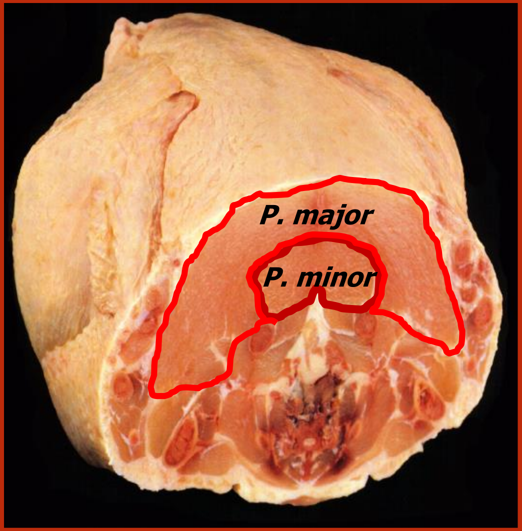
56° Annual Meeting

Associazione Scientifica di Avicoltura

Italian Branch of World's Poultry Science Association

Are we pushing broilers to their biological limits?



Fast muscle growth and meat quality issues

April 22th, 2022

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Massimiliano Petracci

Department of Agricultural and Food Sciences, University of Bologna, Italy

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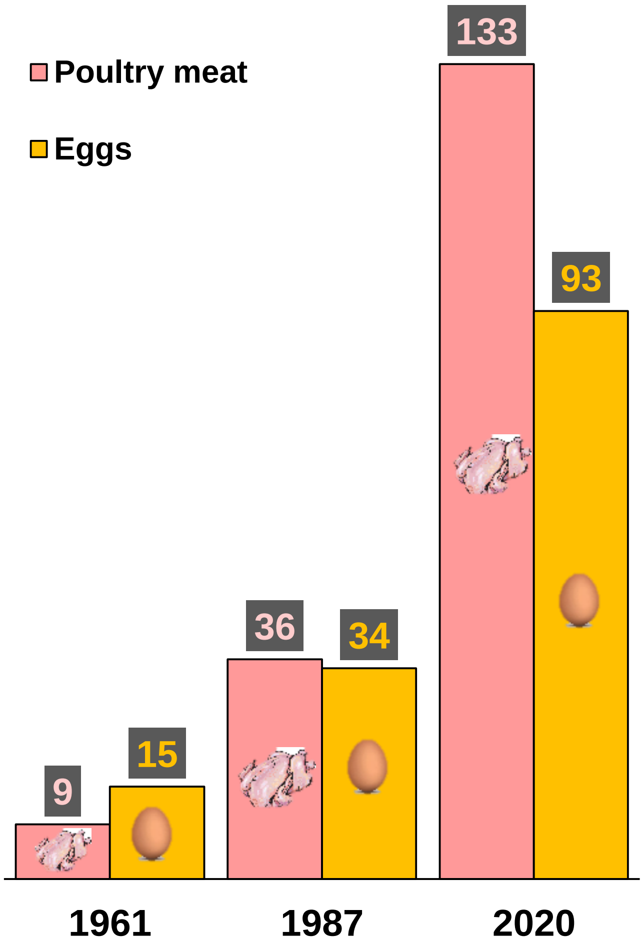
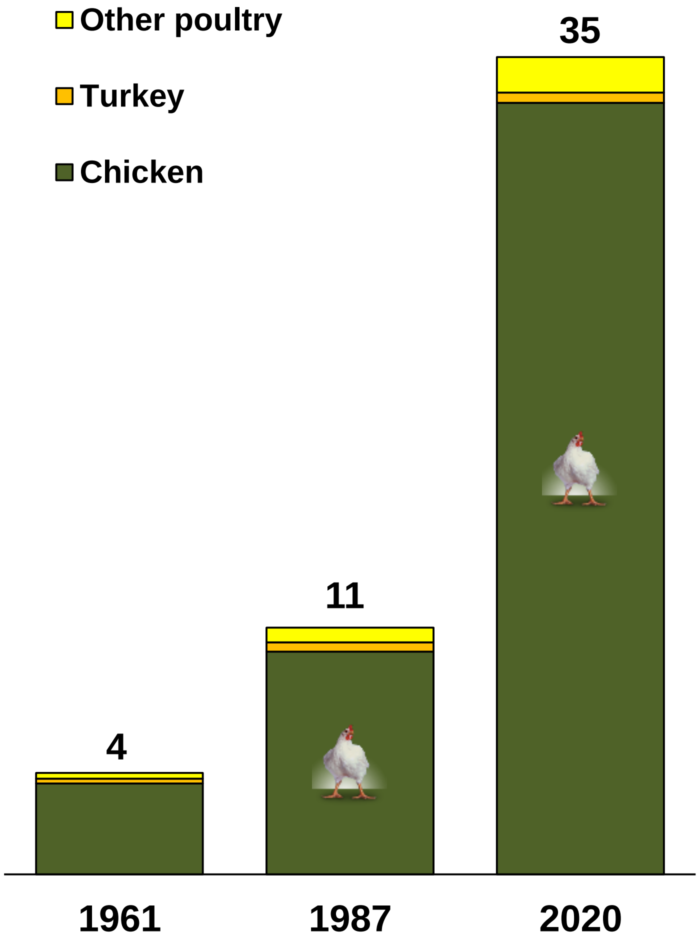
https://www.unibo.it/sitoweb/m.petracci/en

Expansion of global poultry production

Meat and Eggs production
(billion tons)



Poultry population
(billions)



FAOSTAT

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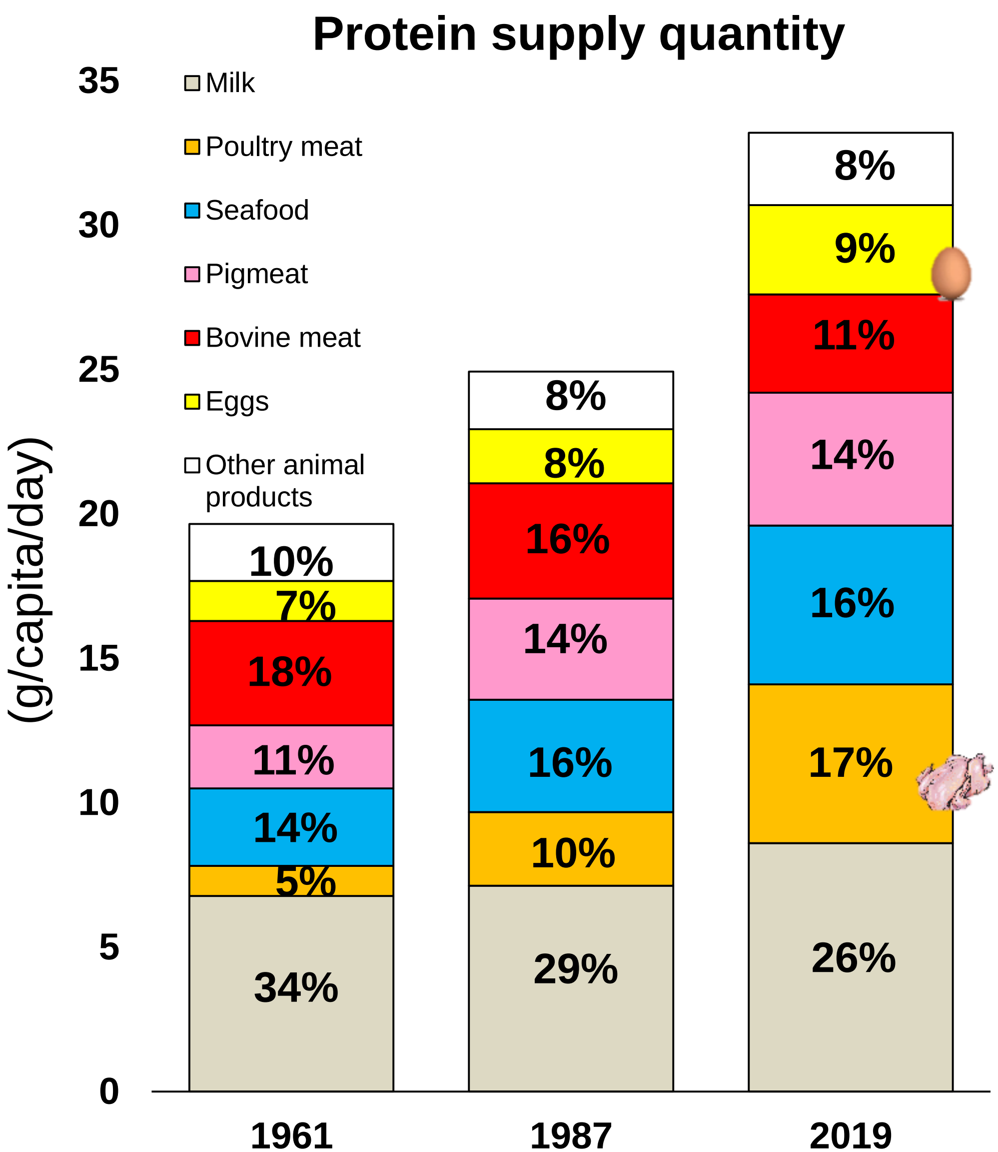
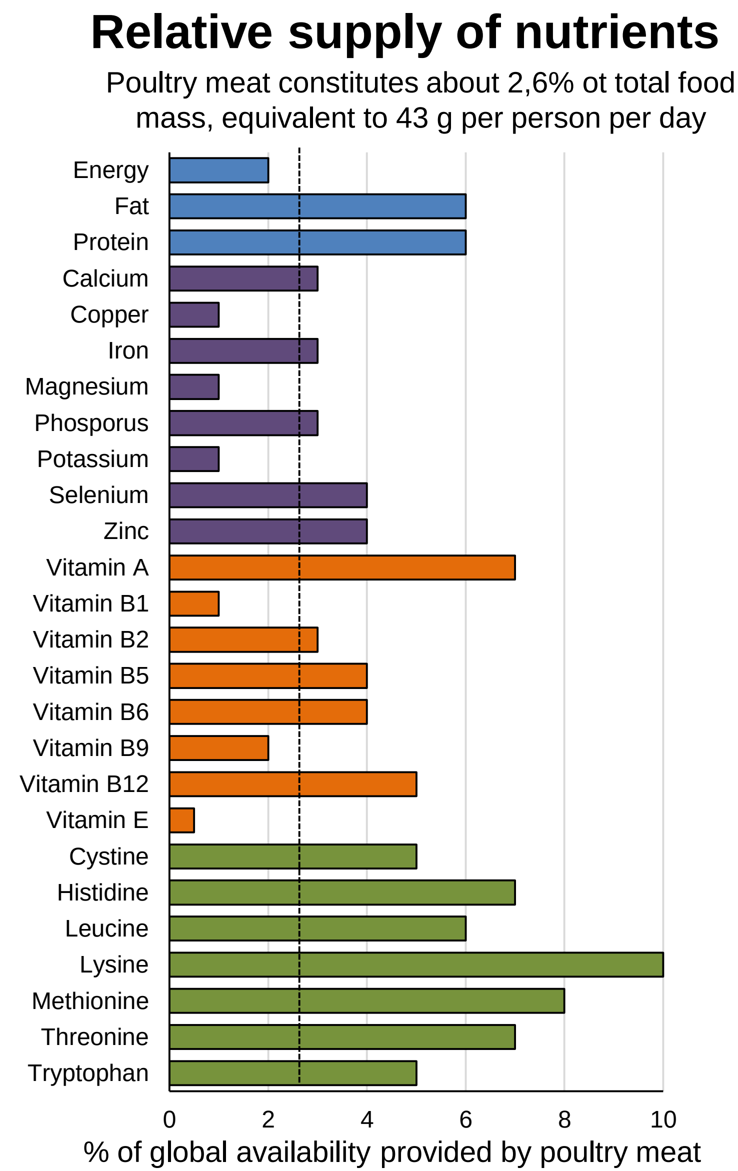
Contribution of poultry to global supply of animal proteins





