vitamin-mineral premix[2]	2.0	2.0
Color premix	1.8	1.8
Analyzed composition[3]		
Dry matter	911	929
Organic matter	773	767
Crude protein	163	179
Gross energy (MJ)	15.0	16.0
Neutral detergent fiber (aNDFom)	123	211
Acid detergent fiber (ADFom)	59	118
Acid insoluble ash	16.4	19.1
Calculated composition		
Metabolizable energy (MJ)	11.5	10.4
Lysine	8.29	9.04
Methionine	4.33	2.44
Methionine + Cysteine	7.27	5.96

[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 provided
[3]Values are the mean of four determinations per diet

5.3.2 Hen types and housing

In the experiment, a modern dual-purpose type (Lohmann Dual, LD; n=10), recently developed by a globally operating company (Lohmann Tierzucht GmbH, Cuxhaven, Germany) and two traditional dual-purpose types (Schweizerhuhn, CH; Belgian Malines, BM; both n=9) were compared with a layer hybrid (Lohmann Brown Plus, LB; n=10). The hens originated from local hatcheries and were kept from the start of lay individually in cages (80 cm × 80 cm × 80 cm) equipped with nest, perch and sand bath. Additionally, containers were installed below the cages enabling the excreta collection. Water and the flour-like feed were provided at ad libitum access. In the entire 16-week experiment, room temperature was maintained at 20°C and the light program provided 14 h of light/day. All procedures concerning the birds were approved by the cantonal veterinary office of Zurich, Switzerland (licence no. ZH267/14).

5.3.3 Experimental protocol

The last 16 weeks of lay were divided into two sub-experiments. In sub-experiment 1, hens were entering week 36 of lay. In a cross-over design, each hen received diet C or diet B for 2 × 4 weeks each. For the 8 weeks of finishing period (sub-experiment 2; weeks 45 through week 52 of lay), hens stayed on the last consumed diet (C or B) from sub-experiment 1 until slaughter. Feed intake and body weight (BW) were determined weekly for each hen. The eggs were collected and weighed daily. These data were used to calculate average daily feed intake (ADFI) and feed efficiency (kg egg mass/kg feed) across each experimental period. In sub-experiment 1, in weeks 39 and 43, feed and excreta samples were collected, total excreta thereby during 4 days in the respective week. During this time, the sand bath was removed from the cages. The excreta samples were frozen at -20°C and lyophilized (model Beta 1-16, Christ, Osterode am Harz, Germany). Feed and excreta samples were then milled through a 0.5 mm sieve with a centrifugal mill (model ZM 1, Retsch GmbH, Haan, Germany). After 10 days on the respective diet, i.e., in week 39, 43 and 51 of lay, one egg per hen was collected to determine egg quality. At the end of week 52, the final BW was determined shortly before slaughter and after fasting overnight. Hens were slaughtered by stunning and exsanguination, subsequently they were eviscerated, and feathers, feet, head, and neck were removed. The carcasses were stored at 4°C for 24 h, the abdominal fat was removed and weighed and then carcasses were weighed. Carcass weight was related to final BW to calculate dressing percentage. Both breast muscles (without bones and skin) and legs were removed from the carcasses and weighed. The legs were skinned and deboned, and the remaining meat was weighed. All breast and leg meat together was considered as meat yield.

5.3.4 Laboratory analysis

In diets and excreta, dry matter (DM) and ash contents were measured with an automatic thermo-gravimetric device (model TGA-500, Leco, St. Joseph, MI, USA). Nitrogen content was determined with a C/N analyzer (model TruMac® CN, Leco, St. Joseph, MI, USA; AOAC (1997) index no. 968.06), and CP was calculated thereof (6.25 × N). Neutral detergent fiber (aNDFom; using heat stable α-amylase from Sigma-Aldrich, St. Luis, USA) and acid detergent fiber (ADFom), both corrected for ash content, were determined following the protocol of the Association of German Agricultural Analytic and Research Institutes (VDLUFA, 2012) and methods 6.5.1 and 6.5.2, respectively, using the Fibretherm FT 12 (Art. 13-0026, Gerhardt GmbH & Co. KG, Koenigswinter, Germany). Gross energy was measured by combustion with a bomb calorimeter (model Calorimeter System C700 with Cooler C7002, IKA, Staufen, Germany). Acid insoluble ash was measured according to Vogtmann et al., (1975). Coefficients of digestibility of aNDFom and ADFom as well as of metabolizability of energy and nitrogen were calculated as described by Vukić Vranješ et al. (1994) for indicator techniques.

Directly after dissection, the color of the left breast meat was measured on three different positions with a chromameter (model CR-300, Minolta, Ramsey, NJ, USA). The pH was determined with a pH meter (testo 205, Rausser, Ebmatingen, Switzerland). The right breast meat was frozen at -20°C until further analyses. Thaw and cooking loss was determined on the right breast meat after being thawed overnight at 4°C and after cooking to a core temperature of 74°C in a water bath followed by chilling for 5 min under cold running tap water. Shear force was subsequently measured with a Volodkevich device mounted on a texture analyzer (model ProLine table-top machine Z005, Zwick GmbH & Co. KG, Ulm, Germany) using the testing software testXpertII V3.61 (Zwick Roell, Ulm, Germany). For that purpose, at least five cube-shaped stripes of 1 × 1 cm of the cooked breast meat were prepared by cutting with a double knife along the muscle fiber orientation.

Eggshell strength was tested with an electronic hardness tester (type PTB 301, Pharma Test, Hainburg, Germany). The average shell thickness was calculated as the mean of measurements on both poles and the equator performed with a thickness-measuring instrument (Bruetsch, Rueegger, Urdorf, Switzerland). After opening the egg, the height of the egg white was measured to be able to calculate the Haugh Units (Haugh, 1937) as 100 × log(egg white height

- 1.7 × egg weight$^{0.37}$ + 7.6). Then the absolute weights of the yolk and shell were recorded, the latter after cleaning and drying for 24 h at 50°C. The weight of the egg white was calculated as the difference of the egg weight minus shell and yolk weight. Yolk color was assessed objectively with the same Minolta chromameter as used for meat color and by subjectively scoring on the 15-grade scale of a yolk color fan (DSM, JH Heerlen, Netherlands).

5.3.5 Statistical analysis

Data were analyzed by analysis of variance using SAS version 9.4 (SAS Institute Inc., Cary, NC). For the data from sub-experiment 1, the Mixed procedure was used with type, diet and their interaction as fixed effects, sequence as a random effect and hen as the repeated statement. For the finishing period, the GLM procedure was applied considering type, diet and their interaction as fixed effects. Two hens (one BM and one CH) stopped laying temporarily and were therefore excluded from the dataset of sub-experiment 1. The Tukey's procedure was performed for multiple comparisons among means when a significant effect had been identified. For all data, $P < 0.05$ was considered significant. The tables show least square means and standard errors of the mean.

