FACULTY OF BIOTECHNOLOGY
AND FOOD SCIENCES
SUA IN NITRA

MEAT AND LIVER QUALITY OF OVERFED DUCK

Juraj Čuboň • Miroslava Hlebová • Peter Haščík

DOI: https://doi.org/10.15414/2022.9788055224978

Nitra **2022**

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Scientific monograph

2022

DOI: https://doi.org/10.15414/2022.9788055224978

Title: Meat and liver quality of overfed duck

Authors: prof. Ing. Juraj Čuboň, CSc. /1.29 AQ/
Institute of Food Sciences
Faculty of Biotechnology and Food Sciences,
Slovak University of Agriculture in Nitra,
Tr. A. Hlinku 2, 949 76 Nitra, Slovakia.

Ing. Miroslava Hlebová, PhD. /3.02 AQ/
Department of Biology,
Faculty of Natural Sciences,
University of SS. Cyril and Methodius,
Nám. J. Herdu 2, SK-91701 Trnava, Slovak Republic.

prof. Ing. Peter Haščík, PhD. /1.28 AQ/
Institute of Food Sciences,
Faculty of Biotechnology and Food Sciences,
Slovak University of Agriculture in Nitra,
Tr. A. Hlinku 2, 949 76 Nitra, Slovakia.

Reviewers: prof. Ing. Stanislav Kráčmar, DrSc.
College of Business and Hotel Management, Brno,
Bosonožská 9, 625 00 Brno,
Czech Republic.

Assoc prof. Ing. Soňa Felšöciová, PhD.
Institute of Biotechnology,
Faculty of Biotechnology and Food Sciences,
Slovak University of Agriculture in Nitra,
Tr. A. Hlinku 2, 949 76 Nitra, Slovakia.

The scientific monograph was published with the financial support of Drive4SIFood 313011V336, co-financed by the European Regional Development Fund.

Approved by the Rector of the Slovak University of Agriculture in Nitra on the 6th July 2022 as an online scientific monograph.

ISBN 978-80-552-2497-8

DOI: https://doi.org/10.15414/2022.9788055224978

Acknowledgment

The team of authors thanks the staff of the Institute of Food Sciences, Faculty of Biotechnology and Food Sciences of the Slovak University of Agriculture in Nitra for creating working conditions and for helping with the analysis and evaluation of the results of the experiment. The scientific monograph was implemented with the support of Drive4SIFood 313011V336, co-financed by the European Regional Development Fund.

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Introduction

Waterfowl have been used by people for more than 5,000 years as food for meat, fattened roast eggs and eggs. Waterfowl is more comfortable for regions with hot and humid climates such as chickens. One of the birds for slaughter is the Muscovy duck. Musk ducks have better adaptability to hot climates and suitable for farmers in Africa, especially in Egypt, has contributed to food security. Even today, Egypt is a leading producer of 39,000 tons of duck meat and 43,000 tons of goose meat. This suggests that the production of waterfowl in is generally gaining more attention in Egypt than a source of animal protein. Forced feeding is an ancient practice, first recorded in ancient Egypt. The tradition of forced feeding is very old, dating back to Egypt 2500 BC. Forced feeding is an ancient practice in Egypt and only a few species of waterfowl are currently used to produce fat in the liver.

Ducks prefer wet mash due to difficulties in swallowing dry mash. Ducks may be grown on dry mash, a combination of dry and wet mash or pellets. The use of range, pond or supplementary green feed, reduces the feed cost. Ducks are good foragers. Ducks should never have access to feed without water. During the first eight weeks, birds should always have access to feed, but later on they may be fed twice a day. At traditional system duck consumes about 12.5 kg of feed to age of 20 weeks.

Ducks prefer wet mash due to have no teeth; food is swallowed whole and goes into the crop where it is stored and mixed with saliva. The feed passes into the stomach where it mixes with the juices before passing into the roundish, thick walled, muscular organ gizzard. The gizzard contains small stones which the bird has eaten to help the gizzard to grind up the food for digestion. Nutrients are absorbed as ground up feed passes along the intestine.

Foie gras is mainly produced in Europe. France is the most important producer country in the world with 19,310 tons per year which represents 73% of total world production, followed by Bulgaria with production 2,600 tons per year and Hungary 2,590 tons per year. French production of goose foie gras is 462 tons per year. The foie gras duck production system is in two phases, at first the rearing period from hatching to 10 weeks, followed by the fattening period which lasts between 9 and 20 days during which the poultry are fed a mixture composed mainly of corn and water.

For many centuries, ducks have been the focus of human interest, both in terms of meat and egg production. In many countries, duck meat is a popular dish and especially the liver is considered a delicacy. In the case of forced feeding, especially corn, the duck can produce large livers with a high fat content both in the liver and in the carcass. A by-product of duck farming

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is feathers, which, however, do not match those of goose. In some countries, ducks are also kept for egg production. Duck eggs are nutritionally identical to hen eggs and are an important source of protein. In the ancient past, ducks were obtained by dropping nests or capturing birds themselves. For nomadic peoples, duck hunting has been a common means of subsistence in many parts of the world. Although most ducks are flying, it is very easy to trim their wings and establish a simple captivity. Because many species nest on land, obtaining hatching eggs would be relatively easy. Of the 147 wild ducks, geese, and swans, only four have been domesticated worldwide. Two of them are Greylag geese (*Anser anser*) and Swan Goose geese (*Anser cygnoides*). And two of them are ducks: Muscovy (*Cairina moschata*) and Northern Mulard (*Anas p. Platyrhynchos*). Probably these species are the ancestors of almost all breeds of domestic ducks. The production of poultry, which includes geese and ducks in Slovakia, has been steadily declining since 2000. The share of geese and ducks in the total poultry production in Slovakia is currently only 1.7%. In 2000, Slovakia produced 528 tons of live ducks, but in 2014 it was only 80 tons. The most significant decrease in duck production was between 2002 and 2011 with a drop of 498 tons. The share of duck sales in total poultry production fell from 5.5% to the current 0.9%. The share of goose production is at the level of 0.8%. Between 2013 and 2014, the production of ducks increased by 38%, from 58 to 80 tons. In geese, they recorded an increase from 38 tons in 2013 to 78 tons in 2014. The reason for this increase is not a real improvement in breeding, but the monitoring of production through the Central Livestock Register of Slovak republic, which registered farmers and small farmers who did not provide data before. The transformation of cooperatives in Slovakia, the high EU criteria for the slaughter of poultry and the non-existent subsidies for large-scale farms have caused the gradual disappearance of large-scale farms and slaughterhouses in Slovakia. Aquatic poultry farming is therefore currently focused on smaller farms and small farmers.

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Abstract

The aim of scientific monograph is to analyse the quality of meat, liver and abdominal fat of ducks from overfeeding. The ducks of the overfed group had a significantly higher pre-slaughter weight of 5.96 kg than the control group of 4.58 kg. We found a statistically significant difference in weight after slaughter, an overfed group of 5.53 kg and a control group of 4.16 kg. We found a statistically highly significant difference in the liver weight, which was more than 8 times heavier in the ducks of the overfed group (613.20 g) than in the ducks from the control group (76.21 g). Was found a statistically highly significant difference in the weight of abdominal fat, in the carcass of ducks of the overfed group 981.01 g and in the carcass of ducks of the control group 237.15 g. In the overfed group, the proportion of stearic acid in the breast muscle decreased significantly from 11.68 to 11.09 g.100 g^{-1} FAME in the liver from 14.29 to 9.98 g.100 g^{-1} FAME and in the abdominal fat from 6.28 to 4.08 g.100 g^{-1} FAME. The EPA content decreased from 0.012 to 0.07 g.100 g^{-1} FAME in the overfed group and from 0.13 to 0.09 g.100 g^{-1} FAME in the thigh muscle. MUFA content increased in the overfed group in the breast muscle from 45.02 to 50.75 g.100 g^{-1} FAME in the thigh muscle from 46.89 to 49.41 g.100 g^{-1} FAME, in the liver from 38.52 to 47.49 g.100 g^{-1} FAME and in the abdominal fat from 53.21 to 59,62 g.100 g^{-1} FAME. The SAFA content in the overfed group decreased in the breast muscle from 36.34 to 34.55 g.100 g^{-1} FAME, in the thigh duck muscle from 37.59 to 34.89 g.100 g^{-1} FAME, in the liver from 39.12 to 33.89 g.100 g^{-1} FAME and in the abdominal fat from 33.11 to 28,31 g.100 g^{-1} FAME. The results were used to calculate the correlations. In the breast muscle of the overfed group a positive correlation of carcass weight to liver, fat thickness, myristic acid, palmitic acid, oleic acid, eicosenoic, eicosapentaeonic, docosapentaeonic FA, and SAFA content was confirmed. Negative correlation of carcass weight to ω-3 FA, ω-6 FA and PUFA was confirmed. Positive correlation of liver weight to fat thickness, myristic FA, palmitic acid, oleic acid, eicosenoic, eicosapentaeonic, docosapentaeonic, and SAFA content was confirmed. In the breast muscle of the control group a positive correlation of liver weight to fat thickness, oleic FA, ω-3 FA, linoleic FA, essential FA, DHA, PUFA content and cholesterol content was confirmed. Negative correlation of liver weight to heptadecanoic, myristic, stearic, eicosenoic, ω-6 FA, arachidonic FA, MUFA and SAFA content was confirmed. Positive correlation of fat thickness to liver weight, oleic FA was confirmed. Negative correlation of fat thickness to lauric FA, myristic FA, stearic and eicosenoic FA was confirmed. Positive correlation of cholesterol content to liver weight, ω-3 FA, oleic, conjugated linoleic FA, essential FA, DHA, DPA, and PUFA was confirmed.

DOI: https://doi.org/10.15414/2022.9788055224978

The negative correlation of cholesterol content to heptadecanoic FA, alpha-linoleic, linoleic, myristic, palmitic, stearic, ω-6 FA, MUFA and SAFA content was confirmed. In the thigh muscle of the overfed group a positive correlation of carcass to vaccenic FA, DPA, ω-6, and PUFA was confirmed. Negative correlation of carcass weight to fat thickness, lauric FA, oleic, palmitic, stearic, ω-3 FA was confirmed. Positive correlation of liver weight to essential FA, DHA, DPA, MUFA content was confirmed. Negative correlation of liver weight to palmitic, eicosenioc, arachidonic FA, SAFA content was confirmed. Positive correlation of fat thickness to alpha-linoleic FA, EPA, and PUFA content was confirmed. Negative correlation of fat thickness to oleic FA, palmitic, stearic and cholesterol contents was confirmed. Positive correlation of cholesterol content to lauric FA, arachidonic, palmitic, oleic, ω-3 FA and MUFA content was confirmed. Negative correlation of cholesterol content to carcass weight, fat thickness, heptadecanoic, alpha-linoleic, linoleic, vaccenic, ω-3 FA EPA, PUFA and SAFA content was confirmed. In the thigh muscle of the control group a positive correlation of liver weight to alpha-linoleic FA, palmitic FA, vaccenic, oleic, eicosenoic FA, EPA, PUFA and MUFA content was confirmed. Negative correlation of liver weight to heptadecanoic, myristic, palmitic FA, ω-3 FA, ω-6 FA and DPA was confirmed. Positive correlation of fat thickness to palmitic FA was confirmed. Negative correlation of fat thickness to ω-3, FA ω 6-FA and DPA was confirmed. The positive correlation of cholesterol content to alpha-linoleic FA, linoleic, oleic, eicosenoic FA and EPA was confirmed. The negative correlation of cholesterol content to heptadecanoic, lauric, myristic, oleic, linoleic, essential FA, DHA, arachidonic FA and MUFA content was confirmed. Liver weight of overfed group positively correlates with oleic acid FA, and MUFA content. Liver weight of overfed group is negatively correlated with alpha-linoleic FA, myristic FA and stearic FA. In the liver of the control group. Liver weight of control group positively correlates with ω-3 FA, ω-6 FA oleic FA, stearic FA and MUFA. Liver weight of control group is negatively correlated with palmitic FA and PUFA.

Key words: Mulard, overfeeding, fatty acids, amino acids, liver, abdominal fat, correlation

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Abstrakt

Cieľom vedeckej monografie bolo analyzovať kvalitu mäsa, pečene a brušného tuku kačíc z intenzívneho dokrmu. Kačice skupiny z intenzívneho dokrmu mali pred zabitím výrazne vyššiu hmotnosť 5,96 kg ako kontrolná skupina 4,58 kg. Zistili sme štatisticky významný rozdiel v hmotnosti po zabití, prekŕmenej skupine 5,53 kg a kontrolnej skupine 4,16 kg. Štatisticky vysoko významný rozdiel sme zistili v hmotnosti pečene, ktorá bola u kačíc z prekŕmenej skupiny (613,20 g) viac ako 8-krát ťažšia ako u kačíc z kontrolnej skupiny (76,21 g). Bol zistený štatisticky vysoko významný rozdiel v hmotnosti brušného tuku, v jatočnom tele kačíc z intenzívneho dokrmu 981,01 g a v jatočnom tele kačíc kontrolnej skupiny 237,15 g. V skupine z intenzívneho dokrmu sa výrazne znížil podiel kyseliny stearovej v prsnej svalovine z 11,68 na 11,09 g.100 g^{-1} FAME v pečeni zo 14,29 na 9,98 g.100 g^{-1} FAME a v abdominálnom tuku z 6,28 na 4,08 g.100 g^{-1} FAME. Obsah EPA klesol z 0,012 na 0,07 g.100 g^{-1} FAME v prekrmovanej skupine a z 0,13 na 0,09 g.100 g^{-1} FAME v stehennom svale. Obsah MUFA sa zvýšil v prekrmovanej skupine v prsnom svale z 45,02 na 50,75 g.100 g-1 FAME v stehennom svale zo 46,89 g.100 g^{-1} FAME, na 49,41 g.100 g^{-1} FAME, v pečeni z 38,52 na 47,49 g.100 g^{-1} FAME a v brušnom tuku od 53,21 do 59,62 g.100 g^{-1} FAME. Obsah SAFA v skupine z intenzívneho dokrmu klesol v prsnom svale z 36,34 na 34,55 g.100 g^{-1} FAME, v stehennom kačacom svale z 37,59 na 34,89 g.100 g^{-1} FAME, v pečeni z 39,12 na 33,89 g. 100 g^{-1} FAME a v brušnom tuku od 33,11 do 28,31 g.100 g^{-1} FAME. Zo získaných výsledkov bol stanovené korelácie. V prsnom svale prekrmovanej skupiny bola potvrdená pozitívna korelácia hmotnosti jatočného tela k obsahu pečene, hrúbky tuku, kyseliny myristovej, kyseliny palmitovej, kyseliny olejovej, eikozénovej, eikosapentaeónovej, dokosapentaeónovej a SAFA. Potvrdila sa negatívna korelácia hmotnosti jatočného tela k ω-3 MK, ω-6MK a PUFA. Potvrdila sa pozitívna korelácia hmotnosti pečene k hrúbke tuku, myristovej MK, kyseline palmitovej, olejovej, eikozénovej, eikosapentaeónovej, dokosapentaeónovej a obsahu SAFA. V prsnom svale kontrolnej skupiny bola potvrdená pozitívna korelácia hmotnosti pečene k hrúbke tuku, olejovej MK, ω-3 MK, linolovej MK, obsahu esenciálnych MK, DHA, PUFA a cholesterolu. Potvrdila sa negatívna korelácia hmotnosti pečene s obsahom heptadekanovej, myristickej, stearovej, eikosenovej, ω-6 MK, arachidónovej MK, MUFA a SAFA. Potvrdila sa pozitívna korelácia medzi hrúbkou tuku a hmotnosťou pečene. Potvrdila sa negatívna korelácia hrúbky tuku s laurovou MK, myristovou MK, stearovou a eikosenovou MK. Potvrdila sa pozitívna korelácia obsahu

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cholesterolu s hmotnosťou pečene, ω-3 MK, olejovej, konjugovanej linolovej MK, esenciálnych MK, DHA, DPA a PUFA. Potvrdila sa negatívna korelácia obsahu cholesterolu s obsahom heptadekanovej MK, alfa-linolovej, linolovej, myristovej, palmitovej, stearovej, ω-6 MK, MUFA a SAFA. V stehennom svale prekŕmenej skupiny bola potvrdená pozitívna korelácia jatočného tela s vakcinálnymi FA, DPA, ω-6 a PUFA. Potvrdila sa negatívna korelácia hmotnosti jatočného tela k hrúbke tuku, laurovej MK, olejovej, palmitovej, stearovej, ω-3 MK. Potvrdila sa pozitívna korelácia hmotnosti pečene s obsahom esenciálnych MK, DHA, DPA, MUFA. Potvrdila sa negatívna korelácia hmotnosti pečene s obsahom palmitových, eikoseniovou, arachidónovej MK a SAFA. Potvrdila sa pozitívna korelácia hrúbky tuku s obsahom alfa-linolovej MK, EPA a PUFA. Potvrdila sa negatívna korelácia hrúbky tuku s obsahom olejovej MK, palmitovej, stearovej a cholesterolu. Potvrdila sa pozitívna korelácia obsahu cholesterolu s obsahom laurovej MK, arachidónovej, palmitovej, olejovej, ω-3 FA a MUFA. Potvrdila sa negatívna korelácia obsahu cholesterolu k hmotnosti jatočného tela, hrúbke tuku, heptadekanovej, alfa-linolovej, linolovej, vakcenickej, ω-3 MK obsahu EPA, PUFA a SAFA. V stehennom svale kontrolnej skupiny bola potvrdená pozitívna korelácia hmotnosti pečene s obsahom alfa-linolovej MK, palmitovej MK, vakcénovej, olejovej, eikozénovej MK, EPA, PUFA a MUFA. Potvrdila sa negatívna korelácia hmotnosti pečene s heptadekanovou, myristovou, palmitovým MK, ω-3 MK, ω-6 MK a DPA. Potvrdila sa pozitívna korelácia hrúbky tuku s palmitovou MK. Potvrdila sa negatívna korelácia hrúbky tuku k ω-3, MK ω 6-MK a DPA. Potvrdila sa pozitívna korelácia obsahu cholesterolu s alfa-linolovou MK, linolovou, olejovou, eikozénovou MK a EPA. Potvrdila sa negatívna korelácia obsahu cholesterolu s obsahom heptadekanovej, laurovej, myristovej, olejovej, linolovej, esenciálnych MK, DHA, arachidónovej MK a MUFA. Hmotnosť pečene skupiny z intenzívneho dokrmu pozitívne koreluje s kyselinou olejovou a obsahom MUFA. Hmotnosť pečene skupiny z intenzívneho dokrmu negatívne koreluje s alfa-linolovou MK, myristovou MK a steárovou MK.

Kľúčové slová: Mulard, intenzívny dokrm, mastné kyseliny, aminokyseliny, pečeň, brušný tuk, korelácia

DOI: https://doi.org/10.15414/2022.9788055224978

1 Literature review

1.1 Duck domestication

Domestication of animal was one the major factors to the agricultural revolution. During the Neolithic period, domestication resulted in a shift in human lifestyle from hunting to farming **(Li and Zhang, 2009).** Domesticated animals significantly change in behaviour, morphology, physiology, and reproduction compared with their wild progenitors **(Darwin, 2022).** The main domestication factors are selection.

Mulards (*Anas platyrhynchos*) are the world's most widely distributed and agriculturally in Asia **(Huang et al., 2013).** The first written records of domestic ducks in central China are after 500 BC **(Kiple and Ornelas, 2000).** Southern China is the major centre duck domestication, with records indicating duck farming dating at least 2,000 years, particularly in regions with rice crops **(Bray and Needham, 1984)**.

Domestic ducks were domesticated primarily for meat and eggs production. It is unclear whether ducks were domesticated once and subsequently selected for divergent meat and egg production traits or whether meat and egg populations were derived independently in two domestication events from wild Mulards. Domesticated ducks show many important behavioural **(Miller, 1977)** and morphological differences opposite their wild ancestors. Important differences particularly related to plumage and neuroanatomy **(Duggan et al., 2015).** Population and demographic analyses indicate a complex history of domestication, with early selection for separate meat and egg lineages. Genomic comparison of wild to domesticated duck populations suggests that genes that affect brain and neuronal development have strong positive selection effects during period of domestication. Results indicates that the duck white plumage is affected by selection at the melanogenesis associated transcription factor locus **(Zhang et al., 2018).**

Domestication is the gradual, purposeful transformation of wild animals into species suitable for breeding under artificial conditions. Domesticated animals either provide some benefit (meat, milk) or are kept for pleasure. These animal species can be kept in captivity without much risk **(Ao et al., 2019).**

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1.2 Origin, breeds, and useful types of ducks

1.2.1 Origin of the domestic duck

Ducks bred for their useful properties come from the wild duck - *Anas platyrhynchos*. Wild duck occurs in Asia, Europe, and North America. Wild ducks living in freezing areas in winter are migratory. The colour of the ducks' feathers is grey, brown with a purple green "mirror" on the wings. The duck is a more colourful in the spring and in June to July the so-called “Summer feathering” that is like a duck. Domestication first took place in China, where ducks were also artificially hatched and reared. Later, the duck was domesticated in Northwestern Europe and in ancient Rome **(Hrnčár, 2014).**

1.2.2 Duck breeds

Most duck breeds were bred based on Mulard duck, also called marzipan (*Anas p. platyrhynchos*). It is widespread in Europe, Asia, North Africa, and North America. It was domesticated in China and independently in Germany, France, and Rome. The duck has a pronounced sexual dimorphism. Mulards have also been domesticated in Mangrove forests in China, where there are woody communities located in the tidal zones of tropical and subtropical areas (**Tomlinson, 2016**). The Mangrove Forest area provides a wide range of ecosystems and habitats suitable for duck domestication (**Polgar and Jaafar, 2017**). The mangrove area is still used in China to produce duck meat along with beekeeping, molluscs, fish, shrimp, and crabs **(Bosma et al., 2016).** The pursuit of sustainable use of mangrove resources is a prerequisite for mangrove protection in developing countries **(Ao et al., 2019).**

The Muscovy duck comes from a wild duck (*Cairina muschata*), which is terrestrial and nests in trees, its facial part is feathered, covered with red warty skin **(Greč and Horváth, 1996).**

Duck breeds are divided according to the direction of efficiency into meat, laying and combined. The most widespread and only recognized breed for large-scale production conditions is the white Chinese duck of the American type. This breed has become the basis of duck meat production worldwide. Useful types of ducks were bred based on a white Peking duck. By combining its lines with other breeds and lines, types are obtained which are characterized by excellent reproductive properties, growth rate, meat yield and feed conversion **(Greč and Horváth, 1996).**

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1.2.2.1 Breeds of domestic ducks

- By place of origin:
  - European regional breeds (Pomeranian duck, Runaway duck),
  - Asian breeds (Peking duck, Indian runner),
  - interstitial breeds (American Peking Duck),
  - North American breeds (Kajuga).
- By size:
  - light breeds (Kampbelka),
  - medium breeds (Pomeranian duck, Kajuga),
  - large breeds (Peking duck, Runaway duck),
  - ornamental breeds (egg emerald duck) **(Hrnčár, 2014).**

1.2.2.2 Breeds and utility types of ducks

The ducks were kept domesticated in southern China in time of dynasty Han. This gave rise to domesticated varieties in East and Southeast Asia, from where ducks moved to the eastern Mediterranean. The development of domestic duck breeds, like hens, went in two directions. One direction was to breed suitable carrier (lighter) ducks, the other was to obtain meat (heavier) breeds. Within these breeds, various types of ducks have been developed in recent years, including ducks with combined performance. Most breeds of domestic ducks come from the Mulard duck (*Anas platyrhynchos*), which lives throughout Europe, Asia, and North America. The only exception is the domesticated Muscovy duck, which evolved from its wild form (*Carina moschata*). This duck inhabits the tropical regions of Central and South America and differs from our wild duck in addition to its appearance mainly in that it lives on trees. Pekin duck breed is the finest dual-purpose breed evolved from China which is utilized for egg and meat production in the world. China is also the homeland for dual-purpose breeds like Gaoyou and Linwu. Further Chinese breeds like Shan Ma, Shaoxing, Jingding, and Liancheng excel in egg production. Brown Tsaiya of Taiwan and Indian Runner of East Indies produced more than 330 eggs in a year. England is the homeland Aylesbury for meat purpose, Campbells for egg purpose, and dual-purpose breed Orpington. Duck breed Rouen in France and Swedish and Germany have the European origins. Duck breed Cayuga, Crested duck, and East Indie is

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the homeland in America. Japan breed Mandarin is an ornamental breed. Apart from this, there are many local ecotypes and known breeds, which have only local use **(Su, 2022).**

1.2.2.3 Meat Duck Breeds

In the world, duck breeds are the most bred for meat production:

- Pekin duck,
- Mulard duck,
- Muscovy duck,
- Aylesbury duck,
- Rouen duck.

The Pekin or White Pekin is an American breed of duck, raised primarily for meat production. It derives from ducks brought to the USA from China, and now is bred in the world. It is often known as the American Pekin breed **(Su, 2022).**

The Peking Duck is the most widespread of all duck breeds and is the only recognized economic breed in the Slovak Republic. It occurs in two types. In England and later in Germany, it was further bred, thus creating an upright Peking duck (English type). However, the original Chinese duck was also imported to America. By crossing this duck with the Aylesbury breed, the American Pahner bred the American Peking Duck with an almost horizontal posture and a white feather colour. Over time, this breed has become the basis for most medium-heavy types of ducks worldwide. It has very good reproductive and growth properties, laying eggs is 150-180 pieces per year. The eggs are white and weigh 80 – 100 g. Adult ducks weigh about 3 kg, ducks about 4 kg **(Hlasný et al., 1995).**

The Aylesbury duck breed is a pure white, (most ducks have yellow skin) orange feet and legs, dark grey-blue eyes, and an unusually long, straight pinkish-white bill. The Aylesbury duck has a long body, horizontal carriage, and a characteristically straight, deep keel that nearly reaches the ground.