Source: Smith et al. (2022) Front Nutr 73:766796

Protein feed-to-food conversion efficiencies

Animal species	Population (billions)	Food products	Slaughtered animals (billions)	Total production (milion t)	Total protein production (milion t)	Protein conversion efficiency (%)
Cattle and Buffalo	**1.7**	Beef meat	**0.29**	**72**	**19.9**	**4**
		Milk	**-**	**852**		**24**
Chicken	**33.1**	Chicken meat	**71.0**	**120**	**16.4**	**20**
		Eggs	**-**	**87**		**25**
Pig	**0.95**	Pork meat	**1.51**	**110**	**9.2**	**8**

Adapted by Smil (2001)

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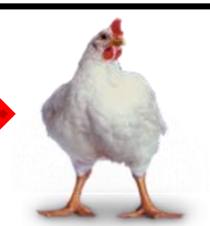
Development of the modern broiler industry

Year	Live performances				Market segments		Market forms		
	market age (d)	market weight (kg)	feed to meat gain (kg)	mortality (%)	retail grocery (%)	food-service (%)	whole (%)	cut-up parts (%)	processed (%)
1940	85	1.30	4.0	12	-	-	-	-	-
1950	70	1.40	3.0	8	-	-	-	-	-
1960	63	1.52	2.5	6	-	-	78	19	3
1970	56	1.64	2.25	5	75	25	70	26	4
1980	53	1.78	2.05	5	71	29	50	40	10
1990	48	1.98	2.00	5	59	41	18	56	26
2000	47	2.28	1.95	5	58	42	10	44	46
2010	47	2.59	1.92	4	56	44	12	43	45
2021	47	2.93	1.79	5	54	46	9	40	50




Source: National Chicken Council

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Body shape change of chicken broilers

Year	Hybrid	BW (g)	Age (d)	Carcass yield (%)	Breast wt. (g)	Breast yield (%)
1957[1]	ACRBC	1,101	85	65.2	133	12.1
2001[1]	Ross 308	2,207	43	72.3	349	15.8
2007[2]	Ross 308	2,200	36	71.8	410	18.6
2012[2]	Ross 308	2,200	35	71.8	464	21.1
2017[2]	Ross 308	2,200	34	72.5	484	22.0
2019[2]	Ross 308	2,200	33	72.6	516	23.5

data referred to male chickens

[1]Havenstein et al. (2003; Poult Sci 82:1509)

[2]Ross 308 Broiler Performance Objectives

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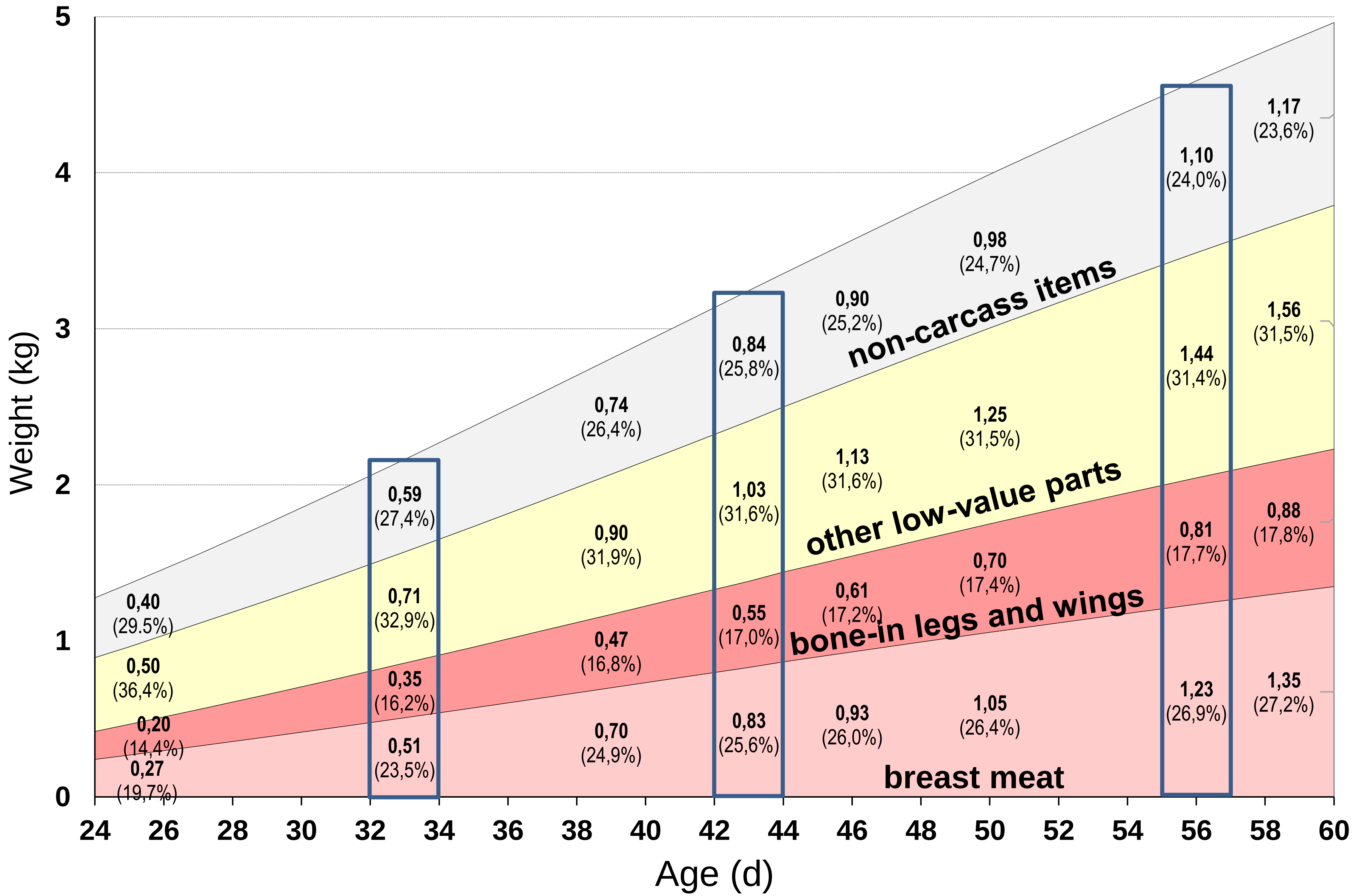
Body composition as affected by age at slaughter



Source: Ross 308 Broiler Performance Objectives (data referred to male chickens)

Penalties due to selection in modern broilers

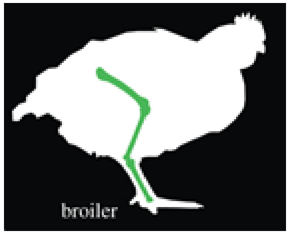
Selection for increased growth-rate and breast-size and increase of slaughter weight

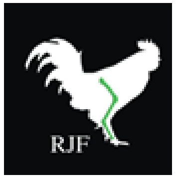
- antagonism between early growth and reproduction
- restricted feeding of broiler breeders

