Breast muscle myopathies: do they limit broiler breeding?

- ❖ achievements of the ongoing breeding for rapid growth and higher BW (since the 1950's)
- ❖ negative consequences ➔ abnormalities = polygenic 'defects' (each was considered a 'selection limit'…)
- ❖ genetic mitigation of defects ➔ overcoming each 'selection limit'

Avigdor Cahaner

The Hebrew University of Jerusalem, ISRAEL

avigdor.cahaner@mail.huji.ac.il

Covering more than 40 years of my own research on genetic mitigation of negative consequences

PDF version will be available

Outlines (*years of my own research*)

- **Genetic elevation in growth rate** (and feed intake, meat yield, etc.)
- **Excessive fat deposition** (*1980-1992*)
- **Leg problems** (very brief)
- **Ascites** (*1993-2008*)
- **Breast muscles myopathies** (*2015-2023*)
- ***Susceptibility to heat*** *(1990-2015)* ***not a 'defect'***

Early history of breeding chickens for meat production (broilers)

- During 1940's *(WW2),* chicken meat became much more popular in North America. Mechanized processing as well as cold-chain shipping and marketing were developed

- Since the late 1940's, rapid growth, as the main determinant of efficient meat production became the most important objective of broiler breeding programs

- **Rapid growth** is essential for **efficient meat production**

  More efficient utilization of: 1. feed 2. facilities 3. labor

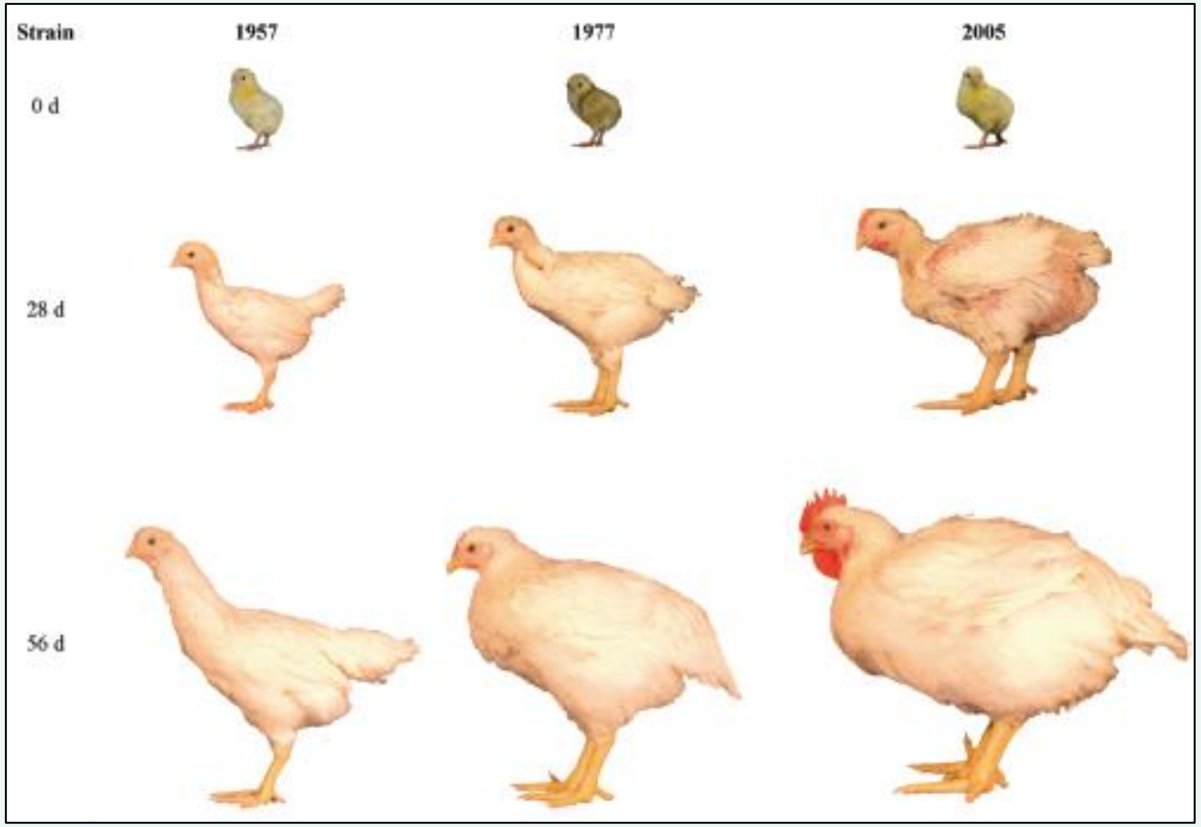
- **Slow-growth = lower efficiency**
  - **elevated negative environmental impacts**
  - **elevated production costs ⇨ higher products' prices**

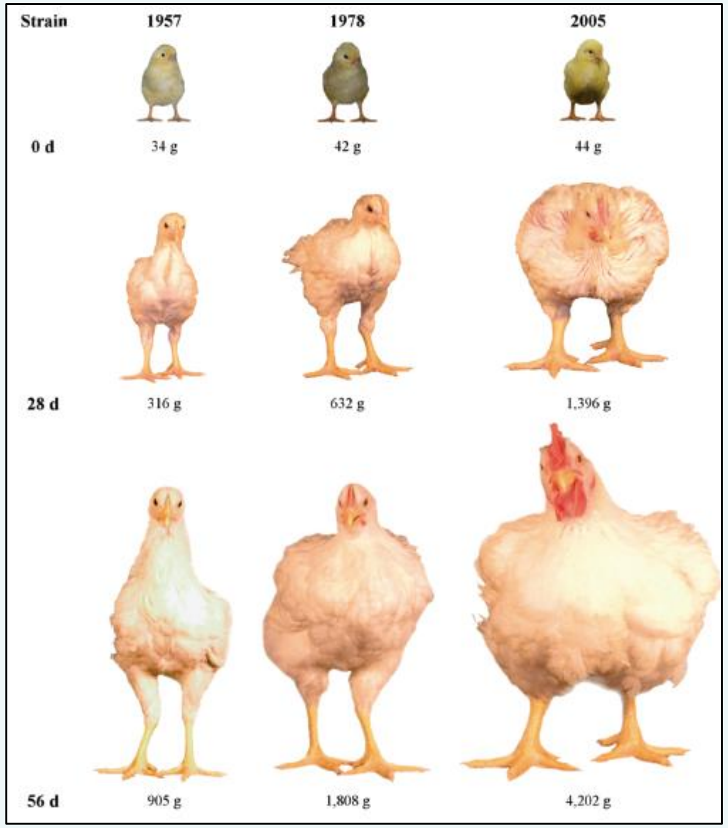
Genetic improvement in growth rate since 1950’s (#2)

Zuidhof et. al. (2014) conducted trial with three broiler strains: two research strains kept in the university with no selection from **1957** and from **1977**, and they were compared with commercial Ross 308 broilers (in **2005**, the year of the trial)

The three strains were reared together with standard feed but low stocking density.

Typical broiler from each strain was photographed at hatch, at 3 ages: 0 days, 28 days and 56 days.





Genetic elevation in <u>growth rate</u> since 1950's

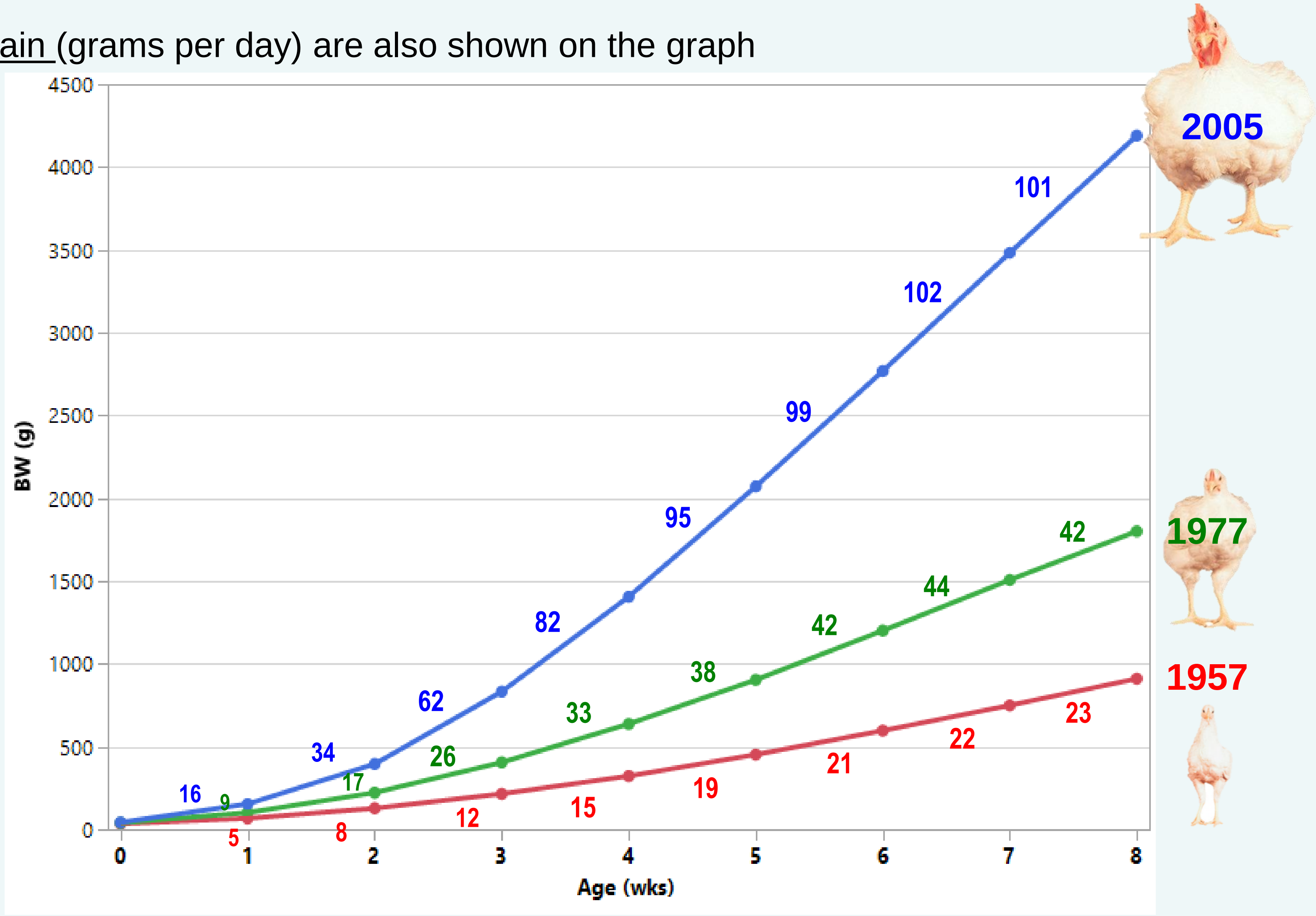
Growth curves of strains kept without selection from **1957** and from **1977**, and Ross 308 broilers in **2005**

Weekly average daily BW gain (grams per day) are also shown on the graph

1957, **1977**, **2005** broilers

experimental facility

low stocking density (4/m²)