5.4 Results

5.4.1 Laying performance

No hen died during the two sub-experiments. Feed intake only differed numerically between hen types when fed the control diet (Table 5.2), but was markedly ($P < 0.05$) reduced in LB and LD with the by-product diet (-46% and -22% of that of diet C, respectively) but not in BM and CH (interaction, $P < 0.001$). In the finisher phase, diet effects on feed intake were no longer significant in LD, but still so, in LB. Body weights of BM were greatest ($P < 0.05$) followed by CH and were similar in LB and LD both during weeks 36 to 44 and at slaughter with 52 weeks. Diet B reduced the BW of the hens independent of hen type (numerically in sub-experiment 1, $P < 0.05$ at slaughter). In both sub-experiments, laying percentage was greatest ($P < 0.05$) in LB, followed by LD, then in CH and BM when fed diet C. In CH and BM laying performance remained at the same level with diet B than with C. Feeding diet B led to a decline in laying percentage of LB and LD to the levels found with BM and CH. Egg weights did not differ among hen types, but were adversely affected ($P < 0.05$) by feeding diet B instead of C in sub-experiment 1. Feed efficiency (g feed/g egg) was more favorable ($P < 0.05$) in LB and LD than in CH and BM, and for diet C than B. The lack of an interaction shows that the response to diet

B did not differ among hen types. Digestibility of aNDFom and ADFom in the by-product diet was smaller ($P < 0.05$) than that found with the control diet, and there were no hen type differences. Nitrogen metabolizability was greatest ($P < 0.05$) for LD and smallest for BM with LB and CH in between. Feeding diet B instead of C led to a decline ($P < 0.05$) in N metabolizability in LB and LD but not in CH and BM (interaction, $P < 0.05$). Energy metabolizability similarly declined ($P < 0.05$) in all hen types when feeding diet B instead of C. Diet C thus also had a greater ($P < 0.05$) realized ME content compared to diet B (on average 11.6 vs. 10.0 MJ/kg diet, respectively). The by-product diet resulted in a greater ($P < 0.05$) excreta DM content (348 vs. 324 g/kg in diet C). Additionally excreta DM content was greater ($P < 0.05$) in LD and BM than in CH and LB (353 for both vs. 320 and 319 g/kg, respectively).

5.4.2 Egg quality

There were differences between hen types in eggshell quality (Table 5.3). Across diets, in weeks 36 to 44 the eggs of LD hens had a greater ($P < 0.05$) shell strength than those of BM, with LB and CH ranging in between. In the finishing phase, eggshell strength of CH and BM declined whereas that of LB and LD remained at about the same level. Similar differences between hen types and from weeks 36 to 44 compared to weeks 45 to 52 were found for shell thickness. In the period from weeks 36 to 44, thicker shells ($P < 0.05$) were found with diet C than with diet B (377 vs. 350 μm on average, respectively) of all hen types. There were no other diet effects on eggshell quality traits and there was no interaction with hen type as well. The BM were superior ($P < 0.05$) to the other types in egg yolk proportion, followed by CH, LD and LB. This was accomplished mainly at the cost of egg white proportion and to a smaller extent of shell proportion. The differences in the proportions of egg yolk and white were quite persistent when comparing the two sub-experiments. The eggs of LB and LD hens had greater Haugh Units compared to BM and CH eggs, this consistently across the experiment. There were no diet effects and interactions in egg composition and Haugh Units. The LD and BM hens had redder ($P < 0.05$) egg yolks than CH, with LB in between and the yolk color fan value was found to be greater ($P < 0.05$) in eggs of BM compared to LB hens, with intermediate scores of LD and CH during weeks 36 to 44. The by-product diet led to darker ($P < 0.05$) and less yellow egg yolks than the control diet.

Table 5.2 Effect of the by-product diet on laying performance, nutrient utilization and egg quality in weeks 36 to 44[1] and 45 to 52[2] of lay

Type of hen	Lohmann Brown Plus		Lohmann Dual		Schweizerhuhn		Belgian Malines			*P*-values		
Diet	Control	By-product	Control	By-product	Control	By-product	Control	By-product	SEM	Type	Diet	Type × diet
Feed intake (g/day)												
Weeks 36 to 44	121^{a}	65^{c}	102^{a}	80^{bc}	114^{a}	116^{a}	110^{a}	101^{ab}	7.1	<0.001	<0.001	<0.001
Weeks 45 to 52	112^{a}	81^{b}	94^{ab}	82^{b}	104^{ab}	125^{a}	111^{ab}	117^{a}	4.9	<0.001	0.438	0.003
Body weight (kg)												
Weeks 36 to 44	1.97^{c}	1.71^{c}	1.96^{c}	1.84^{c}	2.61^{b}	2.57^{b}	3.39^{a}	3.32^{a}	0.099	<0.001	0.074	0.666
Week 52 (final)	1.91^{cd}	1.61^{d}	1.92^{cd}	1.83^{cd}	2.75^{ab}	2.47^{bc}	3.45^{a}	3.05^{ab}	0.161	<0.001	0.016	0.767
Laying percentage												
Weeks 36 to 44	92^{a}	53^{c}	70^{b}	50^{c}	54^{c}	46^{c}	47^{c}	40^{c}	4.6	<0.001	<0.001	<0.001
Weeks 45 to 52	92^{a}	42^{b}	66^{ab}	47^{b}	40^{b}	37^{b}	41^{b}	38^{b}	4.7	<0.001	<0.001	0.003
Egg weight (g)												
Weeks 36 to 44	65.5^{a}	58.2^{b}	64.3^{ab}	59.3^{ab}	59.7^{ab}	58.9^{ab}	62.2^{ab}	60.2^{ab}	2.29	0.322	0.001	0.152
Weeks 45 to 52	64.3	61.8	64.7	57.7	62.5	61.8	60.3	60.4	1.36	0.497	0.066	0.238
Feed efficiency[3]												
Weeks 36 to 44	2.12^{b}	3.26^{ab}	2.47^{b}	3.15^{ab}	3.95^{a}	5.21^{a}	4.89^{a}	5.50^{a}	0.867	<0.001	0.024	0.925
Weeks 45 to 52	1.96^{c}	4.00^{abc}	2.36^{c}	3.38^{bc}	4.86^{abc}	6.61^{ab}	6.23^{ab}	7.07^{a}	0.582	<0.001	0.018	0.854
Apparent digestibility												
aNDFom	0.614^{a}	0.226^{b}	0.591^{a}	0.261^{b}	0.611^{a}	0.295^{b}	0.579^{a}	0.271^{b}	0.0337	0.747	<0.001	0.574
ADFom	0.261	0.154	0.260	0.171	0.256	0.199	0.256	0.177	0.0597	0.968	0.005	0.941
Metabolizability												
Nitrogen	0.429^{a}	0.168^{b}	0.441^{a}	0.276^{b}	0.276^{b}	0.244^{b}	0.235^{bc}	0.102^{c}	0.0535	<0.001	<0.001	0.011
Energy	0.791^{a}	0.626^{b}	0.782^{a}	0.632^{b}	0.771^{a}	0.639^{b}	0.764^{a}	0.616^{b}	0.0115	0.084	<0.001	0.176
ME (MJ/kg diet)[4]	11.7^{a}	10.0^{b}	11.7^{a}	10.1^{b}	11.5^{a}	10.2^{b}	11.4^{a}	9.8^{b}	0.16	0.070	<0.001	0.320
Excreta DM (g/kg)	308^{b}	329^{ab}	342^{ab}	364^{a}	313^{b}	327^{ab}	335^{ab}	371^{a}	18.5	0.004	0.010	0.858