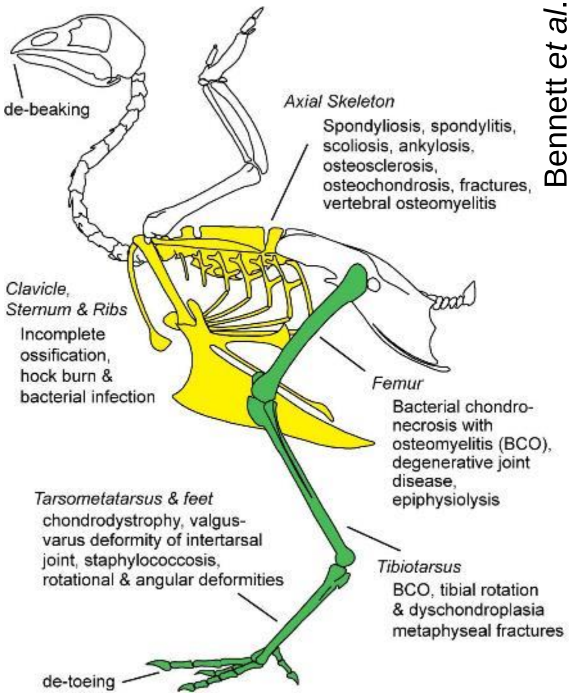
- higher inflammatory response and lower antibody response
- reduced heat tolerance

- unbalanced body conformation
- Increased bone fragility
- leg disorders

- skeletal muscle hypertrophy
- cardiovascular insufficiency (reduced vascularisation and vessel density)
- muscle disorders and meat abnormalities







Bennett *et al.* (2018) R. Soc. Open. Sci. 5:180325

Tixier-Boichard (2020) World Poult Sci J 76:2

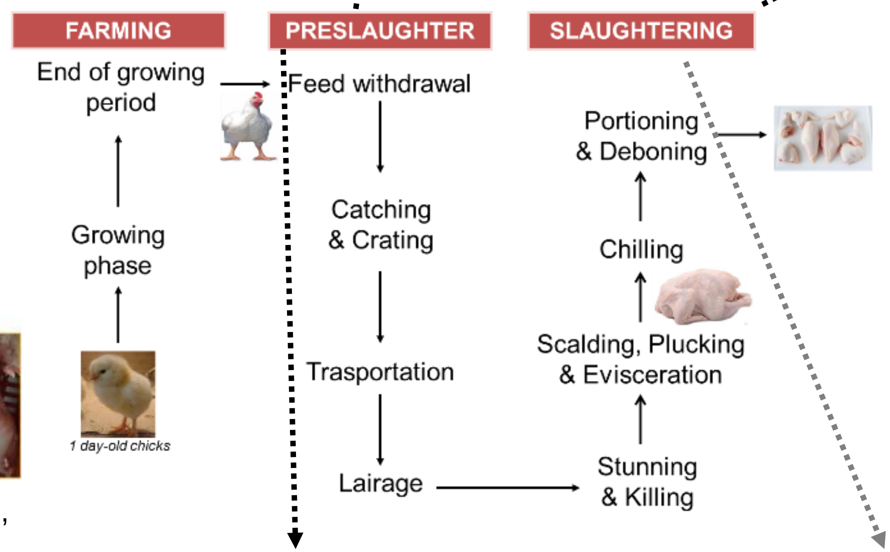
Main meat quality issues in fast-growing broilers

Physical damages due to preslaughter operations

bruises, scratches, bone fractures

Meat abnormalities due to fast growth rate and breast muscle development

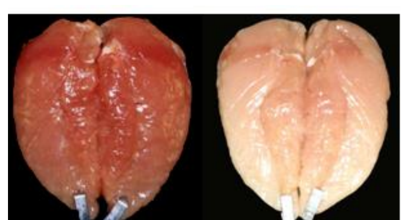
green muscle disease, white striping, wooden breast, spaghetti meat



Physical damages due to slaughtering operations

blood residuals, skin damages, missing parts

Meat abnormalities due to pre-slaughter stress



DFD & PSE-like conditions

Meat quality defects due to slaughtering operations

Toughening due to fast chilling or early deboning, fast post-mortem muscle acidification due to carcass electrostimulation

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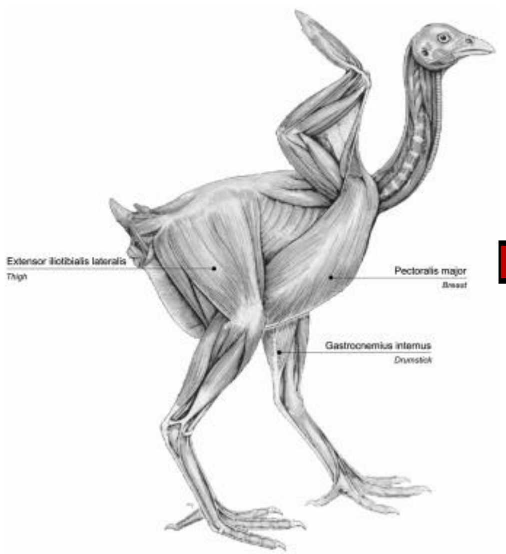
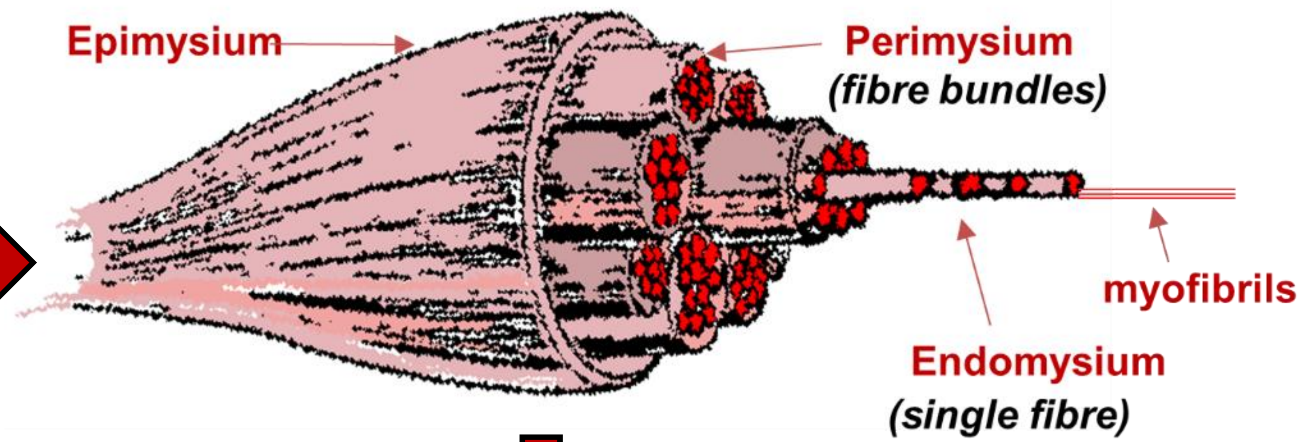
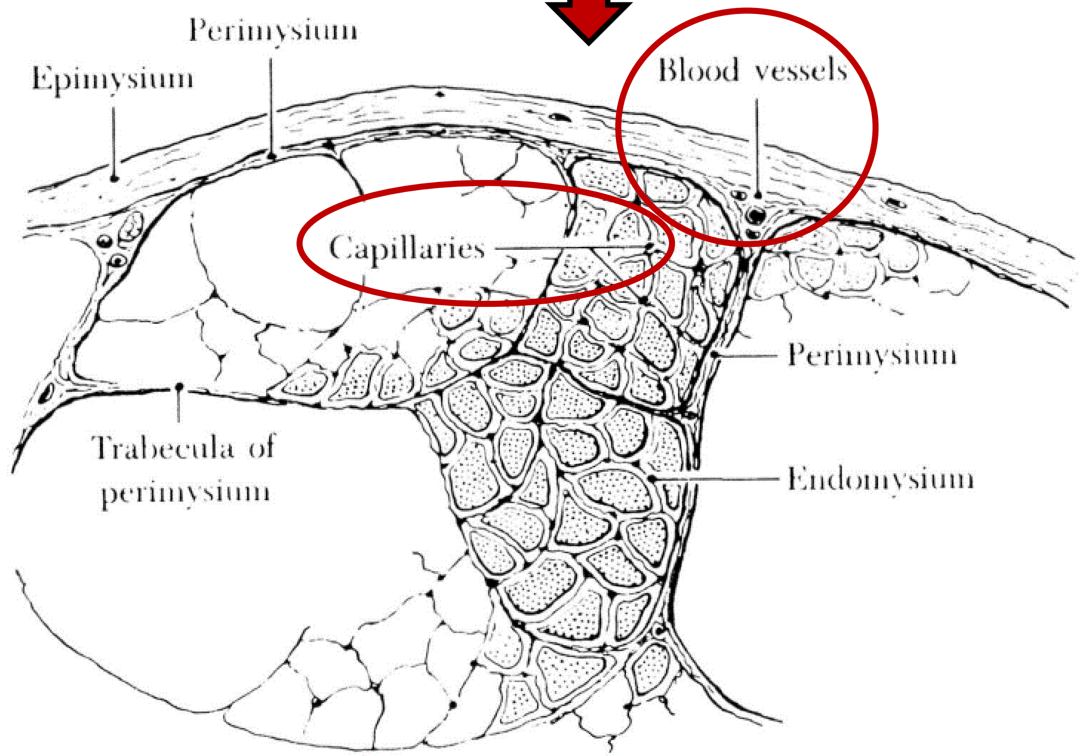
Avian muscle architecture