Zuidhof et al. 2014

Genetic elevation in feed consumption since 1950's

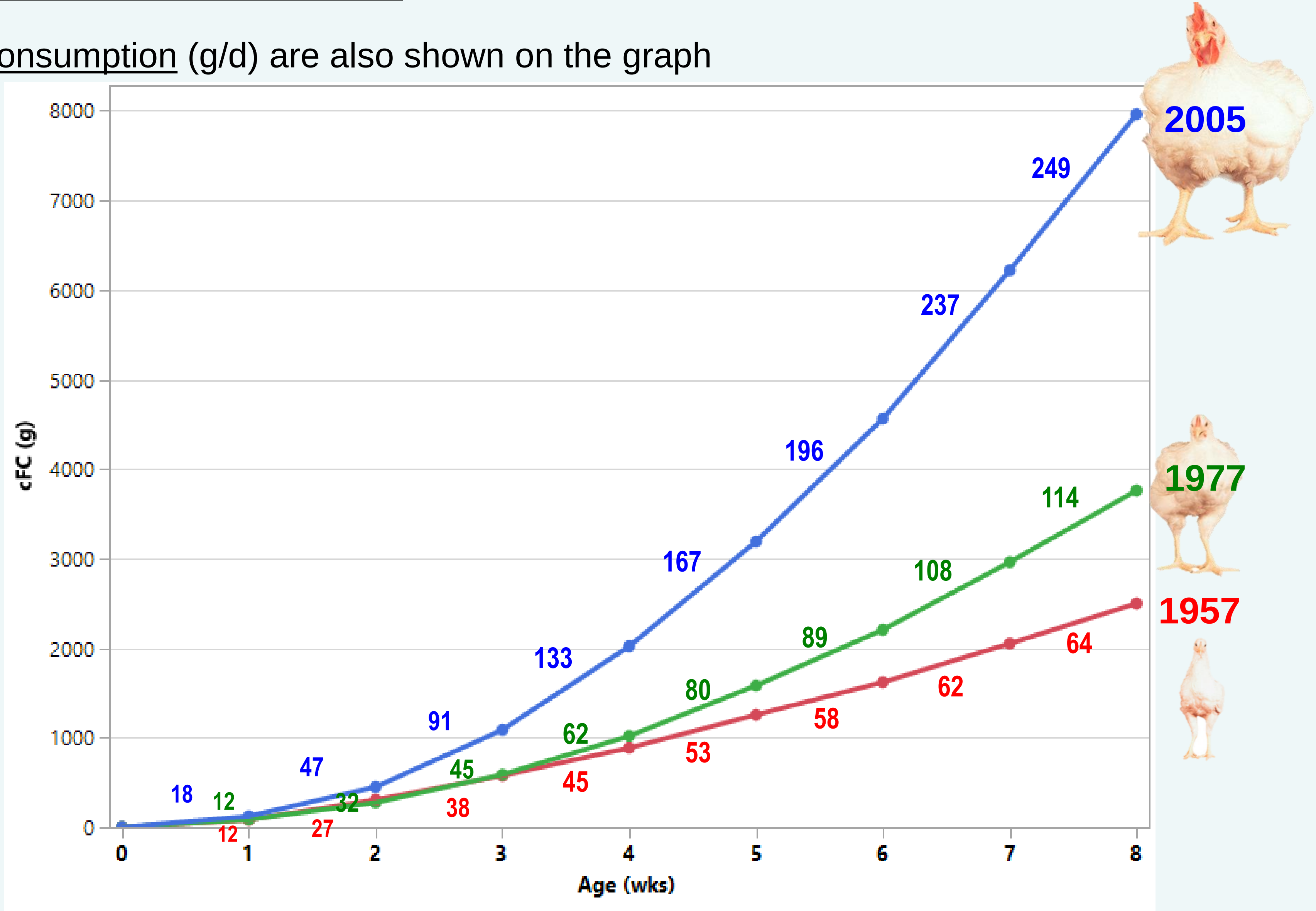
Cumulative feed intake curves of '1957', '1977', and Ross 308 in 2005

Weekly average daily feed consumption (g/d) are also shown on the graph

- 1957, 1977, 2005 broilers
- # experimental facility
- # low stocking density (4/m²)

Rapid growth is driven by higher feed intake!

From **1957** to **1977**, daily feed consumption towards marketing age (8+ wk) almost doubled!



Zuidhof et al. 2014

Excessive Fatness - consequence of elevated feed consumption

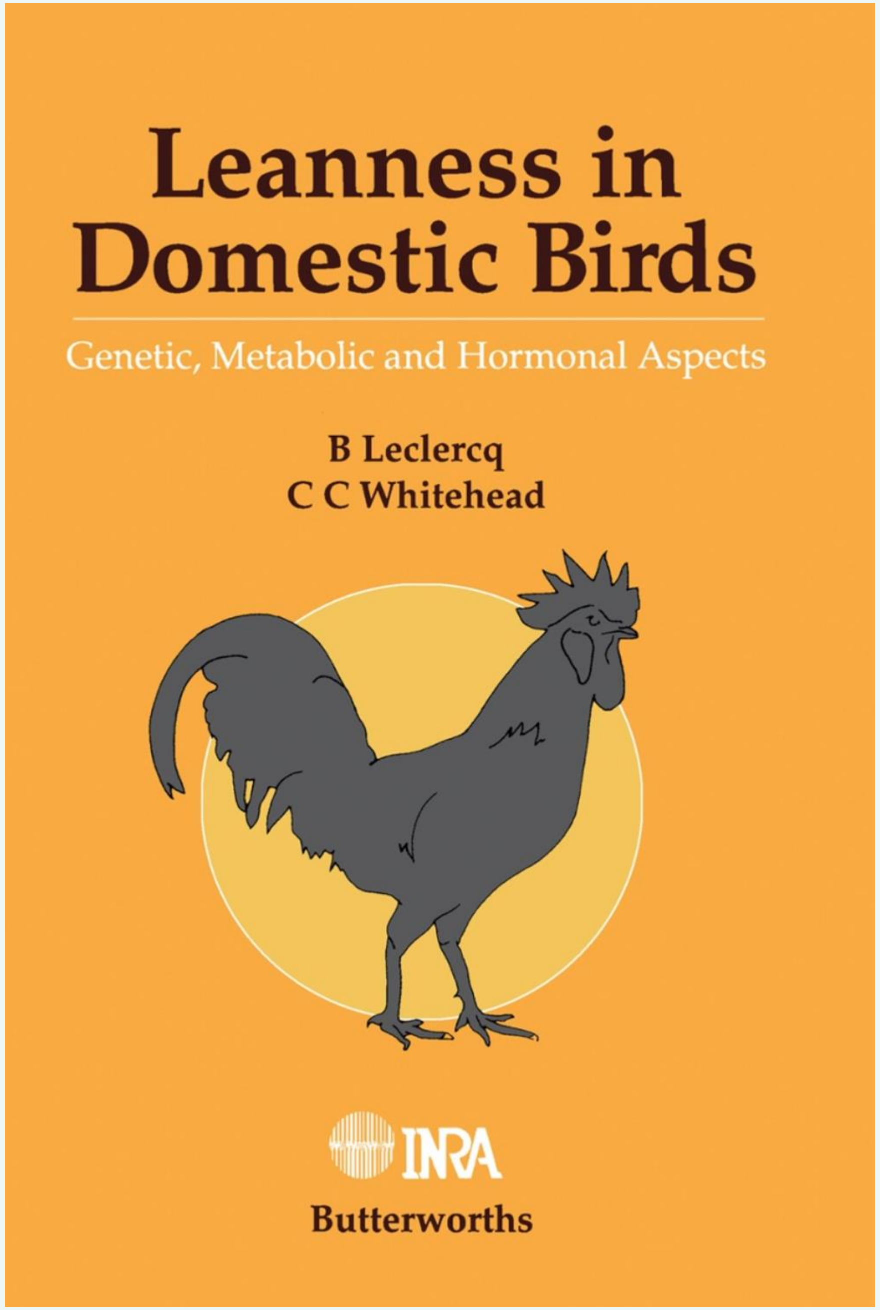
- **Selection for rapid growth has been elevating the appetite** (voluntary feed consumption). The elevation in daily intake of dietary energy increased average body fat deposition.

- The **excessive fat deposition** became an economical problem for the broiler industry during the 1980's, mainly due to the negative attitude of consumers towards carcass fat.

- Due to the apparent genetic association between growth and excessive fatness, the breeding companies suggested more expensive diets (high protein, low energy) and costly processing practices, trying to mitigate the excessive fatness in commercial broilers.

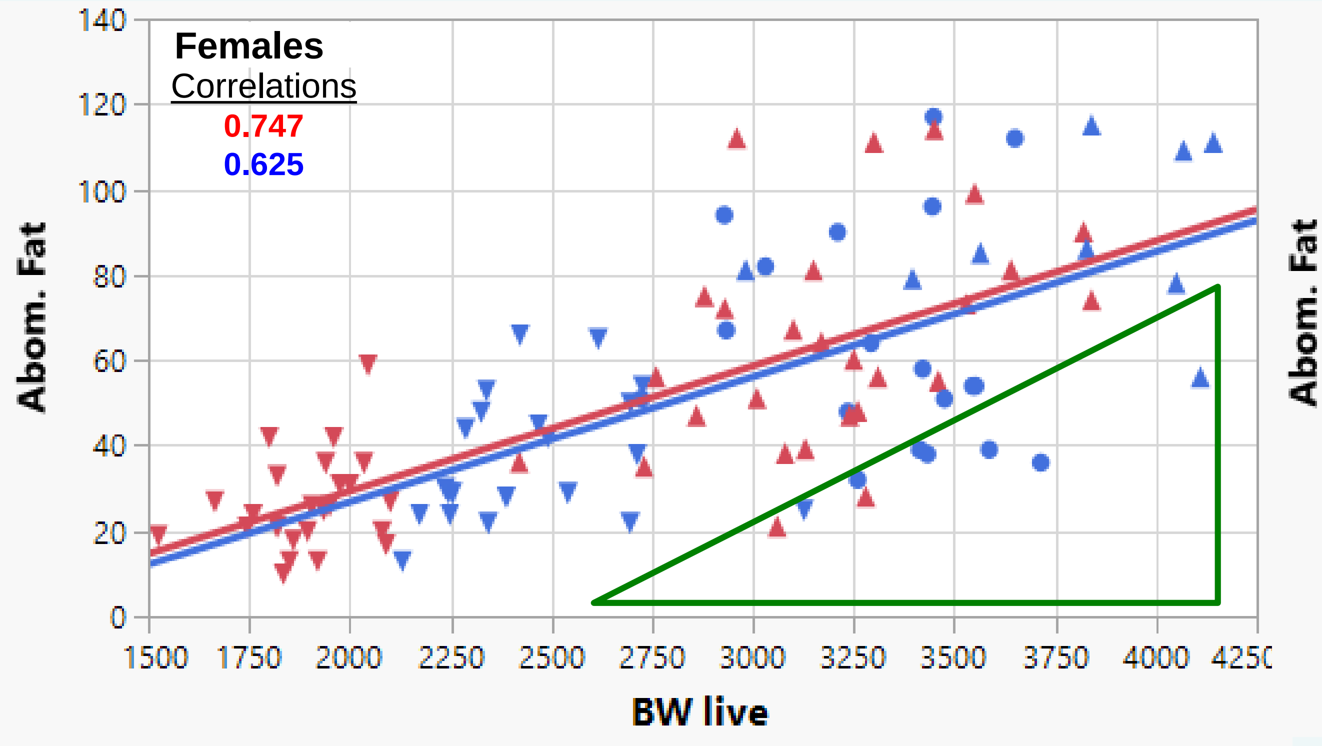
- Much research was done on biological and practical aspects of fat deposition in broilers