The Aylesbury duck is an excellent meat breed with mature males weighing around ten pounds and mature females, 9 pounds. Young Aylesbury ducks will reach slaughter weight – about 5 pounds in fattening to 7 – 9 weeks. The Aylesbury duck is the meat breed in England, preferred over the Pekin favoured in the USA, because its meats is considered more flavourful. Females lay 35 to 125 white or tinted green eggs per year **(Beeton et al., 2000).**

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The Mulard is a cross of two different breeds of domestic duck the Muscovy duck (*Carina moschata domestica*) and the domestic duck (*Anas platyrhynchos domesticus*), derived from the wild Mulard. It is called a type of goose, which is a cross between two breeds of ducks. This duck was bred by geneticists in France. It is a cross between Barbaria and Peking duck breeds. Duckling is almost no different from duckling carcass weight. Mulard have a liver of up to 600 g after forced feeding. Carcass weight is from 4 to 6.5 kg. The carcass weight (4 – 5 kg) is reached at the age of about 10 weeks. After forced feeding (usually 2 – 3 weeks) the so-called when maize is weighed 6.5 kg or more. Ducks can graze during breeding. This technology represents the universal use of duck to produce large liver and excellent juicy and tender meat. Mulards are quiet, do not quack, which does not make unnecessary ducks a characteristic noise in the yard **(Dohner, 2008).**

Muscovy duck is a very popular breed among small breeders, although it is spreading faster in large farms around the world. This breed is often referred to as the duck of the future because it has excellent musculature and carcass characteristics. The colouring of ducks is different – from white to black. Sexual dimorphism is significant, ducks weigh up to 6 kg, ducks only 2.5 kg. The laying is low, a maximum of 60 eggs. In some countries, they cross with Peking duck, but the hybrids are infertile **(Hlasný et al., 1995).**

1.3 Duck fattening

1.3.1 Traditional Duck Feeding

Fattening ducks for fattening, as well as breeding, are divided into two periods. The first period has a higher temperature, and its length is 14 – 21 days in summer and 28 days in winter. The second period with a lower temperature is from the fourth week of age until the end of fattening. Nutrition is also different from breeding. Complete feed mixtures are used, until the age of three weeks a mixture containing 22% nitrogenous substances, loose. From the fourth week until the end of fattening, a mixture with a lower nitrogen content (18%) is served. Feed consumption is 7 kg per piece. By intensive fattening in 47 – 49 days we get ducks with a live weight of 2.8 – 3.0 kg. Intensive methods of fattening are on litter and grids. The ducks are housed in the hall on litter throughout the fattening. The fattening on the litter in combination with the paddock is seasonal and more extensive. The ducks are kept in the hall on the litter or on the grids for the first three weeks, then they are moved to a shelter with a dry or water paddock. A maximum of 500 ducklings are kept on 1 hectare of water area. There is a capacity

DOI: https://doi.org/10.15414/2022.9788055224978

of approximately 1,000 ducks per 1 ha on flow ponds with regulated flow. On flow ponds with a regulated inflow of water, 1,000 ducks per 1 ha are recommended, without a regulated inflow of 500 animals per ha. If the ducks are fed on a fixed enclosure, it is necessary to take to account the occupancy of 8 – 10 pieces per 1 m^2 **(Hlasný et al., 1995; Hrnčár, 2014).**

Quality and cost of feeds and their availability affect production of duck, mainly in the dry period. In the first period, ducks forage on different types of flora and fauna. But the nutritional values of which are still unknown. Duckweed has a fast growth rate, the food protein is 15 to 45% on dry matter, and of biomass availability throughout the year is evaluated as a dietary supplement for chickens or ducks **(Haustein et al., 1994).**

It has also been reported that duckweed can replace 50% of the fishmeal in a conventional diet for ducklings **(Hamid et al., 1993).** Feeding duckweed containing 38.6% crude protein to ducks as a replacement for roasted soybeans showed that duckweed can totally replace soybeans as a protein source for a duck fattening system based on broken rice**.** Feeding fresh *Lemna* to layer ducks up to 24% of the diet as a replacement of rice bran and oil cake, improved egg production and yolk colour **(Hossain 1998).**

Nevertheless, water content 90 to 93% of the biomass and the bulkiness of duckweed often make it difficult for the farmers to minimize the costs of harvesting and processing**. Hossain (1998)** found that a large duck daily consumption is approximately 1300 to 1600 g of fresh duckweed, and the production. Traditional farmers usually allow their ducks to forage on duckweed that grows on different types of wastewaters. Therefore, it is necessary to produce the duckweed in nutrient-rich water with a minimum level of heavy metals and subsequently to evaluate its nutritional value to ducks. A high fresh biomass intake may reduce feed costs without affecting egg and meat production **(Khanum et al., 2005).**

1.3.2 *Ad libitum* feeding

For *ad libitum* feeding the ducks are used growing diet rich in maize (the main component of overfeeding diet) by directly quantifying the hepatic ability for lipid synthesis and lipid secretion. For this purpose, are used an *in vitro* method of incubated liver slices in the presence of linoleic acid (LA, the main FA present in maize), glucose (the main energetic substrate presents in maize) or methionine **(Saez et al., 2008).**

Poultry fattening covers the age period from hatching to maturity. The main direction of meat production in all types of poultry is the so-called broiler fattening. The term broiler (used since 1923 in the USA for chickens, and later for other species of poultry) can be

DOI: https://doi.org/10.15414/2022.9788055224978

characterized by fattened hybrid meat poultry of both sexes, characterized by intense growth, during the ripening period with excellent muscularity and quality of meat, with optimal feed utilization and corresponding to feather maturity **(Lazar, 1981).**

Animal studies have shown that very early life events may have effects on adult metabolism and health. Was analysed effects of embryonic thermal manipulation (TM) on the performance of overfed mule ducks, to produce foie gras (fatty liver). Was designed three embryonic TMs with different protocols for increasing the incubation temperature during the second part of embryogenesis, to determine whether hepatic metabolism could be "programmed" to improve its fattening response to overfeeding at the age of three months. Initial results confirm that an increase in the incubation temperature leads to faster development (observed for all treated groups compared to the control group), and a decrease in the body surface temperature at birth. These results demonstrate that embryonic TM effectively "programs" the metabolic response to the challenge of force-feeding, resulting in increased hepatic steatosis. However, the same cumulative temperature rise leading to a reduction in hatchability (75 and 76% vs. 82% in control), in addition to an increase in the melting rate after cooking **(Massimino et al., 2021).**

1.3.3 Duck overfeeding

In the world France is the largest producer of foie gras. In Canada, foie gras production is a small industry located primarily in the Quebec province. Traditionally foie gras was produced from special breeds of geese; however, more recently it is primarily produced from the hybrid male Mulard duck, a cross breeding between the male Muscovy duck and a female Pekin-type duck. The Mulard drakes are raised in barns until plumage develops, provided a period of free access to feed such as outdoor grazing, and then moved to intensive housing for force-feeding when birds are 12 weeks of age. The fatty liver condition in ducks (steatosis) required to produce foie gras results from subjecting birds to a period of overfeeding lasting 12 to 15 days. During this period, birds are confined to small individual cages or group pens where they are forcibly fed a high-fat corn mash **(Skippon, 2013)**.

The overfeeding of some waterfowl poultry species causes some form of obesity, characterized by severe hepatic steatosis, and is induced by a strong accumulation of lipids in the liver, of which foie gras is the most sought-after product in France. Liver weight can increase more than 10-fold in about 2 weeks and represents up to 10% of body weight **(Hermier et al., 1994).**

DOI: https://doi.org/10.15414/2022.9788055224978

During, the overfeeding period that lasts 9 till 18 days ducks are instrumentally fed twice a day with an increasing amount of feed. This unbalanced diet is mostly composed of corn that can be supplemented with a special premix **(Bonnefont et al., 2019).**

For individual species of aquatic poultry, the production of fatty liver depends on the breed: for example, in geese, the steatosis of the liver in the Landes breed is higher than in the Polish breed **(Davail et al., 2000).** Similarly, Muscovy ducks or Mulards achieve higher fatty liver production than Peking ducks **(Guy et al., 1999).**

However, overfeeding of poultry also causes intense swelling of peripheral tissues such as adipose tissue and muscle. The lipids stored in these tissues are derived from lipids synthesized in the liver and transported by very low-density lipoproteins (VLDL). The uptake of plasma lipids into extrahepatic tissues is mediated by lipoprotein lipase (LPL), which hydrolyses port omicron and VLDL triacylglycerols. Thus, LPL activity may partially regulate lipid deposition between the liver and extrahepatic tissues. In fact, in chickens, an increase in LPL activity can cause dramatic peripheral fat deposition **(Whitehead and Griffin, 1982; Griffin et al., 1987).**

In contrast, in Landes goose, liver fat mass negatively correlates with LPL activity **(Davail et al., 2000),** suggesting that lipoprotein triacylglycerols not hydrolysed by LPL may return to the liver upon absorption by specific lipoproteins and contribute to liver steatosis. All these data suggest that the degree of fatty liver in poultry depends primarily on the intensity of hepatic lipogenesis, but also on the peripheral activity of LPL. These two mechanisms are partially controlled by hormones, particularly insulin, which is known to stimulate the activity of enzyme lipogenesis **(Girard et al., 1994)** and LPL **(Murase et al., 1981).** Glucagon, an insulin antagonist, also appears to be particularly important in regulating metabolic processes in poultry **(Hazelwood, 1984).** For example, in chickens, excessive fat storage is associated with increased plasma insulin **(Raheja et al., 1986)** and glucagon concentrations **(Sinsigalli et al., 1987).**

There are few natural animal populations in which the metabolic processes leading to liver steatosis could be studied. They include free-range bird and fish species in which liver steatosis spontaneously occurs due to pre-migration energy storage **(Pilo and George, 1983).** This process is facilitated in these species because the liver is a major site of de novo lipogenesis **(Henderson and Sargent, 1981)**. In the case of domestic ducks and geese, this specific capacity is used for the commercial production of foie gras. In geese, liver weight can double in two weeks and can account for up to 10% of live weight **(Hermier et al., 1994).** This fatty liver is an almost pure form of acquired hepatic steatosis of nutritional origin, as degenerative changes

DOI: https://doi.org/10.15414/2022.9788055224978

such as necrosis or cirrhosis are rare **(Bénard and Labie, 1998).** In addition, this fatty liver is completely reversible, and the liver returns to its original composition when excessive intake is interrupted **(Babilé et al., 1998; Bénard et al., 1998).** This allows birds to feed on their own and use their energy reserves as they do during migration.

Mule and Pekin duck had higher liver lipid contents than the insulin-treated ducks, but there was no significant difference for Muscovy ducks' breed. There can be three potential effects of insulin, a decreased lipogenesis, an increase e of the triglyceride' s exportation via a more important very light density lipoproteins secretion, and an increased lipid oxidation. The absence of significant differences in Muscovy ducks in the lipid content of the liver between insulin-treated ducks and controls (while treated individuals presented a lower liver weight) can be explained by their general high fat content (50%) which can then hide this effect. Although insulin increased the lipoprotein lipase activity in breed Pekin ducks, this activity had no effect on their triglyceridemic. Increased lipoprotein lipase activity has been very low (1.5 times the control lipoprotein lipase activity in the 2nd and the 8th days) to produce any significant effect on plasma triglycerides. If the insulin treatment stimulated the exportation of the lipid synthesized by liver towards peripheral tissues, we should observe a higher plasma triglycerides rate in insulin-treated individuals. This was not the case unless a triglyceride's measurement only 70 min. after the meal was too late to observe any increase in the plasma triglycerides level. The triglycerides exported by the liver could already have been deposited in the peripheral tissues with a rapid incorporation of the circulating triglycerides due to a greater lipoprotein lipase activity in this species at a peripheral level. Or could be based on a more developed peripheral lipogenesis in Pekin ducks rather than an increase in the hepatic triglycerides export via VLDL (very light density lipoproteins). These would partly explain the decrease of the liver weight in the insulin-treated animals of this species, which subsequently metabolizes glucose *in situ* in the peripheral tissues through a direct oxidative route or storage. The intramuscular lipid content was not increase, the increased weight of the muscles in overfeeding Pekin ducks could relate to an increased synthesis of the muscle proteins, the glycogen stock, or water content, and a decreased proteolysis in the muscles. The increased lipoprotein lipase activity enhanced the increased of lipids, neo-synthesized in the liver, but increased the lipid oxidation in particular the breeds Pekin and Muscovy ducks during the 1st week of the overfeeding period. This explains the low-fat deposition in the peripheral tissues at the end of the overfeeding period. In mule ducks was abdominal fat decreased, together with a decrease of lipid deposition in the breast muscle **(Gontier et al., 2013).**

DOI: https://doi.org/10.15414/2022.9788055224978

In response to overfeeding, *de novo* hepatic carbohydrate lipogenesis in the diet is markedly increased in geese **(Mourot et al., 2000).**

Ducks of the Mulard genotype represent more than 90% of the species of aquatic poultry fattened to produce French foie gras. The ducks are overfed twice a day with increasing amounts of feed. This unbalanced diet usually consists of corn, which can be supplemented with various premixes **(Cifog, 2018).**

Despite increasing concentrations of very low-density lipoproteins (VLDL) and high-density lipoproteins (HDL) **(Fournier et al., 1997),** lipoprotein excretion is reduced and much of the triglycerides remain stored in the liver, leading to in situ steatosis. Interestingly, susceptibility to fatty liver varies between species, but by the end of the group there is a significant difference in the degree of liver steatosis, some animals show no fatty liver, regardless of food composition (**Poujardieu et al., 1994; Hermier et al., 1999**). For example, Landes geese are more suitable for forced feeding and achieve twice the liver weight and twice the liver triglyceride content along with lower VLDL and HDL concentrations than geese of other breeds **(Fournier et al., 1997).** Landes geese have also been found to have higher levels of high-density lipoproteins, phospholipids, and polyunsaturated fatty acids **(Hermier et al., 1999).**

Duck overfeeding affected the richness diversity of ileal and cecal and had a significant effect in modifying the bacterial community in the ileum, whereas genotype mainly affected the ceca. The microbial diversity of ducks' microbiota was dominated by *Firmicutes* and *Bacteroidetes* **(Vasaï et al., 2014a).**

The microbial diversity of overfeeding mule ducks is dominated by *Firmicutes, Bacteroidetes,* and *Proteobacteria,* and overfeeding system modifies bacterial communities of ceca samples, whereas probiotics show an important effect on ileal samples. The increase in lactobacilli through the overfeeding process when adding *L. sakei* as a probiotic could potentially improve the ducks' health and could be of great interest to the duck industry **(Vasaï et al., 2014b).**

Foie gras is a product of French gastronomy composed of a stiffened waterfowl liver. The organoleptic properties of this product depend on the characteristics of the liver, such as liver weight (LW) and technological yield (TY) during cooking. One of the main problems for manufacturers is to classify foie gras with high or low technological quality before cooking. In this area, research focuses on identifying biomarkers of these characteristics with non-invasive biomarkers in ducks. 1 H-NMR (proton nuclear magnetic resonance) analyses were performed on the plasma of male mules at various time points during the overfeeding period to obtain

DOI: https://doi.org/10.15414/2022.9788055224978

a wide range of liver characteristics to identify plasma biomarkers of foie gras. PLS analyses and linear models can be used to identify biomarkers. The researchers identified 18 liver weight biomarkers and 15 technological yield biomarkers. As these two quality parameters were strongly correlated (-0.82), 13 biomarkers were common. Lactate is the most important biomarker, followed by amino acids. Unlike amino acids, lactate increased with liver weight and decreased with technological yield. The identified 5 biomarkers specific for LW -3 carbohydrates: glucuronic acid, mannose, sorbitol and 2 amino acids: glutamic acid and methionine) negatively correlate with liver weight **(Mozduri et al., 2021)**.

1.4. Duck carcass structure

The process of slaughtering ducks differs slightly from that of chickens. In general, slaughter has several steps in duck processing, such as assembly, pre-slaughter handling, slaughter, bleeding, scalding, feather release, inspection and dissection, feather cooling and removal, product slicing and packaging, and storage management. The quality of duck carcases, physic-chemical properties such as shear rate, colour, pH, water retention capacity, cooking loss and drip loss, susceptibility to oxidation, microbiological detection and sensory evaluation are analysed **(Chen, 2022).**

The method and time of storage are the two most important factors in the physical properties of meat. Cooling and freezing slows down chemical reactions, inhibits the growth of microorganisms, and thus prolongs the shelf life of many foods. When frozen for a long time, the lipid and fat fractions of the muscles undergo chemical or structural changes that lead to an undesirable change in taste and texture **(Sikorski, 1978).**

Table 1 Body and tissues weights before overfeeding (at 13 weeks of age) and after 2 weeks of overfeeding in ducks (Davail et al., 2003)

Breed	**Body weight before overfeeding**	**Body weight after overfeeding**	**Liver**		**Pectoralis major muscle**		**Skin+ subcutaneous adipose tissue**	
			(g)	**(% BW)**	**(g)**	**(% BW)**	**(g)**	(% BW)
Muscovy	5523	7290	585	8.02	608	8.34	182	2.50
Mule	4194	5360	218	4.07	447	8.34	135	2.52
Pekin	3436	4137	152	3.67	281	6.79	126	3.05

%, percentage of tissues vs. the body weight after overfeeding

DOI: https://doi.org/10.15414/2022.9788055224978

The live weight (Table 1) after the end of the forced musk breed was 7290 g, Mulard 5360 g, Peking 4137 g. Of the mentioned breeds, the most suitable to produce fatty liver is the musk breed, whose liver weight after feeding was 585 g. Pectoral muscle weight was highest in Muscovy ducks, 608 g. Forced duck abdominal fat is an important raw material for duck ointment production and accounts for 2.5 to 3.05% of the pre-slaughter live weight. Council Regulation EC 853/2004 states for duck soured ointment not more than 1.25% by weight of free fatty acids, peroxides not more than 4 meq.kg^{-1} and total insoluble impurities not more than 0.5% (**Davail et al., 2003)**.

Hermier et al. (2003) report the effect of fattening on the structure of duck carcasses (Table 2). The live weight of Muscovy ducks increased significantly after feeding, from the original 4.36 kg at the age of 11.5 weeks to a weight of 6.37 kg after the end of fattening at the age of 15 weeks, from the Pekin breed from 3.23 kg to 4.74 kg. The weight of Muscovy duck liver was more than 6 times higher after the meal, from the original 65g it increased to 415 g.

Table 2 Structure of the duck carcass before and after fattening (Hermier et al., 2003)

Age	**Before pre-overfeeding**		**After overfeeding**	
	11.5 weeks		**15 weeks**	
Genotype	**Muscovy**	**Pekin**	**Muscovy**	**Pekin**
Body weight (kg)	4.36	3.23	6.37	4.74
Liver weight (g)	65.0	55.8	415	268
Liver weight (% BW)	1.49	1.75	6.48	5.57
Abdominal fat pad (g)	98.3	72.6	230	190
Abdominal fat pad (% BW)	2.26	2.23	3.62	4.03
	Fillet*			
Total (g)	300	213	466	304
Total (% BW)	6.84	6.57	7.30	6.42
Scat+skin (% BW)	1.33	1.92	1.82	2.90
P. major (% breast)	80.1	70.9	74.9	54.8
P. major (% BW)	5.55	4.64	5.47	3.50

* fillet – pectoral muscle with subcutaneous tissue and skin

Huo et al. (2021) reported before fattening duck weight of 821.8 g and an integrated rice-duck farming system weight of 1386 g. The carcass weight of unfed ducks was 667 g and

DOI: https://doi.org/10.15414/2022.9788055224978

the ducks fed Integrated rice-duck farming system 1229.22 g. The carcass yield of unfed ducks was 81.16% and the ducks fed Integrated rice-duck farming system 88.69%. The proportion of pectoral muscle meat of non-fed ducks was 10.36% and the proportion of ducks fed Integrated rice-duck farming system was 11.15%. There was also a higher femoral muscle content of unfed ducks 7.39% and ducks fed Integrated rice-duck farming system 9.87%.

Table 3 Composition (g.100 g^{-1}) of duck foie gras and sub-products (Carrillo et al., 2017)

Product	Water	Lipids	Protein
Foie gras	30.9 ± 1.7	57.1 ± 5.5	7.1 ± 0.56
Foie gras emulsion	40.5 ± 1.5	51.0 ± 5.3	5.4 ± 1.2
Duck fat	0.8 ± 0.3	99.3 ± 0.0	ND
Fat of foie gras	0.2 ± 0.0	99.9 ± 0.0	ND

Table 3 presents chemical composition of duck foie gras (liver), lipid content is 57,1 g.100g^{-1} and proteins 7,1 57,1 g.100 g^{-1} **(Carrillo et al., 2017).**

Table 4 Fatty acid profile for fat of foie gras and duck fat (Carrillo et al., 2017)

		Fatty acid content (g.100 g^{-1} fatty acids)	
Nomenclature	**Denomination**	**Fat of *foie gras***	**Duck fat**
C14:0	Myristic A.	0.9 ± 0.00	0.6 ± 0.01
C14:1	Myristoleic A.	0.1 ± 0.00	0.1 ± 0.00
C16:0	Palmitic A.	28.1 ± 0.05	26.1 ± 0.20
C16:1	Palmitoleic A.	2.9 ± 0.00	3.2 ± 0.01
C18:0	Stearic A.	10.6 ± 0.06	6.5 ± 0.00
C18:1 9t	Elaic A.	0.2 ± 0.01	0.2 ± 0.00
C18:1 9c	Oleic A.	54.9 ± 0.10	53.0 ± 0.17
C18:1 11c	Cis-Vaccenic A.	1.0 ± 0.00	1.0 ± 0.05
C18:2	Linoleic A.	0.9 ± 0.00	9.0 ± 0.04
C18:3	Linolenic A.	-	0.3 ± 0.00
C20:1	Gondoic A.	0.1 ± 0.06	0.2 ± 0.00
Total saturated		39.6	33.2
Total monounsaturated		59.1	57.6
Total polyunsaturated		0.9	9.3

DOI: https://doi.org/10.15414/2022.9788055224978

Carrillo et al. (2017) found higher SAFA content in duck foie gras 39.6 than in duck fat 33.2. PUFA content was only 0.9 in duck foie gras and 9.3 in duck fat.

Density values for duck foie gras ranged from 967 to 1067 $kg.m^{-3}$ **(Carrillo et al., 2017).**

Michailidis et al. (2009) reported the density of animal fat presents values of 920 – 957 $kg.m^{-3}$ while the animal muscle presented higher density values, in the range of 984 – 1080 $kg.m^{-3}$.

1.5 Chemical composition

Duck meat production is based mainly on commercial hybrids of different Peking duck lines **(Zeidler, 1998).** The duck is an aquatic poultry and has a different physiology than the chicken. Ducks are still very popular and in many parts of the world, especially in Asia. However, scientists have paid little attention to them compared to other poultry. Duck meat gained more popularity when it began to be sold in portions and not in whole carcasses. The increasing diversity of poultry species in recent years has made it necessary to update existing data on duck meat quality. It is necessary to identify changes in the physical and chemical properties of muscles and their components of different breeds or crossbreeds. These properties can affect the quality of processed meat products **(Richardson and Jones, 1987).**

1.5.1 Muscle chemical composition

Meat is one of the main sources of protein for human nutrition. From a human point of view, it is essential to know not only the protein content, the presence of amino acids, fatty acids, and minerals. In recent years, with the increased incidence of many, especially coronary heart disease and cancer, there has been a wealth of literature arguing about the role of fatty acids in nutrition. The general opinion is that the incidence of such disorders would be reduced and the health of our society would be improved by reducing the total amount of fat consumed, lowering dietary cholesterol and changing the fatty acid regime in favour of increasing polyunsaturated fatty acids **(Leskanich and Noble, 1997).**

Galal et al. (2011) (Table 5) report the water content in the breast muscle of Muscovy ducks 73.34% and ducks 74.72%. The protein content in the pectoral muscle of male is higher than in female duck. Muscovy males have a protein content in the pectoral muscle identical to the Peking breed (19.65%).

DOI: https://doi.org/10.15414/2022.9788055224978

Table 5 Chemical composition of duck breast muscle (%) (Galal et al., 2011)

Parameters	Sex	Breed			
		Dumyat	Muscovy	Peking	Sudani
Water	**Female**	73.90	74.34	74.50	74.52
	Male	74.35	74.72	75.35	74.78
	Overall	74.13	74.53	74.93	74.65
Protein	**Female**	20.20	19.39	18.92	20.39
	Male	20.77	19.65	19.65	20.61
	Overall	20.48	19.52	19.28	20.50
Fat	**Female**	3.40	3.86	4.48	2.84
	Male	2.60	3.70	3.40	2.76
	Overall	3.00	3.78	3.74	2.80
Minerals	**Female**	1.85	2.14	1.25	2.16
	Male	1.95	1.60	1.43	1.60
	Overall	1.90	1.87	1.34	1.92

Galal et al. (2011) report the fat content in the femoral muscle of Muscovy ducks of 5.46% and of Peking duck 5.40% (Tables 5 and 6). There is a lower fat content in the pectoral muscle of Muscovy ducks (3.86%), also in the Peking breed (4.48%). The ash content is 1.6% in the pectoral muscle of the Muscovy ducks, 1.43% in the Peking duck muscle and 1.56% in the thigh muscle of the Muscovy ducks and 1.27% in the Peking breed. The mentioned authors state a high content of ashes in the breast muscle of Muscovy ducks up to 2.14% and in the thigh muscle 1.34%.