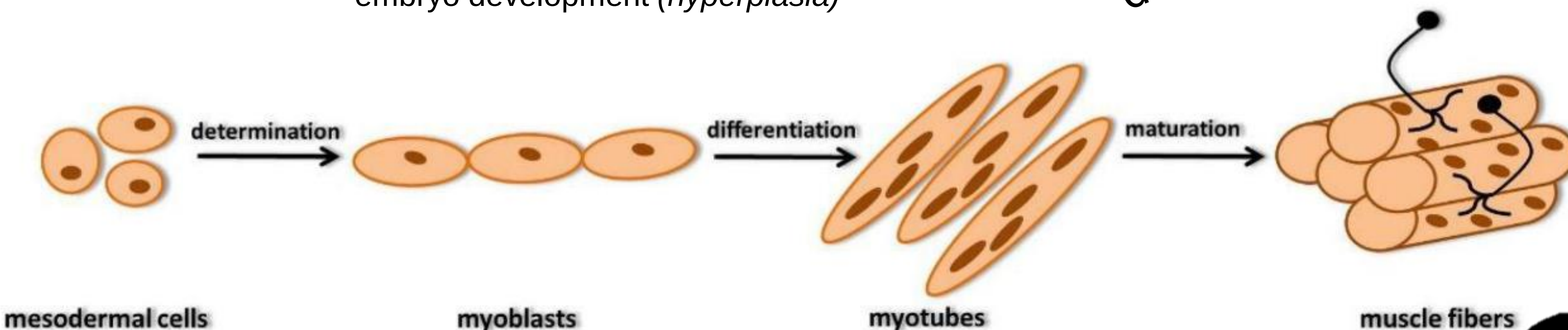


Avian muscle development and growth

Stage #1
Embryonic development

d 0 — d 21

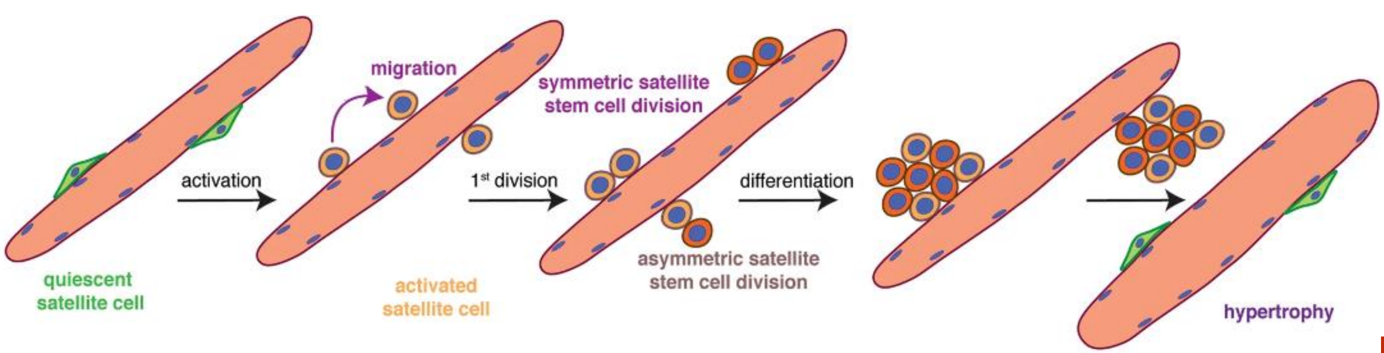
Total number of fibers is mainly determined during embryo development *(hyperplasia)*



Stage #2
Post-hatch growth

d 0 — slaughter age

The increase in skeletal muscle mass is mainly due to an increase in muscle fibre size (hypertrophy)



Velleman (2015) Avian Dis 59:525

First reports on penalties in breast muscle growth

- Deep pectoral myopathy -

POULTRY SCIENCE

AUGUST 1985

VOLUME 64, NUMBER 8

Symposium: Body Growth and the Development, Biochemistry, and Pathology of Avian Muscle

Deep Pectoral Myopathy: A Penalty of Successful Selection for Muscle Growth

WALTER G. SILLER

Agricultural and Food Research Council, Poultry Research Centre, Roslin, Midlothian EH24 9PS, Scotland

ABSTRACT Deep pectoral myopathy (DPM) is a disease that affects commercial poultry selected for large breast muscle development. The muscle affected by the disease is the supracoracoid muscle and usually one side of the breast musculature atrophies. The necrotic muscle has a characteristic pale green color. Heavy breeds of turkeys and broilers can be induced to show DPM by electrical stimulation of the breast muscle itself or by vigorous wing flapping; older birds are more susceptible. The cause of DPM is a fascial compartment too small to accommodate the enclosed supracoracoid muscle during vigorous exercise when the muscle increases its weight (and overall size) by about 20%. The inelastic compartment essentially strangulates the swollen, activated muscle. A possible means of correcting DPM is to train or exercise the flight muscles during the rapid growth phase of chicks or poults. Feed, for example, could be positioned above floor level so that birds would have to flutter up to reach it. There is also evidence to suggest a genetic component to the disease. Hence, an indicator such as high plasma creatine kinase levels may be used as a selection criterion.

(*Key words:* pectoral myopathy, muscle atrophy, broiler growth, turkey growth)

1985 Poultry Science 64:1591–1595

From what has been described and from the observations of Harper *et al.* (1981), Holland *et al.* (1981), and Grunder *et al.* (1984) that wild turkeys and less intensely selected old commercial strains are apparently not susceptible to DPM, it is obvious that this disease is man made. It is a condition coincidental with the production of large-breasted turkeys and broilers, and is, therefore a penalty of successful selection!

First reports on penalties in breast muscle growth

- Failure of connective layers to support growth of muscle fibres -

Turkey Muscle Growth and Focal Myopathy

BARRY W. WILSON, PAMELA S. NIEBERG, and R. JEFFREY BUHR[1]

Department of Avian Sciences, University of California, Davis, California 95616

BARRY J. KELLY and FRED T. SHULTZ

Nicholas Turkey Breeding Farms, Sonoma, California 95476-1209

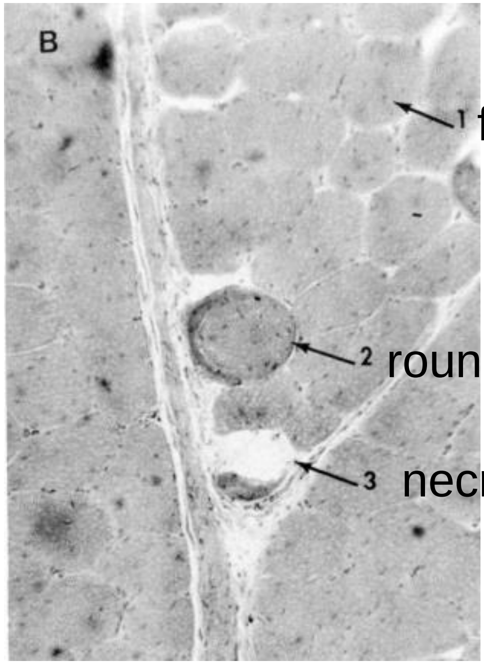
1990 Poultry Science 69:1553–1562

A Note on the Growth of Connective Tissues Binding Turkey Muscle Fibers Together

H.J. Swatland Department of Food Science University of Guelph Guelph, Ontario N1G 2W1

Can. Inst. Food Sci. Technol. J. Vol. 23, No. 4/5, pp. 239-241, 1990

The results of the growth study showed that, on a radial basis, the growth of intramuscular connective tissues does not keep pace with the growth of pectoralis muscle fibers.



fiber size variability

rounded fibre

necrotic fibre

One possibility is that they may have become rounded because the growth of connective tissue had not kept up with the growth of the muscle fibers, thus depriving them of extracellular support.

First reports on penalties in meat quality

- Pale-soft-exudative condition -

Journal of Muscle Foods

January 1998

Volume 9, Issue 1
Pages vii–viii, 1–54

BIOPHYSICAL BASIS OF PALE, SOFT, EXUDATIVE (PSE) PORK AND POULTRY MUSCLE: A REVIEW

M.B. SOLOMON[1], R.L.J.M. VAN LAACK[2] and J.S. EASTRIDGE[1]

[1]*Meat Science Research Laboratory*
Agricultural Research Service, USDA[3]
Beltsville, MD 20705
[2]*Dept. of Food Science and Technology*
University of Tennessee, Knoxville, TN 37901

Journal of Muscle Foods 9 (1998) 1-11.

Pale, Soft and Exudative meat (PSE-like)

Symposium "***Atypical poultry meat in relation to PSE pork: causes, biochemistry, processing and resolutions***" (Lousiana, US, 1996)

The occurrence of PSE muscle and subsequent alterations in meat quality has been shown to be related to increases in muscle size, stressful preslaughter handling conditions, and rate of onset of rigor mortis. Morphological studies have revealed significant increases in fiber size, in addition to structural irregularities in PSE muscle. These structural irregularities include decreased capillary density, hypercontracted (giant) fibers, and myoplasmic calcium loading.