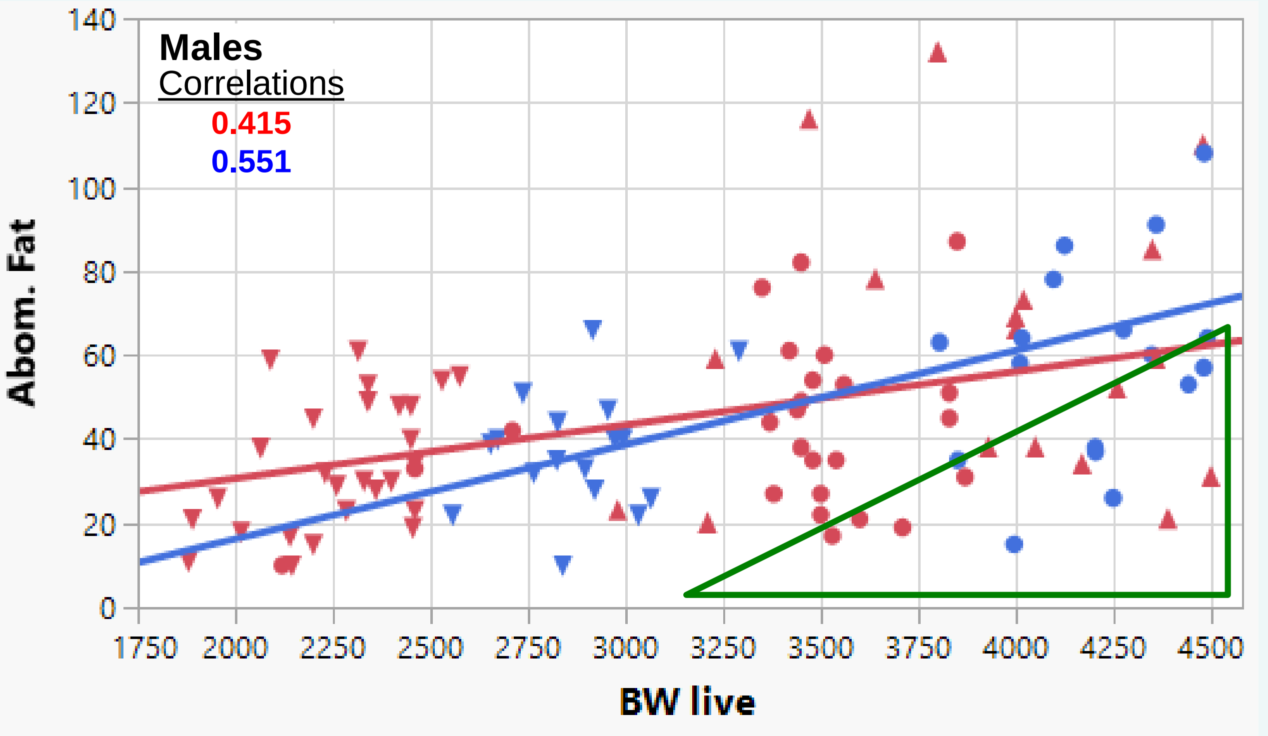
Leanness in domestic birds : genetic, metabolic, and hormonal aspects / [edited by] B. Leclercq and C. C. Whitehead.
p. cm.
Proceedings of a symposium held in Tours, France, from 4th to 6th August 1987.



Abdominal fat data from **Havenstein** trials (Havenstein *et al*., 1994 and 2003) show why selection for higher BW could be combined with selection against excessive fatness

Contemporary broilers (**1991**, **2001**) were slaughtered at 6 (▼), 8 (●) and 10 (▲) wks
The adnominal fat weights of each bird are plotted versus its live body weight (BW)

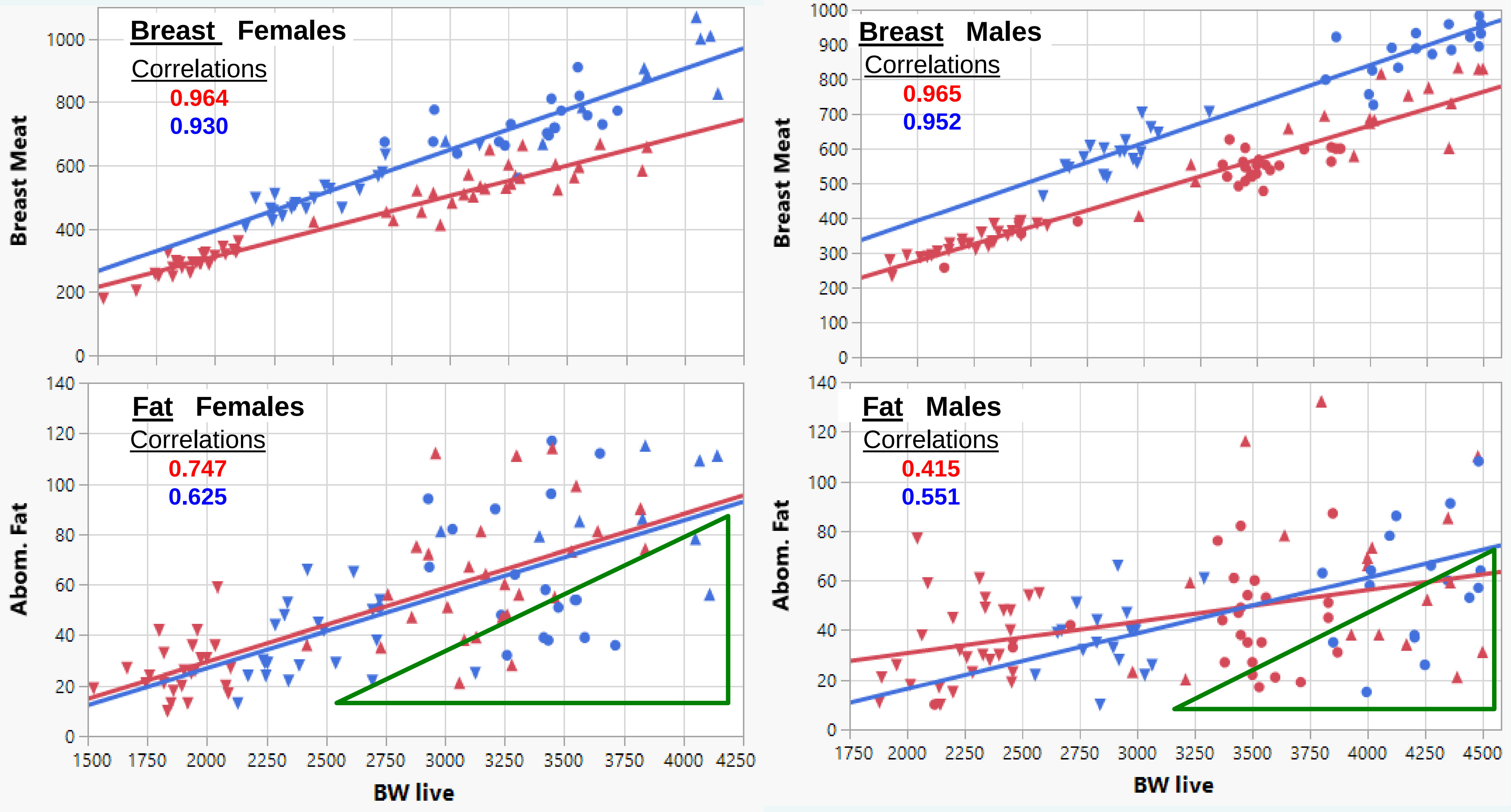




Positive correlation of fat and BW ***supposedly*** hinder combined selection for high BW and low fat.

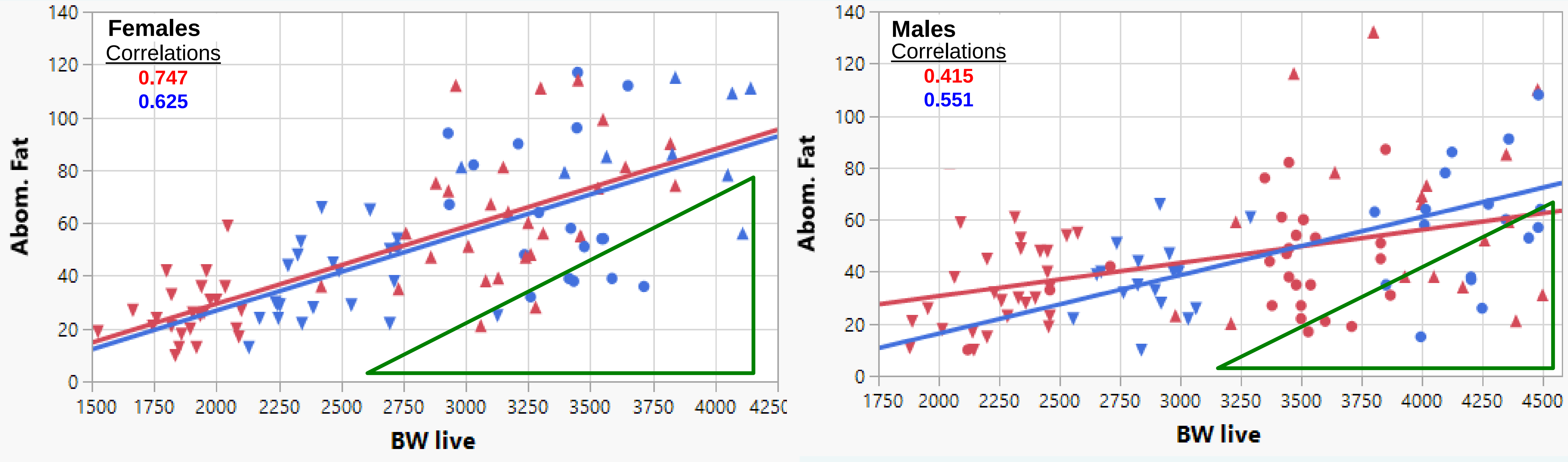
But the association is modest and **a-symmetrical**, facilitating selection for **lean heavy genotypes,** once identified

Most whole-body and body-part associations (=correlations) are very high symmetrical…



Contemporary broilers (1991, 2001) were slaughtered at 6 (▼), 8 (●) and 10 (▲) wks

The breast meat and the adnominal fat weights of each bird are plotted versus its live body weight (BW)



Positive correlation of fat and BW ***supposedly*** hinder combined selection for high BW and low fat.

But the association is modest and **a-symmetrical**, facilitating selection for **lean heavy genotypes,** once identified

Carcass fat is accurately measured on slaughtered birds, but that allows **only sib-selection** against excessive fatness.
For the **more efficient individual selection**, fatness of **live birds** should be assessed, but no feasible way was found.

Excessive fatness has been successfully mitigated by the on-going selection for better FCR
and for higher breast meat yield, because water content is ~80% in muscles and only ~20% in fat tissues

Breeding to improve the efficiency of feed utilization *(skip this slide)*

Feed accounts for 60-70% of the total costs of chicken meat production;
Therefore it has been highly desired to improve the feed conversion ratio (**FCR**)

Total feed consumption (**FC**), from hatch to marketing, consists of two components:
Feed consumed for body **maintenance** + Feed consumed for **growth**

$$\textbf{FCR} = \frac{\text{Total FC (feed cons.)}}{\text{Final body weight}} = \frac{\textbf{FC growth}}{\text{Body weight gain}} + \frac{\text{FC maintenance}}{\text{Body weight}}$$

***Maintenance FCR** improves by faster growth (another slide)*

Growth FCR improves as the broilers deposit less fat and more muscles

Water content is ~80% in muscles and only ~20% in fat tissues,

1 gram feed deposited in muscles, adds **5** gram body weight (**1** gram 'dry matter' + **4** gram water)

1 gram feed deposited in fat tissue, adds **1.25** gram body weight (**1** gram 'dry matter' + **0.25** gram water)

Body weight increases 4-times more by nutrients deposited in muscles than in fat tissues

Excessive fatness has been successfully mitigated by the on-going selection for better FCR
(and also by the direct selection for higher breast meat yield)

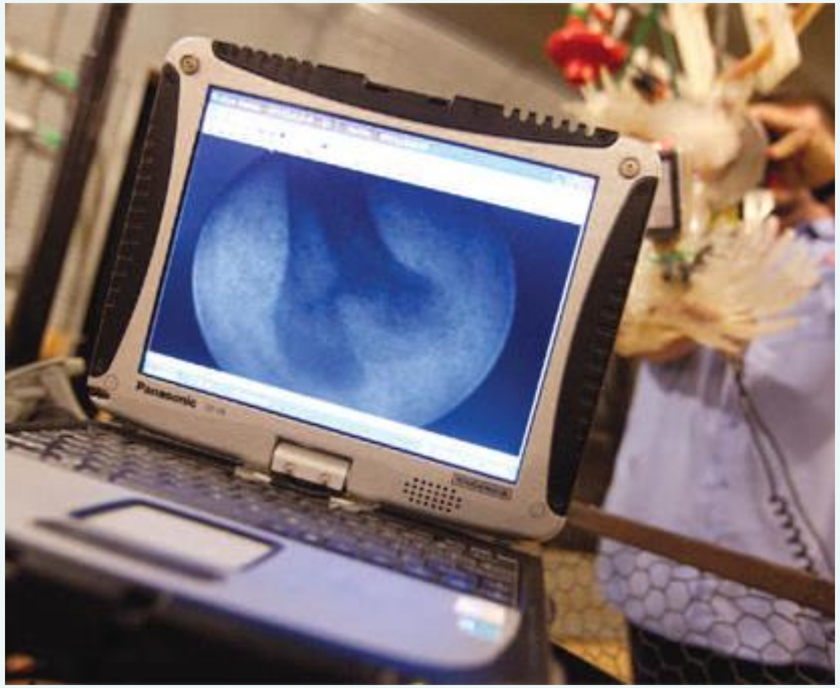
Breeding against <u>leg problems</u>

Leg problems emerged in 1980's and increased as broilers grew faster, and to higher body weight (BW)

Tibia Dyschondroplasia (TD) was identified as the main cause for these problems

This heritable defect affects heavy broilers, <u>but not related genetically to BW</u>

Portable X-ray machine (Lixiscope) facilitated large-scale selection by identifying the broilers prone to develop **TD,** and culling them out.