DOI: https://doi.org/10.15414/2022.9788055224978

Table 6 Chemical composition of the thigh muscle of ducks (%) (Galal et al., 2011)

Parameters	Sex	Breed			
		Dumyat	Muscovy	Peking	Sudani
Water	Female	74.52	74.80	75.30	74.60
	Male	75.75	74.94	76.17	75.78
	Overall	75.13	74.87	75.73	75.19
Proteins	Female	18.30	18.30	17.80	19.19
	Male	19.08	18.38	18.30	19.33
	Overall	18.69	18.34	18.05	19.26
Fat	Female	5.00	5.46	5.40	4.57
	Male	3.30	3.92	4.10	2.97
	Overall	4.15	4.69	4.75	3.77
Minerals	Female	1.58	1.34	1.06	1.41
	Male	1.68	1.56	1.27	1.63
	Overall	1.63	1.45	1.16	1.52

Table 7 Basic chemical composition of the breast and leg muscles of ducks of different genotype (%) (Kokoszyński et al., 2021)

Trait		Breed			
		Pekin		Muscovy	
Water	breast muscles	72.5	74.2	71.4	71.6
	leg muscles	70.7	71.2	69.9	72.8
Protein	breast muscles	25.5	21.9	26.3	23.3
	leg muscles	23.0	22.0	24.7	21.4
Fat	breast muscles	3.0	4.2	0.8	1.2
	leg muscles	5.1	4.6	3.1	2.4
Collagen	breast muscles	1.1	1.1	1.3	1.3
	leg muscles	1.3	1.3	1.5	1.3

Kokoszyński et al. (2021) analysed water, protein, fat, and collagen contents in breast muscles and in the protein contents, and fat contents of leg muscles in Muscovy and Pekin ducks (Table 7). Muscovy ducks was significantly higher in protein and collagen contents and

DOI: https://doi.org/10.15414/2022.9788055224978

less water and fat in the breast muscles compared to Pekin breed. The leg muscles of Muscovy ducks had significantly higher protein content and lower fat than the leg muscles of Pekin breed. Regardless of the breed, males had a significantly higher protein content and lower water content in the breast and leg muscles compared to females. The breast muscles of male contained significantly lower fat components and the male leg muscles had a higher content of fat when compared to female muscles. The genotype-sex interaction was significant for the water and protein content of the breast and leg muscles. In turn, the higher fat content in male leg muscles could result from the lower motor activity of heavier males compared to females, especially in Muscovy breed.

Table 8 Microstructure of *pectoralis major* muscle different genotype of ducks (Kokoszyński et al., 2021)

Parameter	Breed			
	Pekin		Muscovy	
	Male	Female	Male	Female
Share of αW fibres (%)	22.4	23.5	27.7	31.1
Share of βR fibres (%)	77.6	76.5	72.3	68.9
Diameter of αW fibres (μm)	38.9	33.8	43.8	39.7
Diameter of βR fibres (μm)	16.5	16.7	22.7	19.2
Density of fibres (pcs.mm^{-2})	616	647	329	399

(pcs.mm^{-2}) pieces muscle fibres per mm^2

Kokoszyński et al. (2021) found a significantly greater diameter of the white (αW) and red muscle fibres (βR) in the *pectoralis major* muscle of Muscovy compared to Pekin ducks (Table 8). Muscle fibre density (fibre/mm^2) was significantly lower in the *pectoralis major* muscle of Muscovy compared to Pekin breed. Males were characterized by significantly greater diameter of both muscle fibre types compared to females. The genotype-sex interaction was not significant for the microstructural characteristics of the pectoralis major muscle.

Table 9 show in duck breast lower protein content (21.14%) than chicken breast (23.69%), approximately identical intramuscular fat content (3.11% – duck breast, 3.07% – chicken breast). After roasting for 10 minutes, the fat content of the duck breast increased to 5.23%. Weight loss during roasting for 10 minutes is 42.52% in chicken breasts and 44.23% in ducks (**Liao et al., 2010).**

DOI: https://doi.org/10.15414/2022.9788055224978

Table 9 Chemical composition and pH values in raw and heat-treated chicken and duck breasts (Liao et al., 2010)

Poultry	Condition	Water (%)	Protein (%)	Fats (%)	Glucose (umol.g^{-1} dry matter)	Creatine+ creatinine (mg.g^{-1} dry matter)	pH	Weight loss (%)
Chicken breast	**Raw**	74.42	23.69	3.07	10.46	21.74	5.93	-
	Fried 5 min.	69.52	28.13	1.37	8.72	14.15	5.91	22.28
	Fried 10 min.	53.77	43.69	4.62	4.57	16.10	6.10	45.42
	Grilled	65.20	32.77	1.54	6.50	11.25	6.00	31.44
	Roasted	65.81	31.41	1.65	8.84	15.99	5.84	28.74
Duck breast	**Raw**	76.50	21.14	3.11	23.26	20.29	6.10	-
	Fried 5 min.	69.44	27.63	1.23	5.82	14.39	6.14	21.90
	Fried 10 min.	52.66	43.79	5.23	9.35	17.04	6.09	44.23
	Grilled	65.20	31.32	1.81	10.42	11.51	6.14	30.74
	Roasted	65.32	33.97	1.81	12.71	17.01	6.13	29.85

The protein content of the fried duck breasts increased significantly compared to the raw duck breasts, and the duck breasts fried for 10 minutes at 180 °C had a higher protein content than fried for 5 minutes at 180 °C (Table 9). As a result of the heat treatment of the meat, the water content decreases, and the protein content generally increases. The fat, glucose, creatine and creatinine content of the raw duck meat was higher than the content of the heat-treated meat, except for the fat content of the meat fried for 10 minutes at 180 °C. Glucose, creatine and creatinine are precursors in reactions forming heterocyclic aromatic amines (HAA). The glucose content and the total creatine and creatinine content in the heat-treated meat were lower **(Liao et al., 2010)**

Chartrin et al. (2006) report losses of cooked duck meat of the Peking breed 18.38%, Mulard 15.20% and Muscovy 15.73%.

DOI: https://doi.org/10.15414/2022.9788055224978

Because lipid levels in poultry meat are low (about 1 to 2% in raw poultry meat **(Rabot, 1998)**. However, in duck meat fat content is higher than in chicken and guinea pig meat **(Baéza et al., 2002)**.

Intramuscular fat (IMF) is involved in meat quality, especially sensory and nutritional properties **(Ruiz et al., 2001).** In poultry meat, it is easy to influence the quality of lipids, especially the fatty acid profile, by using different sources of lipids in feed **(Cortinasetal, 2004).** Many studies have analysed the effects of increasing the content of polyunsaturated fatty acids in meat. The fatty acid profile affects quality, focusing on the sensory properties and acceptability of heat-treated meat and processed products and on the oxidation of lipids during storage of fresh and frozen meat and processed products.

Various livestock species and genotypes are used for meat production, including national duck breeds, Peking ducks (*Anas platyrhynchos*), Muscovy ducks (*Cairina moschata*) and hybrids such as Mulard ducks. The feed significantly increases the lipid content of duck meat **(Zanusso et al., 2003)**. Using different genotypes of ducks (Muscovy, Pekin, Mulard and Hinny) in combination with 2 feeding methods (*ad libitum* versus forced feeding).

Chartrin et al. (2003) report that great variability in breast muscle lipid content can be achieved, IMF in breast muscles balanced from 2.26 to 7.57%. There are few studies on the genetic impact on meat quality parameters in ducks. **Le Bihan-Duval et al. (2002)** found medium to high heredity values for meat quality traits, demonstrating the applicability of genetic knowledge to improve duck meat quality. When comparing fed Peking ducks, Muscovy, Hinna and Mulard breeds. **Larzul et al. (2002)** found significant genetic influences on pectoral muscle quality, *post-mortem* maturation, colour, and stiffness of duck breasts in the raw state and after heat treatment.

DOI: https://doi.org/10.15414/2022.9788055224978

Table 10 Amino acid content in the breast muscle of Peking, Polish, and Mini-duck hybrids (%) (Woloszyn et al., 2005)

Amino acid	Duck breed		
	Polish Peking	Crossbreed "mini duck"	Peking
Asparagine	9.28	8.50	9.11
Threonine	4.11	4.15	4.45
Serine	3.74	3.81	4.00
Glutamic acid	17.91	17.95	17.82
Proline	4.35	3.86	4.22
Cysteine	0.97	0.88	1.03
Glycine	3.96	3.92	4.05
Alanine	5.78	5.94	6.17
Valine	3.68	3.74	3.67
Methionine	2.29	2.32	2.09
Isoleucine	3.21	3.24	3.24
Leucine	7.67	7.88	7.78
Tyrosine	3.14	3.27	3.03
Phenylalanine	2.87	3.04	3.36
Histidine	2.60	3.35	3.38
Lysine	8.87	8.68	8.60
Arginine	7.14	7.13	6.04
Tryptophan	1.14	1.15	1.25

Proportion (%) of amino acids stated in the total protein content

DOI: https://doi.org/10.15414/2022.9788055224978

Table 11 Amino acid content of the thigh muscle of Peking, Polish, and mini-duck hybrids (%) (Woloszyn et al., 2005)

Amino acid	Duck breed		
	Polish Peking	Crossbreed "mini duck"	Peking
Asparagine	8.78	8.89	8.80
Threonine	4.22	4.33	4.26
Serine	3.93	3.98	3.97
Glutamic acid	18.75	18.93	18.45
Proline	4.28	4.39	5.38
Cysteine	0.93	1.02	1.10
Glycine	4.04	4.04	4.20
Alanine	5.96	5.97	5.90
Valine	3.66	3.82	3.63
Methionine	2.35	2.34	2.46
Isoleucine	3.26	3.29	3.25
Leucine	7.69	7.89	7.46
Tyrosine	3.33	3.57	3.12
Phenylalanine	2.94	3.27	2.92
Histidine	3.10	3.42	3.21
Lysine	9.03	9.04	8.92
Arginine	7.31	7.18	5.74
Tryptophan	1.09	1.20	1.09

Proportion (%) of amino acids stated in the total protein content

Table 12 shows the content of fatty acids in the thigh muscle of Nanjing ducks at different stages of processing (g.100 g^{-1} FAME). Contents of saturated fatty acids (SFA) in raw ducks thigh was 39.08 g.100 g^{-1} FAME, monounsaturated fatty acids (MUFA) 22.11 g.100 g^{-1} FAME and polyunsaturated fatty acids (PUFA) 38,81 g.100 g^{-1} FAME. Content of linoleic acid in raw duck meat was 7.6 g.100 g^{-1} FAME, and there was a high content of docosahexaenoic fatty acid 3.28 g.100 g^{-1} FAME **(Xu et al., 2008).**

DOI: https://doi.org/10.15414/2022.9788055224978

Table 12 Fatty acid profiles in the thigh muscle of Nanjing ducks at different stages of processing (g.100 g^{-1} FAME) (Xu et al., 2008)

Fatty acid	Raw meat	Dried - salted	Marinated
Myristic fatty acid C14:0	3.78	4.79	5.37
Myristoleic fatty acid C14:1	4.79	4.54	4.32
Palmitic fatty acid C16:0	16.41	16.79	17.13
Stearic fatty acid C18:0	18.89	21.87	23.8
Oleic fatty acid C18:1	17.32	16.97	16.48
Linoleic fatty acid C18:2	7.60	6.81	6.27
Arachidonic fatty acid C20:4	25.14	24.01	23.79
Docosatetraenoic fatty acid C22:4	2.79	1.48	0.74
Docosahexaenoic fatty acid C22:6	3.28	2.74	2.1
∑ SFA	39.08	43.45	46.3
∑ MUFA	22.11	21.51	20.8
∑ PUFA	38.81	35.04	32.9

1.5.2 Technological quality of meat

Table 13 report the weight of pectoral muscle in breeds Peking 196 g, Muscovy 386 g and Mulard 303 g, of these breeds the highest proportion of intramuscular fat in breast muscle has Peking breed (4.81%) **(Chartrin et al., 2006a).** Based on shear force analysis (WB), **Chartrin et al. (2006b)** state that Beijing duck fattening meat is finer (46.13 N) than intensive feed duck meat (48.24 N). In contrast, Mulard has finer meat from intensive feed (51.86 N) than from fattening (53.04 N).

DOI: https://doi.org/10.15414/2022.9788055224978

Table 13 Influence of genotype on cooking losses and shear strength of cooked duck breasts (Chartrin et al. (2006b)

Genotype	Feeding level	N	Cooking losses (% of raw meat)	Shear force value (N)	Shear force value (J)
	Fattening	68	17.18	52.69	179.44
	Ad libitum	77	15.21	49.76	168.44
	Effect of feeding level		P < 0.0001	0.1892	0.1772
Pekin		31	18.38	46.88	150.70
Mulard		41	15.20	52.43	175.66
Hinny		41	15.68	53.09	181.53
Muscovy		32	15.73	51.07	182.98
	Genotype effect		P < 0.0001	0.1124	0.0071
Pekin	**Fattening**	11	21.08	48.24	155.44
	Ad libitum	20	16.90	46.13	148.10
Mulard	**Fattening**	21	15.86	51.86	175.74
	Ad libitum	20	14.51	53.04	175.57
Hinny	**Fattening**	21	16.61	56.41	185.10
	Ad libitum	20	14.70	49.60	177.79
Muscovy	**Fattening**	15	16.98	51.90	194.31
	Ad libitum	17	14.63	50.34	172.99

1.6 Foie gras

Foie gras is one of the main products of French gastronomy. In France, it is a protected cultural heritage of gastronomy. It is defined as goose liver (*Anser anser*) or muscovy ducks (*Cairina moschata*) or Mulard ducks (*Cairina moschata x Anas Platyrhynchos*), which are over-fed to produce fatty liver **(Jorf, 2006).**

For the label "*foie gras"*, duck livers must weigh more than 300 g and for the label "*foie gras* entier" (intact *foie gras* lobe) the melting rate during the cooking process must not exceed 30% **(Bonnefont et al., 2019).**

Technological yield of foie gras decreases during the second half of the overfeeding period. The compromise between foie gras weight and its quality highlights negative

DOI: https://doi.org/10.15414/2022.9788055224978

correlations of technological yield with liver weight (-0.83) and with liver lipid content (-0.71). Also was established an accurate model to predict technological yield with non-invasive measures (liver weight and liver colour values $R^2 = 0.71$). The studies of liver metabolism with proteomic approaches provided more accurate information on the shift of liver metabolism during the overfeeding period and on the cellular mechanism of melting process of foie gras **(Bonnefont et al., 2019)**.

Foie gras duck livers must weigh more than 300 g **(Joeu, 2008)** and for foie gras entier (intact foie gras lobe) the melting rate during the cooking process must not exceed 30% **(Jorf, 1993).**

Melting rate is one of the main parameters for estimating the quality of foie gras, as it affects the organoleptic properties. They are measured using the technology yield (TY). The higher the melting rate, the lower the TY. This affects many biological and death factors TY have already been identified **(Théron et al., 2013a).** The higher the melting rate, the lower the TY (**Marie-Etancelin et al., 2011; Théron et al., 2012**) and feeding programs (number of meals and amount of corn delivered per meal) strongly affect TY (**Robin et al., 2002; Arroyo et al., 2016, 2018**).

TY value as a melting rate is determined for livers over 300 g. TY value analysis - livers are frozen in individual vacuum bags by immersion in alcohol at -20 °C to ensure an even freezing process. The livers are stored at -20 °C. The livers are then heat treated (80 °C = 70 minutes). After 2 months of storage at + 4° C, the cooking yield (TY) is determined by weighing the cooked fat livers after removal of visible molten lipids and the percentage is calculated as raw weight minus the weight after cooking is divided by the raw weight x 100 **(Rémignon et al., 2018)**. On the other hand, **Bonnefont et al. (2019)** report a heat treatment time of 170 minutes at the same temperature. Fat loss during foie gras cooking is a major problem for both producers and consumers. Despite efforts by the processing industry to control fat breakdown, fatty acid variability remains a major technological problem **(Theron et al., 2013).**

DOI: https://doi.org/10.15414/2022.9788055224978

1.6.1 Chemical composition of the duck liver

Table 14 Percentages of main fatty acids in duck fatty livers (Rukke et al., 2008)

Fatty acid	Range	Average
C14	0.28-1.21	0.71
C16	17.61-29.26	23.64
C16:1	1.46-5.59	2.43
C18	8.69-24.15	16.97
C18:1	46.86-60.13	53.19
C18:2	0.70-1.87	1.22

Some of the newly synthesized triacylglycerols are stored in liver lipoproteins, especially very low-density lipoproteins (VLDL), which are excreted in the blood. However, if the intensity of this lipogenesis is higher than the liver's capacity to synthesize and secrete low-density lipoproteins, the newly synthesized triacylglycerols accumulate in hepatocytes and can cause severe hepatic steatosis **(Hermier et al., 1991).**

Table 15 Chemical composition (%) of the liver before and after fattening (Hermier et al., 2003)

	Before overfeeding		**After overfeeding**	
Age	**11.5 weeks**		**13 weeks**	
Genotype	**Muscovy**	**Common**	**Muscovy**	**Common**
Water	71.5±0.9	72.7±1.7	32.0±3.4	39.6±4.8
Protein	22.7±0.9	22.5±0.9	7.29±1.45	9.65±1.83
Ash	1.45±0.07	1.51±0.21	0.92±0.23	1.15±0.24
Lipids	4.75±1.07	4.84±0.58	61.9±7.4	50.1±6.6
Triglycerides (% lipids)	5.90±2.67	10.40±2.88	96.7±0.9	93.7±1.7
Cholesterol esters (% lipids)	18.7±9.6	22.3±9.7	0.311±0.300	0.876±0.45
Free cholesterol (% lipids)	7.82±1.35	6.95±0.55	0.243±0.057	0.516±0.103
Phospholipids (% lipids)	67.6±8.7	60.3±10.8	2.73±0.70	4.88±1.65

DOI: https://doi.org/10.15414/2022.9788055224978

Hermier et al. (2003) show that the proportion of water in the liver at the age of 11.5 weeks is 71.5% and at the age of 13 weeks, after intensive feeding only 32%. The protein content in duck liver was 22.7% at the age of 11.5 weeks and 7.21% after intensive feeding. The lipid content in the liver of ducks at the age of 11.5 weeks was 4.75% and after intensive feeding 61.9%.

The imbalance between the synthesis and secretion of lipids in the blood can be explained by liver fattening of some species of aquatic poultry **(Fournier et al., 1997).** Fatty liver induced by excessive feeding of poultry is the result of intensive lipogenesis from feed carbohydrates, which are most stored in the liver **(Saadoun and Leclercq, 1987).**

Table 16 Effects of overfeeding and genotype on chemical composition (% tissue) of livers of 14-week-old ducks (Chartrin et al., 2006)

Genotype	Feeding levels	Water	Proteins	Lipids	Triglycerides	Phospholipids
	Overfed	32.61	7.00	55.44	53.06	1.97
	Control	70.65	19.61	5.82	2.73	1.89
Overfeeding effect		***	***	***	***	NS
Muscovy		47.41	13.56	37.64	35.36	1.92
Hinny		43.89	13.08	40.98	38.72	1.88
Mule		43.87	12.22	39.78	37.29	2.02
Pekin		54.16	14.36	25.17	22.74	1.92
Genotype effect		**	ns	**	*	NS
Muscovy	Overfed	32.60	5.98	58.68	56.55	1.82
	Control	69.62	21.14	6.08	3.59	2.08
Hinny	Overfed	30.71	6.72	58.34	56.15	1.85
	Control	71.55	19.44	4.40	2.11	1.94
Mule	Overfed	30.90	5.69	56.63	54.07	2.11
	Control	71.11	18.75	4.41	2.05	1.84
Pekin	Overfed	39.48	9.60	43.11	40.51	2.13
	Control	70.31	19.11	5.44	3.18	1.70
Interaction effect		***	**	**	***	NS

The highest cholesterol content in the liver of ducks in the control group of Peking breeds (0.56 $g.100g^{-1}$), after their fattening this value was lower only 0.47 $g.100g^{-1}$ **(Chartrin et al., 2006)**.

DOI: https://doi.org/10.15414/2022.9788055224978

Table 17 Influence of fattening and genotype on duck liver fatty acid content (g.100 g^{-1} FAME) (Chartrin et al., 2006)

Fatty acids	Breed							
	Muscovy		Hinny		Mule		Pekin	
	O	C	O	C	O	C	O	C
C14:0	0.98	0.20	0.66	0.02	0.70	0.06	0.74	0.26
C16:0	30.80	24.79	25.54	23.17	25.63	23.21c	22.62	23.10
C18:0	11.86	18.26	19.19	21.97	16.69	20.75	14.34	17.19
C20:0	0.11	nd	0.25	nd	0.29	nd	0.45	nd
C24:0	nd	0.62	nd	1.83	nd	1.50	nd	1.35
Σ SFA	43.75	43.26	45.64	45.16	43.31	44.02	38.15	40.54
C16:1 n-7	4.10	1.36	1.84	0.79	2.16	0.90	2.27	1.62
C18:1 n-9	50.25	31.31	50.79	23.63	52.81	24.62	56.94	36.32
C22:1 n-9	0.05	0.02	0.08	nd	0.07	0.02	0.19	nd
Σ MUFA	54.40	32.57	52.71	24.42	55.04	25.53	59.40	37.94
C18:2 n-6	1.64	8.38	1.42	10.08	1.42	10.17	1.76	7.38
C20:4 n-6	0.18	13.27	0.17	15.80	0.19	16.33	0.58	11.29
C22:4 n-6	nd	1.09	nd	1.89	nd	1.78	nd	1.29
C22:5 n-3	0.03	0.70	0.05	0.83	0.04	0.66	0.11	0.22
Σ PUFA	1.85	23.45	1.64	28.59	1.65	28.94	2.45	20.17
UFA/SFA	1.29	1.30	1.20	1.18	1.31	1.24	1.63	1.45
PUFA/SFA	0.04	0.54	0.04	0.63	0.04	0.66	0.06	0.50
Σ n-6	1.82	22.74	1.59	27.76	1.61	28.28	2.34	20.29
Σ n-3	0.03	1.80	0.05	2.71	0.04	2.45	0.11	1.51

O – Overfed, C – Control

The proportion of lipids **(Chartrin et al., 2006)** in the liver of ducks after forced feeding reached up to 58.68% in the Muscovy breed. In duck liver of the Mulard genotype (Table 5), the proportion of saturated fatty acids before fattening was 44.02 g.100 g^{-1} FAME and after feeding almost the same 43.31 g.100 g^{-1} FAME. The proportion of MUFA in the liver increased significantly with the feed, before the supplement the content was 25.53 g.100 g^{-1} FAME and after the supplement 55.04 g.100 g^{-1} FAME. On the contrary, the proportion of PUFA significantly decreased, before 28.94 g.100 g^{-1} FAME and after 1.65 g.100 g^{-1} FAME.

DOI: https://doi.org/10.15414/2022.9788055224978

The proportion of fatty acids n-3 and n-6 decreased significantly after the feed, n-3 from 2.45 g.100 g^{-1} FAME before feed to 0.04 g.100 g^{-1} FAME after feed and n-6 out of 28.28 g.100 g^{-1} FAME before feed to 1.61 g.100 g^{-1} FAME. **Juodka et al. (2022)** found in duck liver the highest content of oleic acid 30.62 and palmitic acid 19.76 g.100 g^{-1} FAME, content of SAFA 38.02, MUFA 35.48 and PUFA 25.12 g.100 g^{-1} FAME (Tables 18 and 19).

Table 18 Effect of dietary hempseed or camelina cake on liver SAFA and MUFA profile (g.100 g^{-1} FAME) (Juodka et al., 2022)

Parameter	Groups		
	Control	**Experimental - HE**	**Experimental - CA**
Total lipids (%)	4.59	4.61	4.65
Lauric (C12:0)	0.02	0.01	0.01
Myristic (C14:0)	0.30	0.32	0.27
Pentadecenoic C15:0)	0.04	0.03	0.04
Palmitic (C16:0)	19.76	20.70	19.17
Margaric (C17:0)	0.12	0.12	0.15
Stearic (C18:0)	15.62	15.37	17.15
Arachidic (C20:0)	0.07	0.07	0.09
Heneicosanoic (C21:0)	0.09	0.06	0.08
Behenic (C22:0)	2.01	1.20	1.47
SFA	38.02	37.88	38.41
Myristoleic (C14:1*n*-7)	0.01	0.02	0.00
Palmitoleic (C16:1*n*-7)	0.39	0.30	0.37
Palmitoelaidic (C16:1*n*-7 trans)	0.03	0.03	0.03
Hexadecenoic (C16:1*n*-9)	1.40	1.47	0.90
Heptadecenoic (C17:1*n*-9)	0.04	0.03	0.04
Elaidic (C18:1*n*-9 trans)	0.35	0.29	0.24
Oleic (C18:1*n*-9)	30.62	28.39	21.77
Vaccenic (C18:1*n*-7)	2.07	1.83	1.75
Eicosenoic (C20:1*n*-9)	0.54	0.57	1.02
Erucic (C22:1*n*-9)	0.01	0.03	0.10
Nervonic (C24:1*n*-9)	0.01	0.02	0.02
MUFA	35.48	32.97	26.23

Control (C) – diet with 15 – 20% rapeseed cake; Experimental (HE) – diet with 15 – 20% hempseed cake; Experimental (CA) – diet with 15 – 20% camelina cake.