ADFom: acid detergent fiber; aNDFom: neutral detergent fiber; DM: dry matter; ME: metabolizable energy

[a-c]Means in the same row without common superscript differ significantly ($P < 0.05$). SEM, standard error of the mean

[1]Lohmann Brown Plus and Lohmann Dual, both n=10 per diet; Schweizerhuhn and Belgian Malines, both n=8 per diet

[2]Lohmann Brown Plus and Lohmann Dual, both n=5 per diet; Schweizerhuhn n=5 for control, n=4 for by-product; Belgian Malines n=4 for control, n=5 for by-product

[3]kg egg mass/kg feed

[4]Calculated as outlined by Vukić Vranješ et al. (1994) for indicator techniques

Table 5.3 Effect of the by-product diet on egg quality in weeks 36 to 44[1] and 45 to 52[2] of lay

Type of hen	Lohmann Brown Plus		Lohmann Dual		Schweizerhuhn		Belgian Malines			*P*-values		
Diet	Control	By-product	Control	By-product	Control	By-product	Control	By-product	SEM	Type	Diet	Type × diet
Shell strength (N)												
Weeks 36 to 44	42.2^{a}	32.2^{ab}	39.4^{ab}	41.6^{ab}	34.5^{ab}	33.0^{ab}	32.4^{ab}	27.6^{b}	4.86	0.010	0.116	0.203
Weeks 45 to 52	40.2^{ab}	44.9^{a}	38.6^{ab}	38.7^{ab}	26.3^{b}	27.9^{ab}	20.6^{b}	23.8^{b}	3.71	<0.001	0.465	0.947
Shell thickness (μm)												
Weeks 36 to 44	404^{a}	349^{b}	396^{a}	374^{a}	371^{ab}	360^{ab}	339^{b}	320^{b}	19.8	<0.001	0.004	0.288
Weeks 45 to 52	386^{ab}	400^{a}	380^{ab}	368^{ab}	343^{abc}	329^{abc}	267^{c}	321^{bc}	14.0	<0.001	0.402	0.249
Shell (g/kg egg)												
Weeks 36 to 44	97.1^{a}	88.0^{a}	96.0^{a}	93.7^{a}	91.7^{ab}	91.9^{ab}	79.7^{b}	76.7^{b}	5.16	<0.001	0.135	0.523
Weeks 45 to 52	91.7^{ab}	98.1^{a}	91.3^{abc}	93.1^{ab}	85.2^{abc}	80.1^{abc}	66.3^{c}	75.8^{bc}	3.94	<0.001	0.371	0.543
Yolk (g/kg egg)												
Weeks 36 to 44	251^{c}	262^{c}	278^{bc}	280^{bc}	298^{b}	305^{ab}	339^{a}	348^{a}	12.6	<0.001	0.208	0.923
Weeks 45 to 52	260^{c}	255^{c}	293^{abc}	263^{bc}	308^{ab}	286^{abc}	343^{a}	335^{a}	9.7	<0.001	0.070	0.652
White (g/kg egg)												
Weeks 36 to 44	652^{a}	650^{a}	626^{ab}	626^{ab}	610^{bc}	603^{bc}	582^{bc}	575^{c}	14.3	<0.001	0.565	0.967
Weeks 45 to 52	649^{a}	647^{a}	616^{ab}	644^{ab}	607^{ab}	634^{ab}	591^{ab}	589^{b}	10.2	0.001	0.159	0.441
Haugh Units												
Weeks 36 to 44	88.5^{a}	94.5^{a}	91.9^{a}	94.2^{a}	70.1^{b}	75.7^{ab}	71.5^{b}	73.0^{b}	5.06	<0.001	0.100	0.862
Weeks 45 to 52	89.9^{ab}	92.9^{ab}	91.3^{ab}	96.2^{a}	74.4^{b}	79.0^{ab}	85.5^{ab}	81.1^{ab}	6.52	0.008	0.569	0.810
Yolk lightness (L*)												
Weeks 36 to 44	47.7^{a}	45.6^{ab}	47.2^{a}	43.0^{b}	46.1^{ab}	45.5^{ab}	46.2^{ab}	43.5^{b}	1.23	0.093	<0.001	0.173
Weeks 45 to 52	48.2^{a}	45.8^{ab}	46.3^{ab}	43.2^{b}	47.1^{a}	44.6^{ab}	45.4^{ab}	42.9^{b}	0.68	0.007	<0.001	0.975
Yolk redness (a*)												
Weeks 36 to 44	8.10^{ab}	6.32^{b}	7.85^{ab}	8.58^{a}	6.80^{ab}	6.20^{b}	8.10^{ab}	8.35^{ab}	0.754	0.002	0.333	0.040
Weeks 45 to 52	7.26	6.81	7.88	7.75	6.89	6.26	7.36	7.19	0.567	0.365	0.500	0.983
Yolk yellowness (b*)												
Weeks 36 to 44	29.1^{ab}	25.0^{bc}	30.0^{a}	23.7^{c}	26.3^{abc}	25.0^{bc}	28.0^{abc}	26.0^{abc}	1.62	0.530	<0.001	0.091
Weeks 45 to 52	28.8	24.3	28.4	24.4	27.7	22.8	26.0	24.9	1.24	0.774	0.003	0.683
Yolk color fan value												
Weeks 36 to 44	12.1^{ab}	11.4^{b}	12.3^{ab}	12.6^{a}	12.2^{ab}	12.2^{ab}	12.8^{a}	12.7^{ab}	0.45	0.008	0.635	0.306
Weeks 45 to 52	11.4	11.9	11.5	12.4	11.6	12.0	12.5	12.9	0.34	0.127	0.085	0.918