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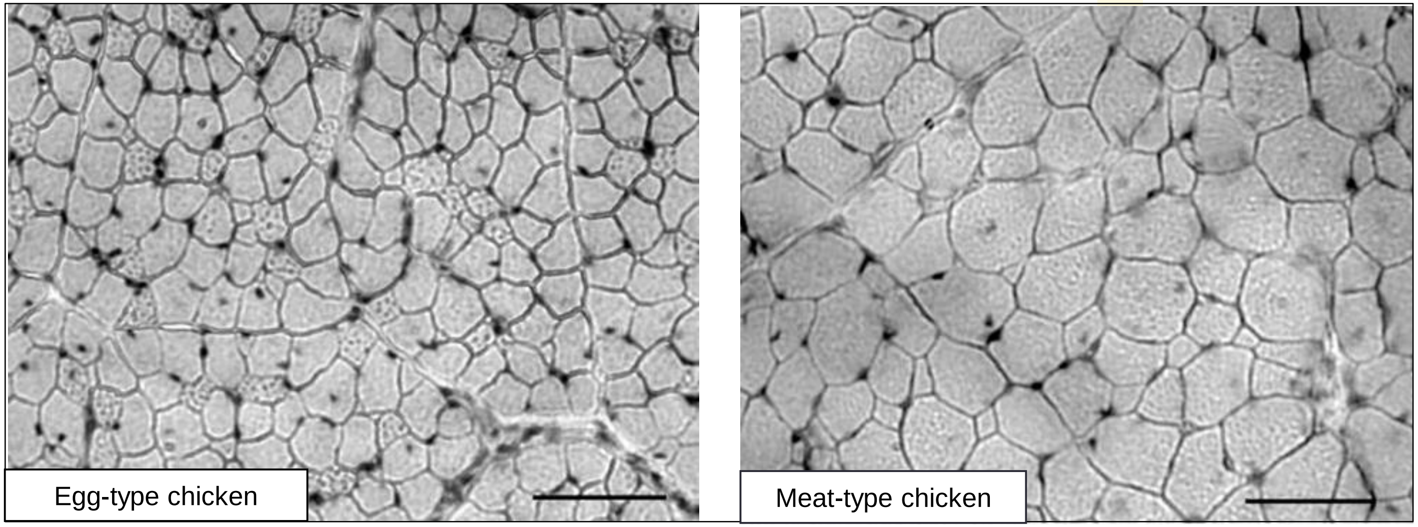
Full awareness of penalties in muscle fibre morphology and metabolism

Muscle structure: *Pectoralis major*



- Higher proportion of white-fibres and hypertrophy of the fibers
- Shift towards the glycolytic metabolism (anaerobic production of energy for muscle contraction)
- Reduced capillary density (capillary-to-fiber ratio)
- High sarcoplasmic calcium concentrations
- Fast post-mortem acidification

Dransfield & Sosnicki (1999); Scheurs (2000); Sandercock & Mitchell (2003); Schuermann et al. (2004)

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First signs of muscle fibre growth failure

A Comparison of Breast Muscle Characteristics in Three Broiler Great-Grandparent Lines

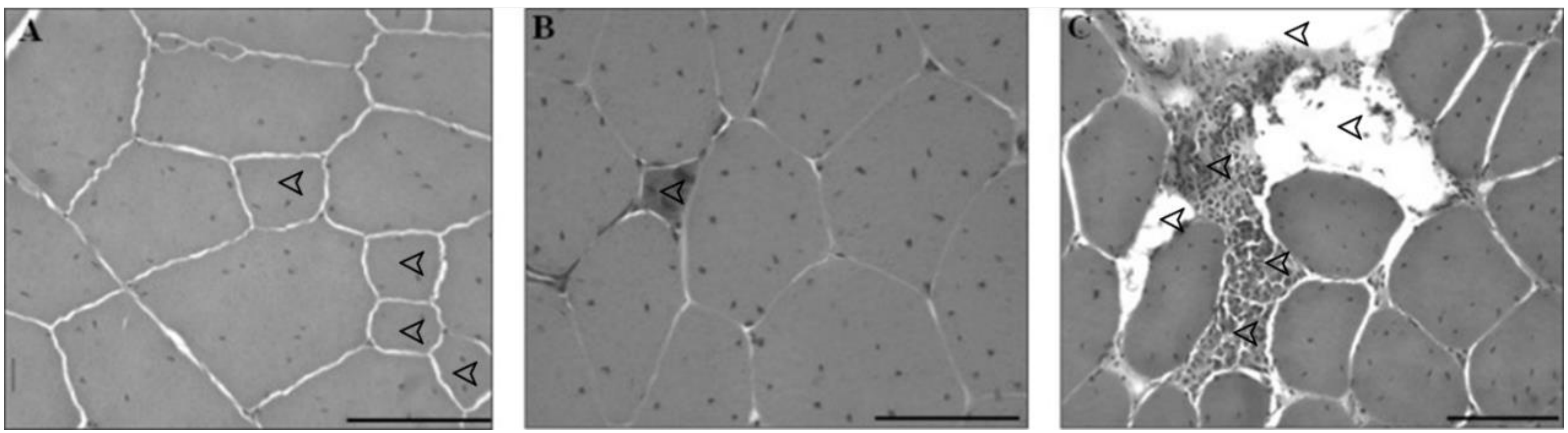
V. E. MacRae,*[1] M. Mahon,† S. Gilpin,† D. A. Sandercock,* R. R. Hunter,* and M. A. Mitchell*
*Roslin Institute (Edinburgh), Roslin, Midlothian, EH2 9PS, UK; and †School of Medicine, Keele University, Staffordshire ST5 5BG, UK

ABSTRACT Genetic selection of broiler chickens has led to a gross overdevelopment of the broiler breast muscle pectoralis major. This may have resulted in increased myopathy and detrimental effects on meat quality.

a) fiber variation size in many of the sections including tiny fibers (<10 μm in diameter)

b) low incidence of basophilic (regenerative) fibers

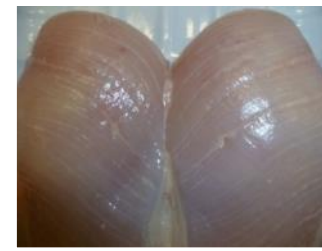
c) necrotic fibers (irreversible cell death induced by structural damage) with fatty tissue replacement



McRae et al. (2007) Poult Sci 86:382

Emergence of growth-related breast meat abnormalities

104 Occurrence of white striping in chicken breast fillets in relation to broiler size. L. J. Bauermeister*[1], A. U. Morey[1], E. T. Moran[1], M. Singh[1], C. M. Owens[2], and S. R. McKee[1], [1]*Auburn University, Auburn, AL*, [2]*University of Arkansas, Fayetteville*.



Veterinary Pathology
00(0) 1-5

DOI: 10.1177/0300985813497488
vet.sagepub.com

Myodegeneration With Fibrosis and Regeneration in the Pectoralis Major Muscle of Broilers

H.-K. Sihvo[1], K. Immonen[1], and E. Puolanne[1]

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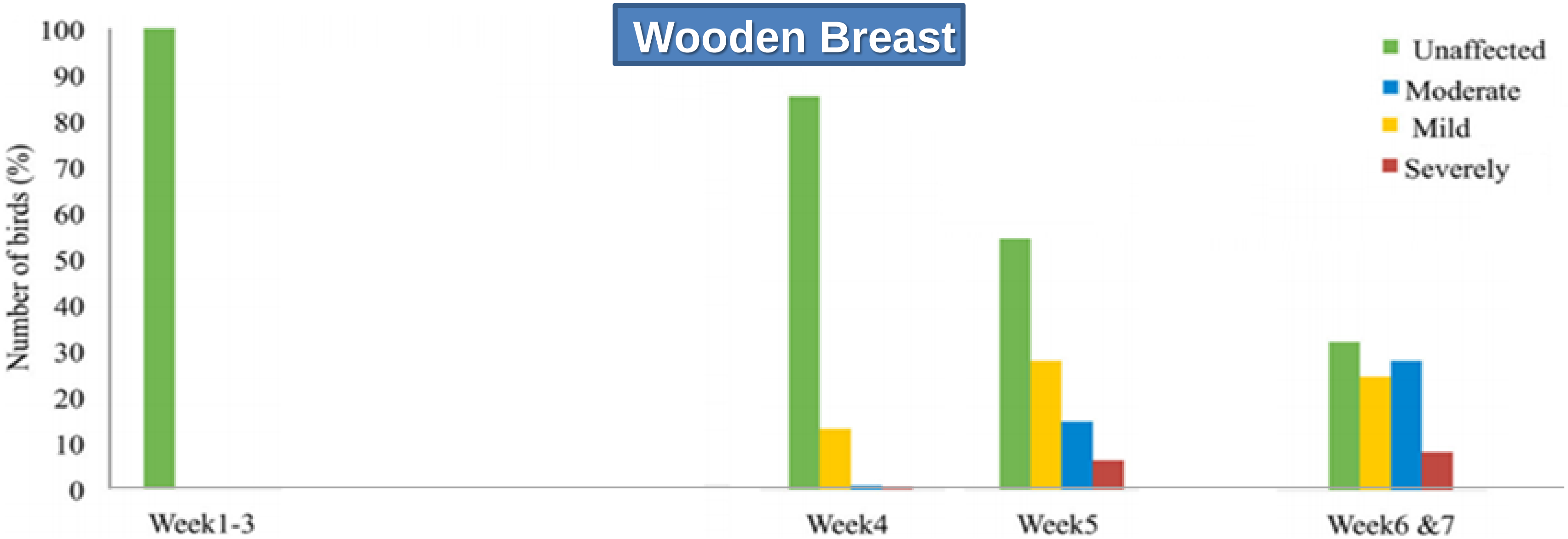
FEBRUARY 2015
AU DEPARTMENT OF POULTRY SCIENCE