DOI: https://doi.org/10.15414/2022.9788055224978

Table 19 Effect of dietary hempseed or camelina cake on liver PUFA profile (g.100 g^{-1} FAME) (Juodka et al., 2022)

Parameter	Groups		
	Control (C)	**Experimental 1 (HE)**	**Experimental 2 (CA)**
Linoleic (C18:2*n*-6)	7.30	7.54	9.52
Linolelaidic (C18:2*n*-6trans)	0.04	0.04	0.07
Octadecadienoic (C18:2*n*-6 cis, trans)	0.05	0.04	0.04
Octadecenoic (C18:2*n*-6 trans,cis)	0.04	0.02	0.01
γ-Linolenic (C18:3*n*-6)	0.15	0.15	0.16
α-Linolenic (C18:3*n*-3)	0.34	0.49	1.16
Eicosadienoic (C20:2*n*-6)	0.34	0.32	0.64
Eicosatrienoic (C20:3*n*-3)	0.10	0.09	0.23
Eicosatrienoic (C20:3*n*-6)	1.55	1.43	2.06
Arachidonic (C20:4*n*-6)	11.79	13.78	13.09
Eicosapentaenoic (C20:5*n*-3)	0.74	0.66	1.80
Docosadienoic (C22:2*n*-6)	0.03	0.03	0.16
Docosatrienoic (C22:4*n*-6)	0.68	0.76	0.59
Dodosapentaenoic (C22:5*n*-3)	0.60	0.65	1.15
Docosahexaenoic (C22:6*n*-3)	1.38	1.48	3.44
LC *n*-6 PUFA	14.38	16.32	16.54
n-6 PUFA	21.83	24.00	26.21
LC *n*-3 PUFA	2.81	2.88	6.61
n-3 PUFA	3.15	3.37	7.77
PUFA	25.12	27.48	34.09
PUFA/SFA	0.66	0.72	0.89
n-6/*n*-3	6.91	7.18	3.38
Linoleic/*α*-linolenic	22.08	16.33	9.01
Trans-fatty acids	0.52	0.43	0.38
Hypocholesterolemic/hypercholesterolemic	2.70	2.18	2.73
Atherogenic index	0.35	0.36	0.34
Thrombogenic index	0.93	0.9	0.74

Control (C) – diet with 15 – 20% rapeseed cake; Experimental 1 (HE) – diet with 15 – 20% hempseed cake; Experimental 2 (CA) – diet with 15 – 20% camelina cake.

DOI: https://doi.org/10.15414/2022.9788055224978

Archaeological excavations in ancient Egypt have proved that goose husbandry was common as early as the third millennium BC. Foie gras would have been used by the Egyptians who appreciate the tasty flesh of geese come to spend the winter on the edges and delta marshes of the Nile. Egyptians understood that the animals naturally created their fattened liver by overfeeding to accomplish long migratory flights. Amazed by the size and taste of these geese livers, Egyptians would have one only had to reproduce this operation to discover Foie Gras. There are Egyptian tomb paintings dating to 4th and 5th dynasties. There is reference to this practice in the satires by Horace (Book ii, Chapter pIII) and in the statuette of a fattened goose more than 4,500 years old from the Ancient Egyptian Empire exhibited at the Louvre. Other authors such as Herodotus and Homer have also described practices corresponding to force feeding in their works. The ancient Romans also sacrificed geese to their highest goddess Juno. The geese feeding according to the method carried out in Gascogne, south-west part of France was described in 1619 "et jecur anseris albae pastum ficis pinguibus" the translation of which is "and the liver of a white goose fattened with oily figs". The foie gras, put of king at the table of Louis XV, reached the celebrity with Louis XVI, thanks to a meat pie receipt **(Nistor et al., 2010).**

Overfeeding is a very old practice, recorded was in ancient Egypt, but until the 1950's foie gras production remained in volume limited. Foie gras is currently produced in various countries but 80% of world production and consumption takes place in France.

Geese, which were the most common specie been overfed until recently, now account for less than 10% of the total world foie gras production. Ducks such as the Muscovy duck (*Cairina moschata*) account for less than 5%, and mule ducks for the rest. So, more than 35 million mule ducks were overfed in France in 2001, it is nearly 95% of the domestic foie gras production. This increase was possible affected by technical progress in specific breeding programmes and overfeeding practice. However, the future of this production is uncertain, in Europe. However, many experimental approaches have shown that there is no scientific evidence that validates such adverse comment, this procedure is highly criticised in terms of animal welfare. The Council of Europe therefore adopted in 1999 two specific recommendations and although overfeeding is not banned at present, it is limited to the areas where it is already practised and only under specific rearing conditions **(Guémené and Guy, 2004).**

Every country has its own unique culinary heritage that has developed over time and that has led to specific eating behaviours, eating patterns, and attitudes toward food. In this thesis, Foie gras is a controversial product: in France, it is a prized national dish deeply

DOI: https://doi.org/10.15414/2022.9788055224978

embedded within the culture. In the US, it is a luxury product that is denounced by multiple animal rights organizations despite being relatively unknown. The value that each country places on foie gras has influenced the legislation surrounding it. For France, this means protecting foie gras from increased legislation by the European Union. For the US, this has translated to bans on foie gras in multiple states due to the industry being small and relatively powerless. The future of foie gras remains uncertain in the US while remaining relatively stable within French culture, though there are some potential strategies in which both sides may meet in the middle to preserve this cherished French dish **(Oleson and Oleson, 2017)**.

Ethical concerns against foie gras production have been particularly amplified, at least in France, since in 1998 the Scientific Committee on Animal Health and Animal Welfare (SCAHAW) reported to the European Commission that overfeeding is detrimental to the welfare of the poultry. The banning of individual housing of ducks in 2016, replaced by collective housing, was one of the consequences of this debate. Further this response to European union regulation on animal housing, scientific projects dedicated to the welfare of ducks and geese for foie gras production have been implemented, some of them being co-funded by the professional sector. A 1st set of studies published in the early 2000's was dedicated to the exploration of stress and pain responses to the overfeeding procedure. The use of current physiological and metabolic indicators of stress responses did not show indication that force-feeding was perceived as an acute or chronic stress **(Fernandez, 2018).**

Foie gras, the pinkish, creamy-colored liver is extremely delicate and must be cooked with care since all the fat can melt away easily with high or prolonged heat. Livers are divided to two quality classes; A livers are the top quality, largest, and firm to the touch, smooth in texture, with consistent color, and no blemishes for example blood spots. Top-quality livers will be shiny with sweet smell. Preferred are for simple preparations like searing and sautéing, and for a classic terrine. The whole liver is cooked in a porcelain terrine in a water bath, then chilled and served cold, in slices. B quality class of foie gras is in size smaller, a little softer in texture, flatter, and they can have some blood or minor defects of surface, and more prominent veins than A quality of livers. This grade of foie gras is just as delicious as the top-quality livers but is more often used in preparations like mousse and terrine, where the blood content will melt away in cooking. B foie gras quality class can also be seared, but chefs usually insist on using the firmer, more aesthetically pleasing A livers quality class for this purpose. The C foie gras quality class is only sporadically available and pales in comparison to both "A" and "B" foie gras and mainly are used to flavor and thicken sauces (**URL 1**).

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The word pâté is sometimes used synonymously with foie gras. Pâté may by any ground meat that is slowly cooked in a mold but is not specific to foie gras, so „pâté de campagne“ is a style country, coarse pate made with pork but without foie gras. Torchon is one of basic pure foie gras preparation, named after the dish towel in which pieces of raw foie gras are wrapped before being in water, wine, or stock. Terrine of foie gras is whole foie gras, and foie gras *entier* all refer to whole, deveined, cleaned, and cooked liver. Plain and simple, these are the purest forms of prepared foie gras. Basic ingredients such as salt, pepper, and a bit of Sauternes wine are all that is needed to create these recipes. Another processing like mousse of foie gras, bloc of foie gras, puréed foie gras are less expensive ways to get that silky flavour of foie gras, because in these preparations, there is water or wine added, and the product is blended or emulsified and baked. May be whipped black truffles into the creamy mousse. Canned foie gras must be cooked to an internal temperature of 212F degrees to be shelf-stable, mainly in the texture and flavor (**URL 1**).

1.7 Abdominal fat

The abdominal fat pad is a reliable parameter for judging total body fat content because it is linked directly to total body fat content in avian species. In poultry, most fatty acids are synthesized in the liver and transported via low-density lipoproteins or chylomicrons for storage in adipose tissues as triglycerides. The abdominal fat tissue is crucial in poultry because it grows faster compared with other fat tissues. Nutritional factors regulate body fat deposition. In general, it is accepted that inhibiting the absorption of dietary fat and fatty acid synthesis and promoting fatty acid β-oxidation reduces abdominal fat deposition by decreasing the size and/or number of abdominal adipose cells **(Fouad et al., 2014).**

Kowalska et al. (2020) found a high proportion of SAFA in the abdominal fat of male ducks 59.42 FAME and females 59.88 g.100 g^{-1}. Of the fatty acids, they found the highest proportion of palmitic acid at 45.64 in duck males and 46.68 g.100 g^{-1} FAME in females.

DOI: https://doi.org/10.15414/2022.9788055224978

Table 20 Fatty acid composition (g.100 g^{-1} FAME) in abdominal fat of ducks (Kowalska et al., 2020)

Fatty acids	Group		Sex		*P* value	
	A	B	Males	Females	Group	Sex
C14:0	1.15	1.10	1.12	1.13	0.318	0.704
C15:0	0.11	0.12	0.13	0.11	0.226	0.051
C16:0	46.20	46.17	45.64	46.68	0.889	0.065
C16:1	1.95	2.04	1.82	2.14	0.593	0.045
C17:0	0.15	0.16	0.17	0.14	0.294	0.014
C18:0	12.38	11.54	12.26	11.73	0.278	0.545
C18:1 n-9	28.87	29.40	29.03	29.20	0.649	0.935
C18:2 n-6	8.33	8.46	8.86	7.97	0.593	0.007
C18:3 n-3	0.59	0.67	0.65	0.61	0.025	0.187
C20:1 n-9	0.20	0.23	0.22	0.21	0.000	0.099
C22:0	0.08	0.11	0.11	0.08	0.024	0.043
SFA	60.07	59.21	59.42	59.88	0.453	0.658
UFA	39.93	40.80	40.58	40.13	0.452	0.661
MUFA	31.08	31.78	31.18	31.63	0.606	0.758
PUFA	8.92	9.12	9.51	8.57	0.513	0.007
n-3	0.59	0.67	0.65	0.61	0.024	0.160
n-6	8.33	8.46	8.86	7.97	0.649	0.006
n-9	29.06	29.63	29.25	29.41	0.647	0.916
DFA	52.31	52.33	52.83	51.86	0.969	0.101
OFA	47.35	47.28	46.76	47.81	0.901	0.072
UFA/SFA	0.67	0.69	0.69	0.67	0.473	0.570
MUFA/SFA	0.52	0.54	0.53	0.53	0.583	0.983
PUFA/SFA	0.15	0.15	0.16	0.14	0.191	0.000
DFA/SFA	0.87	0.88	0.89	0.87	0.639	0.287
DFA/OFA	1.11	1.11	1.13	1.09	0.942	0.078
n-6/3	14.08	12.75	13.76	13.17	0.004	0.174
n-9/6	3.55	3.52	3.34	3.71	0.911	0.118
n-9/3	49.76	44.95	45.78	49.02	0.157	0.293

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2 The aim of the work

The aim of the scientific monograph was to analyse the structure of the carcass and the quality of meat, liver, and fat of ducks of the Mulard genotype after fattening and after overfeeding.

To meet the goal, we monitored:

- carcass structure,
- protein content,
- amino acids,
- fat contents,
- fatty acids.

The basic chemical composition was monitored in the pectoral and thigh muscles. Fatty acid content was monitored in the pectoral and thigh muscles as well as in the liver and abdominal fat.

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3 Material and methods

Duck of the Mulard genotype, a cross between a Peking duck and a Muscovy duck, were included in the experiment. Basic carcass indicators, meat quality and basic chemical composition were monitored in duck farms. All ducks were purchased at approximately 4 to 5 days of age. Until the age of 5 months, the ducks were fed wheat, barley, corn grits, grated pumpkins, and bulk green fodder. In the overfeeding group, this period was followed by a forced corn supplement, which lasted 21 days. The feed mixture for overfeeding formed corn is flooded with water, salt, sugar, and oil. The mixture was allowed to stand until morning. All ducks in the overfeeding group were fed equally. For the purposes of the experiment, ducks (n=5) were killed after breeding and ducks after overfeeding (n=5). Overfeeding lasted 21 days. After overfeeding (21 days), the ducks were weighed, slaughtered, carcassed, and precision and femoral muscle samples were taken for analysis.

Each duck was weighed before and after fattening, slaughter, and processing. The individual carcasses were weighed separately. Muscle samples were taken from pectoral and femoral muscle (from the centre of the muscle, always from the same place), liver and abdominal fat. The samples were analysed within 24 hours.

Analysed parameters:

- live weight before fattening (kg),
- by live weight before slaughter (kg),
- live weight after slaughter (kg),
- carcass weight (g),
- weight of liver (g),
- gizzard weight (g),
- neck weight (g),
- heart weight (g),
- wings weight (g),
- weight of breast with bone (g),
- back weight (g),
- weight of the hindquarters (g), divided between Ilium and *Thoracis vertebrae*
- fat thickness at the base of the tail (cm).

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After slaughter, the duck carcass was divided into:

- back,
- thighs,
- breasts,
- wings.

Subsequently, the individual parts of the carcase were weighed individually (g).

Analysis of the basic composition of meat and fat by FTIR method

Samples of pectoral, thigh muscle, liver, and abdominal fat weighing approximately 30 g were homogenized. The homogenized samples were compressed into thin tablets. The tablets were then analysed. The Nicolet 5700 instrument was used to analyse breast, thigh muscle, liver, and abdominal fat samples. The device measures the absorption of infrared radiation of various wavelengths by the analysed sample. The measurement and its principle are based on the absorption of infrared radiation, the passage of homogenized pectoral, thigh muscle, liver and abdominal fat through the sample, during which there are changes in vibrational and rotational energy states of molecules depending on changes in the dipole moment of the molecule.

Using the Nicolet 5700 device in the pectoral and thigh muscles, the following parameters were analysed:

- water content (g.100 g^{-1}),
- total protein content (g.100 g^{-1}),
- fat content (g.100 g^{-1}),
- amino acid content (g.100 g^{-1}):
  - lysine,
  - leucine,
  - methionine,
  - threonine,
  - valine,
  - isoleucine,
  - histidine,
  - phenylalanine,
  - cysteine,
  - arginine.

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The content of fatty acids in the breast and thigh muscles is expressed from the extracted intramuscular fat (g.100 g^{-1} FAME):

- C 12:0 lauric FA (g.100 g^{-1} FAME),
- C 14:0 myristic FA (g.100 g^{-1} FAME),
- C 16:0 palmitic FA (g.100 g^{-1} FAME),
- C 17:0 heptadecanoic FA (g.100 g^{-1} FAME),
- C 18:0 stearic FA (g.100 g^{-1} FAME),
- C 18:1 11c/15t vaccenic FA (g.100 g^{-1} FAME),
- C 18:1 n-9 oleic FA (g.100 g^{-1} FAME),
- C 18:2 n-6 linoleic FA (g.100 g^{-1} FAME),
- C 18:2 9c/11t conjugated linoleic FA (g.100 g^{-1} FAME),
- C 18:3 α-linoleic FA (g.100 g^{-1} FAME),
- C 20:1 eicosenoic FA (g.100 g^{-1} FAME),
- C 20:4 n-6 arachidonic FA (g.100 g^{-1} FAME),
- C 20:5 n-3 eicosapentaeonic FA (g.100 g^{-1} FAME),
- C 22:5 n-3 docosapentaeonic FA (g.100 g^{-1} FAME),
- C 22:6 n-3 docosahexaeonic FA (g.100 g^{-1} FAME),
- Essential FA (g.100 g^{-1} FAME),
- ω-3 FA (g.100 g^{-1} FAME),
- ω-6 FA (g.100 g^{-1} FAME),
- MUFA (g.100 g^{-1} FAME),
- PUFA (g.100 g^{-1} FAME),
- SAFA (g.100 g^{-1} FAME).

In the liver and abdominal fat, we monitored the content of fatty acids (MK) expressed from extracted fat (g.100 g^{-1} FAME):

- C 14:0 myristic FA (g.100 g^{-1} FAME),
- C 16:0 palmitic FA (g.100 g^{-1} FAME),
- C 18:0 stearic FA (g.100 g^{-1} FAME),
- C 18:1 n-9 oleic FA (g.100 g^{-1} FAME),
- C 18:2 n-6 linoleic FA (g.100 g^{-1} FAME),
- C 18:3 α-linoleic FA (g.100 g^{-1} FAME),
- ω-3 FA (g.100 g^{-1} FAME),
- ω-6 FA (g.100 g^{-1} FAME),

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- MUFA (g.100 g^{-1} FAME),
- PUFA (g.100 g^{-1} FAME),
- SAFA (g.100 g^{-1} FAME).

Mathematical and statistical processing of results

The results of the analyses were processed statistically using SAS (2008) 9.3 Enhanced Logging Facilities, Cary, NC: SAS Institute Inc., 2008. Summary statistics including count, averages, standard deviation, coefficient of variation, minimum, maximum and range were analysed for each parameter separately by Multiple-Variable Analysis process incorporated into Regression analysis and Multiple factors. Spearman R correlation between all obtained parameters were done. Differences between groups were tested using Student T-test.
Relationship correlations were used to analyse the relationships and are shown in a heat map using Microsoft Excel and GraphPad Prism 6 (GraphPad Software, San Diego, USA).

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4 Results and discussion

The scientific monograph evaluated the structure of the carcass, the quality of the pectoral and thigh muscles, as well as the presence of fatty acids in the liver and abdominal fat of ducks of the Mulard genotype after breeding and after overfeeding which lasted 21 days.

The Figure 1 and Table 1 (Annexes) shows the carcass structure and the weight of the internal organs of the ducks not fed (control group) and overfeed (experimental group). Before fattening, at the age of 5 months, the weight of the ducks was not fed 2.66 kg and the ducks intended for overfed were 2.64 kg. The ducks were then fed for 21 days at the same feed ration as at the age of 5 months, and the overfed group of ducks were forcibly fed for 21 days. After feeding and 24 hours of fasting, the weight of overfed ducks was statistically significantly higher (5.96 kg) than control group (4.58 kg). We found a statistically highly significant difference in the liver weight of the ducks of the experimental group (613.2 g) and the control group (76.91 g). There was not find statistically significant differences in the weight of internal organs (Figure 2).

The weight of abdominal fat was statistically highly (981.01 g) in the group overfed ducks and 237.15 g in the control group. The thickness of the subcutaneous fat before the tail root, which was statistically significantly higher in the overfed group (2.28 cm) and in the control group (1.08 cm).

The weight of the neck was higher in the overfed group (171 g than in the control group 164.01 g). The ducks from the overfed group had a significantly lower gizzard weight (73.01 g) than in the control group (90.76 g).

Omojola (2007) analysed the carcass structure of Peking ducks, but at a lower carcass weight (1750 g). Compared to our results, found a higher wing weight of 275 g, a lower thigh weight of 161.77 g and a breast weight of 256.37 g. Compared to our results of control group found a lower liver weight (45.43 g), heart (15.92 g) and gizzard (38.97 g).

Compared to our results of control group **Hermier et al. (2003**) found in Muscovy ducks of higher live weight (6.37 kg) at the slaughter age of 15 weeks. The authors report a liver weight of 415 g. They found the weight of the abdominal fat approximately in agreement with our results of the control group (230 g). **Mona and Younis (2015)** similarly with our results presented liver weight ducks from traditional fattening 69.41g (Mulard breed) and 90 g (Muscovy breed), which presents 1.63 % (Mulard breed) a 1.85 % (Muscovy breed) from carcass weight. The authors found abdominal fat contents in Mulard 14.83 g and Muscovy 57 g.

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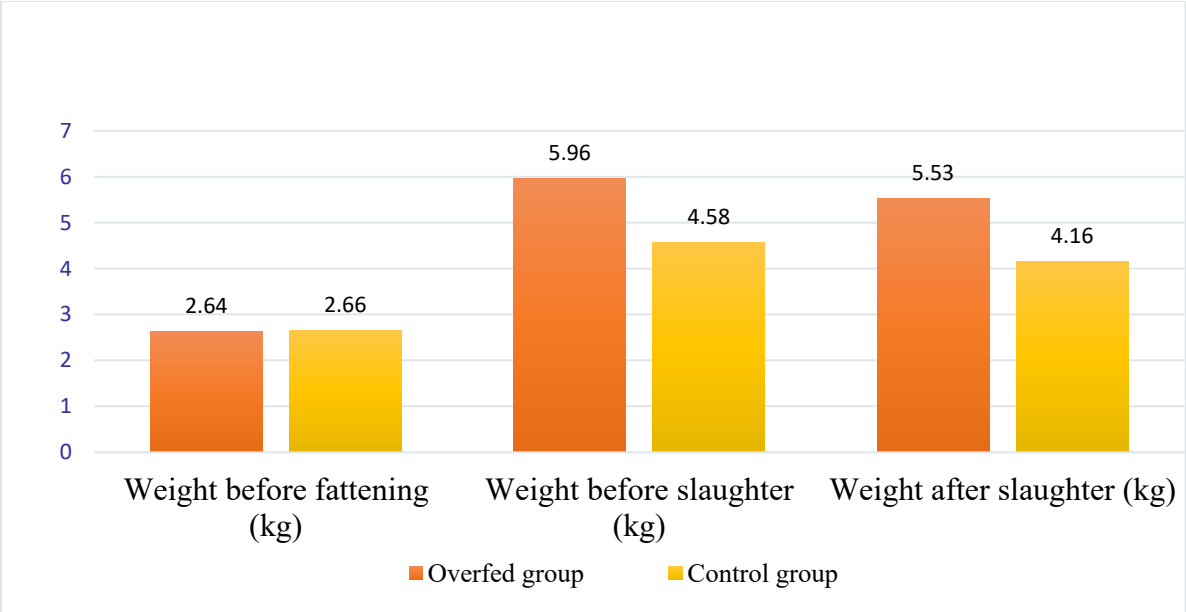

Figure 1 Basic slaughter parameters

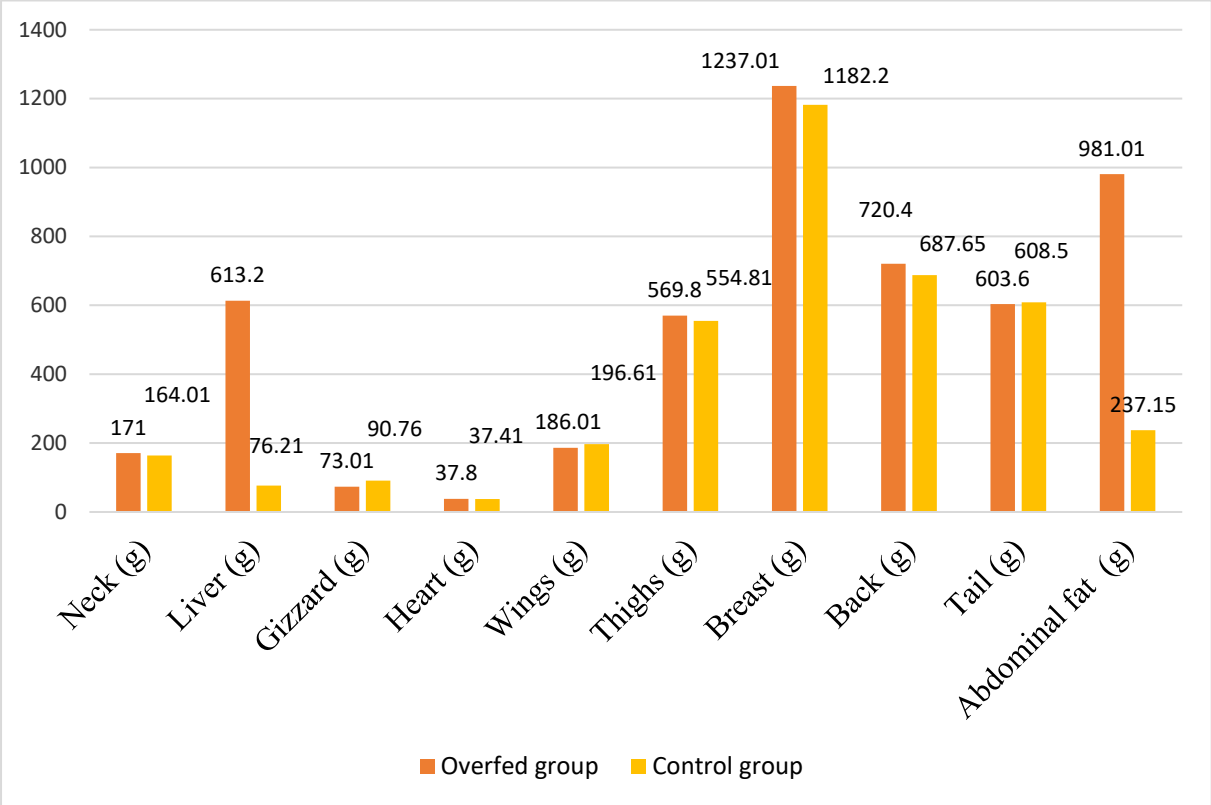

Figure 2 Duck carcass structure

Figure 3 and Table 2 (Annexes) shows the basic chemical composition of the breast muscle of non-fattened ducks (control group) and crossbreeds of Mulard ducks from overfeed group. The intramuscular fat content in the breast muscle of the control group ducks was

DOI: https://doi.org/10.15414/2022.9788055224978

significantly lower (0.96 g.100 g^{-1}) than in the experimental group ducks (3.02 g.100 g^{-1}). The water content was not significantly higher (74.70 g.100 g^{-1}) in the control group than in the overfed group (73.67 g.100 g^{-1}). The ducks in the control group had a statistically significant higher protein content (24.37 g.100 g^{-1}) than in the overfed group (22.38 g.100 g^{-1}). **Liao et al. (2010)** analyzed water, protein, fat, glucose, creatine and pH values in raw and heat-treated chicken and duck breasts. Compared to our results, they show a lower protein content in raw duck breasts of 21.14 g.100^{-1}, while this value increased during cooking by grilling to 31.32 g.100 g^{-1}. **Galal et al. (2011)** report a higher fat content in comparison with our results in Peking ducks 4.48 and in Muscovy ducks 3.86 g.100 g^{-1}.