[a-c]Means in the same row without common superscript differ significantly ($P < 0.05$)

[1]Lohmann Brown Plus and Lohmann Dual, both n=10 per diet; Schweizerhuhn and Belgian Malines, both n=8 per diet

[2]Lohmann Brown Plus and Lohmann Dual, both n=5 per diet; Schweizerhuhn n=5 for control, n=4 for by-product; Belgian Malines n=4 for control, n=5 for by-product

5.4.3 Carcass and meat quality

The greatest ($P < 0.05$) carcass weight was obtained by the BM hens, followed by the CH hens, and the carcasses of the LD and LB hens were lightest (Table 5.4). The type effects had been more pronounced compared to final BW, as dressing percentage was also greatest ($P < 0.05$) for BM (4.5 % greater compared to LD and CH and 10 % greater compared to LB). Carcass weight was greater ($P < 0.05$) with diet C than with diet B by about 10% across all hen types. Breast meat proportion was greater ($P < 0.05$) in LD hens and thigh proportion was smallest ($P < 0.05$) compared to all other hen types. The thigh proportion increased ($P < 0.05$) with diet B compared to diet C in LB, but not in the other hen types (interaction, $P < 0.05$). Abdominal fat proportion was smaller ($P < 0.05$) in LB and LD than in CH and BM, and smaller ($P < 0.05$) with diet B than with diet C. Total meat yield per hen was greatest ($P < 0.05$) in BM, followed by CH and similar in LD and LB, whereas the diet did not have an effect. Breast meat yield was greatest ($P < 0.05$) in BM, followed by CH and LD, and lightest in LB. Hens fed diet C had a greater ($P < 0.05$) breast meat yield than hens fed B.

The pH of the left breast muscle remained unaffected by hen type and diet. Thaw loss was greatest ($P < 0.05$) in breast meat from LD fed diet B and smallest in CH and BM regardless of the diet (interaction, $P < 0.05$). Intermediate values were found for the breast meat of LB. Cooking loss was not affected by hen type, but was greater ($P < 0.05$) when hens were fed diet B than C. The cooked breast meat of the LD had a smaller ($P < 0.05$) maximal shear force than that of LB, with CH and BM in between. Feeding diet B led to a greater ($P < 0.05$) shear force of the meat compared to diet C. The breast meat was redder ($P < 0.05$) in LD than LB hens, with intermediate values for CH and BM. The breast meat from LD was more ($P < 0.05$) yellow than that from all other types. Diet B led to a greater ($P < 0.05$) yellowness compared to diet C (b^*, on average 1.17 vs. 0.42, respectively).

Table 5.4 Effect of the by-product diet on the slaughter performance, meat yield and meat quality

Type of hen	Lohmann Brown Plus		Lohmann Dual		Schweizerhuhn		Belgian Malines			*P*-values		
Diet	Control	By-product	Control	By-product	Control	By-product	Control	By-product	SEM	Type	Diet	Type × diet
Carcass weight (kg)	1.10^{cd}	0.93^{d}	1.19^{cd}	1.10^{cd}	1.67^{b}	1.52^{bc}	2.17^{a}	1.96^{ab}	0.109	<0.001	0.039	0.963
Dressing percentage	56.5^{d}	57.6^{cd}	61.7^{ab}	59.7^{bcd}	60.7^{abc}	61.6^{ab}	62.8^{ab}	64.3^{a}	0.96	<0.001	0.531	0.189
Carcass composition (g/kg carcass)												
Breast meat	177^{b}	177^{b}	240^{a}	234^{a}	177^{b}	178^{b}	190^{b}	188^{b}	7.3	<0.001	0.751	0.964
Thigh[1]	330^{b}	388^{a}	324^{b}	326^{b}	348^{ab}	358^{ab}	365^{ab}	367^{ab}	11.4	0.002	0.024	0.028
Abdominal fat	45^{bc}	0^{c}	31^{c}	19^{c}	168^{a}	127^{a}	175^{a}	109^{ab}	10.8	<0.001	<0.001	0.361
Meat yield (g/hen)												
Total	437de	387^{e}	547^{cde}	505^{cde}	691^{bc}	627^{cd}	940^{a}	870^{ab}	51.3	<0.001	0.100	0.991
Breast meat	191de	166^{e}	284^{bc}	255^{cde}	294^{bc}	269^{cd}	414^{a}	368^{ab}	22.3	<0.001	0.040	0.951
Breast meat quality												
pH	5.67	5.82	5.70	5.66	5.84	5.78	5.75	5.69	0.050	0.071	0.885	0.079
Thaw loss (%)	2.4^{b}	3.8^{ab}	2.7^{b}	5.4^{a}	1.7^{b}	1.8^{b}	2.8^{b}	1.8^{b}	0.53	<0.001	0.029	0.006
Cooking loss (%)	14.1	17.1	14.4	15.9	13.8	13.8	14.3	17.0	0.91	0.138	0.005	0.295
Shear force[2] (N)	18.8^{ab}	22.5^{a}	14.3^{b}	19.1^{ab}	18.5^{ab}	19.1^{ab}	17.9^{ab}	20.6^{a}	1.42	0.033	0.003	0.449
Color												
Lightness (L*)	52.8	55.7	52.6	54.2	50.5	51.2	51.4	52.2	1.38	0.047	0.107	0.790
Redness (a*)	2.02	1.47	2.84	2.61	2.43	1.81	2.56	2.44	0.349	0.047	0.146	0.876
Yellowness (b*)	0.21^{b}	1.06^{ab}	1.75^{ab}	2.84^{a}	0.11^{b}	0.60^{ab}	-0.39^{b}	0.17^{b}	0.523	<0.001	0.036	0.918

[a-e]Means in the same row without common superscript differ significantly ($P < 0.05$)

[1]With skin and bones

[2]Measured with the Volodkevich device

5.5 Discussion

The primary objective of the present study was to investigate whether dual-purpose types, being either the result of crossbreeding specialized layer and broiler lines (Damme et al., 2015b) or representing traditional breeds, would better tolerate a diet with lesser quality than specialized layer hybrids in the late laying phase. With that, poultry diets could be more sustainable in terms of feed-food competition, replace the controversially discussed soybean-based feeds and avoid supplementation of synthetic methionine. The resulting by-product diet tested was consequently considering these goals. This was possible at a decline in calculated ME content and a decline in calculated methionine content.