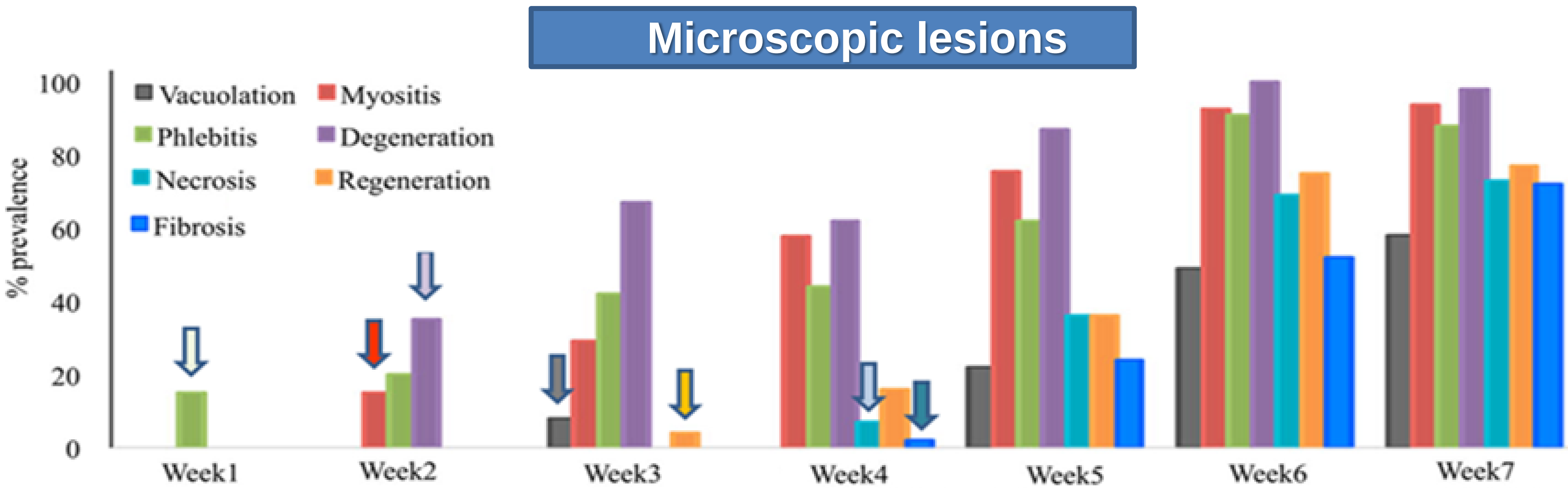
Worthwhile Operational Guidelines & Suggestions

BROILER CHICKEN MYOPATHIES IV. STRINGY/MUSHY BREAST

Origin of growth-related abnormalities

- Progression of microscopic lesions -





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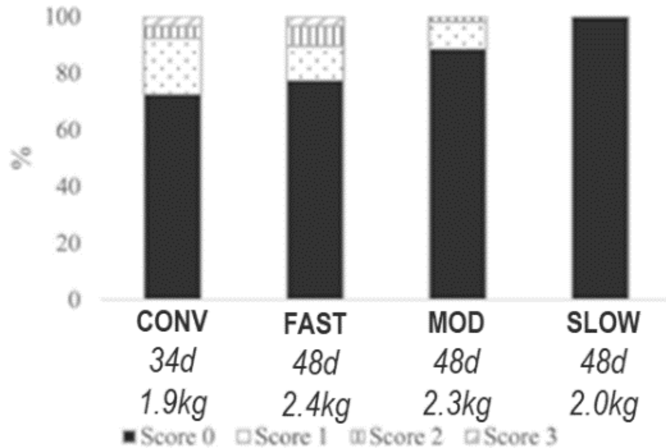
Papah et al. (2017) Avian Pathol 46:623

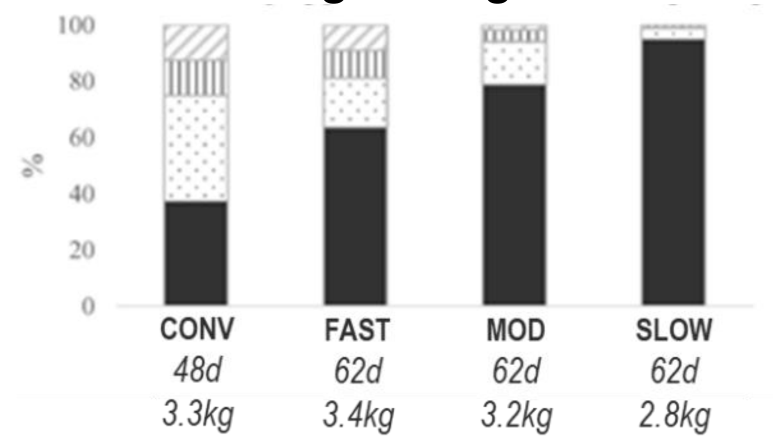
Origin of growth-related abnormalities

- Relationship with genotype and slaughter weight -

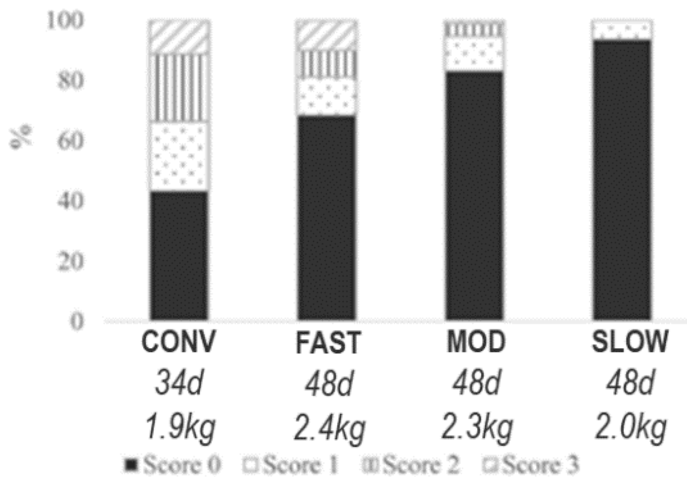
Target weight #1 / Target weight #2

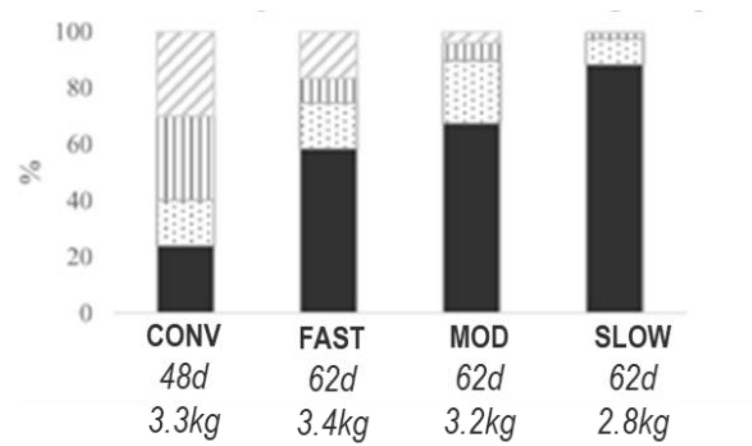
White striping





Wooden breast





Santos et al. (2021) Poult Sci 100:101309

Conventional (**CONV**; ADG0-48=**66.0 to 68.7 g/d**)
Fastest slower-growing (**FAST**; ADG0-62=**53.5 to 55.5 g/d**)
Moderate slower-growing (**MOD**; ADG0-62=**50.2 to 51.2 g/d**)
Slowest slower-growing (**SLOW**; ADG0-62=**43.6 to 47.7 g/d**)