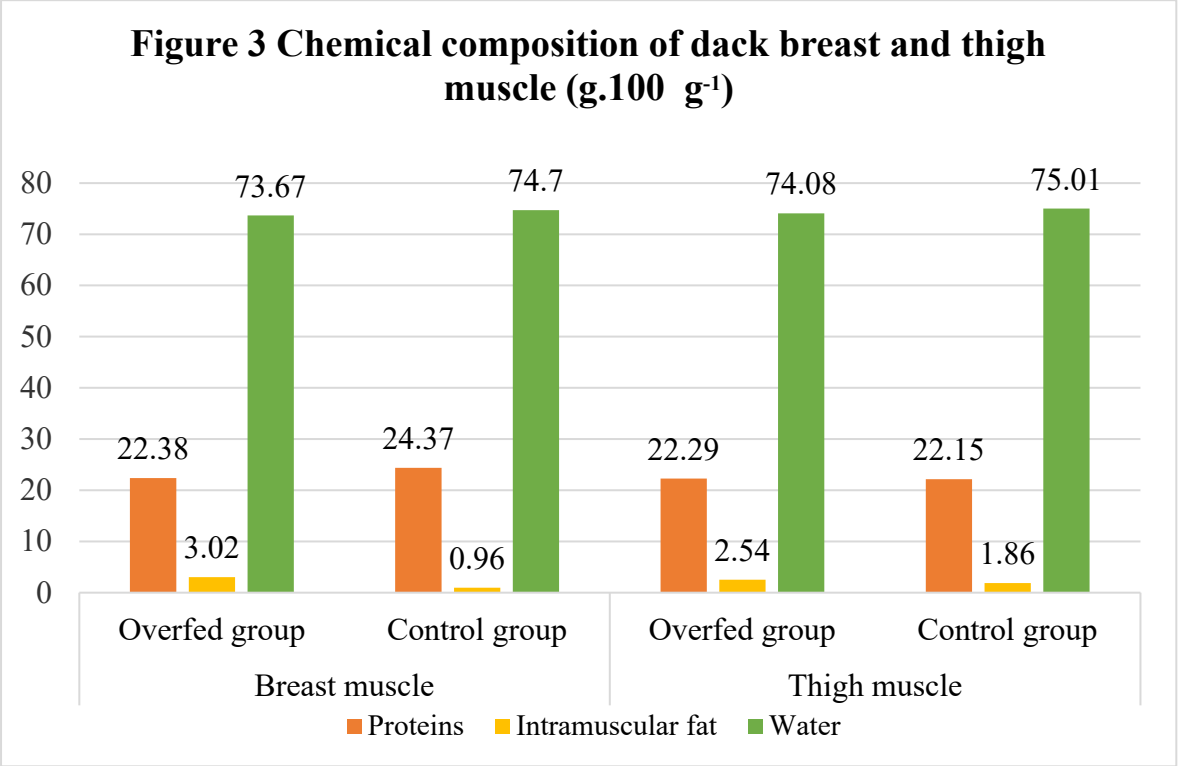

Figure 3 Chemical composition of dack breast and thigh muscle (g.100 g^{-1})

Figure 3 and Table 3 (Annexes) shows the basic chemical composition of the thigh muscle of non-fattened ducks (control group) and duck overfed group. The content of intramuscular fat in the thigh muscle of the overfed group of ducks was 2.54 g.100 g^{-1} and of the control group 1.86 g.100 g^{-1}. The protein content in the control group was 22.15 g.100 g^{-1} and the overfed 22.29 g.100 g^{-1}, we also found an inconclusive difference in the water content of 74.08 g.100 g^{-1} (overfed group) and 75.01 g.100 g^{-1} (control group).

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Galal et al. (2011) report a higher fat content in the thigh muscle in Muscovy ducks up to 5.46 g.100 g^{-1} and in Peking breeds 5.40 g.100 g^{-1}.

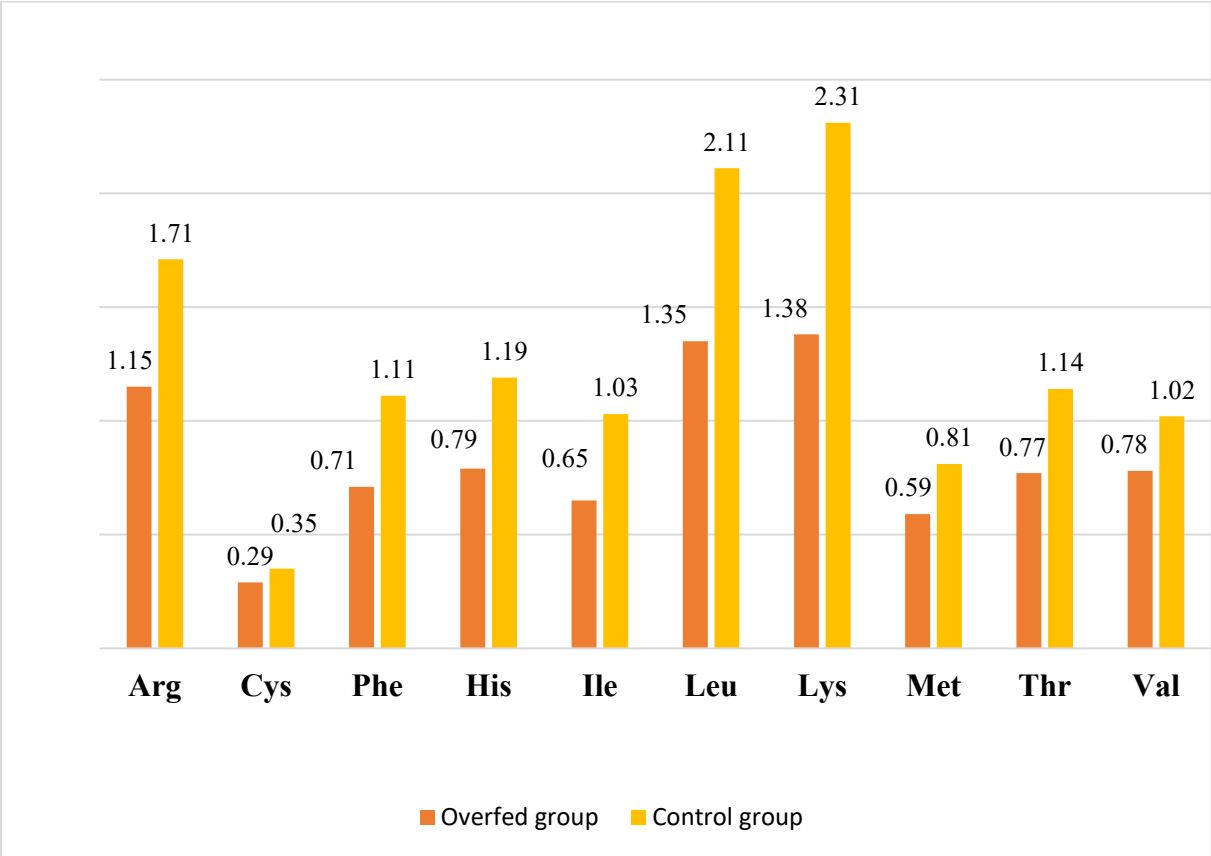

Figure 4 Amino acid composition of duck breast muscle (g.100 g^{-1}

Figure 4 and Table 4 (Annexes) shows the amino acid content in the breast muscle of non-fattened ducks and ducks from overfed (21-day) feed. For all monitored amino cids, a statistically significant difference in their content was found in the control and experimental groups. The content of lysine, an essential amino acid which, together with methionine and threonine, poultry cannot synthesize at all, was 1.38 g.100 g^{-1} in the experimental group and 2.31 g.100 g^{-1} in the control group. In the control group in pectoral muscle there was a statistically significant higher content of arginine 1.71 g.100 g^{-1}, cysteine 0.35 g.100 g^{-1}, histidine 1.19 g.100 g^{-1}, leucine 2.11 g.100 g^{-1}, methionine 0.81 g.100 g^{-1} as in the overfed group.

Woloszyn et al. (2005) found out lysine content in Peking ducks breast muscle from 8.60 to 8.87 g.100 g^{-1}, but the authors report the proportion of amino acids in contrast to our results from all proteins, not from the original mass. The mentioned authors also found a high content of glycine 17.91 and arginine 7.14 g.100 g^{-1}.

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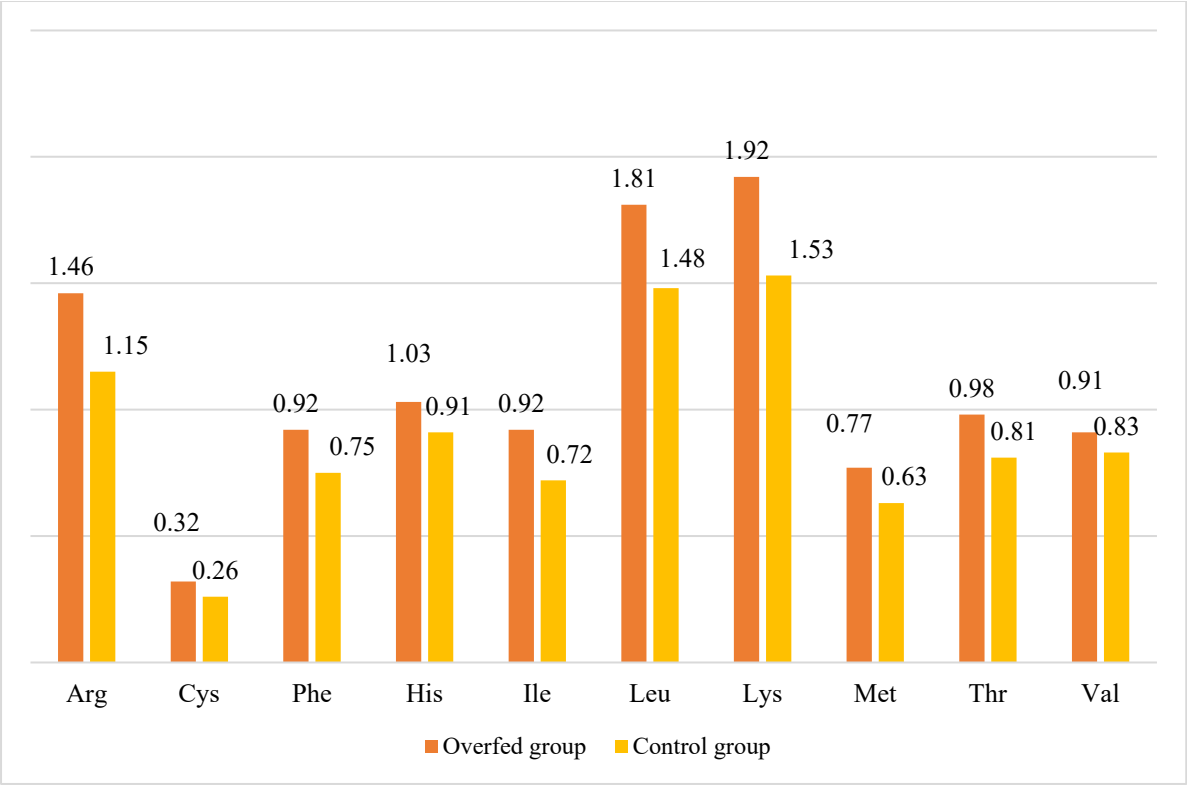

Figure 5 Amino acid composition of duck thigh muscle (g.100 g^{-1})

Figure 5 and Table 5 (Annexes) shows the amino acid content of the thigh muscle of non-fattened ducks (control group) and ducks from overfed group. The content of essential amino acids lysine, methionine and threonine was statistically significantly higher in ducks after intensive feed. The lysine content in the duck muscle of the control group was 1.52 g.100 g^{-1} and in the overfed group 1.92 g.100 g^{-1}, the methionine content in the control group was 0.63 g.100 g^{-1}, in the overfed group 0.77 g.100 g^{-1} and the threonine content in the control group was 0.81%, in the overfed group g.100 g^{-1}.

Woloszyn et al. (2005) found out lysine content in Peking ducks thigh muscle from 8.82 to 9.03 g.100 g^{-1}, but the authors report the proportion of amino acids in contrast to our results from all proteins, not from the original mass. The mentioned authors also found a high content of glycine 18.75 and arginine 7.31 g.100 g^{-1}.

Also, **Aronal et al. (2012)** report lysine content of 9.12 g.100 g^{-1}, methionine 10.12 g.100 g^{-1} and threonine 4.70 g.100 g^{-1}, but in contrast to our results, values are given in g.100 g^{-1} of protein.

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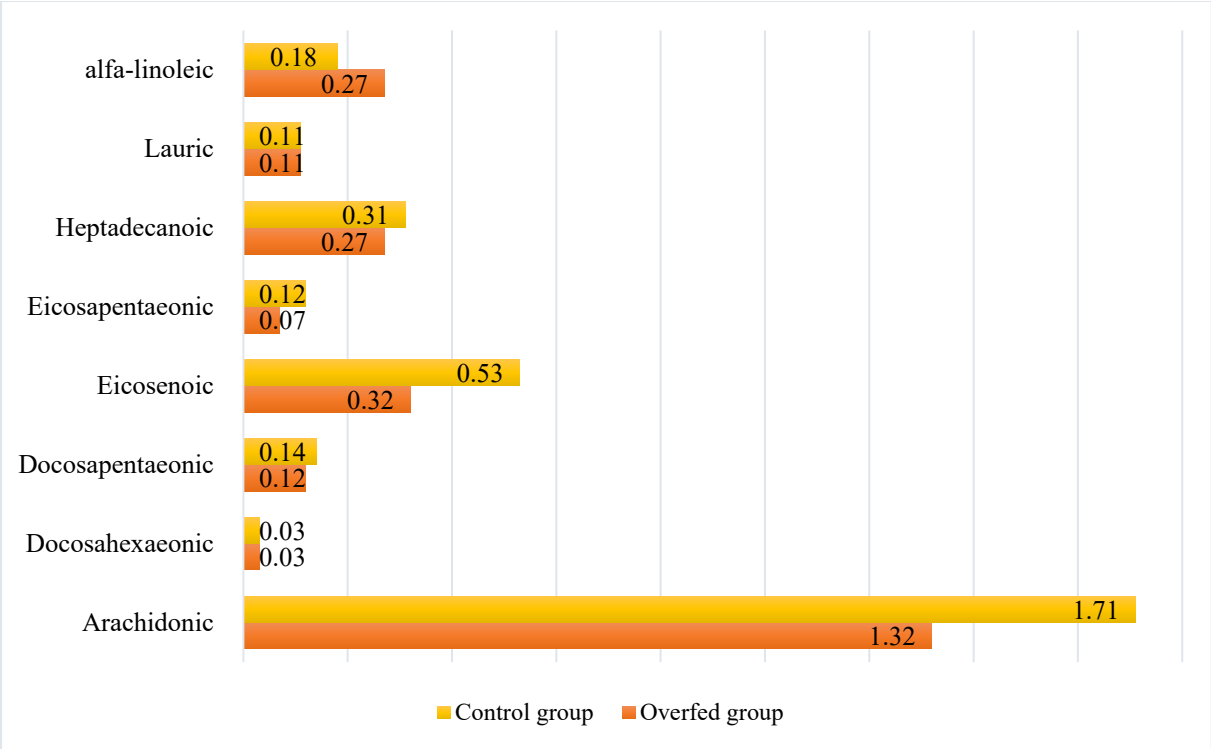

Figure 6 Fatty acid content in duck breast muscle (g.100 g^{-1} FAME)

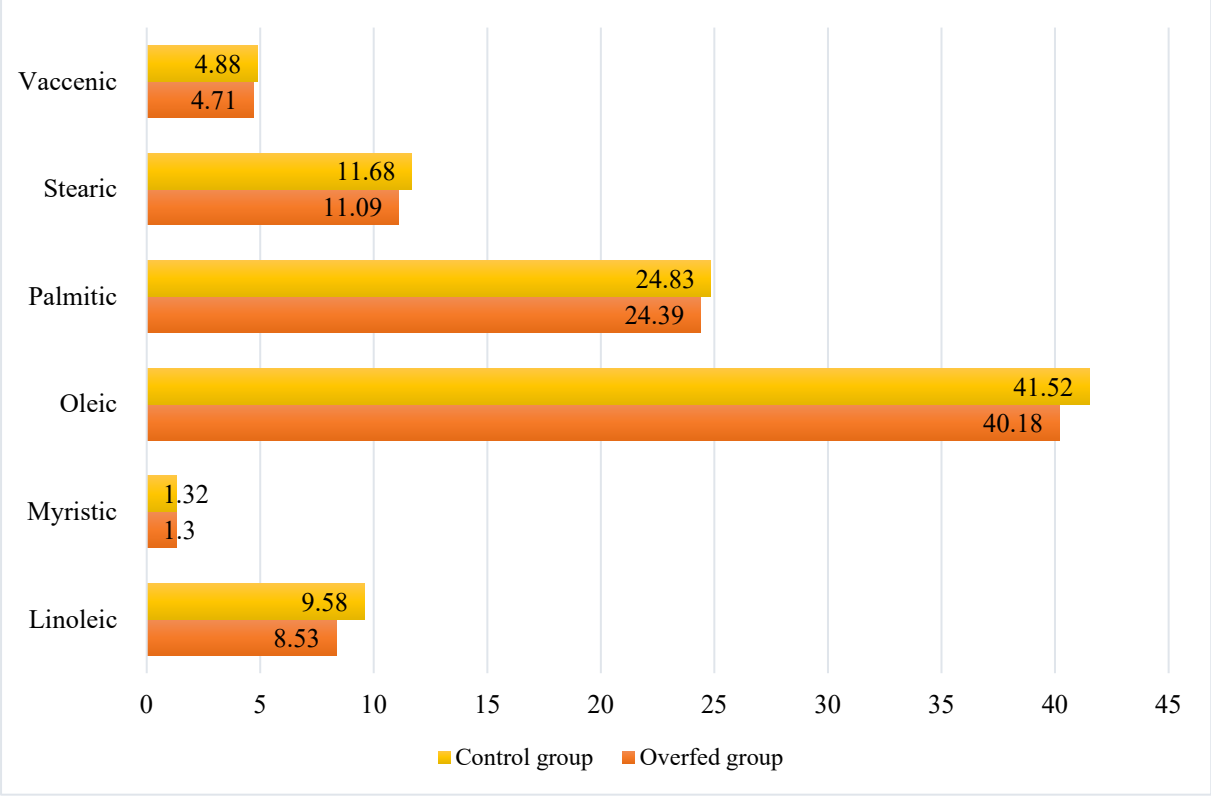

Figure 7 Fatty acid content in duck breast muscle (g.100 g^{-1} FAME)

DOI: https://doi.org/10.15414/2022.9788055224978

The fatty acid content and cholesterol in the breast muscle of the ducks are shown in Figure 6, 7, 8 and Table 6 (Annexes). The cholesterol content (0.58 mg.kg^{-1}) was statistically significantly higher in the breast muscle of the duck overfed group than in the control group 0.42 mg.kg^{-1}. In contrast to our results **Woloszyn et al. (2005)** report a higher cholesterol content (95.17 mg.100 g^{-1}).

We found a statistically significant difference in the content of stearic acid (C18: 0), which was 11.09 g.100 g^{-1} FAME in the ducks of the overfed group and 11.67 g.100 g^{-1} FAME in the control group. The content of conjugated linoleic acid in the duck breast muscle of the overfed group was significantly lower (0.12) than in the control group (0.19 g.100 g^{-1} FAME). Also, a significantly higher proportion of arachidonic acid was in the exact muscle of the ducks of the control group (1.71 g.100 g^{-1}) than the overfed group (1.32 g.100g^{-1} FAME). Compared to our results, **Woloszyn et al. (2005)** found lower oleic acid content (22.07 g.100 g^{-1}), higher stearic acid content (12.74 g.100 g^{-1} FAME) and lower myristic acid content 0.82 g.100 g^{-1} FAME) in the breast muscle of Peking duck. **Juodka et al. (2018)** found in accordance with our results, a palmitic acid content of 22.65 g.100 g^{-1}, a higher oleic acid content of 45.4 g.100 g^{-1} they also found a higher DPA content of 0.32 g.100 g^{-1} and a DHA contents of 0.27 g.100g^{-1} FAME.

The content of ω-3 polyunsaturated fatty acids in the breast muscle of ducks was insignificantly higher in the overfed group (0.68) than in the control group (0.58 g.100 g^{-1} FAME). The content of ω-6 polyunsaturated fatty acids in the exact muscle of ducks was almost identical (overfed group 11.28 g.100 g^{-1} and control group 11.12 g.100 g^{-1} FAME).

There was also a difference in the content of monounsaturated fatty acids, which were in the ducks overfed group 50.75 g.100 g^{-1} and in the control group only 45.02 g.100 g^{-1} FAME. The content of polyunsaturated fatty acids was 13.92 g.100 g^{-1} FAME in the experimental group and 12.29 g.100 g^{-1} FAME in the control group, the content of saturated fatty acids was 34.55 g.100 g^{-1} FAME in the overfed group and in the control group 36.31 g.100g^{-1} FAME. **Woloszyn et al. (2005)** report a content of monounsaturated fatty acids of 23.46 g.100 g^{-1} FAME, polyunsaturated fatty acids of 26.66 g.100 g^{-1} FAME, and saturated fatty acids of 42.07 g.100 g^{-1} FAME in the breast muscle of Peking ducks.

Juodka et al. (2018) found almost in agreement with our results the content of MUFA 51.74 g.100 g^{-1} SAFA 31.04 g.100 g^{-1} and PUFA 15.5 g.100 g^{-1} FAME.