5.5.1 Response of dual-purpose types vs. layers to a by-product diet in laying performance

The response to the by-product diet by the layer type, Lohmann Brown Plus, in laying performance was quite drastic. A typical reaction of laying hens to a diet with a lower energy density would be an increase in feed intake as shown with Lohmann Brown hens by Li et al. (2013). However, in the present study, the opposite was the case. Feed intake was reduced with diet B and, along with the lower ME and methionine content of this diet, supply with ME and methionine was smaller. There could be two mechanisms explaining the intake depression. The first would be limitations by gut fill enhanced by the greater content of fiber. The other an impaired palatability of the diet or certain ingredients thereof, which, in addition changed visibly the color of the diet. It is well-established that an increasing fiber content in the diet has a diluting effect and at the same time, energy and nutrient digestibility is decreasing (Enting et al., 2007) because of negative effects of fibers on the digestive process (Mateos et al., 2012). A clear sign of an energy deficiency with the by-product diet was the reduction of abdominal fat. In contrast, there was no impairment of laying performance with the same hens in earlier periods of lay by omitting synthetic methionine (Mueller et al., 2016a) and by the same time reducing also ME density from 11.5 to 10.5 MJ ME/kg (Mueller et al., 2016b). Different from the present study, feed intake was not affected, and the methionine content of the soybean-based diet was higher even without supplementation (2.4 vs. 3.1 g methionine/kg diet).

The hens of the modern dual-purpose type, Lohmann Dual, were apparently slightly more tolerant to an unfavorable feed quality than the LB, but they also experienced performance losses and did not compensate the lower energy density of the by-product diet with a greater feed intake. The smaller laying percentage found in LD compared to LB with the control diet reflects the smaller persistence of laying performance (Icken and Schmutz, 2013; Urselmans et al., 2015). In both LB and LD extending the time on the by-product diet for the finishing period did not increase much the signs of deficiency (level of depression in laying percentage, egg size, body weight), but there were also no clear indications of adaptation in feed intake and performance to the by-product diet. Despite the far lower feed intake, the feed efficiency was (numerically) even poorer with the by-product diet than with the control diet in both LB and LD.

For the traditional dual-purpose types, Schweizerhuhn and Belgian Malines, the by-product diet seemed to be sufficient in this phase of laying. A possible reason could be the already small laying performance, and therefore the lower energy and nutrient requirements. Their laying performance was on the same level with both diets as with the by-product diet in LB and LD. The heavier BM did not consume more feed than the CH despite their higher maintenance requirements. In general, the feed efficiency of CH and BM was always poor compared to that of LB and LD, but got numerically even worse with the by-product diet.

5.5.2 Response of dual-purpose types vs. layers to a by-product diet in egg quality

Although egg quality is influenced by genetics, health, age and management system, nutrition may has an effect as well (Roberts, 2004). In the present experiment, there were mostly hen type effects, but also some diet effects were distinguishable. With age of the hens, the eggshell strength is decreasing (Tumova et al., 2014; Wolc et al., 2012) resulting in a breaking strength of 30 to 40 N in the late laying phase (Grashorn, 2018). The eggs produced by LB and LD were always in this range whereas eggshell strength was partly too weak in the traditional dual-purpose types especially during the last 8 weeks of lay, which would be an issue when such eggs should be marketed. The strength of the eggshell depends on both, the eggshell thickness and its weight, and the two traits are smaller in BM hens and CH hens, but for the latter in a smaller extent. Szentirmai et al. (2013) reported a positive correlation between body fat content of the hen (in the present study estimated as abdominal fat proportion at slaughter) and egg yolk proportion. This phenomenon would explain the present differences in yolk proportion of the egg composition between hen types. Haugh Units are an important measurement of the protein quality, which describes processing properties like foaming ability. The eggs of the LB and LD hens had greater Haugh Units. Akter et al. (2018) described a relationship between Haugh Units and feed efficiency. Hens selected for a favorable feed efficiency had greater Haugh Units. This would explain the advantage of LB and LD over CH and BM hens in this trait. The egg yolk color is an important factor in determining the acceptability of a product by consumers (Grashorn, 2016). They link it directly to the quality of the egg, although it does not refer to freshness or to the nutritive value of the egg. Even though the same amount of red and yellow pigments was added with the premix, it seems that the omission of corn in the by-product diet led to a smaller b*-value and therefore to a less yellow pigmented egg yolk, as corn is known to contain a great content of zeaxanthin, a yellow color pigment. However, these differences are considered rather small, as they could not be distinguished with the yolk color fan.

5.5.3 Response of dual-purpose types vs. layers to a by-product diet in carcass and meat quality

The value of spent hens depends on the amount of meat harvested per bird, as this is a process, which needs to be efficient to be maintained at all. Meat yield per hen depends on slaughter weight, dressing percentage and size of the muscles. In the present comparison, the BM hens were most favorable in this respect, followed by CH. The LD and LB hens had the least meat yield. It is questionable if the higher meat yield of BM and CH may counterbalance the disadvantage of a greater daily demand for energy and protein over one year of lay together with the unfavorable laying performance. Meat yield of the LB was similar small to that found by Loetscher et al. (2015) in another brown layer genotype (Isa Warren). Unexpectedly, total meat yield was not affected by the diet, even though final BW and carcass weight were lower with the by-product diet. Still, breast meat yield was impaired by this diet. There were differences in breast meat and thigh proportions between LD and LB, with greater breast meat proportions and smaller thighs in the LD. Here the broiler genes present in LD but not LB (Damme et al., 2015b) may have contributed. In addition, the dwarf gene (Damme et al., 2015b) shortens the legs giving the LD a characteristic appearance.

Regarding meat quality, the level of pH in the breast meat found is consistent with that found by Loetscher et al. (2014), and also Rizzi et al. (2007) found mostly similar pH values in a number of different hen types. Shear force correlates with tenderness (Lyon and Lyon, 1990). Meat from spent hens is known to be tougher than that from broilers due to the greater collagen content and cross-linkage (Chueachuaychoo et al., 2011). However, it seems that in processed food this toughness remains unnoticed because the consumer acceptance did not differ between patties produced from broiler or spent hen meat (Biswas et al., 2006). However, when consumed as cooked carcass instead, the meat from the LD was most favorable in this respect, although even the LB meat had a smaller shear force in the present study than that described by Loetscher et al. (2014). As the hens of both diet groups were slaughtered at a similar age, it was unexpected that the by-product diet obviously led to a higher shear force of the meat compared to the control diet. As breast meat of poultry has a very small fat content, differences in fat deposition can be excluded as a factor. It also remains unclear, why water-holding capacity (thaw and cooking loss) was less favorable with diet B than with C. Concerning meat color, hen type had a greater influence than diet. This is consistent with results from other studies, where meat color depended on hen type (Berri et al., 2005; Rizzi et al., 2007). Unexpectedly, the meat of the hens fed the by-product diet was more yellow than that from hens fed the control diet, even though corn was omitted in diet B and egg yolk yellowness was correspondingly less pronounced.