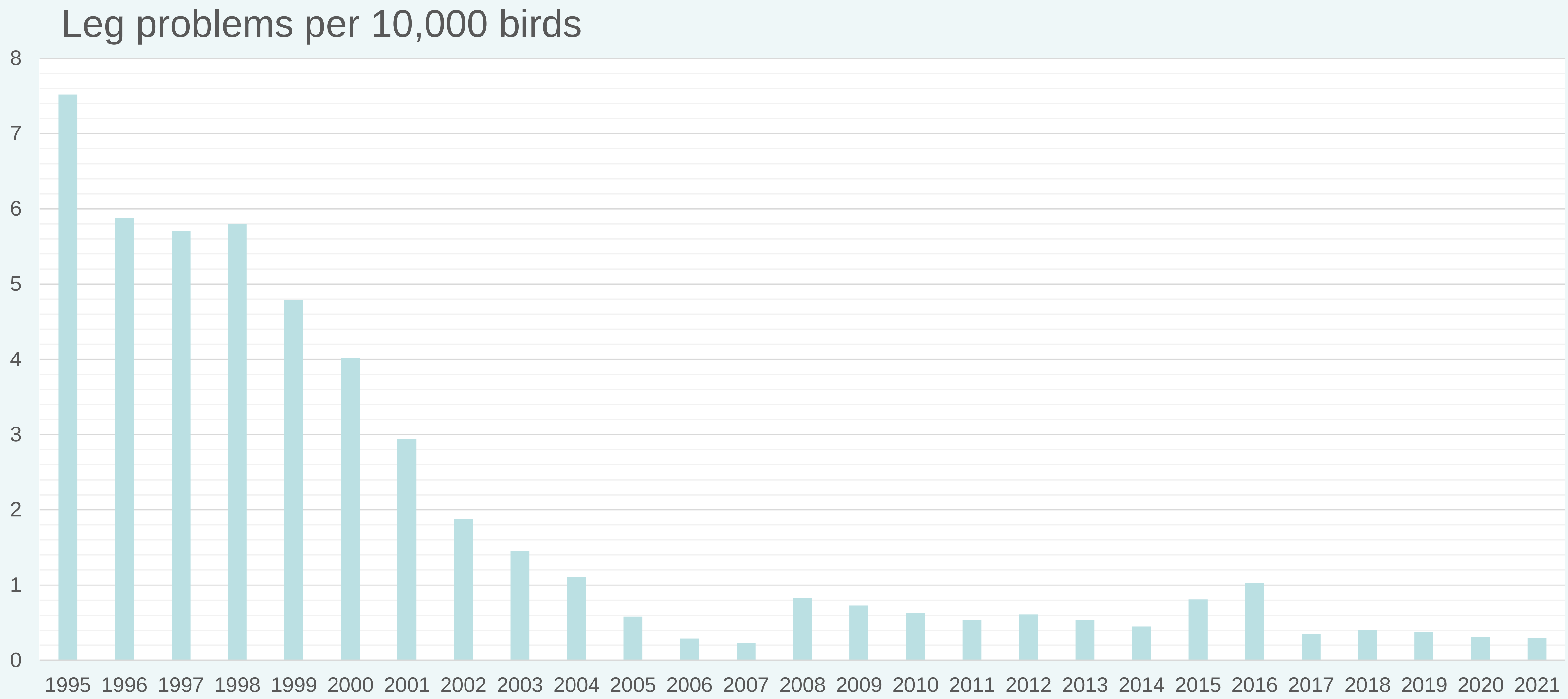


The <u>a-symmetrical association</u> between the incidence of TD and BW *(as between excessive fatness and BW)* allowed successful breeding against TD, without compromising the rapid growth and high BW

The use of portable X-ray machine to identify the individuals prone to develop **TD** and cull them out, is a routine on-going practice in all broiler breeding programs. *(picture and text from Aviagen's website)*

Aviagen utilizes an X-ray unit called a Lixiscope, which offers the opportunity to safely detect and identify Tibial Dyschondroplasia (TD). The introduction of the Lixiscope has enabled Aviagen to identify TD accurately and select against its presence and improve overall leg health in the breeding program. Aviagen was the first to implement use of the Lixiscope and in combination with individual bird walking assessment, it has significantly improved leg strength in all our products worldwide.

Leg problems condemnation in Canadian slaughterhouses



Agriculture and Agri-Food Canada, Poultry Condemnation Report, 2022

Ascites syndrome

Broilers with the ascites syndrome accumulate ascitic fluid, stop growing, and many of them die shortly before marketing.

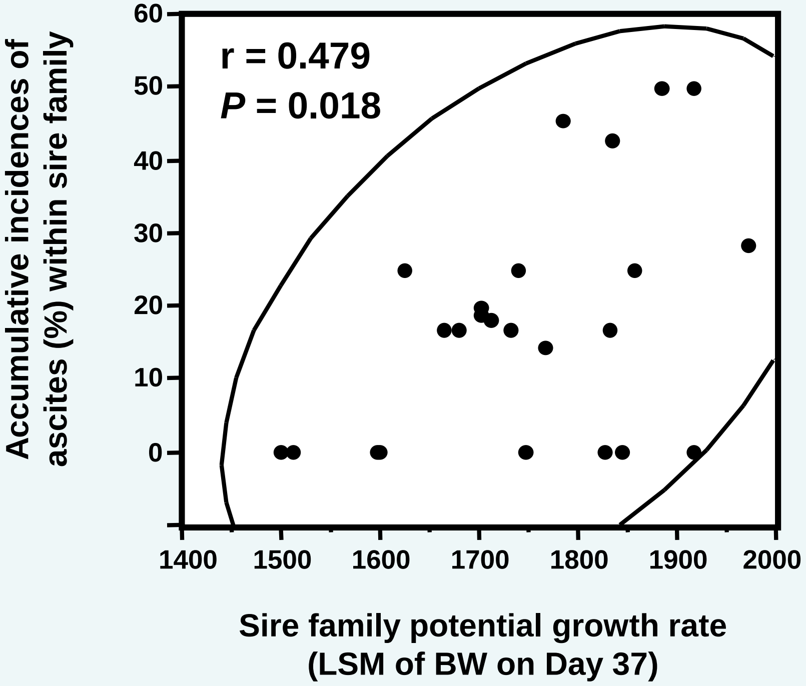
Ascites syndrome develops in broilers suffering from insufficient supply of oxygen

High growth rate ⬄ high feed intake ⇨ high metabolic rate ⇨ high demand for oxygen

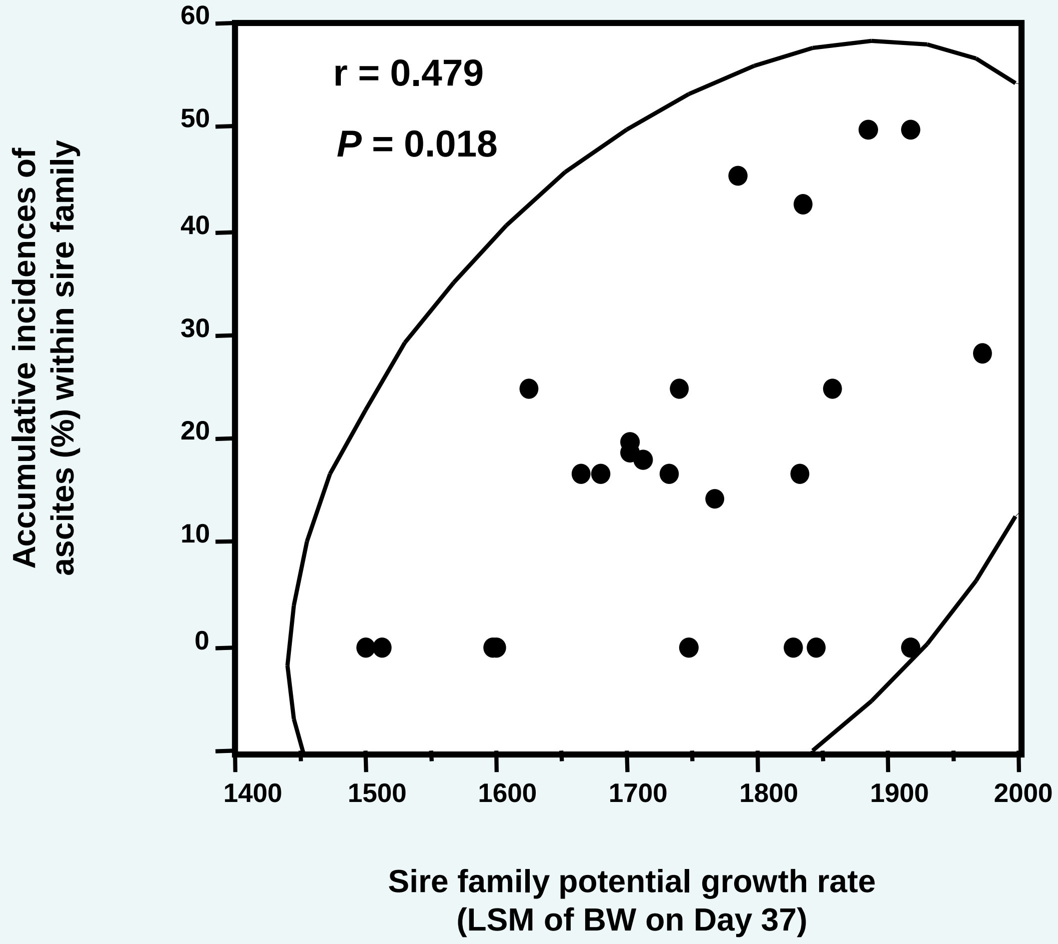
Broilers with higher growth rate need more oxygen, hence more prone to develop ascites

The genetic association between growth rate and ascites was evident:

- The incidence increased from 1980's, as broilers were bred to grow faster
- Results from controlled studies that we conducted during the 1990's
  (e.g. Deeb, Shlosberg and Cahaner, 2002)



Association between growth rate and incidence of ascites was evident from controlled studies