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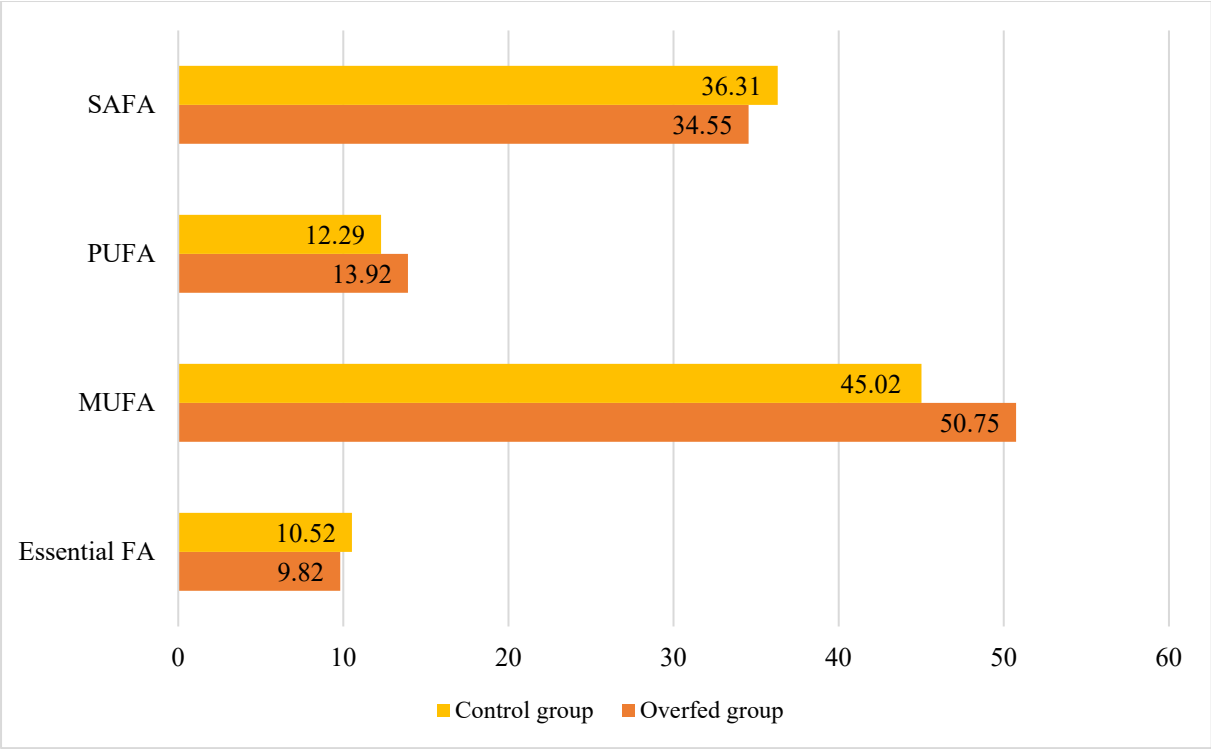

Figure 8 Content of MUFA, PUFA, SAFA and esential FA in duck breast muscle (g.100 g^{-1} FAME)

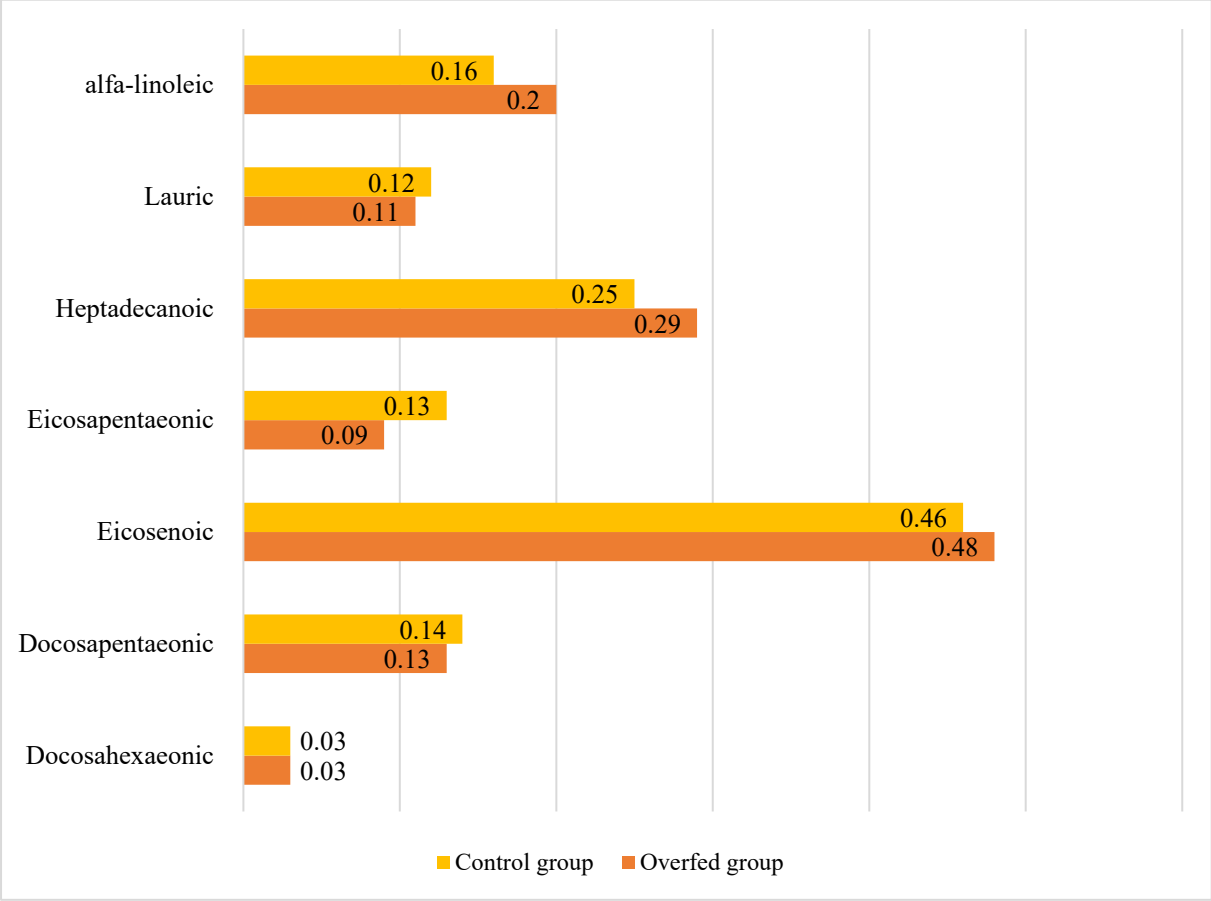

Figure 9 Fatty acid content in duck thigh muscle (g.100 g^{-1} FAME)

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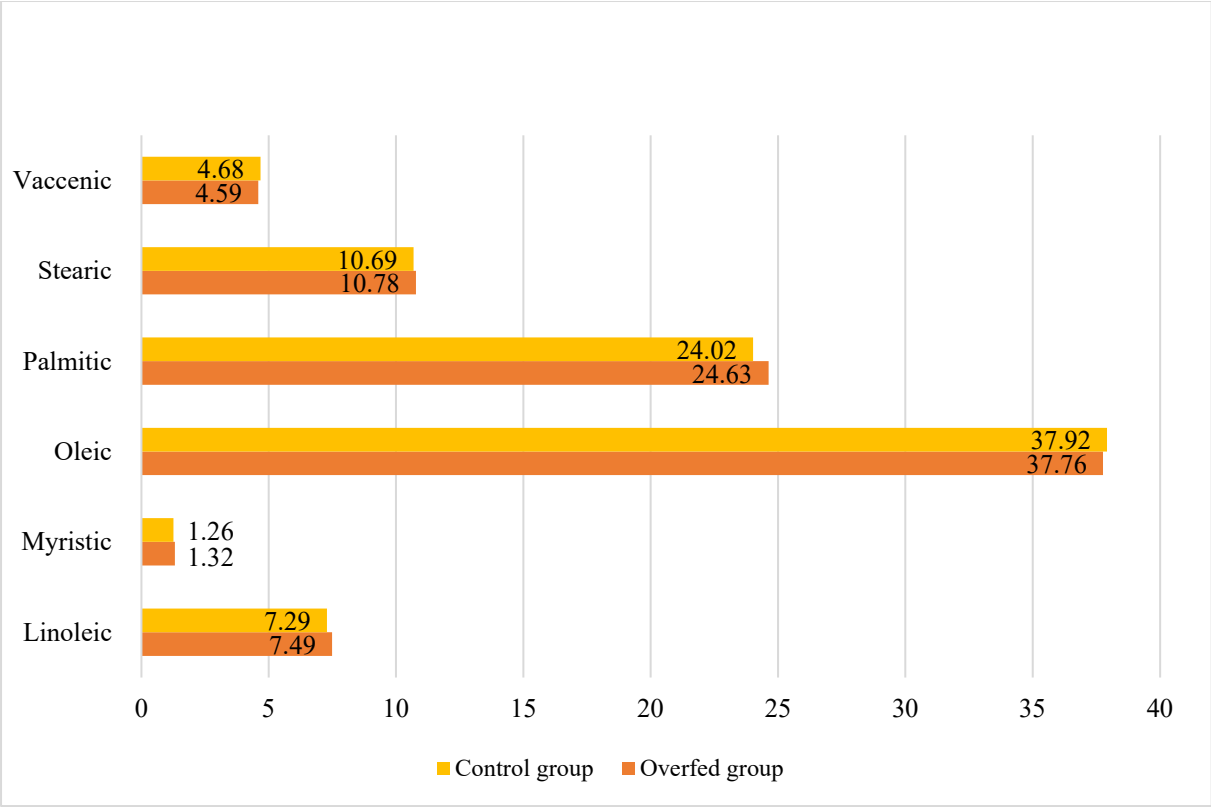

Figure 10 Fatty acid content in duck thigh muscle (g.100 g^{-1} FAME)

Pictures 9, 10, 11 and Table 7 (Annexes) show the fatty acid content in the thigh muscle of the control group ducks and the overfed group ducks). The oleic acid content in the overfed group thigh muscle was 37.76 g.100 g^{-1} and control almost the same 37.92 g.100 g^{-1} FAME. The content of palmitic acid in the overfed group thigh muscle was 24.63 g.100 g^{-1} and control group 24.02 g.100 g^{-1} FAME. The DHA content was 0.03 g.100 g^{-1} FAME in both the overfed and control groups. The significantly higher content of EPA was 0.13 g.100 g^{-1}in the thigh muscle of the control group than in the overfed group 0.09 g.100 g^{-1} FAME. Compared to our results significantly higher proportion of ω 3 polyunsaturated fatty acids was 0.56 g.100 g^{-1} in the thigh muscle of the overfed group than in the control 0.48 g.100 g^{-1} FAME. **Juodka et al. (2018**) reported a higher content of oleic acid in the thigh muscle of Peking ducks 48.93 g.100g^{-1} FAME, they also found a higher linoleic acid content of 10.06 g.100 g^{-1} FAME. The content of monounsaturated fatty acids was higher in the overfed group (49.41 g.100 g^{-1} FAME) than in the control group (46.89 g.100 g^{-1} FAME). In contrast, the content of saturated fatty acids (SAFA) was higher in the control group (37.59 g.100 g^{-1} FAME) than in the overfed group (34.89 g.100 g^{-1} FAME). The difference in the content of ω 3 polyunsaturated FA was highly statistically significant, which was 0.56 g.100 g^{-1} FAME in the overfed group and 0.48 g.100 g^{-1} FAME in the control group**. Xu et al. (2008)** report the content of saturated fatty

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acids in the thigh muscle of Nanjing ducks 39.08 g.100 g^{-1} FAME. The mentioned authors state the content of monounsaturated fatty acids 22.11 g.100 g^{-1} FAME, which is a significantly lower value compared to our results, in the experimental group we found the content of 49.33 g.100 g^{-1} FAME. **Juodka et al. (2018)** report a higher content of ω-3 polyunsaturated fatty acids 2.17 g.100 g^{-1} FAME, also ω-6 polyunsaturated fatty acids 12.00 g.100 g^{-1} FAME compared to our results. **Woloszyn et al. (2005)** report a lower myristic fatty acid content of 0.74 g.100 g^{-1} FAME, a vaccenic acid of 3.93 g.100 g^{-1} FAME, and a lower palmitic acid content of 19.12 g.100 g^{-1} FAME compared to our results. These authors found approximately the same SAFA content of 34.99 g.100 g^{-1} FAME, a lower MUFA content of 30.75 g.100 g^{-1} FAME, and a higher PUFA content of 25.97 g.100 g^{-1} FAME in the Peking duck thigh muscle compared to our results.

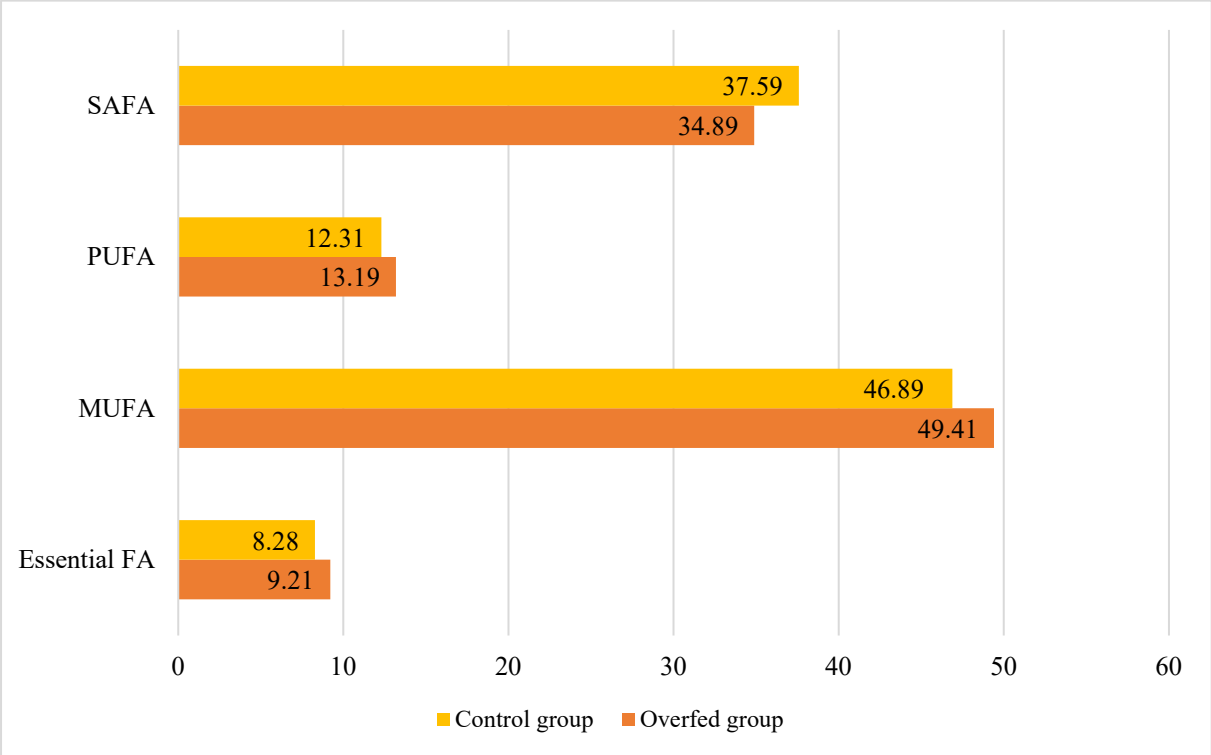

Figure 11 Content of MUFA, PUFA, SAFA and esential FA in duck breast muscle (g.100 g^{-1} FAME)

We found a higher proportion of oleic acid 40.18 g.100 g^{-1} FAME in the breast muscle of the overfed group than in the thigh muscle, we also found a higher content of linoleic FA (8.35 g.100 g^{-1} FAME) in the pectoral muscle of the overfed group than in the thigh muscle (7.49 g.100 g^{-1} FAME). In contrast, the thigh muscle of the overfed group had a higher content of palmitic acid 24.63 g.100 g^{-1} FAME, arachidonic acid 1.57, eicosenoic FA 0.48 and myristic

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FA 1.32 g.100 g^{-1} FAME. The content of MUFA, PUFA and SAFA in the breast and thigh muscles was approximately the same, MUFA 50.75 g.100 g^{-1} (breast muscle) resp. 49.41 g.100 g^{-1} FAME (thigh muscle), PUFA 13.92 (breast muscle) resp. 13.19 g.100 g^{-1} FAME (thigh muscle), and SAFA 34.55 g.100 g^{-1} FAME (breast muscle) resp. 34.89 g.100 g^{-1} FAME (thigh muscle). Cholesterol content was higher in the overfed group in both pectoral muscle 0.58 mg.kg^{-1} and in thigh muscle 0.59 mg.kg^{-1}.

In the analysis of the both analysed muscles, we can state that overfed had a significant effect only on the reduction of eicosapentaenoic FA (in breast muscle 0.22 to 0.07 g.100 g^{-1} FAME and in thigh muscle from 0.13 to 0.09 g.100 g^{-1} FAME). Also, in both monitored muscles, the overfed significantly affected reduction of SAFA, in the breast muscle from 36.31 to 34.55 g.100 g^{-1} FAME and in the thigh muscle from 37.59 to 34.85 g.100 g^{-1} FAME. In contrast, the MUFA content increased overfeed in the breast muscle from 45.02 to 50.75 g.100 g^{-1} FAME and in the thigh muscle from 46.89 to 49.41 g.100 g^{-1} FAME.

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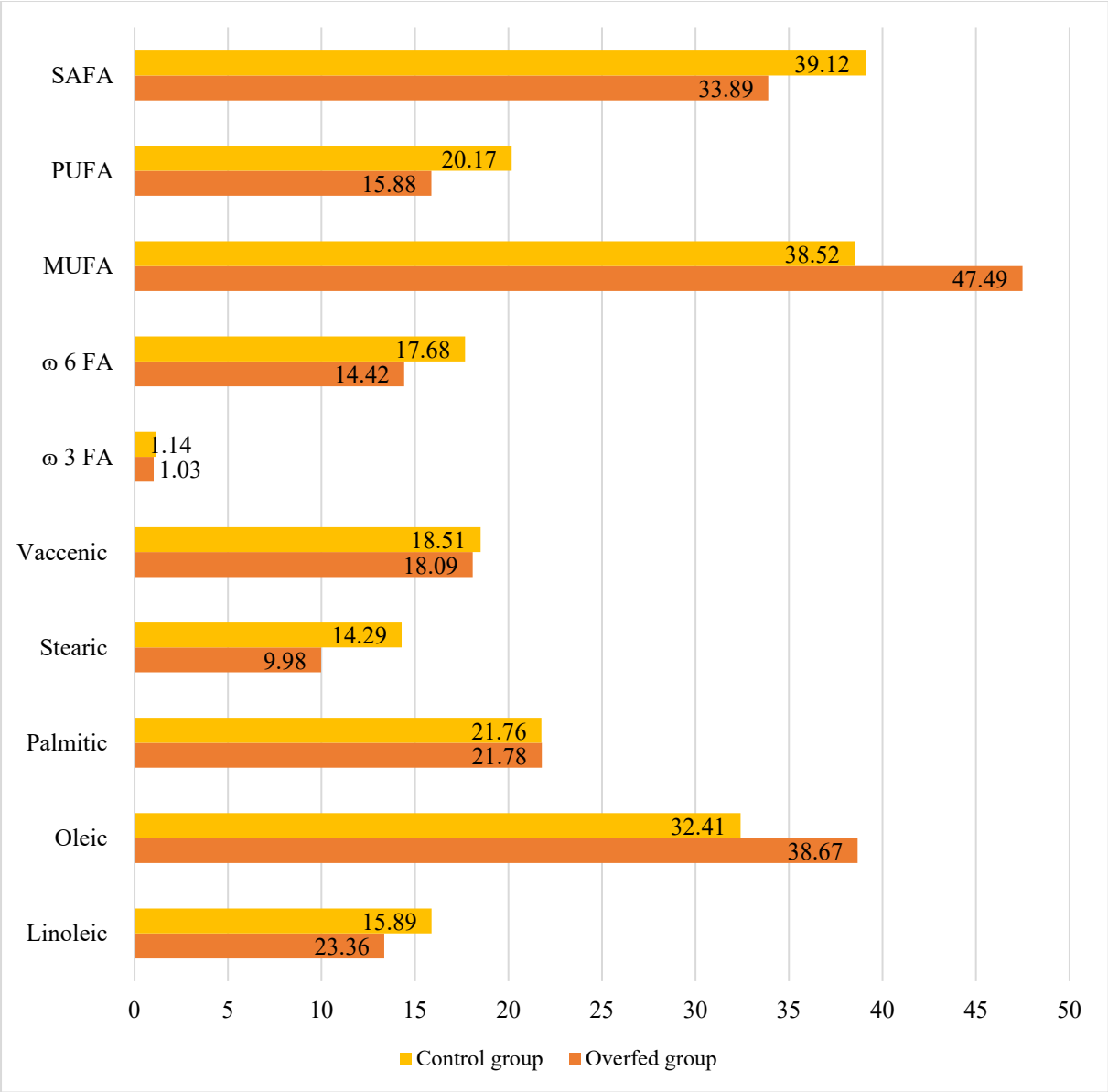

Figure 12 Fatty acid content in the liver of overfed a control group of ducks (g.100 g^{-1} FAME)

Figure 12 and Table 8 (Annexes) show the fatty acid content of the overfed duck liver and the control group. The oleic acid content was statistically significantly lower in the control group 32.41 g.100 g^{-1} than in the overfed group 38.67 g.100 g^{-1} FAME. A significant difference in the content of linoleic FA was also confirmed, in the overfed group it was 13.36 g.100 g^{-1} and in the control group 15.89 g.100 g^{-1} FAME. The content of saturated fatty acids in the liver of Mulard hybrids in the control group was 39.12 g.100 g^{-1} FAME and in the ducks from overfed group 33.89 g.100 g^{-1} FAME. The overfed group had a significantly higher content of monounsaturated fatty acids in the liver 47.49 g.100 g^{-1} FAME compared to the control group 38.52 g.100 g^{-1} FAME. The difference in the content of ω 6 polyunsaturated fatty acids is highly

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statistically significant, in the ducks of the control group 17.68 g.100 g^{-1} FAME and in the experimental group 14.42 g.100 g^{-1} FAME. **Chartrin et al. (2006)** reported a monounsaturated fatty acid content of ducks of the Mulard genotype in a control group of 25.53 g.100 g^{-1} FAME and increased to 55.04 g.100 g^{-1} FAME after feeding.

In comparison with our results, **He, et al. (2012)** lower content of alpha-linoleic FA 0.55 g.100 g^{-1} FAME, myristic FA 0.489 g.100 g^{-1} FAME, and higher content of vaccines FA 40.168 g.100 g^{-1} FAME, palmitic FA 25.77 g.100 g^{-1} and oleic FA 40.168 g.100 g^{-1} FAME.

In comparison with our results **Juodka et al. (2022)** found lower content oleic FA 30.62 g.100 g^{-1} FAME, MUFA 35.48 g.100 g^{-1} and higher SAFA content 38.02 g.100 g^{-1} FAME in duck liver.

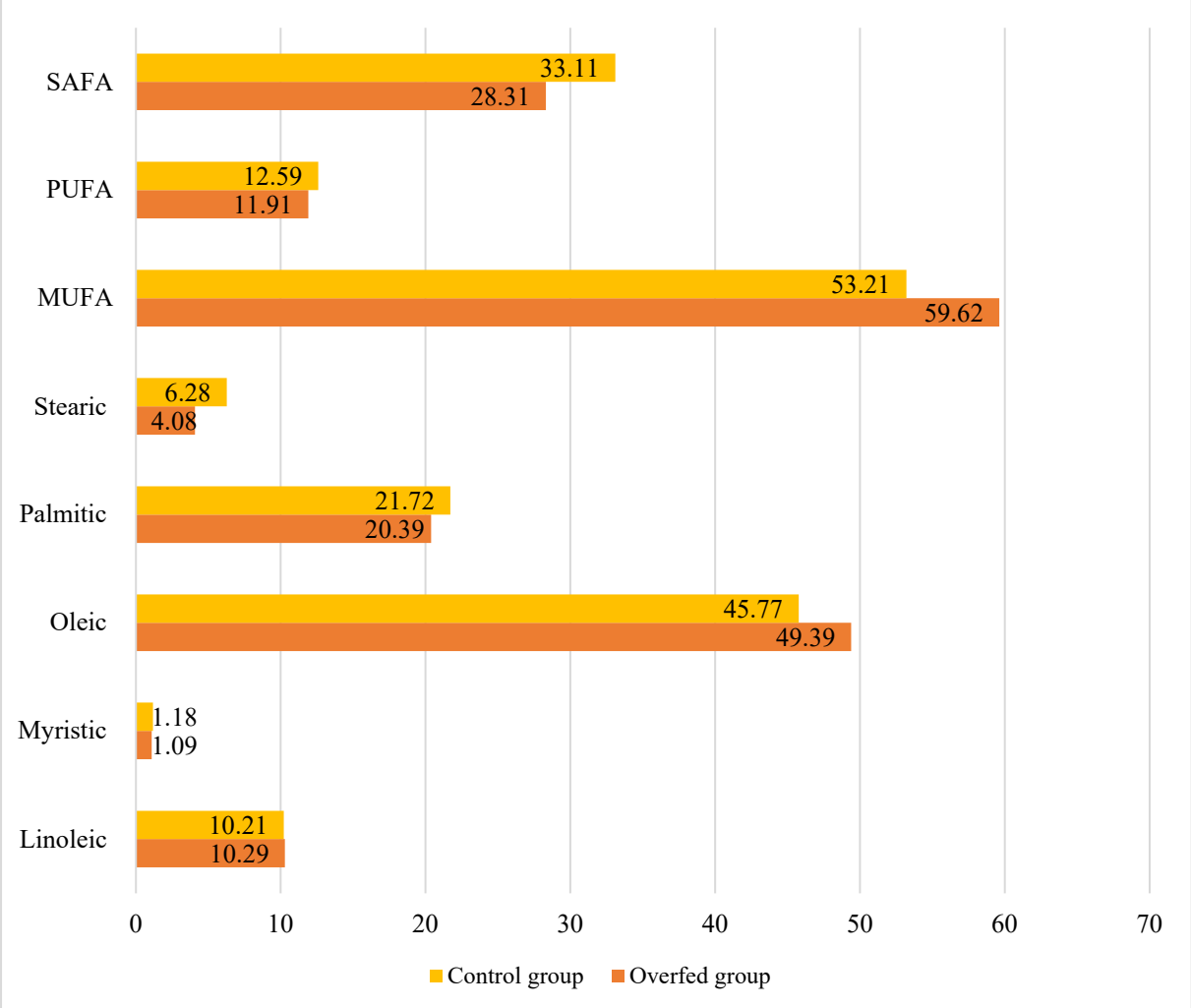

Figure 13 Fatty acid content in the abdominal fat of overfed a control group of ducks (g.100 g^{-1} FAME)

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Figure 13 and Table 9 (Annexes) show the content of fatty acids in the abdominal fat of ducks, we found a significant difference in the content of oleic acid, in ducks overfed group 49.39 g.100 g^{-1} FAME and in the control group 45.77 g.100 g^{-1} FAME. The content of palmitic acid was significantly higher in the control group 21.72 g.100 g^{-1} than in the abdominal fat overfed group 20.39 g.100 g^{-1} FAME. The content of ω-3 polyunsaturated acids was almost identical in both groups, in the experimental 0.79 g.100 g^{-1} FAME and in the control 0.75 g.100 g^{-1} FAME. The statistically significant difference between the overfed and the control group was in the content of monounsaturated fatty acids, the content of which in the overfed group was 59.62 g.100 g^{-1} FAME in the control 53.21 g.100 g^{-1} FAME and in the content of saturated fatty acids (SAFA) 28.31 g.100g^{-1} FAME in the abdominal fat overfed group and 33.11 g.100 g^{-1} FAME in the control group.

Kowalska et al. (2020) found approximately the same content of myristic FA 1.15 g.100 g^{-1} FAME, higher palmitic FA contents 46.20, stearic 12.38 g.100 g^{-1} FAME, SAFA 60.07 g.100 g^{-1} and lower MUFA content 31.08 g.100 g^{-1} FAME and PUFA content 8.92 g.100 g^{-1} FAME in duck abdominal fat compared to our results.

The total content of fatty acids in all monitored tissues we found a significant increase in MUFA in the overfed group, in breast muscle it increased from 45.02 to 50.75 g.100 g^{-1} FAME, in thigh muscle from 46.89 to 49.41 g.100 g^{-1} FAME, liver from 38.52 to 47,49 g.100 g^{-1} FAME and in abdominal fat from 53.21 to 59.62 g.100 g^{-1} FAME. On the other hand, the SAFA content in the breast muscle decreased from 36.31 to 34.55 g.100 g^{-1} FAME, in the thigh muscle from 37.59 to 34.89 g.100 g^{-1} FAME, in the liver from 39.12 to 33.89 g.100 g^{-1} FAME and in the abdominal fat from 33.11 at 28.31 g.100 g^{-1} FAME. These changes were not confirmed in the whole group for any of the monitored fatty acids. Palmitic and stearic FA content increased in breast muscle, palmitic and myristic FA content in thigh muscle, palmitic and stearic FA content in abdominal fat.