5.6 Conclusions

The present study showed that a diet where all potential foods were exchanged by agrifood industry by-products and where, consistent with organic farming regulations, synthetic methionine supplementation was omitted, clearly impaired laying performance of specialized layers and of modern dual-purpose hens. Although the performance depression was lower in the dual-purpose types with the by-product diet, it declined to the same level found in the layers, which makes it impossible to state whether the diet was really less detrimental in the dual-purpose type. This has to be tested by less drastic diet differences and in different phases of lay in order to determine whether diets of lesser quality may be fed to modern dual-purpose laying hens or not. The investigated traditional dual-purpose types, with their small laying performance at the end of lay, instead, tolerated the by-product diet without significant impairment. Egg production systems using such traditional breeds may therefore minimize feed-food competition and produce spent hens with a favorable meat yield and average meat quality. However, due to the lack of intensive selection, eggshell quality is of concern at the end of lay.

Chapter 6

General Discussion and Conclusions

Concerns about animal welfare in production systems, markets, politics and the public in general, as well as respective demands, are increasing. In the poultry sector, one big issue is the culling of day-old male layers in conventional as well as organic farming. To omit this practice, there are different possible solutions. This doctoral thesis investigated on the one hand the potential of dual-purpose types and on the other hand the feasibility of fattening the male layers. Different dual-purpose types, two traditional and two modern types, for meat and egg production were tested. They were compared with the respective specialized hybrids on the layer and the meat side. In addition, in depth analyses of meat and egg quality were conducted. The research project examined the characteristics, the opportunities and the potential constraints of dual-purpose systems. Additionally, the use of food industry by-products with alternative protein and energy sources was tested for such types, as it could have an enhanced potential to contribute to a sustainable resource utilization and food security according to the "feed no food" concept.

6.1 Dual-purpose types approach

When looking at dual-purpose types, it gets obvious that both traits, meat and egg production, suffer from lower performances because of the combination of a meat and an egg strain in one type (Damme et al., 2015b). Chickens from conventional meat production reach around 2.2 kg in five weeks and hens lay more than 310 eggs in one year. The type Lohmann Dual, according to the company's statements (Icken and Schmutz, 2013), performs reasonably well in egg yield (250 eggs per year) but also in weight gain (1.5 kg in 56 days or 3.0 kg in 70 days). Therefore, the dual-purpose strategy seems to be an especially interesting option for organic farming, where lower performances are aimed at. Bio Suisse (2018) recommend a minimum fattening period of 63 days with a maximum daily gain of 27.5 g. Therefore, in the present thesis a fattening period of 63 days was chosen. Fattening a modern and two traditional dual-purpose types showed that the performance of the latter was similar or only slightly better than that of layer cockerels, and confirmed previously reported insufficient growth and slaughter performances (Hörning et al., 2011). The modern dual-purpose type, however, performed very similar to the slow-growing broiler. This finding was of particular practical relevance and, therefore, two modern dual-purpose types were investigated in-depth in a subsequent large-scale practice-oriented upscaling experiment. They were compared with a slow-growing broiler and a layer type, and combined with an additionally prolonged fattening period of 84 days in order to get an optimal carcass weight (Chapter 3). Regarding growth and slaughter characteristics of the males, the dual-purpose types performed very similar to the slow-growing broiler, yet, two major drawbacks were observed in meat production. Firstly, feed efficiency was inferior by 0.2 kg/kg, which means 200 g more feed was needed per kg weight gain (Chapter 3). Thus, additional production costs of 2300 Swiss francs would be required when referring to a whole year of production (organic), when a maximum of 3000 birds are kept and a turnover rate of 5.5 is assumed. Secondly, a lower breast meat proportion represents a notable limitation, as the breast meat is the most valuable cut. Similarly, there are higher costs in the egg production with dual-purpose types than with specialized layer hybrids (Damme et al., 2015b). Therefore, it is obvious that the price of such dual-purpose products, produced under organic labels, is elevated compared to the standard organic production (Gangnat et al., 2018). Regarding meat and egg quality, no major constraints were detected. Only, especially at the beginning of lay, dual-purpose types laid smaller eggs. This means, compared to a specialized layer type, which lay around 3 % eggs in the S size (< 53 g/egg) dual-purpose types laid between 13 and 34 % eggs in the S size (Damme et al., 2015b).

6.2 Fattening of male layers

To avoid chick culling, the organic egg marketer Hosberg AG started with the label henne & hahn at the beginning of 2016 (Hosberg, 2018). They advertise that all chicks hatched for this label are used for production, even the males are fattened. These cockerels are fattened under organic conditions for 70 days and then breast meat, thighs or wings are offered as individual cuts or they can be purchased as "coquelet" with a carcass weight of about 600 g (Gallina, 2018). However, these products are not available in grocery stores, they can only be ordered on internet or purchased directly on the farm. The fattening of laying cockerels is financed by the higher meat prices compared to the standard organic meat prices. For layer cockerel breast meat, the price is CHF 75 vs. CHF 52 to 57 in grocery stores. The price for 6 eggs of the henne & hahn label, however, is similar to the price of 6 eggs from standard organic production, CHF 4.49 vs. CHF 4.85 to 5.25, respectively. A fattening period of 49 days as it is promoted by Koenig et al. (2012) is not feasible, as for organic production a minimum of 63 days is required to justify subsidies. The results of the present thesis show that growth performance and carcass quality are noncompetitive to other types. In the small-scale experiments (Chapter 2 and 4), the final body weight of the laying cockerels was between 42 and 49% smaller compared to the slow-growing broilers or the dual-purpose types. In the large-scale experiment, the difference in final body weight from the laying cockerels compared to dual-purpose types and the slow-growing broiler was between 37 and 39% (Chapter 3). Additionally, the most valuable part of the carcass, the breast meat, was thinner, shorter and lighter in layer males than in all other types. The present results are in line with other studies (Lichovníková et al., 2009; Murawska and Boncho, 2007). The analyzed meat quality of laying cockerels revealed that it is similarly high as found in the other types (Chapter 2, 3, 4).