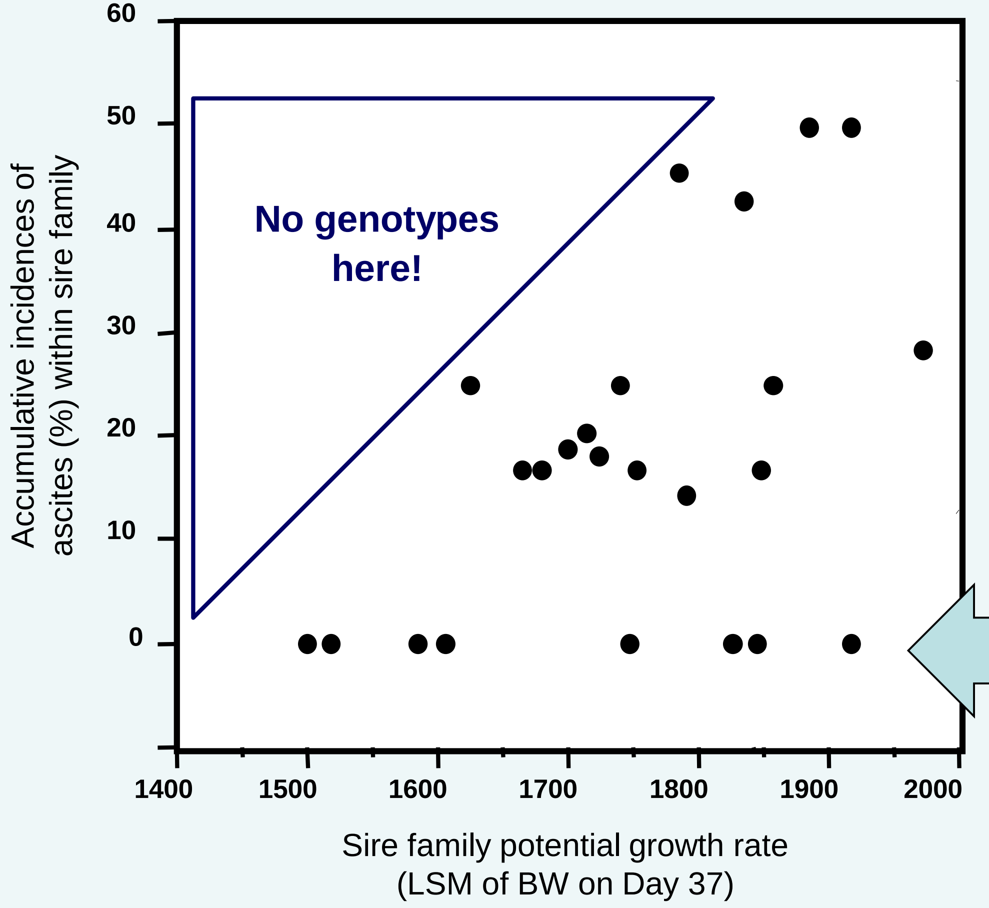


Deeb, Shlosberg and Cahaner, 2002

Association between growth rate and incidence of ascites was evident from controlled studies

But this association is a-symmetrical…

as the associations of BW with excessive fatness and with leg problems (TD)



The genotypes with high growth rate and low ascites incidence selected as breeders

Deeb, Shlosberg and Cahaner, 2002

Genetic differences in susceptibility to Ascites

Broilers reared (in 2002) under extreme ascites-inducing conditions, and many of them died from ascites.

At 38 days, all surviving broilers were inspected for ascites

Broilers with ascites (mean BW=1.5 kg)

In the same flock:

Healthy broilers (mean BW=2.5 kg)

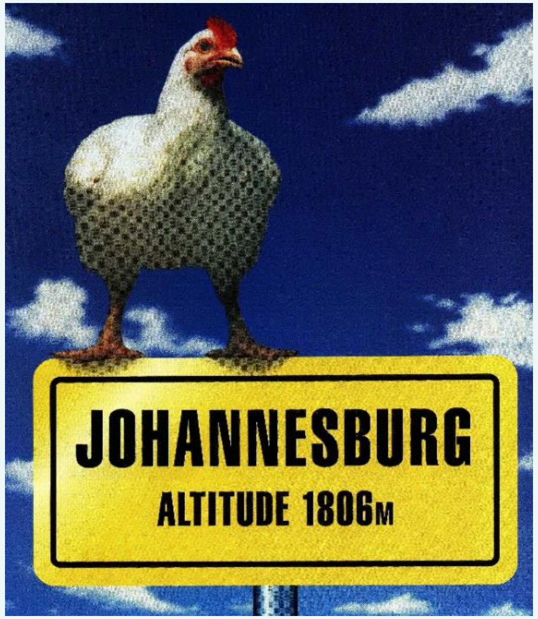
They were healthy in spite of their rapid growth to a high BW

They were truly **genetically resistant**!

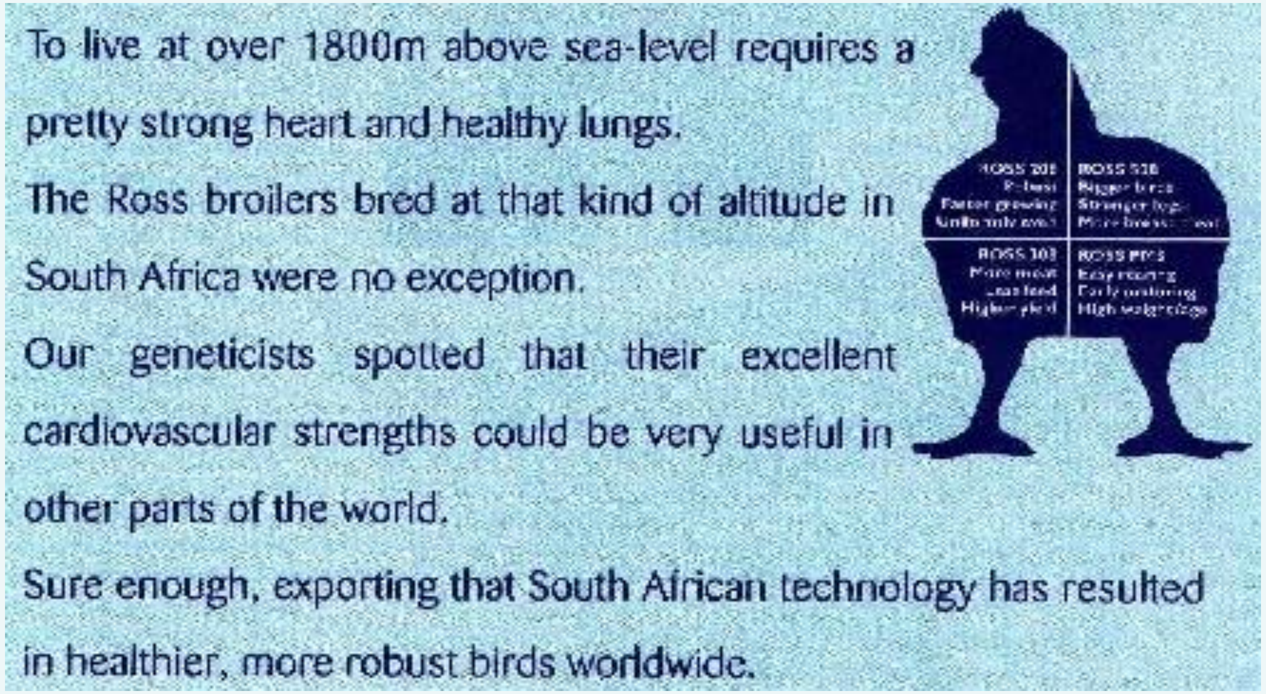
Identifying and culling susceptible individuals was expected to genetically reduce ascites incidence in broiler stocks

Broiler stock advertisements at the 1990's

When breeding stocks were reared at high altitudes, mortality of ascites-susceptible individuals led to **natural selection**, and improved the stocks' resistance to ascites



This approach does not allow multi-trait breeding program, therefore breeding companies moved to indirect measurement of live broilers' capacity to meet higher oxygen demand



Breeding against the tendency to develop ascites

At the early 2000's we suggested that **ascites** develops due to heritable sub-clinical cardiopulmonary **defect**, expressed in broilers challenged by oxygen deficiency, either externally (low temp, low O_2), or internally (high metabolism), or both.

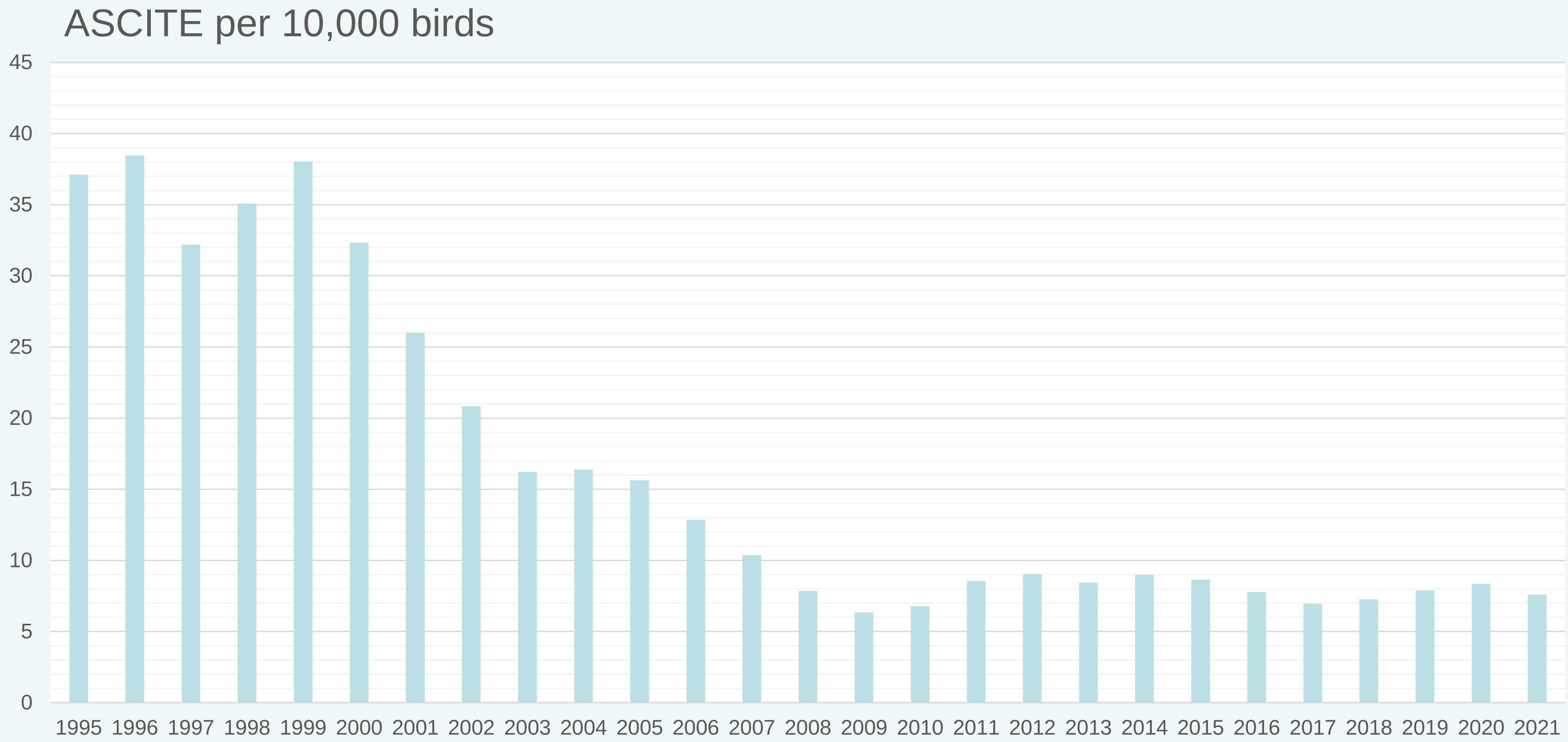
Individuals with this defect can be detected by low levels of blood **oxygen saturation** (indicating poor cardiopulmonary function) and culled from the breeding populations

Veterinary Oximeter (pictured), detects the bird's heart beat (345 b/m here) from the wing, and then accurately measures oxygen saturation (96% here).