DOI: https://doi.org/10.15414/2022.9788055224978

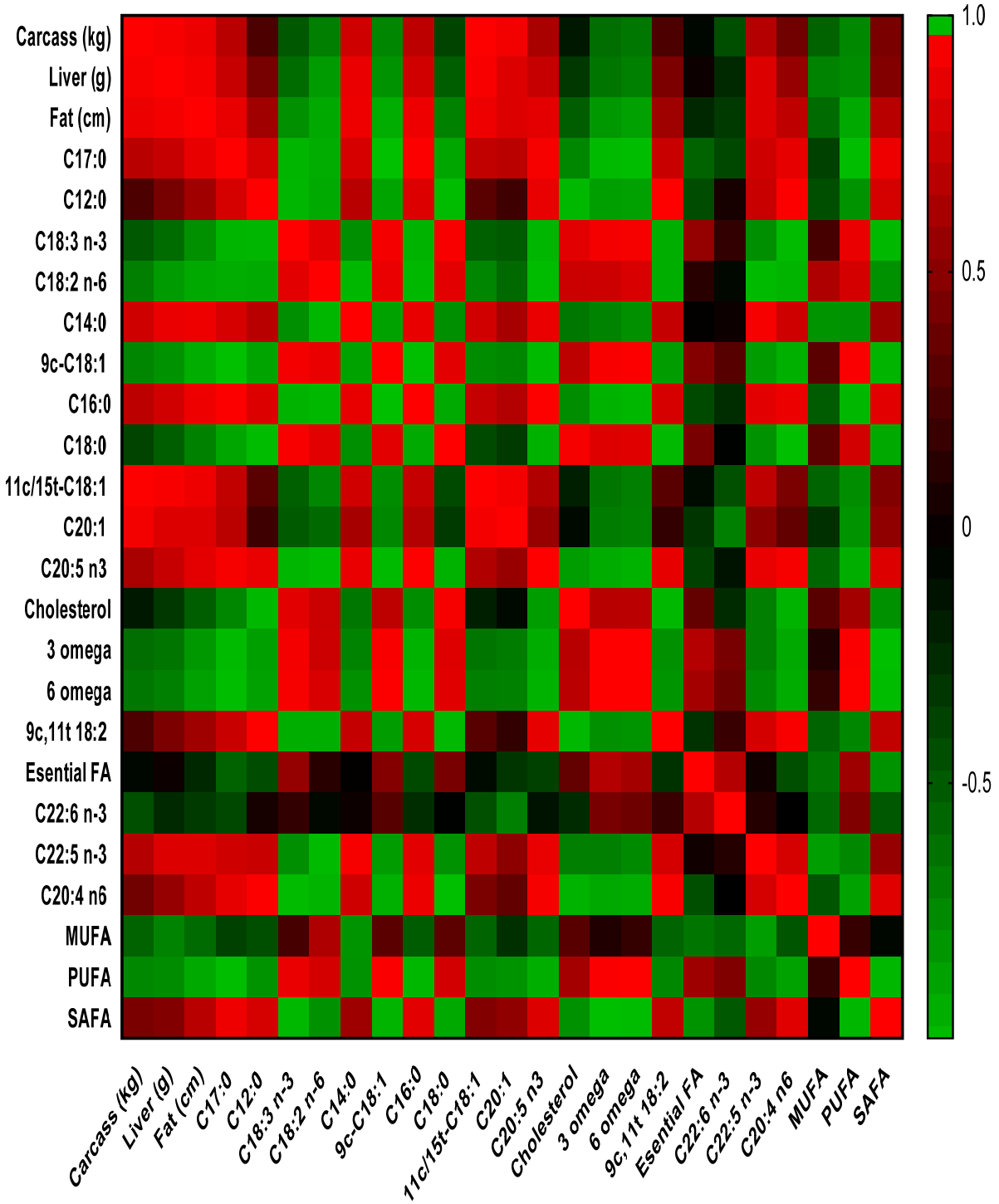

Figure 14 Correlations between the breast muscle parameters of the overfed group

Figure 14 shows the correlations between carcass parameters, liver weight and fatty acid content in the breast muscle of the overfed group. A positive correlation of carcass weight to liver, fat thickness, myristic acid, palmitic acid, oleic acid, eicosenoic FA, eicosapentaeonic FA, docosapentaeonic FA, and SAFA was confirmed.

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A negative correlation of carcass to omega-3 FA, omega-6 FA and PUFA was confirmed.

A positive correlation of liver weight, fat thickness, myristic fatty acid, palmitic acid, oleic acid, eicosenoic, eicosapentaeonic, docosapentaeonic, and SAFA was confirmed.

The negative correlation of liver to omega-3 FA, omega-6 FA and PUFA was confirmed.

A positive correlation of fat thickness to myristic acid, palmitic acid, oleic acid, eicosenoic, eicosapentaeonic, docosapentaeonic, and SAFA was confirmed.

The positive correlation of cholesterol content to alpha-linoleic FA, vaccenic FA, oleic, stearic, omega-3 FA and omega-6 FA was confirmed.

Negative correlations of cholesterol content to liver weight, fat thickness, lauric, EPA, linoleic FA, SAFA content and arachidonic FA were confirmed.

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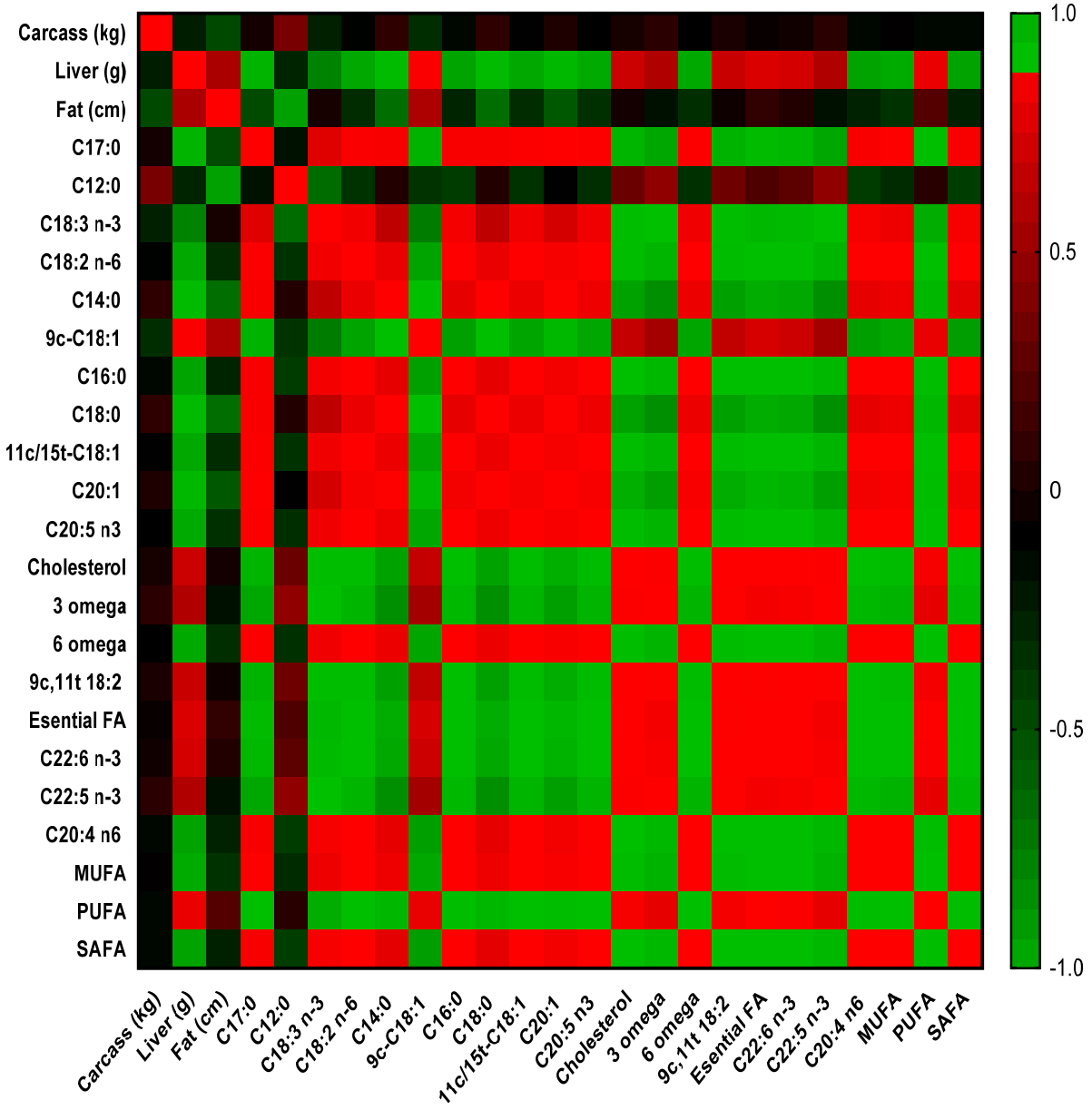

Figure 15 Correlations between the breast muscle parameters of the control group

Figure 15 shows the correlations between carcass parameters, liver weight and fatty acid content in the breast muscle of the control group.

A positive correlation of liver weight to fat thickness, oleic FA, cholesterol content, omega-3 FA, linoleic FA, essential FA, DHA and PUFA was confirmed.

A negative correlation of liver weight to heptadecanoic, myristic, stearic, eicosenoic, omega-6 FA, arachidonic FA, MUFA and SAFA was confirmed.

A positive correlation of fat thickness to liver weight, oleic FA was confirmed.

DOI: https://doi.org/10.15414/2022.9788055224978

A negative correlation of fat thickness to lauric FA, myristic FA, stearic and eicosenoic FA was confirmed.

A positive correlation of cholesterol content to liver weight, omega-3 FA, oleic, conjugated linoleic FA, essential FA, DHA, DPA, and PUFA was confirmed.

The negative correlation of cholesterol content to heptadecanoic FA, α-linoleic, linoleic, myristic, palmitic, stearic, omega-6 FA, MUFA and SAFA was confirmed.

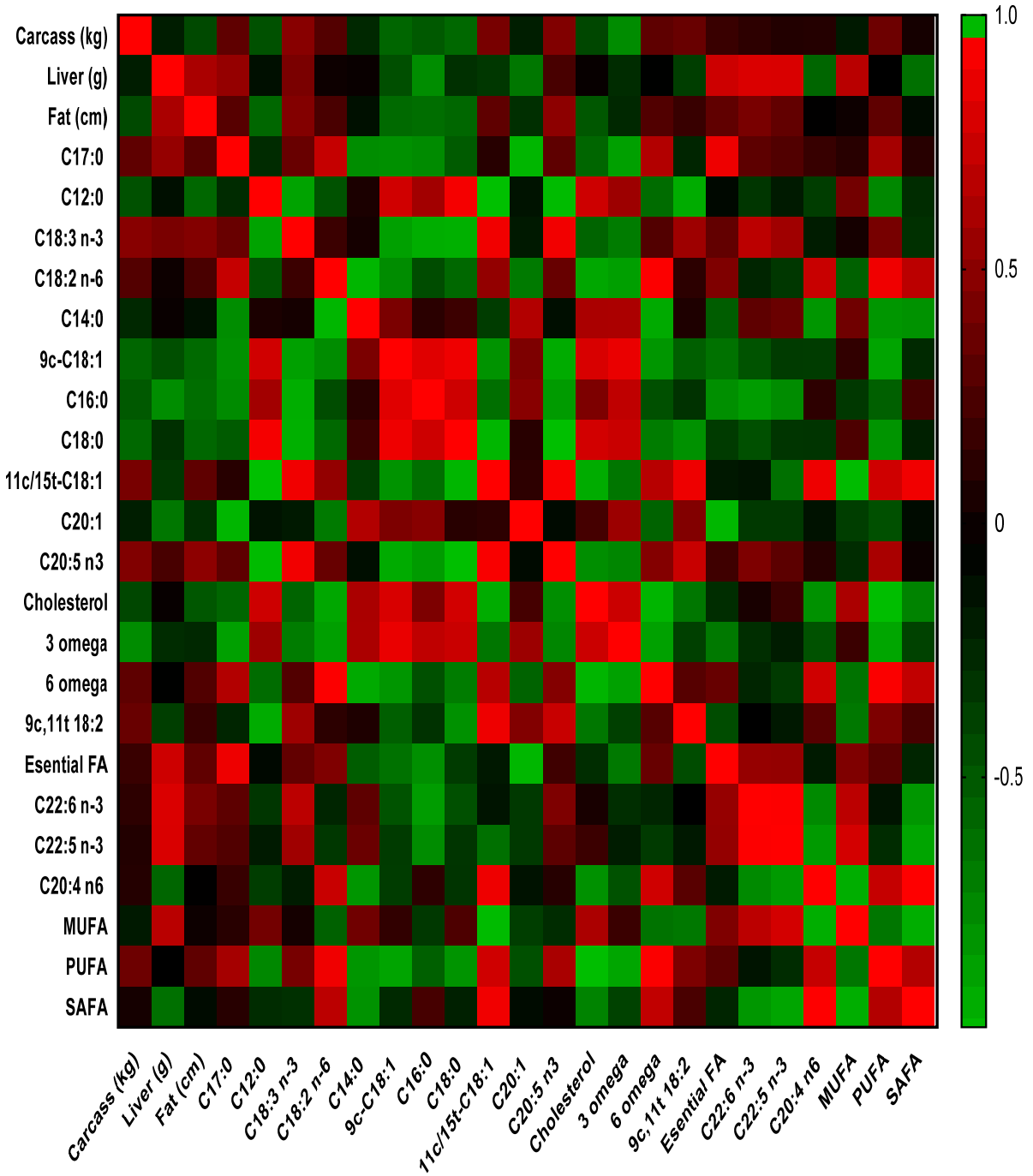

Figure 16 Correlations between the thigh muscle parameters of the overfed group

DOI: https://doi.org/10.15414/2022.9788055224978

Figure 16 shows the correlations between carcass parameters, liver weight and fatty acid content in the thigh muscle of the overfed group.

A positive correlation of carcass to vaccenic, DPA, omega-6, and PUFA was confirmed.

A negative correlation of carcass weight to fat thickness, lauric FA, oleic, palmitic, stearic, omega-3 FA was confirmed.

A positive correlation of liver weight to essential FA, DHA, DPA, MUFA was confirmed.

A negative correlation of liver weight to palmitic, eicosenioc, arachidonic FA, SAFA was confirmed.

A positive correlation of fat thickness to alpha-linoleic FA, EPA, and PUFA was confirmed.

A negative correlation of fat thickness to oleic FA, palmitic, stearic and cholesterol contents was confirmed.

A positive correlation of cholesterol content to lauric FA, arachidonic, palmitic, oleic, omega-3 FA and MUFA was confirmed.

A negative correlation of cholesterol content to carcass weight, fat thickness, heptadecanoic, α -linoleic, linoleic, vaccenic, omega 3 FA EPA, PUFA and SAFA was confirmed.

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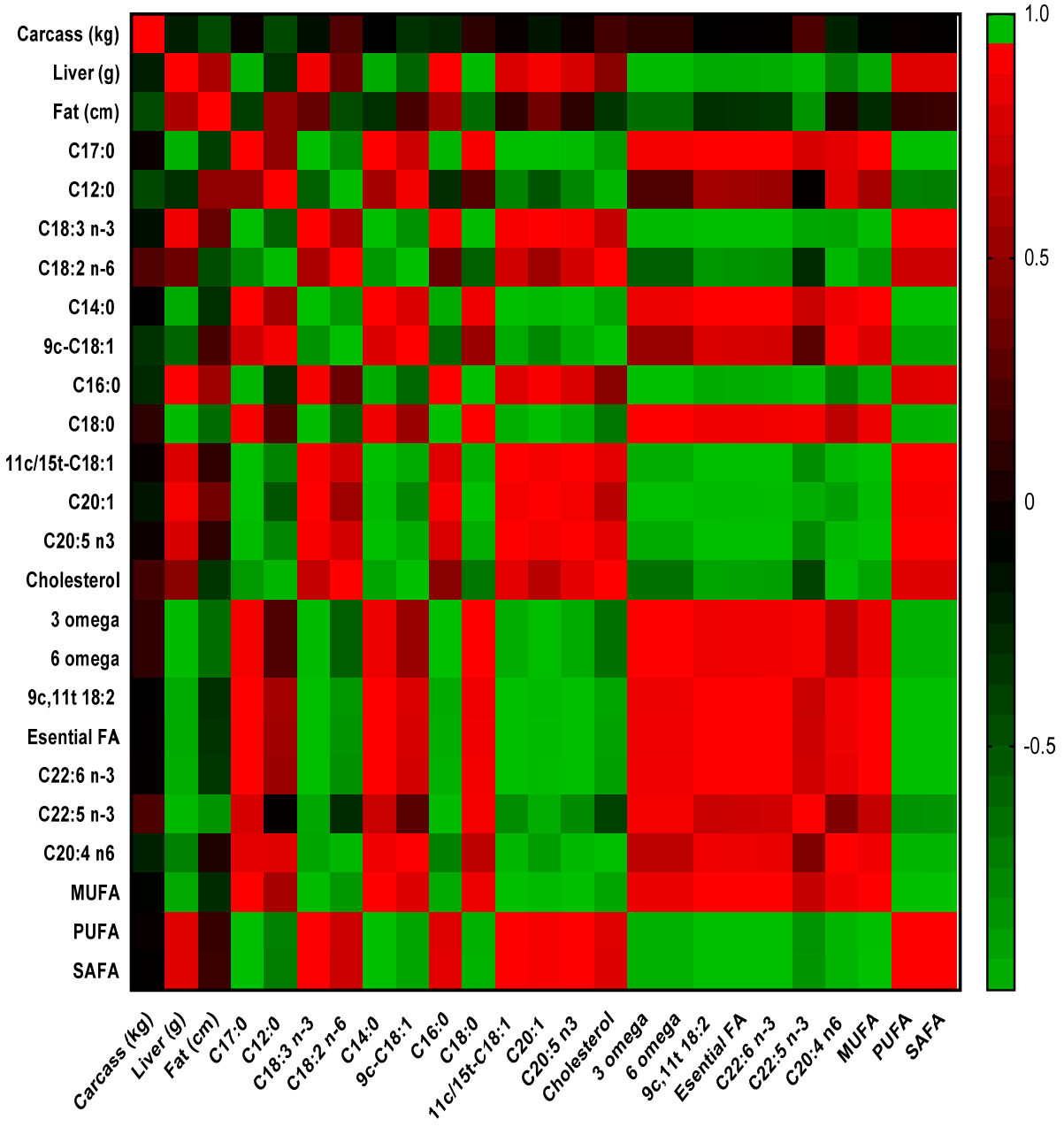

Figure 17 Correlations between the thigh muscle parameters of the control group

Figure 17 shows the correlations between carcass parameters, liver weight and fatty acid content in the thigh muscle of the control group.

A positive correlation of liver weight to α-linoleic FA, palmitic FA, vaccenic, oleic, eicosenoic, EPA, PUFA and MUFA was confirmed.

A negative correlation of liver weight to heptadecanoic, myristic, palmitic, omega-3 FA, omega-6 FA and DPA was confirmed.

A positive correlation of fat thickness to palmitic FA was confirmed.

DOI: https://doi.org/10.15414/2022.9788055224978

A negative correlation of fat thickness to omega-3, FA omega-6 FA and DPA was confirmed.

The positive correlation of cholesterol content to α-linoleic FA, linoleic, oleic, eicosenoic FA and EPA was confirmed.

The negative correlation of cholesterol content to heptadecanoic, lauric, myristic, oleic, linoleic, essential FA, DHA, arachidonic FA and MUFA content was confirmed.

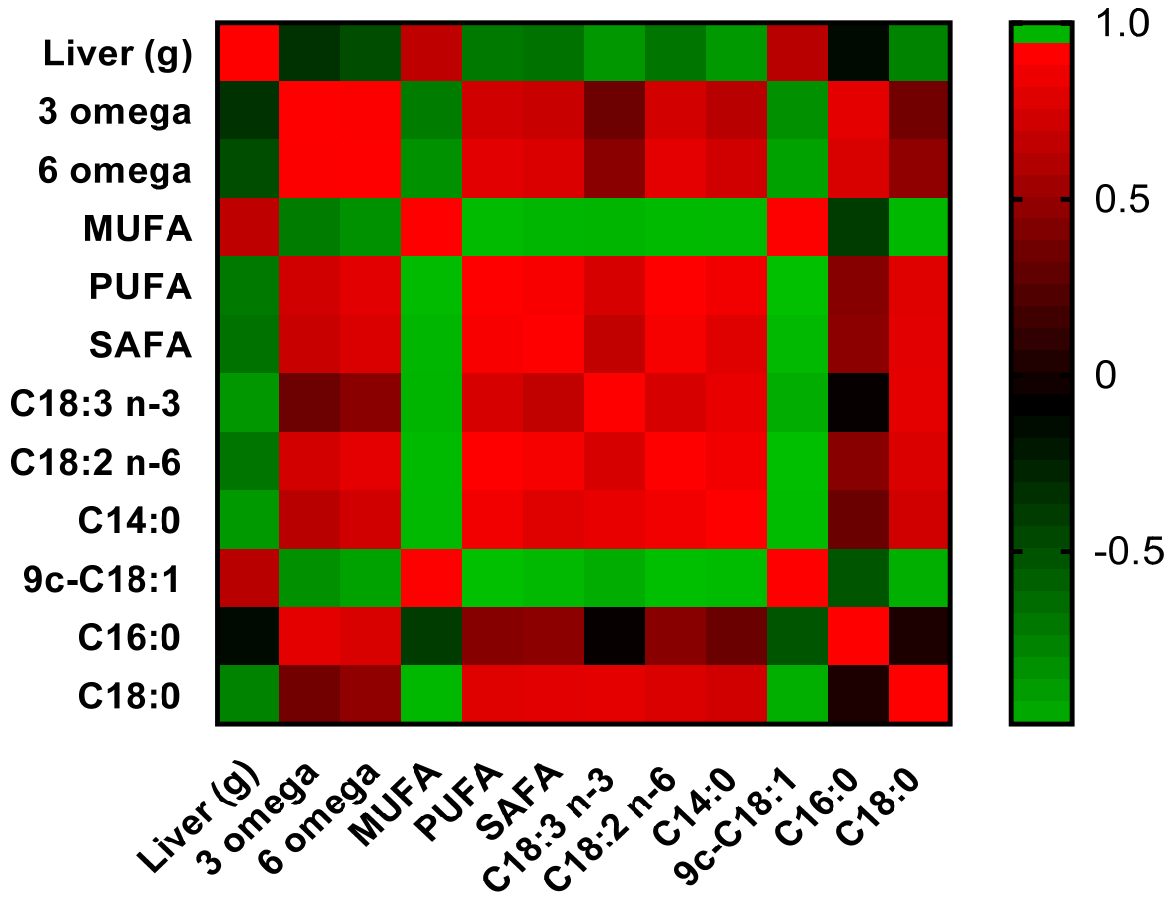

Figure 18 Correlations between the liver weight and fatty acids of the overfed group

Figure 18 shows correlations between the liver weight and fatty acids of the overfed group. Liver weight positively correlates with oleic acid FA, and MUFA content. Liver weight is negatively correlated with alpha -linoleic FA, myristic FA and stearic FA.

DOI: https://doi.org/10.15414/2022.9788055224978

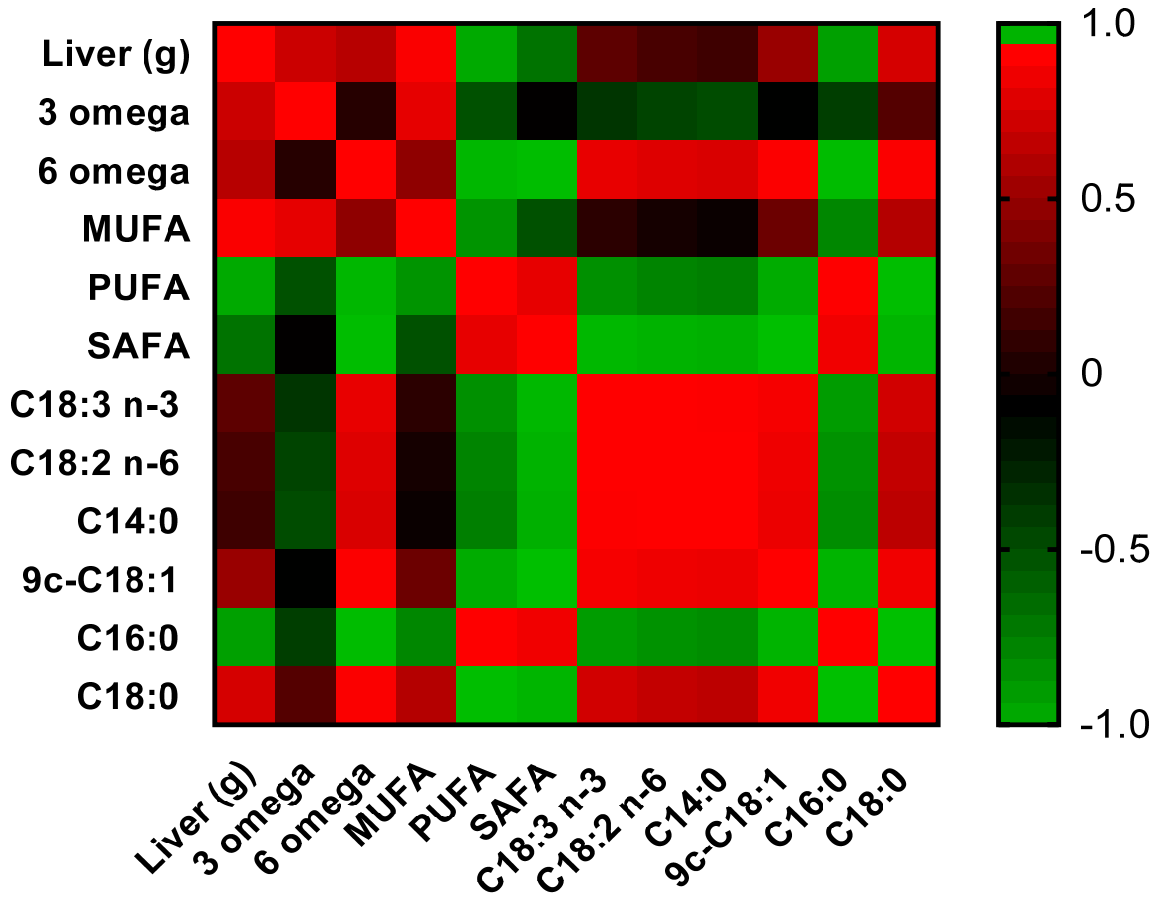

Figure 19 Correlations between the liver weight and fatty acids of the control group

Figure 19 shows correlations between the liver weight and fatty acids of the control group. Liver weight positively correlates with omega-3 FA, omega-6 FA oleic FA, stearic FA and MUFA. Liver weight is negatively correlated with palmitic FA and PUFA.