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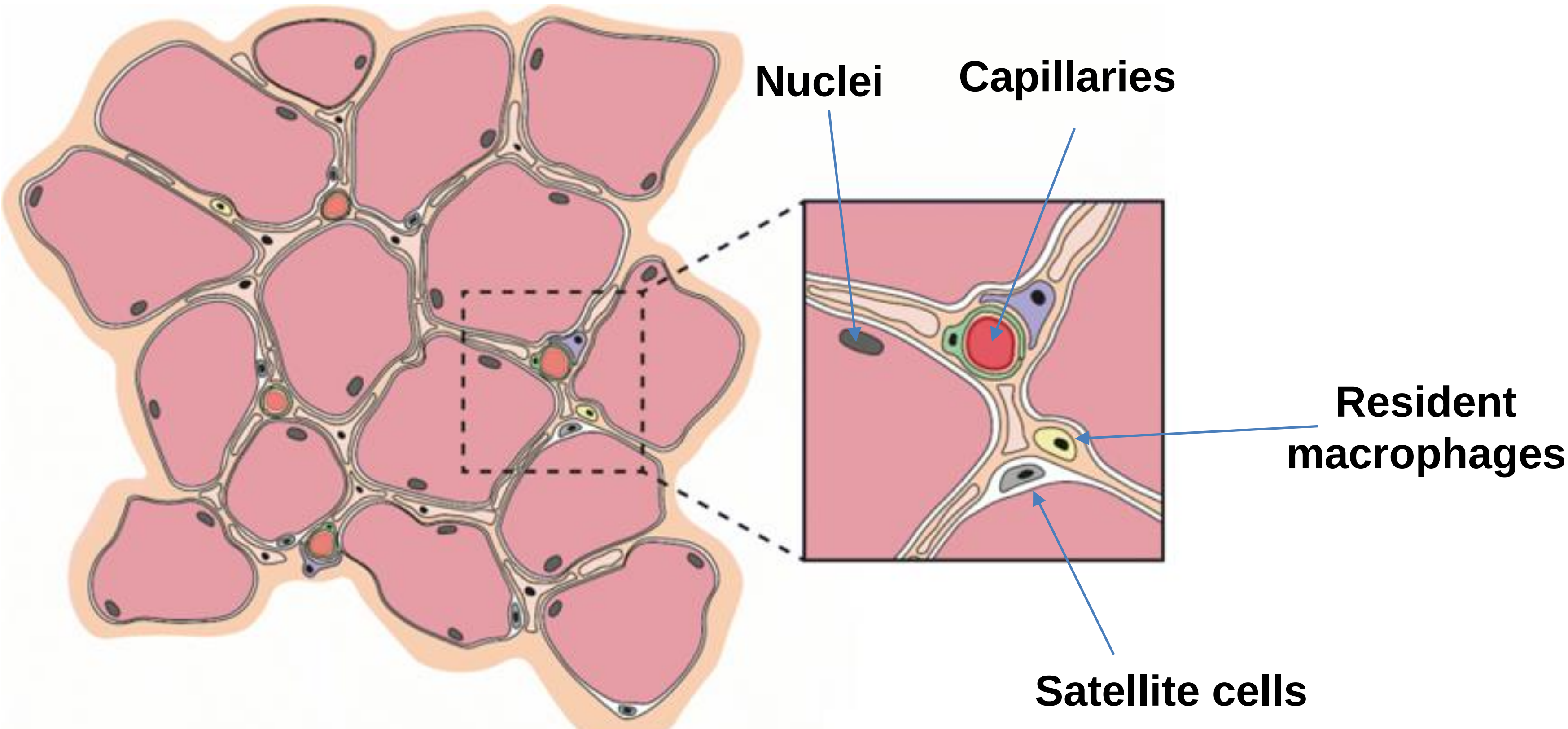
Origin of growth-related abnormalities

- Importance of extracellular environment -

- Space between fibre bundles (perimysium) and individual muscle fibres (endomysium) is necessary for liveability of the muscle

Interstitial spaces
(between fibres and fibre bundles)



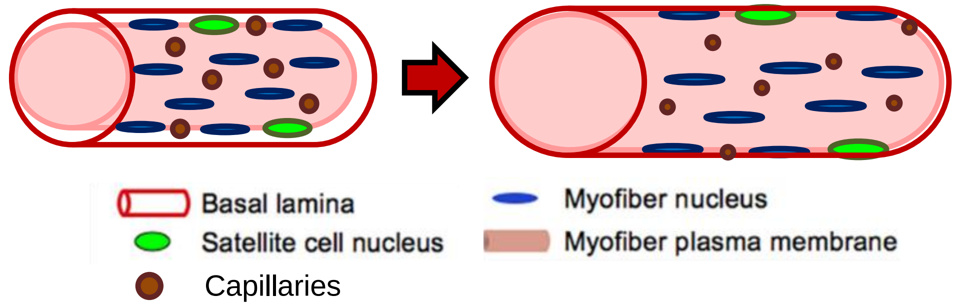
- Satellite cells require appropriate niche environment and vascularization for muscle fibre regeneration

Ausems et al. (2021) Stem Cell Rev Rep 17:878

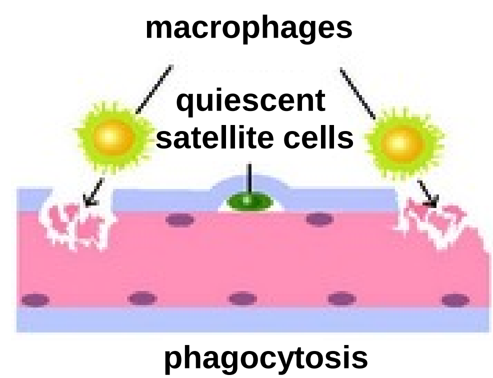
Origin of growth-related abnormalities

- Possible explanation of causative mechanism -

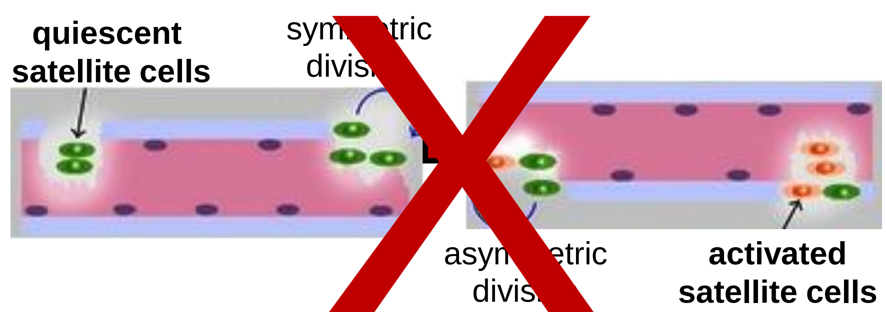
1 Lacking in connective tissue spacing between fibre bundles (perimysium) and individual fibers (endomysium) and oxidative stress causes fibre degeneration



2 Necrosis of muscle fibres leads to immune responses with infiltration of immune cells (neutrophils and macrophages) and satellite cell-mediated repair mechanisms are invoked



3 Reduced vascularization and circulatory supply suppress satellite cell-mediated myofiber regeneration



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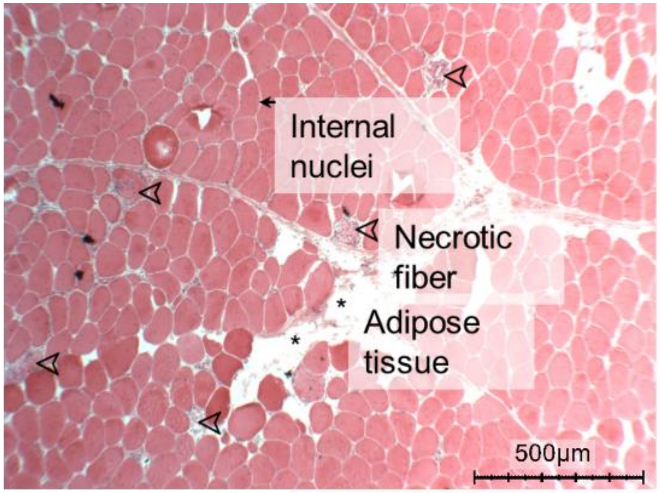
Velleman (2020) Front Physiol 11:461

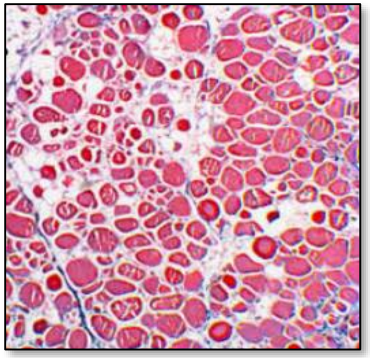
Origin of growth-related abnormalities

- Possible explanation of causative mechanism -

4 Chronic muscle fibre degeneration (necrosis) leads to increased deposition of extracellular matrix proteins like collagen and proteoglycans (fibrosis) as well as fat depots (lipidosis) with general replacement of muscle fibres with connective and adipose tissues

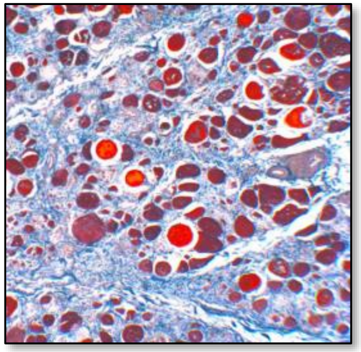


Courtesy by Maurizio Mazzoni



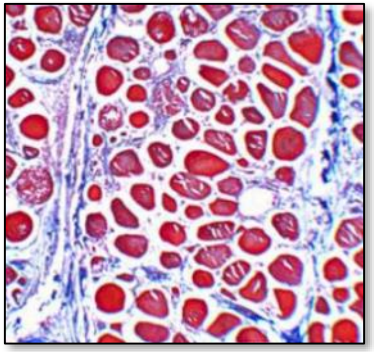
Abnormal deposition of adipose tissue

White striations



Excessive deposition of tightly packed and cross-linked collagen fibrils

Wooden texture



Abnormal deposition of diffuse and poorly cross-linked collagen fibrils

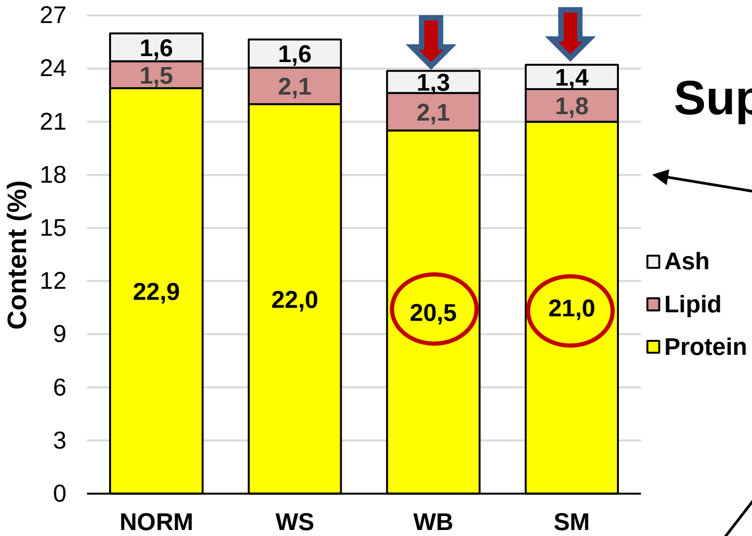
Spaghetti breast

Velleman (2020) Front Physiol 11:461; Baldi et al. (2020). Meat Muscle Biol 4:9503