We predicted that in ascites-resistant stocks, **all** broilers can fully express their genetic potential for high feed intake, rapid growth, and high body weight, even under ascites-inducing conditions

This expectation proved true: despite the ongoing elevation in growth rate, ascites is now very rare

Ascites condemnation in Canadian slaughterhouses



Agriculture and Agri-Food Canada, Poultry Condemnation Report, 2022

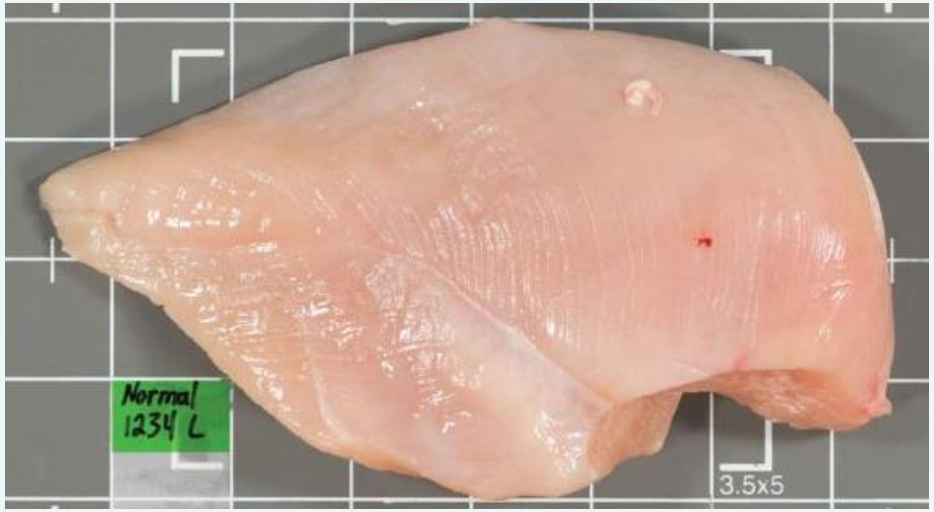
New defects: <u>**breast muscle myopathies**</u>

During the last 15 years, 3 breast muscle myopathies emerged in flocks reared under conditions allowing rapid growth to high BW

WS White Striping *(Striation)* (first reports in 2007)

WB Wooden *(Woody)* Breast (first reports in 2011)

SM Spaghetti *(Stringy)* Meat (first reports in 2015)



Normal breast

Spaghetti Meat

Wooden Breast

White Striping

Due to their substantial negative impacts, especially of **WB** around 2016-2020, these myopathies were considered by many as **limits** to further selection for higher growth rate and breast meat yield

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Biophysical Basis of Breast Muscle Myopathies in Broilers

Stampa Email
Categoria: PSA - 2023

PSA - 2023

During the symposium of the Myopathies in broilers: **Supply chain approach to provide answers/solutions to challenges of raising fast growing broilers**.

Professors: *Massimiliano Petracci, Giulia Baldi, Martina Bordini, Marco Zampiga, Federico Sirri & Francesca Soglia* from the Department of Agricultural and Food Sciences, University of Bologna, Bologna, Italy have presented:

Biophysical Basis of Breast Muscle Myopathies in Broilers

Speaker: Prof. Massimiliano Petracci

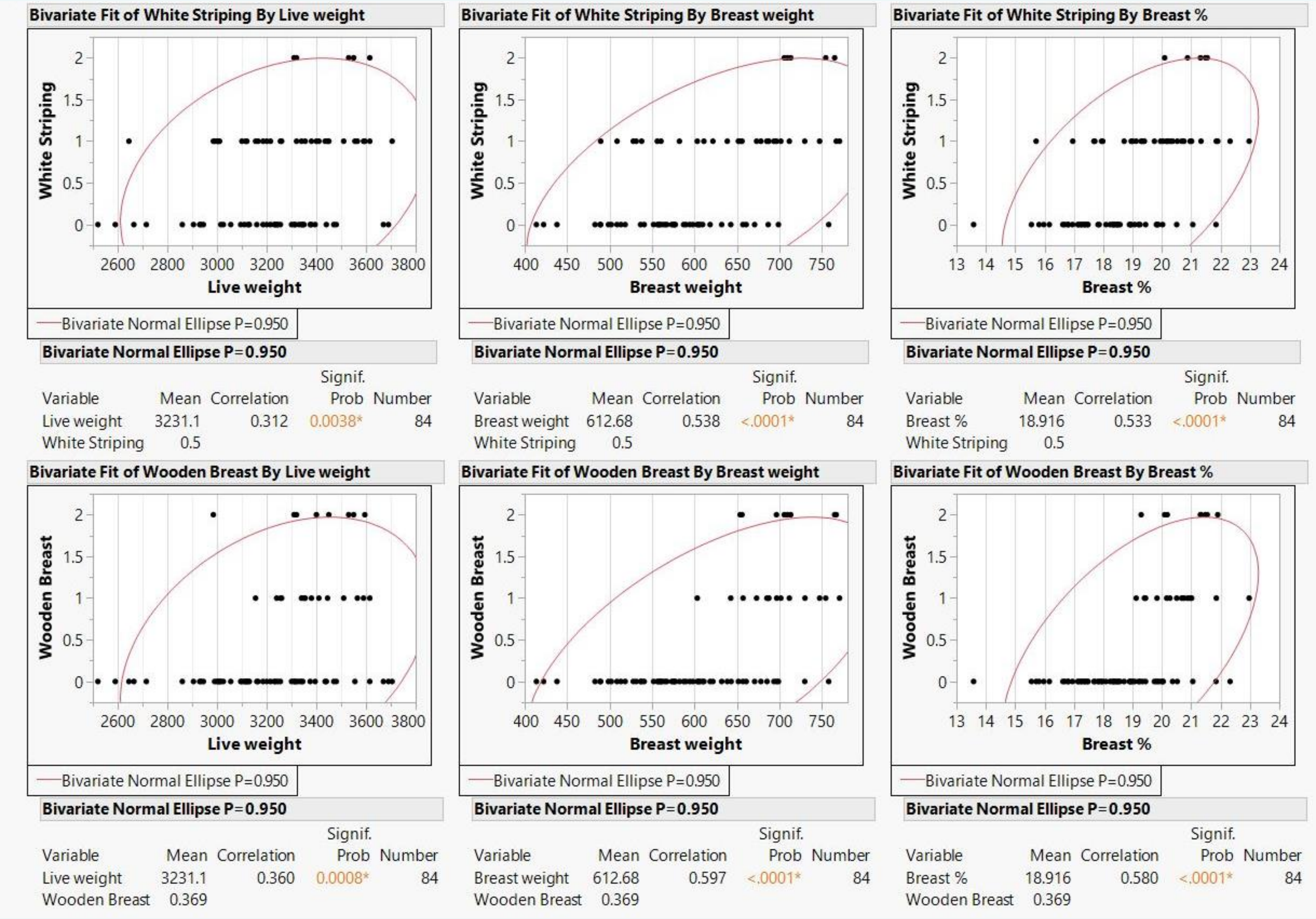
OUTLINE:

- Relationship Between Improvement of Broiler Performances and Meat Quality Issues
- Evolution of Meat Abnormalities and Myopathies in Poultry
- Possible Origin and Causative Mechanisms Underlying Growth-related Myopathies In Broilers
- Conclusions

DOWNLOAD THE COMPLETE PRESENTATION

Link in **WPSA Newsletter**, August edition (https://www.wpsa.it/home/index.php?option=com_content&view=article&id=254&Itemid=187)

WS and **WB**, scored on individual broilers using gradual 3-levels scale: **0** / **1** / **2** *(from none to severe)*, plotted by individual body weight, breast weight, and breast yield *(% of body weight)* of females+males



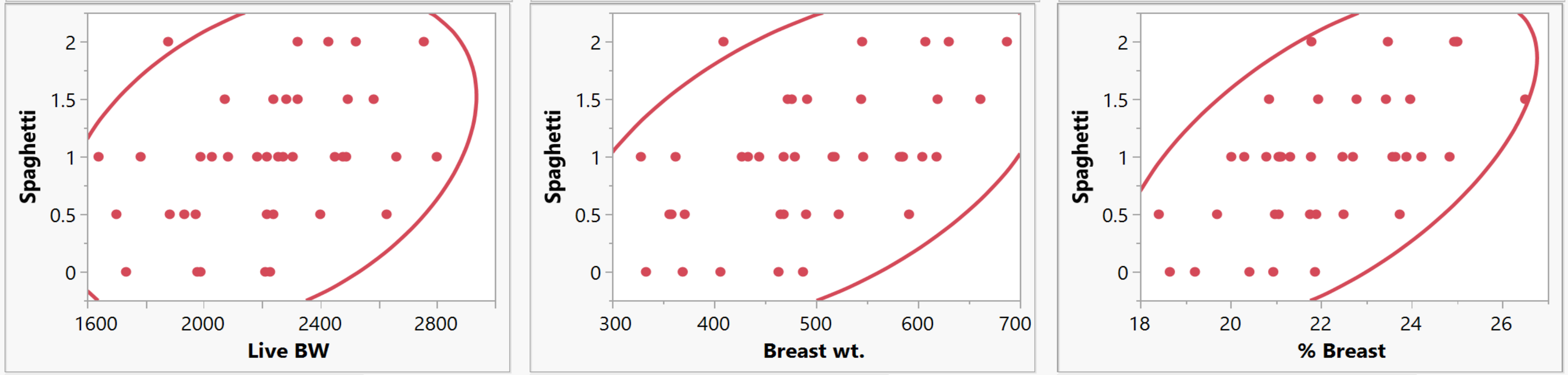
WS (White Striping)

Positive yet a-symmetrical association with body weight and breast yield suggest the feasibility of breeding for improved performance combined with less **WS** and **WB** *(as done previously with lower fatness and less ascites)*

WB (Wooden Breast)

Spaghetti Meat (**SM**), scored on individual broilers using 5-levels gradual scale: **0** / **0.5** / **1** / **1.5** / **2** *(from none to severe)* and plotted by body weight, breast weight, and breast yield *(% of body weight)* of females and of males

Bivariate Fit of Spaghetti By Live BW Sex=Fem. | Bivariate Fit of Spaghetti By Breast wt. Sex=Fem. | Bivariate Fit of Spaghetti By % Breast Sex=Fem.