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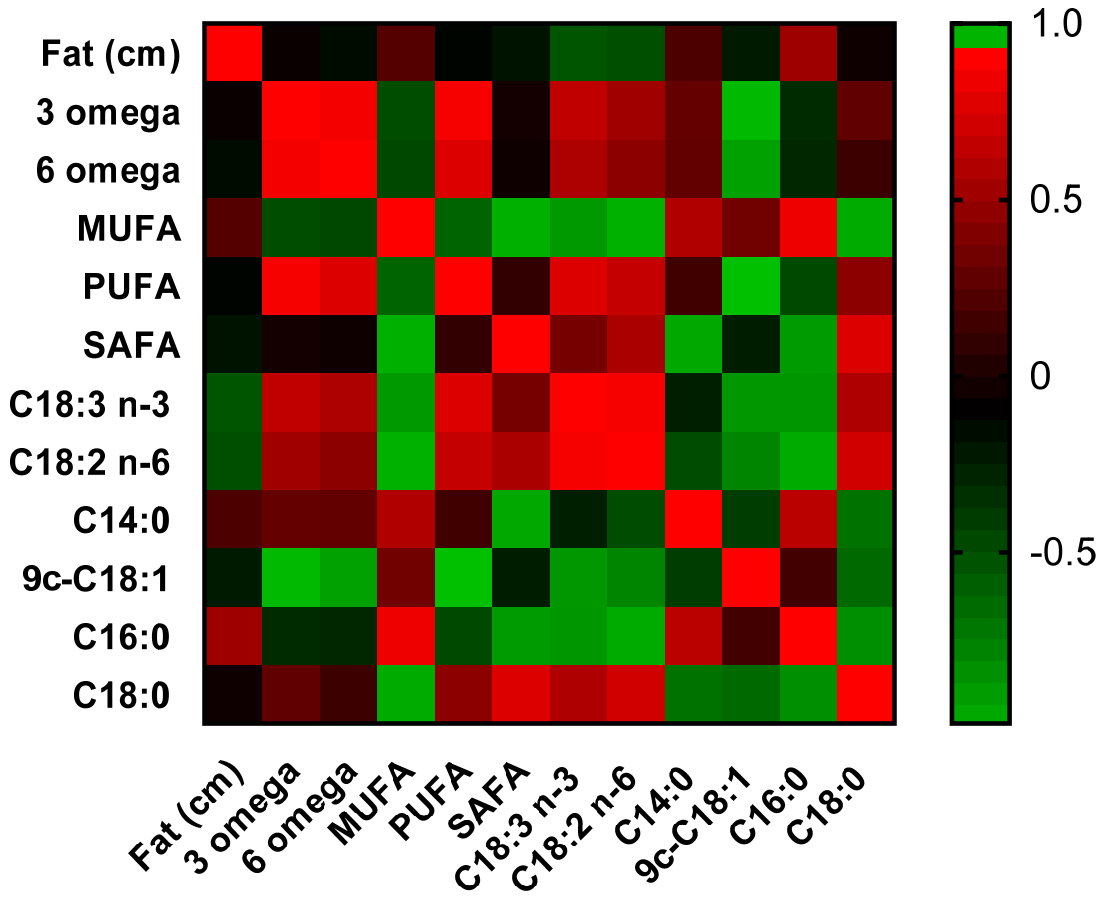

Figure 20 Correlations between the fat thickness and fatty acids of the overfed group

Figure 20 shows correlations between the fat thickness and fatty acids of the overfed group. Fat thickness correlates positively with palmitic acid. On the other hand, fat thickness correlates negatively with α-linoleic FA and linoleic FA.

DOI: https://doi.org/10.15414/2022.9788055224978

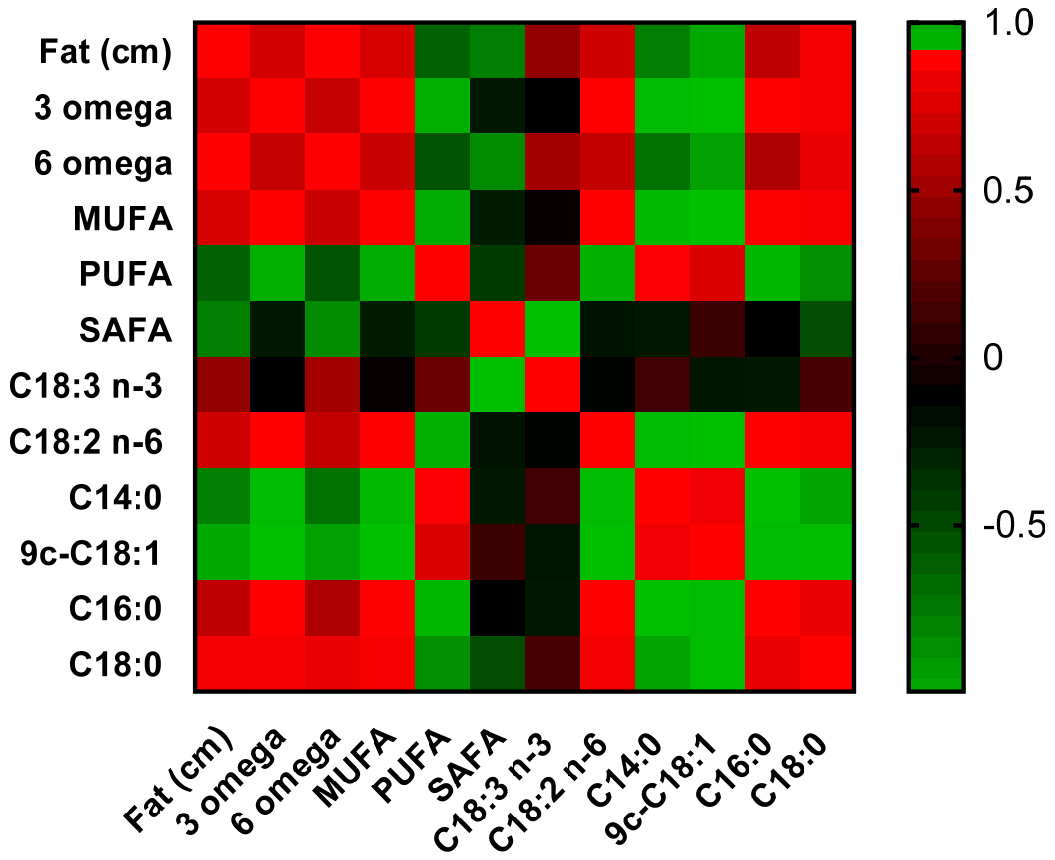

Figure 21 Correlations between the fat thickness and fatty acids of the control group

Fat thickness measured on the back positively correlates with omega-3 FA, omega-6 FA and MUFA contents. Fat thickness correlates negatively with SAFA contents and oleic acid.

DOI: https://doi.org/10.15414/2022.9788055224978

5 Conclusion

The scientific monograph evaluates the quality of meat, liver, and abdominal fat of ducks from overfeeding. The ducks of the overfed group had a significantly higher pre-slaughter weight than the control group. We found a statistically significant difference in weight after slaughter, an overfed group. Was found a statistically highly significant difference in the weight of the liver weight, which was more than 8 times heavier in the ducks of the overfed group than in the ducks from the control group. Was found a statistically highly significant difference in the weight of abdominal fat, in the carcass of ducks of the overfed group opposite control group 237.15 g. In the overfed group, the proportion of stearic acid in the breast muscle decreased significantly in the liver and in the abdominal fat. The EPA content decreased in the overfed group and in the thigh muscle. MUFA content increased in the overfed group in the breast muscle, in the thigh muscle, in the liver, and in the abdominal fat. The SAFA content in the overfed group decreased in the breast muscle, in the thigh muscle, in the liver and in the abdominal fat.

The results were used to calculate the correlations. In the breast muscle of the overfed group a positive correlation of carcass weight to liver, fat thickness, myristic acid, palmitic acid, oleic acid, eicosenoic, eicosapentaeonic, docosapentaeonic FA, and SAFA content was confirmed. A negative correlation of carcass weight to ω-3 FA, ω 6-FA and PUFA was confirmed. A positive correlation of liver weight to fat thickness, myristic FA, palmitic acid, oleic acid, eicosenoic, eicosapentaeonic, docosapentaeonic, and SAFA content was confirmed. In the breast muscle of the control group a positive correlation of liver weight to fat thickness, oleic FA, ω-3 FA, linoleic FA, essential FA, DHA, PUFA content and cholesterol content was confirmed.

Liver weight of overfed group positively correlates with oleic acid FA, and MUFA content. Liver weight of overfed group is negatively correlated with alpha-linoleic FA, myristic FA and stearic FA. Liver weight of control group positively correlates with ω-3 FA, ω-6 FA oleic FA, stearic FA and MUFA. Liver weight of control group is negatively correlated with palmitic FA and PUFA content.

During the overfeeding period, which lasted 21 days, the weight gain was 3.32 kg and the live weight was 1.38 kg higher than the control group. The liver weight was 536.99 g higher in the overfed group than in the control group.

DOI: https://doi.org/10.15414/2022.9788055224978

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7 Annexes

Table 1 Slaughter parameters and structure of duck carcasses overfed and control group

Parameter	Overfed group				Control group				T test
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	
Weight before fattening (kg)	2.64	0.15	0.07	5.74	2.66	0.16	0.07	6.29	-
Weight before slaughter (kg)	5.96	0.35	0.16	5.88	4.58	0.19	0.08	4.20	++
Weight after slaughter (kg)	5.53	0.33	0.15	6.12	4.16	0.04	0.02	1.01	++
Neck (g)	171.0	21.34	9.54	12.48	164.01	2.55	1.14	1.55	-
Liver (g)	613.20	79.72	35.65	13.01	76.21	1.78	0.81	2.35	+++
Gizzard (g)	73.01	12.79	5.92	17.52	90.76	1.71	0.85	1.88	-
Heart (g)	37.80	5.07	2.27	13.41	37.41	1.52	0.67	4.06	-
Wings (g)	186.01	10.07	4.51	5.42	196.61	3.64	1.61	1.86	-
Thighs (g)	569.8	60.02	26.84	10.53	554.81	3.27	1.46	0.59	-
Breast with bone (g)	1237.01	107.51	53.73	8.69	1182.2	34.21	17.06	2.81	-
Back (g)	720.4	199.3	89.15	27.67	687.65	6.08	3.19	0.79	-
Tail (g)	603.6	15.66	7.01	2.59	608.50	5.67	2.53	0.93	-
Fat thickness above the back cm)	2.28	0.28	0.12	12.17	1.08	0.13	0.05	12.07	+++
Abdominal fat (g)	981.01	340.03	170.01	32.86	237.15	13.40	6.78	5.59	+++
Unusable waste (g)	360.25	2.91	1.46	0.76	315.10	12.80	6.35	4.19	++

- $P > 0.05$; + $P \leq 0,05$; ++ $P \leq 0,01$; +++ $P \leq 0,001$

DOI: https://doi.org/10.15414/2022.9788055224978

Table 2 Basic chemical composition of breast muscle of overfed and control group ducks (g.100 g^{-1})

Parameter	Overfed group				Control group				T test
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	
Proteins	22.38	0.65	0.29	2.92	24.37	0.36	0.16	1.49	+
Intramuscular fat	3.02	0.73	0.33	24.38	0.96	1.15	0.51	23.71	+
Water	73.67	1.33	0.66	1.82	74.70	0.78	0.35	1.14	-

- P > 0.05; + P ≤ 0,05; ++ P ≤ 0,01; +++ P ≤ 0,001

Table 3 Basic chemical composition of the thigh muscle of overfed and control group ducks (g.100 g^{-1})

Parameter	Overfed group				Control group				T test
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	
Proteins	22.29	0.81	0.35	3.61	22.15	0.23	0.10	1.05	-
Intramuscular fat	2.54	0.61	0.27	23.71	1.86	0.51	0.21	24.43	-
Water	74.08	0.79	0.36	1.01	75.01	0.41	0.20	0.55	-

- P > 0.05; + P ≤ 0,05; ++ P ≤ 0,01; +++ P ≤ 0,001

Table 4 Amino acid content in duck breast muscle of overfed and control group (g.100 g^{-1})

Amino acid	Overfed group				Control group				T test
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	
Arginine	1.15	0.01	0.003	0.75	1.71	0.31	0.16	19.29	+
Cysteine	0.29	0.02	0.004	0.28	0.35	0.06	0.04	16.18	+
Phenylalanine	0.71	0.02	0.004	0.26	1.11	0.21	0.11	18.21	+
Histidine	0.79	0.02	0.003	0.16	1.19	0.21	0.11	17.16	+
Isoleucine	0.65	0.02	0.004	1.81	1.03	0.20	0.09	20.06	+
Leucine	1.35	0.01	0.002	0.21	2.11	0.40	0.19	19.01	+
Lysine	1.38	0.02	0.006	1.18	2.31	0.41	0.21	19.03	+
Methionine	0.59	0.01	0.003	0.69	0.81	0.18	0.08	16.15	+
Threonine	0.77	0.01	0.003	0.28	1.14	0.21	0.09	19.17	+
Valine	0.78	0.02	0.006	1.28	1.02	0.14	0.06	13.27	+

- P > 0.05; + P ≤ 0,05; ++ P ≤ 0,01; +++ P ≤ 0,001

DOI: https://doi.org/10.15414/2022.9788055224978

Table 5 Amino acid content in duck thigh muscle of overfed and control group (g.100 g^{-1})

Amino acid	Overfed group				Control group				T
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	test
Arginine	1.46	0.08	0.04	4.96	1.15	0.01	0.009	1.53	++
Cysteine	0.32	0.01	0.01	2.32	0.26	0.001	0.001	0.29	++
Phenylalanine	0.92	0.03	0.01	4.16	0.75	0.004	0.002	0.64	++
Histidine	1.03	0.06	0.03	6.24	0.91	0.006	0.003	0.81	+
Isoleucine	0.92	0.04	0.02	5.22	0.72	0.002	0.001	0.48	++
Leucine	1.81	0.09	0.05	4.79	1.48	0.002	0.001	0.18	++
Lysine	1.92	0.09	0.05	4.82	1.53	0.02	0.01	1.95	++
Methionine	0.77	0.04	0.02	5.76	0.63	0.002	0.001	0.38	++
Threonine	0.98	0.05	0.03	4.89	0.81	0.001	0.001	0.22	++
Valine	0.91	0.04	0.02	4.67	0.83	0.002	0.001	0.26	+

- $P > 0.05$; + $P \leq 0,05$; ++ $P \leq 0,01$; +++ $P \leq 0,001$

DOI: https://doi.org/10.15414/2022.9788055224978

Table 6 Fatty acid content of breast muscle of overfed a control group of ducks (g.100 g^{-1} FAME)

Fatty acid	Overfed group				Control group				T
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	test
C20:4 arachidonic FA	1.32	0.22	0.11	16.39	1.71	0.14	0.07	7.63	++
C22:6 n-3 docosahexaeonic FA	0.03	0.004	0.001	8.55	0.03	0.005	0.003	14.73	-
C22:5 n-3 docosapentaeonic FA	0.12	0.005	0.002	3.53	0.14	0.01	0.004	8.34	-
C20:1 eicosenoic FA	0.32	0.14	0.05	37.86	0.53	0.01	0.009	3.29	+
C20:5 n-3 eicosapentaeonic FA	0.07	0.02	0.01	29.70	0.12	0.01	0.003	6.08	+
C17:0 heptadecanoic FA	0.27	0.05	0.03	20.42	0.31	0.003	0.001	0.96	-
C12:0 lauric FA	0.11	0.01	0.004	11.58	0.11	0.001	0.001	0.66	-
C18:3 n-3 α-linoleic FA	0.27	0.07	0.03	25.83	0.18	0.004	0.001	2.51	-
C18:2 n-6 linoleic FA	8.35	0.61	0.33	7.69	9.58	0.05	0.03	0.67	+
C14:0 myristic FA	1.30	0.03	0.01	1.65	1.32	0.003	0.001	0.35	-
9c-C18:1 oleic FA	40.18	0.45	0.23	1.19	41.52	0.08	0.04	0.36	+
C16:0 palmitic FA	24.39	0.29	0.12	0.96	24.83	0.05	0.03	0.29	-
C18:0 stearic FA	11.09	0.09	0.05	0.76	11.68	0.04	0.01	0.53	++
11c/15t-C18:1 vaccenic FA	4.71	0.07	0.03	1.45	4.88	0.15	0.06	2.67	+
C 18:2 9c/11t Conjugated linoleic FA	0.12	0.06	0.02	10.86	0.19	0.02	0.01	0.76	+++
ω 3 polyunsaturated FA	0.68	0.11	0.06	15.91	0.58	0.01	0.01	2.22	-
ω 6 polyunsaturated FA	11.28	0.63	0.33	6.32	11.12	0.26	0.13	2.33	-
Essential FA	9.82	1.11	0.64	12.15	10.52	0.25	0.12	1.99	-
MUFA	50.75	0.83	0.41	1.65	45.02	0.14	0.08	0.43	+++
PUFA	13.92	1.25	0.62	9.61	12.29	0.04	0.01	0.37	-
SAFA	34.55	0.91	0.51	2.86	36.31	0.15	0.06	0.39	+
Cholesterol (mg.kg^{-1})	0.58	0.06	0.02	9.21	0.42	0.05	0.03	6.58	++

- $P > 0.05$; + $P \leq 0,05$; ++ $P \leq 0,01$; +++ $P \leq 0,001$

DOI: https://doi.org/10.15414/2022.9788055224978

Table 7 Fatty acid content of thigh muscle of overfed a control group of ducks (g.100 g^{-1} FAME)

Fatty acid	Overfed group				Control group				T test
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	
C20:4 arachidonic FA	1.57	0.11	0.05	6.52	1.56	0.01	0.004	0.62	-
C22:6 n-3 docosahexaeonic FA	0.03	0.01	0.002	12.45	0.03	0.01	0.003	32.22	-
C22:5 n-3 docosapentaeonic FA	0.13	0.01	0.002	5.55	0.14	0.01	0.002	4.84	-
C20:1 eicosenoic FA	0.48	0.07	0.03	12.82	0.46	0.01	0.007	3.88	-
C20:5 n-3 eicosapentaeonic FA	0.09	0.01	0.005	14.52	0.13	0.01	0.009	13.97	+
C17:0 heptadecanoic FA	0.29	0.01	0.006	3.72	0.25	0.01	0.002	1.53	-
C12:0 lauric FA	0.11	0.01	0.004	6.45	0.12	0.01	0.003	2.94	-
C18:3 n-3 α-linoleic FA	0.20	0.02	0.01	13.62	0.16	0.01	0.003	2.26	-
C18:2 n-6 linoleic FA	7.49	1.25	0.59	11.28	7.29	0.01	0.006	6.45	-
C14:0 myristic FA	1.32	0.02	0.01	2.16	1.26	0.02	0.01	2.48	+
9c-C18:1 oleic FA	37.76	1.04	0.49	2.72	37.92	0.04	0.01	1.11	-
C16:0 palmitic FA	24.63	0.28	0.16	0.99	24.02	0.01	0.002	0.87	+
C18:0 stearic FA	10.78	0.31	0.15	2.78	10.69	0.01	0.006	1.94	-
11c/15t-C18:1 vaccenic FA	4.59	0.11	0.05	2.26	4.68	0.05	0.02	2.11	-
C 18:2 9c/11t Conjugated linoleic FA	0.12	0.01	0.004	6.29	0.12	0.01	0.002	2.45	-
ω 3 polyunsaturated FA	0.56	0.01	0.001	2.24	0.48	0.01	0.004	2.59	+++
ω 6 polyunsaturated FA	11.21	1.78	0.89	6.94	9.72	0.02	0.01	5.23	-
Essential FA	9.21	0.85	0.42	5.05	8.28	0.17	0.08	3.95	-
MUFA	49.41	1.42	0.72	2.25	46.89	0.51	0.27	1.96	+
PUFA	13.19	1.31	0.64	10.11	12.31	2.25	1.12	13.18	-
SAFA	34.89	1.79	0.88	5.16	37.59	0.59	0.29	4.66	+
Cholesterol (mg.kg^{-1})	0.59	0.05	0.02	7.83	0.58	0.01	0.002	4.28	-

- $P > 0.05$; + $P \leq 0,05$; ++ $P \leq 0,01$; +++ $P \leq 0,001$

DOI: https://doi.org/10.15414/2022.9788055224978

Table 8 Fatty acid content in the liver of overfed a control group of ducks (g.100 g^{-1} FAME)

Fatty acid	Overfed group				Control group				T
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	test
C18:3 n-3 α-linoleic FA	0.94	0.08	0.04	8.52	1.07	0.02	0.01	3.79	+
C18:2 n-6 linoleic FA	13.36	1.15	0.55	7.52	15.89	0.28	0.09	1.76	+
C14:0 myristic FA	1.51	0.12	0.06	8.72	1.52	0.16	0.07	10.33	-
9c-C18:1 oleic FA	38.67	3.51	1.78	8.92	32.41	0.48	0.22	5.39	+
C16:0 palmitic FA	21.78	0.41	0.20	1.96	21.76	0.03	0.01	1.15	-
C18:0 stearic FA	9.98	2.69	1.31	11.02	14.29	0.09	0.04	5.60	+
11c/15t-C18:1 Vaccenic FA	18.09	1.22	0.61	7.60	18.51	1.21	0.51	7.48	-
ω 3 polyunsaturated FA	1.03	0.08	0.03	7.11	1.14	0.05	0.02	5.91	+
ω 6 polyunsaturated FA	14.42	1.21	0.61	8.28	17.68	0.31	0.11	6.85	++
MUFA	47.49	4.41	2.21	9.29	38.52	1.16	0.32	7.74	+
PUFA	15.88	1.31	0.61	7.36	20.17	1.03	0.51	5.98	-
SAFA	33.89	2.91	1.43	8.66	39.12	0.80	0.39	7.18	+

- $P > 0.05$; + $P \leq 0,05$; ++ $P \leq 0,01$; +++ $P \leq 0,001$

DOI: https://doi.org/10.15414/2022.9788055224978

Table 9 Fatty acid content in the abdominal fat of overfed a control group of ducks (g.100 g^{-1} FAME)

Fatty acid	Overfed group				Control group				T
	Mean	S.D.	S.E.	CV%	Mean	S.D.	S.E.	CV%	test
C18:3 n-3 α-linoleic FA	0.70	0.05	0.02	6.56	0.71	0.02	0.01	3.09	-
C18:2 n-6 linoleic FA	10.29	0.61	0.31	5.73	10.21	0.22	0.10	3.42	-
C14:0 myristic FA	1.09	0.11	0.05	10.58	1.18	0.03	0.01	2.86	+
9c-C18:1 oleic FA	49.39	1.12	0.54	2.35	45.77	0.46	0.23	1.64	+++
C16:0 palmitic FA	20.39	0.36	0.15	1.86	21.72	0.07	0.03	1.34	++
C18:0 stearic FA	4.08	1.36	0.69	3.10	6.28	0.21	0.09	3.21	+
ω 3 polyunsaturated FA	0.79	0.04	0.02	8.45	0.75	0.15	0.07	14.42	-
ω 6 polyunsaturated FA	10.15	0.79	0.39	7.88	10.43	0.11	0.05	5.94	-
MUFA	59.62	1.72	0.85	2.88	53.21	1.16	0.59	2.21	++
PUFA	11.91	0.69	0.32	5.91	12.59	0.81	0.41	6.41	-
SAFA	28.31	1.65	0.81	5.77	33.11	0.71	0.38	4.02	++

- $P > 0.05$; + $P \leq 0,05$; ++ $P \leq 0,01$; +++ $P \leq 0,001$

DOI: https://doi.org/10.15414/2022.9788055224978

Figure 1 One-day ducklings (URL 2)

Figure 2 Duck feeding funnel (URL 3)

Picture 3 ducks for fattening (photo authors)

DOI: https://doi.org/10.15414/2022.9788055224978

Figure 4 Carcass overfed ducks (URL 4)

Figure 5 Liver of overfed duck (URL 5)

Figure 6 Duck liver of the control group (photo authors)

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Scientific Monograph

Authors: Čuboň Juraj, Hlebová Miroslava, Haščík Peter

Publisher: Slovak Unversity of Agriculture in Nitra

Edition: 1st

Form: online scientific monograph

AQ – PQ: 5.59 – 5.76

Not edited at the Publishing Centre of the SUA in Nitra.

ISBN 978-80-552-2497-8

DOI: https://doi.org/10.15414/2022.9788055224978