6.3 Effect of agrifood industry by-products

To assess the exact nutrient requirements of modern dual-purpose types for fattening is important not only for economic reasons but also for the concept of feed no food. At the same time, the use of agrifood industry by-products could contribute to a sustainable agriculture. Koreleski and Świątkiewicz (2008) fed dual-purpose chickens with two levels of protein in the grower and finisher period and did not find any differences in body weight after 83 days. However, the reduction in protein was only 5 %. Additionally, their study was conducted with a crossbreed of traditional dual-purpose types (♂ Barret Rock × ♀ New Hampshire), which have even a slower growth compared to the modern dual-purpose types. These results could be confirmed with the experiments of the present doctoral project (Chapter 2 and 5) and also by Hörning et al. (2011). In another study, the effect of protein restriction (3 and 10 %, respectively to the control diet) in Lohmann Dual chickens was tested (Urban et al., 2018). Reducing the dietary protein content did not impair body weight development, which suggest a certain flexibility regarding nutrient requirements of dual-purpose types compared to fast-growing (Lewis et al., 1997) and slow-growing meat types (Quentin et al., 2003; Chapter 4). In order to get an overview of the characteristics of alternative protein and energy sources, industry by-products were used for a broiler and for a layer diet. In the broiler diet, soybean cake was partially substituted with rapeseed and sunflower cake, which resulted in a 20 % reduced crude protein content in the diet (Chapter 4). Protein reduction impaired growth performance and carcass quality, but this effect was less pronounced in the dual-purpose and the layer type than in the slow-growing broiler. Nevertheless, this raises the question whether the chosen substitution level in the present thesis was too high for all types. It is suggested that there is a threshold of reducing the dietary protein content. Accordingly, when fed a diet with a protein content reduced by 16% laying type cockerels were lighter (Halle et al., 2012). Regarding the same study of Halle et al. (2012) it is indicated that also the dietary energy content together with the protein content could have an effect on the cockerels development. They concluded that for a fattening of 49 days, a feed efficiency of 2.02 kg/kg and a body weight of 800 g could only be reached with an intensive fattening diet containing a crude protein content of 215 g/kg (instead of 200 and 180 g/kg) and an energy content of 12.5 MJ/kg metabolizable energy (instead of 11 and 12 MJ/kg metabolizable energy). In line with this suggestion are the results of Koenig et al. (2012) where laying type cockerels were fed a laying hen diet and a broiler diet, with a better body weight gain of the latter feed. The broiler diet was characterized by a greater metabolizable energy and a greater crude protein content than the laying hen diet (Koenig et al., 2012). The energy content played also an important role in the layer diet of the present project (Chapter 5). For the end of the laying period, a diet was composed without any potential food components, resulting in 1 MJ/kg smaller energy content, and an elevated dietary protein content of about 10%. The feasibility of composing such a diet is relevant, when the objective is to introduce it into the practice. First, because of the availability of alternative protein and energy sources, second because of the antinutritive compounds and third because of the methionine content, which is low in most plant derived protein sources and therefore unfavorable. Additionally, the maximum content of the different ingredients has to be respected, which could be complicated, especially when no other alternative source is available. Overall, the traditional dual-purpose types tolerated the by-product diet better than the modern types but the performance level was not the same (Chapter 5). Therefore, the formulation of this diet should be revised. The 7% of rapeseed cake was probably too high, as a maximum of 5% is suggested for layers with white eggs (Jeroch and Dänicke, 2013). It is suggested that this threshold could also be accepted for brown-egg layers as the Lohmann Tierzucht Company eliminated the gene for the inability to metabolize trimethylamine in all laying hens of Lohmann and H&N origin (Pottgüter, 2006) and therefore no "fishy taint" eggs occur anymore from 2007 onwards. Another possible disadvantage, which occurred especially at the beginning of the diet change, could have been the change of the diet color as the diet contained 5% of dark brown molasses. This resulted in a darker feed color and as hens are examining everything with their eyes, the color change did not remain unnoticed. Nevertheless, the idea of feeding industry by-products should not be put aside, as Havenstein et al. (2003) showed in fast-growing broiler types from the 50ies and 90ies, which were fed with standard feeds from these periods, that 10 - 15% of the improved growth rate and feed efficiency could be attributed to improvements in feed formulations. The same could be expected for the performance of layer types. The majority of the progress has, therefore, been achieved by genetic selection and, thus, the potential of such by-products should be used. Still, when formulating the diets, the potential of a 10 - 15% influence on performance should be taken into account.

6.4 Aspects of spent hen health and valorization

Current laying hen breeding programs focus on bone stability and egg shell quality in a prolonged laying cycle and shorter beaks, as a ban of the beak treatment is expected (Andersson, 2018; Eek, 2017; Schmutz, 2017; Preisinger, 2018). Together with the shorter beaks, a good plumage of the hens should be reached (Schmutz, 2017). Giersberg et al. (2017) reported a better plumage condition of Lohmann Dual hens compared with Lohmann Brown plus hens in the 70th week of life on farm level. Noticeable is that 0.5% of the Lohmann Brown plus flock was fully feathered on the back. In contrast, only 4.5% and 7% of the LD hens showed minor feather loss on the head/neck and breast/belly region, respectively. This is a clear advantage of the Lohmann Dual type, especially when hens have access to a pasture and can be observed at any time by the public. The question that remains is, if there is a relationship between the performance of the hens and the plumage condition. In this case, the lower yielding Lohmann Dual had a better plumage condition than the specialized layer hybrid Lohmann Brown Plus (Giersberg et al., 2017). A good bone health of the hens is important in all stages of production and gets even more necessary when prolonging the laying cycle. Keel bone fractures are a big issue in laying hen welfare, and, therefore different approaches to reduce such fractures are proposed (Stratmann et al., 2015; Toscano et al., 2018) but also breeding may contribute (Andersson, 2018). If dual-purpose type hens have a better bone strength remains unclear at the moment due to the lack of targeted studies, but it should be further investigated. Bone strength of dual-purpose type males was greater than of layer males (Chapter 2), which would be a great advantage for dual-purpose types when the same results could be found for hens. The handling of the hens, especially during depopulation can cause bone fractures (Andersson, 2018) which could have an impact on the processing after slaughter when undesired bone fragments are in the meat. Regarding animal welfare, not only the housing system and the health status during productivity are important but also the appreciation after the production cycle. This means that after one year of production, the spent hens should be slaughtered, where the use of their meat is possible. In 2016, 70% of all Swiss spent hens were slaughtered and only 30% were culled on the farms and discarded in biogas plants (Wahl, 2017). Instead of selling the whole carcasses, the meat could be harvested from the carcasses and then processed to sausages or convenience food (Arya et al., 2017; Lee et al., 2003; Loetscher et al., 2015), which was realized in Switzerland (Wahl, 2017). Additionally, it was shown that the tougher meat from spent hens compared to broiler meat was less recognized by consumers, when it was processed (Biswas et al., 2006). However, efficient processing needs a significant meat yield per carcass, which is well known to be unsatisfactory in layer hybrids, whereas with traditional dual-purpose types it was favorable (Chapter 5). Nevertheless, it should be taken into account that laying performance is more important for hens than meat yield after a year of production. Therefore, the traditional dual-purpose types with a low laying percentage should be excluded as a possibility for introducing to the practice. The meat yield with Lohmann Dual was on average 114 g greater per hen compared to Lohmann Brown plus, even if not significant (Chapter 5). Calculated for a flock of organic production, where a maximum of 4000 hens are kept (Bio Suisse, 2018) it results in a 456 kg greater meat yield with Lohmann Dual, which is a remarkable quantity that is lost, when culling directly on the farm.