Bivariate Normal Ellipse P=0.950

Bivariate Normal Ellipse P=0.950

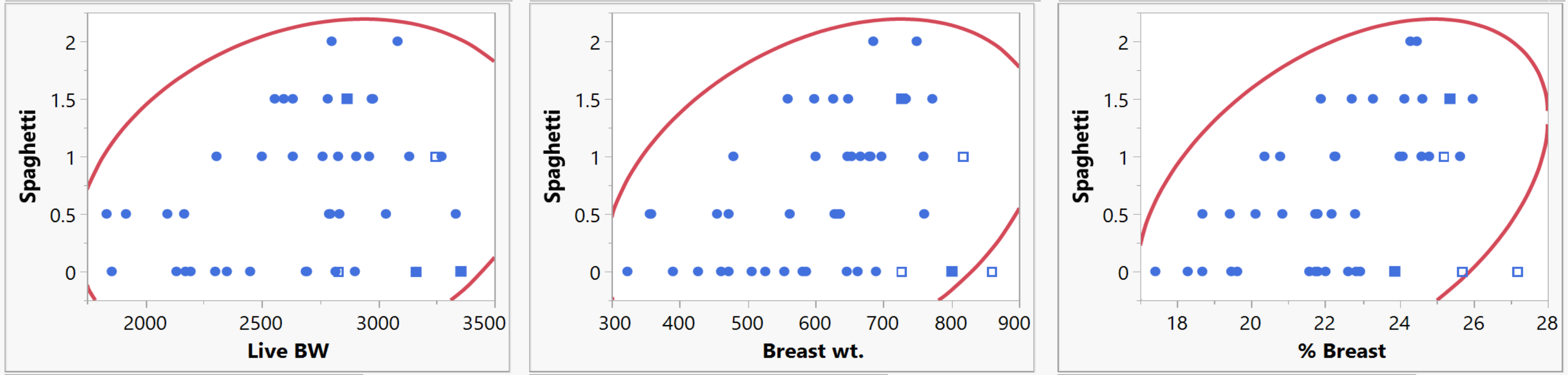
Variable	Mean	Correlation	Signif. Prob	Number
Live BW	2221.43	0.378	0.0176*	39
Spaghetti	0.974359			

Variable	Mean	Correlation	Signif. Prob	Number
Breast wt.	495.2308	0.522	0.0007*	39
Spaghetti	0.974359			

Variable	Mean	Correlation	Signif. Prob	Number
% Breast	22.1408	0.607	<.0001*	39
Spaghetti	0.974359			

Fit Group Sex=Male

Bivariate Fit of Spaghetti By Live BW Sex=Male | Bivariate Fit of Spaghetti By Breast wt. Sex=Male | Bivariate Fit of Spaghetti By % Breast Sex=Male



Bivariate Normal Ellipse P=0.950

Bivariate Normal Ellipse P=0.950

Variable	Mean	Correlation	Signif. Prob	Number
Live BW	2692.534	0.249	0.1034	44
Spaghetti	0.659091			

Variable	Mean	Correlation	Signif. Prob	Number
Breast wt.	610.0682	0.362	0.0157*	44
Spaghetti	0.659091			

Variable	Mean	Correlation	Signif. Prob	Number
% Breast	22.46497	0.443	0.0026*	44
Spaghetti	0.659091			

SM in Females

The a-symmetrical association with body weight and breast yield (in females and males) suggest the feasibility of breeding for improved performance combined with lower incidence and severity of **SM** *(also as done previously with lower fatness and less ascites)*

SM in Males

The genetic basis of pectoralis major myopathies in modern broiler chicken lines

Richard A. Bailey,*,[1] Kellie A. Watson,* S. F. Bilgili,† and Santiago Avendano*

*Aviagen Ltd., Newbridge, Midlothian EH28 8SZ, UK; and †Department of Poultry Science, Auburn University, Auburn, AL 36849-5416

2015 Poultry Science 94:2870–2879
http://dx.doi.org/10.3382/ps/pev304

line A is a high-yielding chicken and line B is a moderate-yielding bird. The phenotypic data spans six generations collected over four years from 219 flocks

Trait	Line A Mean	Line A SD	Line B Mean	Line B SD
Body weight*kg (BW)	2.33	0.29	1.91	0.23
Processing body weight† (kg) (PW)	2.47	0.30	2.39	0.29
% Breast yield (BY)	29.4	2.09	21.66	1.49
% Deep pectoral myopathy (DPM)	6.96	1.66	0.41	0.03
% Wooden breast (WB)	3.19	0.54	0.16	0.01
% White striping (WS)	49.6	8.68	14.46	3.08

*42 d of age Line A, 32 d of age Line B.
†47 d of age Line A, 40 d of age Line B.

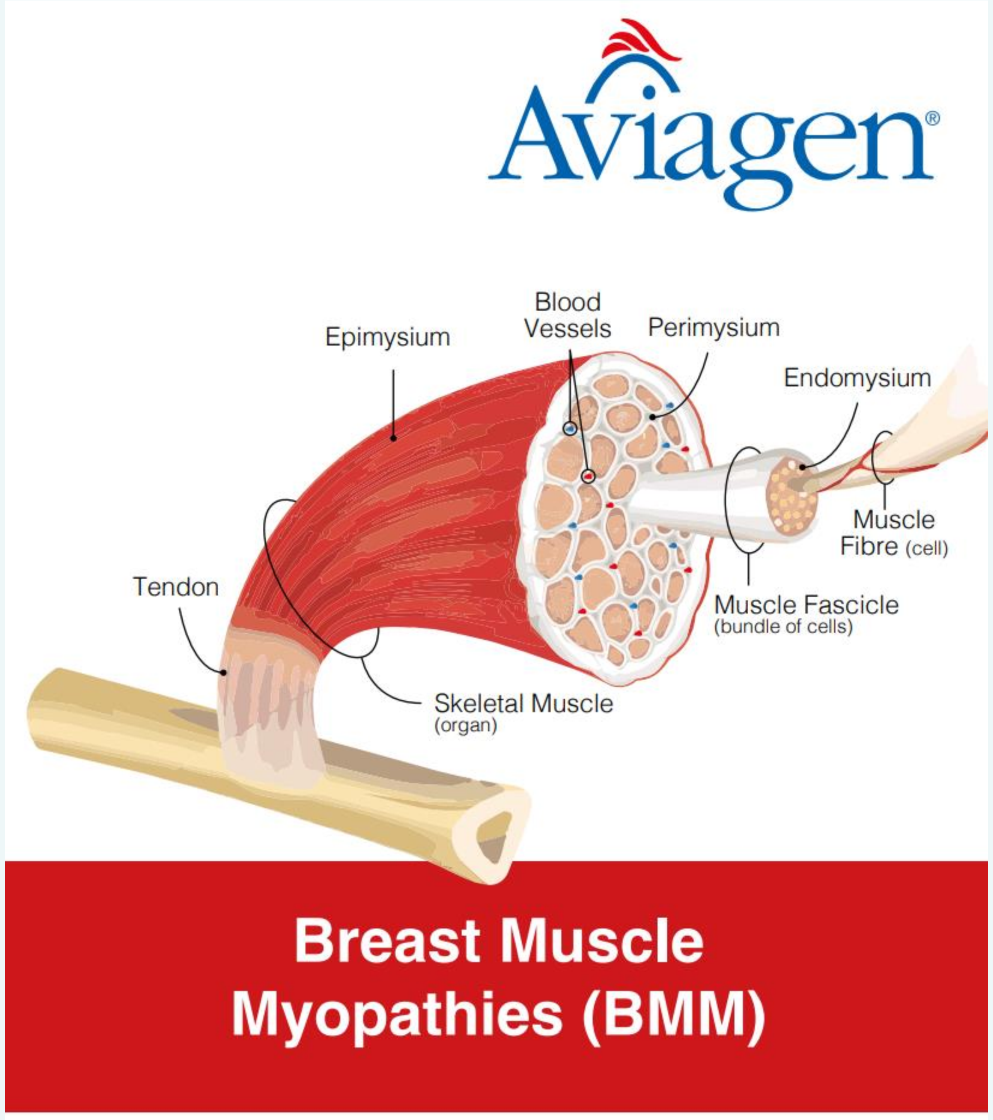
The very low heritabilities of WB are **not** indicative - the WB incidence in the reported lines was very low

The differences between lines A and B in the incidence of myopathies indicate substantial genetic background

Table 4. Estimates of heritabilities (bold, diagonal), genetic correlations (above diagonal) and phenotypic correlations (below diagonal) for body weight (BW), processing weight (PW), breast yield (BY), deep pectoral myopathy (DPM), wooden breast (WB) and white striping (WS). Standard errors are displayed in parentheses.

BW	PW	BY	DPM	WB	WS
Line A					
0.413 (0.011)	0.983 (0.002)	−0.099 (0.037)	0.132 (0.059)	−0.027 (0.055)	0.076 (0.038)
0.911	**0.360** (0.012)	−0.076 (0.039)	0.117 (0.060)	−0.051 (0.056)	0.057 (0.039)
0.028	0.041	**0.323** (0.020)	0.092 (0.067)	0.002 (0.064)	0.033 (0.008)
0.001	−0.001	−0.023	**0.059** (0.007)	0.120 (0.081)	−0.070 (0.067)
0.048	0.045	0.026	0.020	**0.097** (0.010)	0.208 (0.060)
0.116	0.111	0.080	−0.013	0.054	**0.338** (0.020)
Line B					
0.355 (0.010)	0.971 (0.003)	0.066 (0.030)	0.037 (0.070)	0.160 (0.072)	0.228 (0.037)
0.836	**0.271** (0.010)	0.080 (0.032)	−0.007 (0.071)	0.171 (0.073)	0.222 (0.039)
0.216	0.254	**0.418** (0.018)	0.190 (0.069)	0.141 (0.072)	0.248 (0.041)
0.011	−0.007	0.011	**0.021** (0.003)	0.060 (0.016)	0.180 (0.079)
0.020	0.016	0.020	−0.002	**0.024** (0.004)	0.350 (0.074)
0.148	0.156	0.022	0.025	0.038	**0.185** (0.012)

This paper demonstrates the polygenic nature of these traits and the low genetic relationships with BW, PW, and BY, which facilitates genetic improvement across all traits in a balanced breeding _

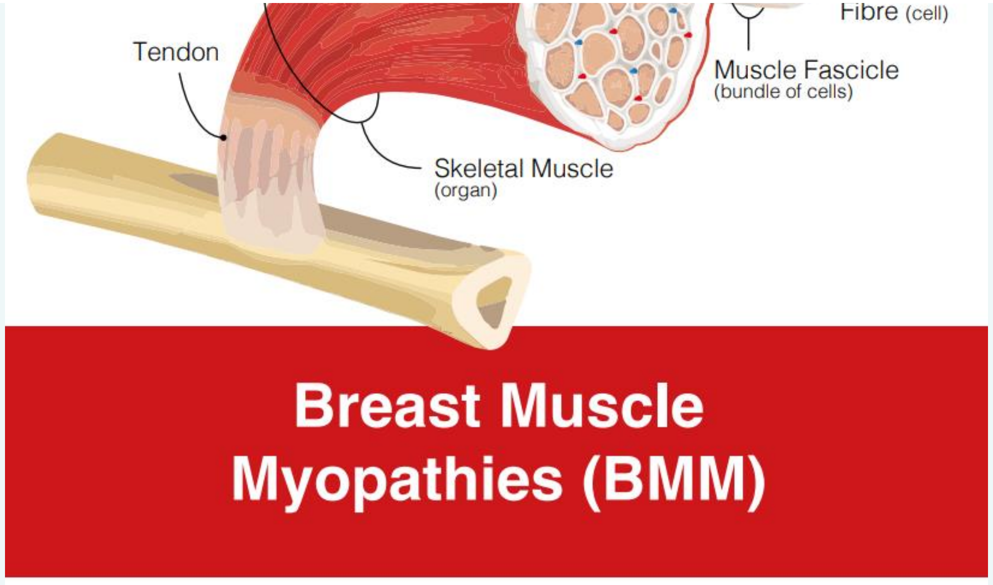


Document on BMM, published by Aviagen in 2019

While DPM has been part of Aviagen's breeding goal for many years, WS, WB and SS were added to the breeding goal in 2012 with the objective to reduce the genetic propensity to express these conditions in the field.

Aviagen selects against the genetic propensity to breast myopathies within a balanced breeding goal which also includes other traits related to biological efficiency, yield, robustness, welfare and reproductive fitness. Given the low genetic basis of breast myopathies (Bailey et al. 2015) and the time it takes for changes at pedigree level to reach broiler level, it is expected that the genetic propensity to exhibit these myopathies should have started to reduce in 2018. It should be noted that it is unlikely that the incidence of breast myopathies will reach zero solely due to genetic selection as non-genetic factors also affect the incidence of myopathies

(paragraph on Genetics and Breeding)



Document on BMM, published by Aviagen in 2019

frontiers in Physiology

ORIGINAL RESEARCH
published: 20 August 2020
doi: 10.3389/fphys.2020.01041

Characterising the Influence of Genetics on Breast Muscle Myopathies in Broiler Chickens

Richard A. Bailey[1], Eduardo Souza[2] and Santiago Avendano[1]*

[1] Aviagen, Newbridge, United Kingdom, [2] Aviagen, Huntsville, AL, United States

The phenotypic data spans four generations collected over 3 years from 105 flocks, with the inclusion of an extra generation of pedigree relationships for the estimation of the genetic parameters. Within this study the key phenotypic traits of interest were broiler body weight (BW), breast meat yield (BY), deep pectoral myopathy (DPM), WB, SB and WS (**Table 1**).