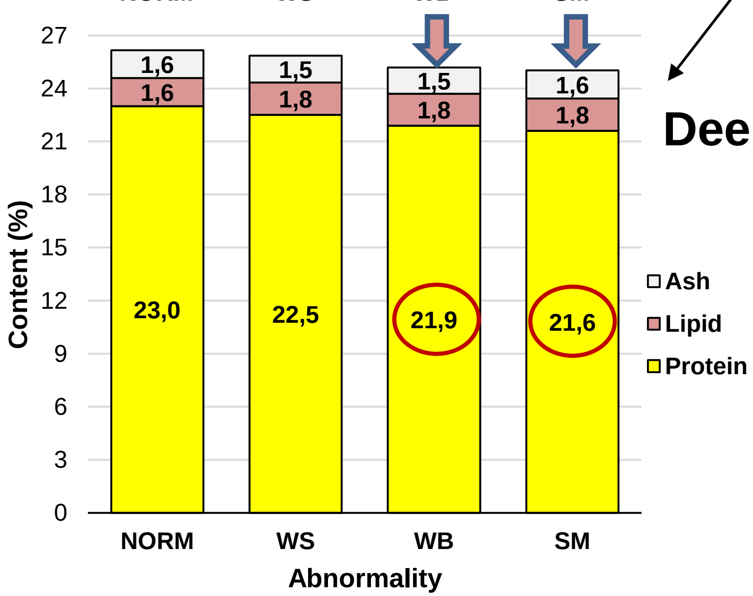
Consequences of growth-related abnormalities

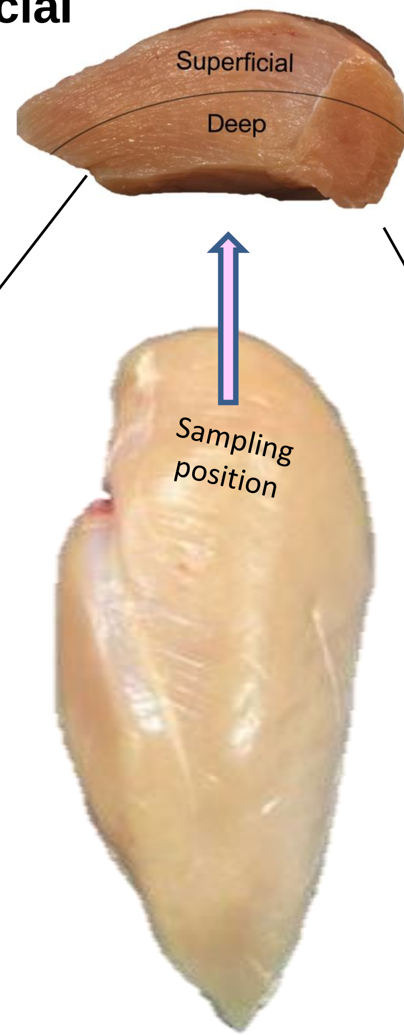
- Large reduction in meat protein content -

Superficial

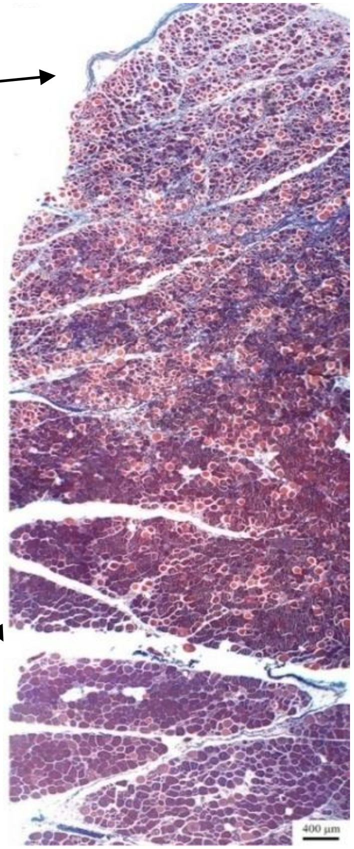


Deep





Severe histopathological lesions



Moderate histopathological lesions

Soglia et al. (2016) Poult Sci 95:651

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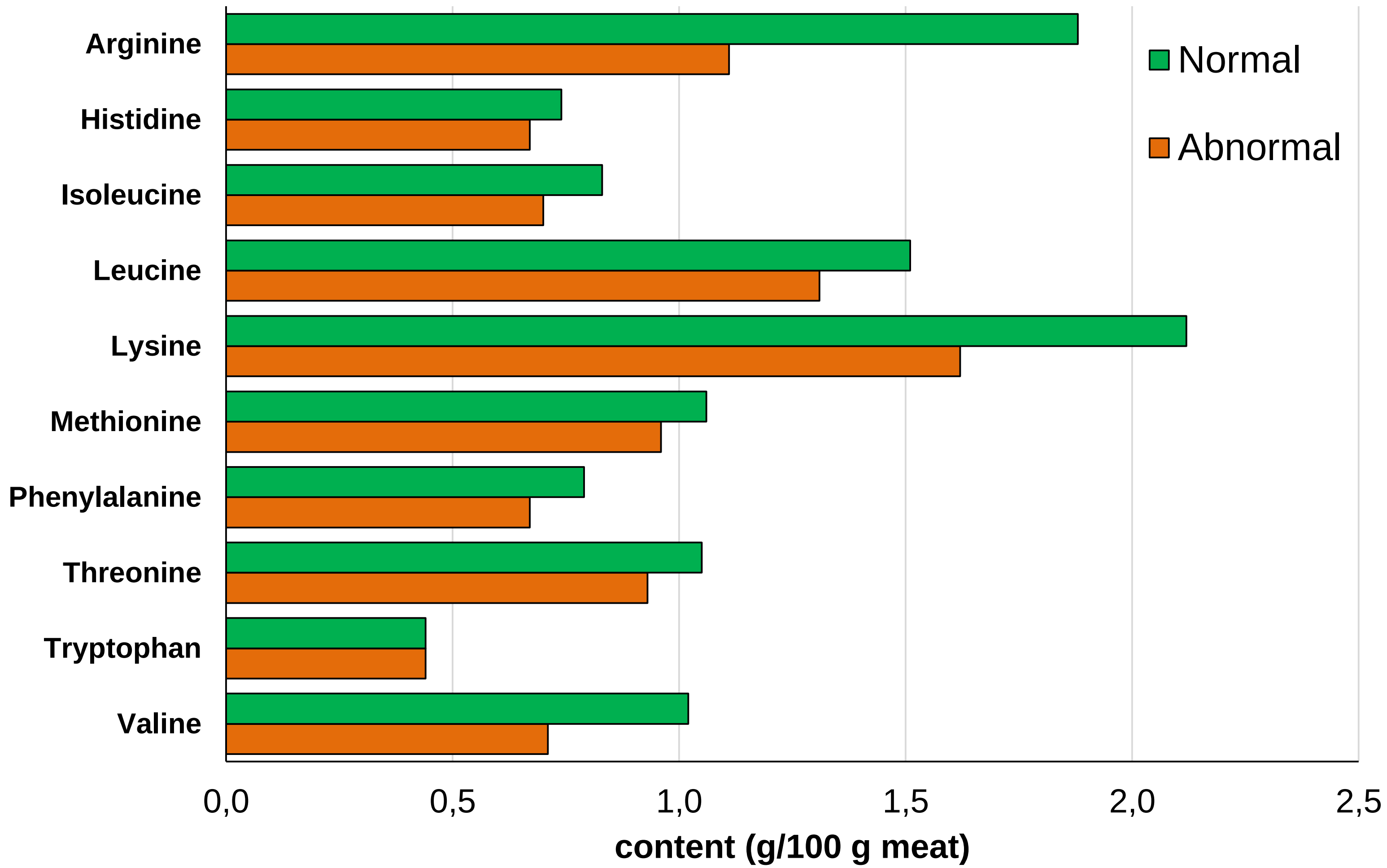
Baldi et al. (2019) Food Res Int 115:369

Consequences of growth-related abnormalities

- Large reduction in essential aminoacid content -



Dalle Zotte et al. (2020) Poult Sci 99:1797

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Conclusions

- Nowadays, broiler production is the most efficient terrestrial animal system for producing sustainable muscle proteins at global level
- Artificial selection for muscle growth through post-hatch fiber hypertrophy has likely reached the biological limit in breast muscles of modern hybrids used for meat production
- The results of the growth study showed that, on a radial basis, the growth of intramuscular connective tissues does not keep pace with the growth of pectoralis muscle fibers.

  (Wilson et al., 1990)

  One possibility is that they may have become rounded because the growth of connective tissue had not kept up with the growth of the muscle fibers, thus depriving them of extracellular support.

  (Swatland et al., 1990)

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Conclusions

- The pressure to meet rising the demand for breast meat is proving to be progressively unsustainable due to increasing relevance of penalties as well as inefficient use of other edible parts (i.e. non-food purposes)
- There is a need to rethink and reframe the way of consumption and therefore of production of poultry meat in order to continue the success story of chicken in the near future

Acknowledgements