6.5 Consumers expectations

New food technologies or new food products can only be successfully introduced when consumers are willing to accept them (Siegrist, 2008). As there are huge differences between experts and laypersons' acceptance of animal production methods (Delezie et al., 2007; Zingg and Siegrist, 2012) it is crucial to investigate the consumers' willingness to buy new chicken products at an early stage of product development, because the producers are dependent on the consumers. In the present case, dual-purpose types are only used in the organic production, which is accompanied with an increase of the products' price compared to the conventional and the standard organic poultry production (Gangnat et al., 2018). Experiences show that Swiss consumers appreciate animal-friendly and free-range housing. This can be derived from the acceptance of higher prices of Swiss eggs compared to imported eggs. Swiss eggs had a market share of 78.6% of total shell eggs in 2017 (Aviforum, 2018). Additionally, 17.2% of the total Swiss egg production is achieved under the organic label (Aviforum, 2018) and therefore, the egg production is the most important part in the organic sector. An earlier conducted in-store customer survey revealed that Swiss consumers are willing to pay a premium price for chicken meat produced in Switzerland (Bolliger and Réviron, 2008). A recently conducted study about the consumers' willingness to pay a higher price for dual-purpose type products reported that there is a segment of consumers willing to pay 13% more for dual-purpose chicken meat than the observed prices for conventional Swiss chicken breast meat but not as much as for standard organic chicken breast meat (Gangnat et al., 2018). This suggests that dual-purpose chicken meat and eggs are only purchased by consumers, which are not price-sensitive. Additionally, it was shown, that the meat quality was not inferior (Chapter 2, 3, 4). Moreover, in western countries there are no serious food shortages, which allows putting the focus on healthy food.

In addition, with the promotion of specific food ingredients and the relationship to health the consumers got more health-conscious. This awareness led to the trend towards healthy and nutritious foods. Therefore, the advantage of chicken meat compared to other meat is the low fat content and the high amount of unsaturated fatty acids (Swiss Food Composition Database, 2018; Chapter 4). In addition, the fatty acid content in chicken meat can be altered regarding a decrease of the n-6:n-3 ratio by the diets the animals receive (Chapter 4), which have an important health impact to humans (Young et al., 2017) as a great n-6:n-3 ratio is associated with metabolic and coronary heart diseases (Lavie et al., 2009; Molendi-Coste et al., 2011). Dietary fatty acid composition can also alter the fatty acid composition in eggs, exclusively the egg yolk (Poureslami et al., 2012). This could be an advantage for poultry products as they could have a beneficial effect on health and at the same time, they are produced environmentally friendly, particularly if food industry by-products can be used. However, it is crucial that the consumers are informed about the possible beneficial effects of such products (Gangnat et al., 2018).

6.6 General conclusions and outlook

For a type screening, a first fattening experiment was conducted with a modern and two traditional dual-purpose types. As expected, none of the dual-purpose types could compete with the fast-growing broiler but the modern dual-purpose type was very similar to the slow-growing broiler used in organic production. The traditional dual-purpose types performed similar or only slightly superior to the male laying cockerels in growth and subsequent slaughter. Thus, the first hypothesis underlying the present doctoral thesis can be partially verified. This is also confirmed by the laying experiment, where the traditional dual-purpose types performed clearly less than the modern dual-purpose type. Due to the antagonistic characteristics of meat accretion and laying performance, the Lohmann Brown males grew very slowly in all experiments. Even a prolonged fattening period to 84 days could not improve slaughter performance and carcass quality. Only when the fattening period lasted for 126 days, the carcass quality was comparable to the modern dual-purpose types fattened for only 67 days, which make the former clearly inferior to the dual-purpose types. Nevertheless, a fattening period of 126 days is not realistic because of the economic loss for the farmer. Therefore, these results verified the second hypothesis. Regarding the two hypotheses mentioned above and taking Switzerland as example, it cannot be answered if it is more beneficial to use dual-purpose types, where the egg and the meat production are suffering from lower performances, or instead to fatten male layer cockerels, where the egg production remains unchanged but the fattening performance of such types is poor. It is suggested that every farmer should decide for himself, which is the best solution to avoid chick culling. It is noteworthy, however, that the meat quality of such laying cockerels is comparably high to the one of dual-purpose types and slow-growing broiler types and even slightly enhanced compared with fast-growing broilers. Therefore, the fourth hypothesis could be verified.

With two experiments, the use of food industry by-products was tested, as it was expected that with a lower performance, the requirements are lower. To substitute to some extent the ingredients with alternative protein and energy sources is possible, yet, the exact protein and amino acid level in the diets and requirements of the birds have to be further investigated. It seems that a dietary crude protein reduction of 20% for fattening is too drastic. Additionally, the experiments took place in a very controlled setting and further testing should also be conducted in a more practice-oriented environment. Regarding the meat quality, it remained unchanged or could even be improved as the fatty acid profile was altered in a constitutional way. In addition, outer and inner egg quality remained similarly high with the food industry by-product diet. The only point that needs to be considered is the egg yolk color, which may change depending on the ingredients used. However, the third hypothesis can be partly verified, as the performance was impaired but not the product quality. A greater influence on egg quality had the type, but the differences found were small and do not impair egg quality. Thus, hypothesis five can be confirmed.

For the hens, only the small-scale experiment was conducted and it could give deeper insights about the performance, when testing in a more practice-oriented trial. Overall, it is suggested to use only modern dual-purpose types for an economic poultry production as the performance of the traditional ones was found to be insufficient. Additionally, in such an experiment more traits to investigate the health status and bone strength of dual-purpose types should be taken into account.

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