Trait	Mean
Body weight Kg (BW)	3.03
% Breast Yield (BY)[1]	28.9
Deep pectoral myopathy (DPM)[2]	0.15
Wooden breast (WB)[2]	0.19
Spaghetti breast (SB)[2]	0.04
White striping (WS)[2]	0.30

TABLE 5 | Genetic parameter results for study 1.

BW	BY	DPM	WB	SB	WS
0.31 **(0.03)**	−0.06 (0.02)	0.14 (0.03)	0.20 (0.04)	−0.06 (0.03)	0.23 (0.04)
0.15	**0.40** **(0.02)**	0.23 (0.02)	0.41 (0.03)	0.36 (0.02)	0.31 (0.01)
0.03	0.02	**0.06** **(0.02)**	0.46 (0.02)	0.04 (0.03)	0.34 (0.03)
0.08	0.13	0.10	**0.07** **(0.04)**	−0.04 (0.02)	0.74 (0.04)
0.02	0.17	0.03	−0.02	**0.04** **(0.02)**	0.02 (0.01)
0.23	0.22	0.12	0.25	0.05	**0.25** **(0.02)**

Estimates of heritabilities (bold, diagonal), genetic correlations (above diagonal), and phenotypic correlations (below diagonal) for body weight (BW), breast yield (BY), deep pectoral myopathy (DPM), wooden breast (WB), spaghetti breast (SB) and white striping (WS). Standard errors are displayed in parentheses.

As part of Aviagen's ongoing strategy to reduce the genetic propensity for the expression of BMM every selection candidate of all lines is assessed and scored on farm for WB through palpation, while their siblings are assessed and scored for the presence of all BMM through carcase evaluation following processing. This data is then used to select against individuals with a higher propensity for the BMM.

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ORIGINAL RESEARCH
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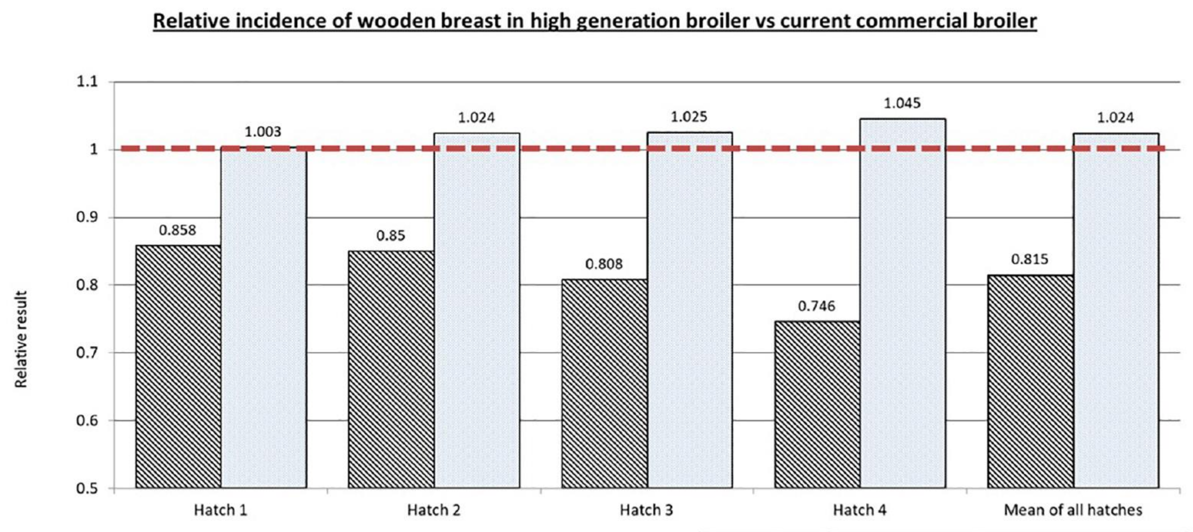
Characterising the Influence of Genetics on Breast Muscle Myopathies in Broiler Chickens

Richard A. Bailey[1], Eduardo Souza[2] and Santiago Avendano[1]*

[1] Aviagen, Newbridge, United Kingdom, [2] Aviagen, Huntsville, AL, United States



	Mean Incidence of WB		Mean Breast Yield	
Hatch	Com. 708	HG 708	Com. 708	HG 708
1	16.3%	14.0%	33.0%	33.1%
2	20.5%	17.4%	33.1%	33.9%
3	17.8%	14.4%	31.5%	32.3%
4	17.5%	13.1%	31.4%	32.8%

FIGURE 5 | Relative results for wooden breast incidence (scores 1, 2 and 3) and breast yield of the high generation broiler compared to the current commercial broiler in study 2. Mean WB incidence and BY values are also given for all groups. An overall decrease in total wooden breast incidence can be seen as a result of genetic selection whilst simultaneously improvements in breast yield can be achieved.

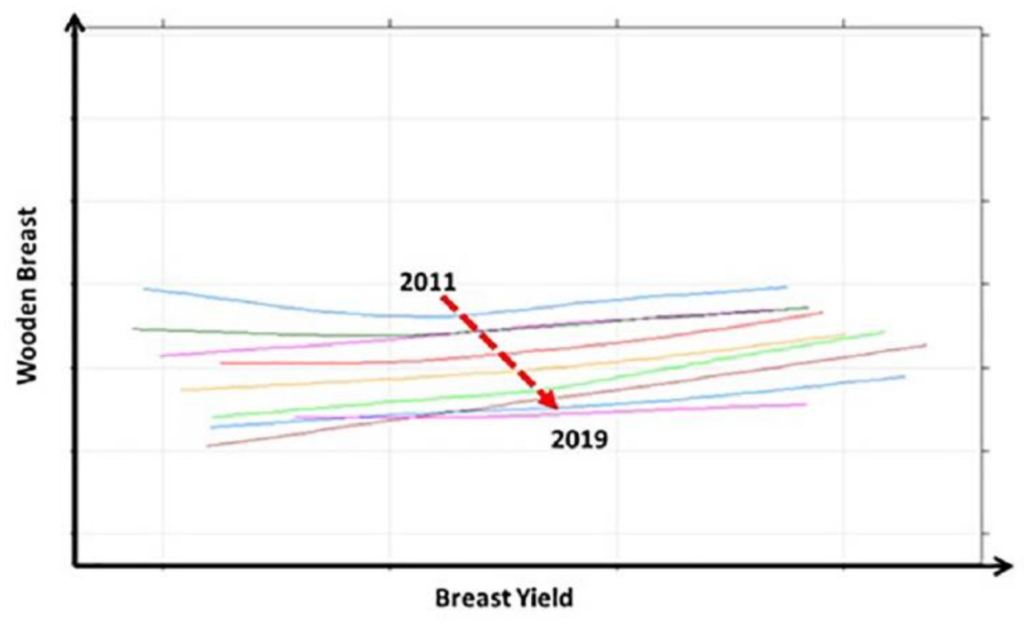
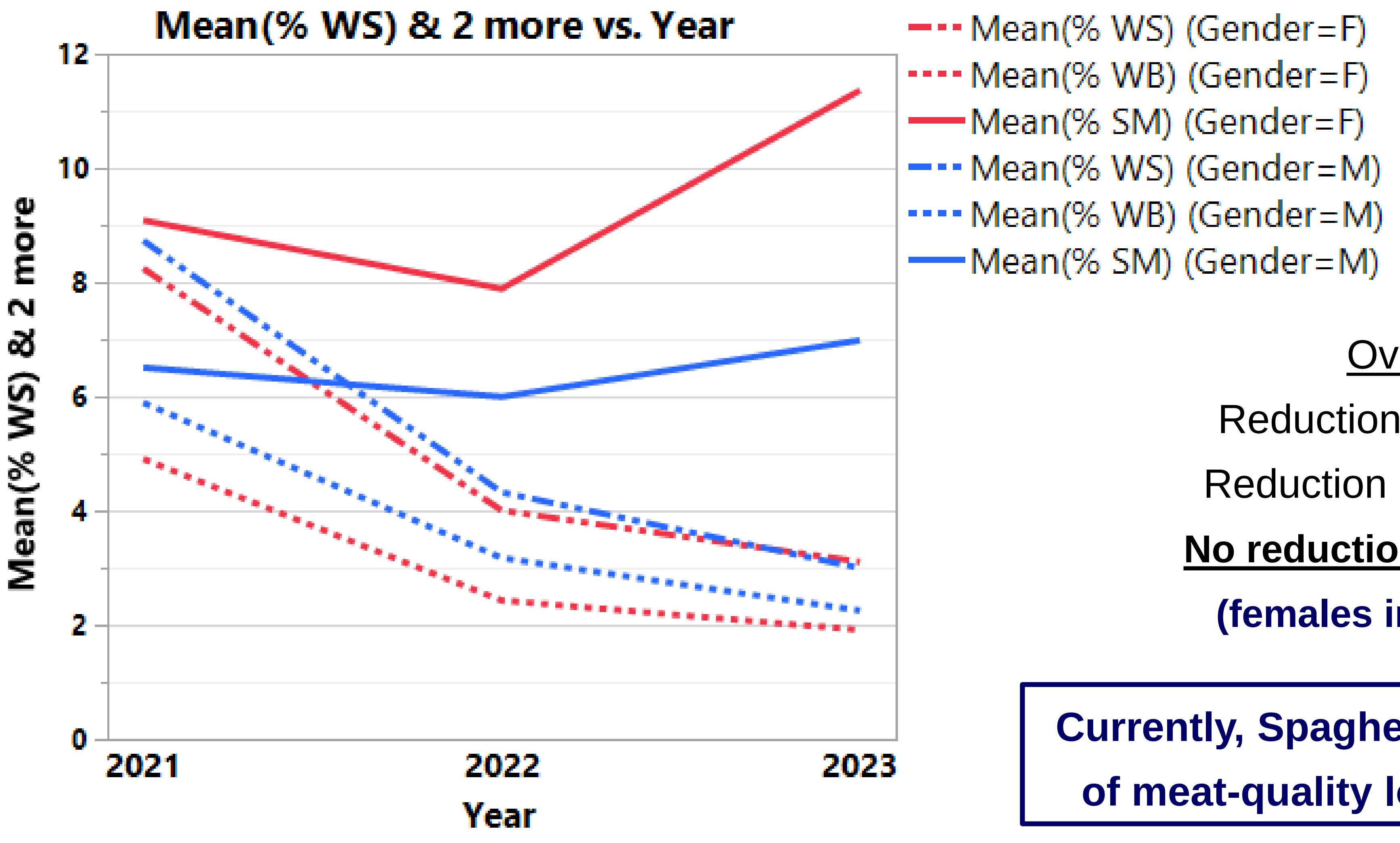


FIGURE 6 | The long term relationship between breast yield (%) and wooden breast (%) for the years 2011 to 2019 is displayed in this graph. The different coloured lines each represent the year long relationship between breeding values for each trait for each year. The broken arrow shows the movement of the mean breeding value for each trait from 2011 to 2019. It shows that there has been a yearly decrease in the mean breeding value for wooden breast whilst the mean breeding value for breast yield has increased.

Incidences of 3 breast muscles myopathies in 2021, 2022, and 2023

Data from a slaughterhouse in Italy; about 1000 flocks/year from each gender



<u>Over the last 3 years</u>:

Reduction in % White Striping (**WS**)

Reduction in % Wooden Breast (**WB**)

<u>No reduction in % Spaghetti Meat (SM)</u>

(females in 2023 – increase in SM?)

Currently, Spaghetti Meat is the main cause of meat-quality losses, <u>mainly in females</u>

Strategies and opportunities to control breast myopathies: An opinion paper

Frontiers in Physiology

Richard A. Bailey*

Aviagen Ltd, Newbridge, United Kingdom

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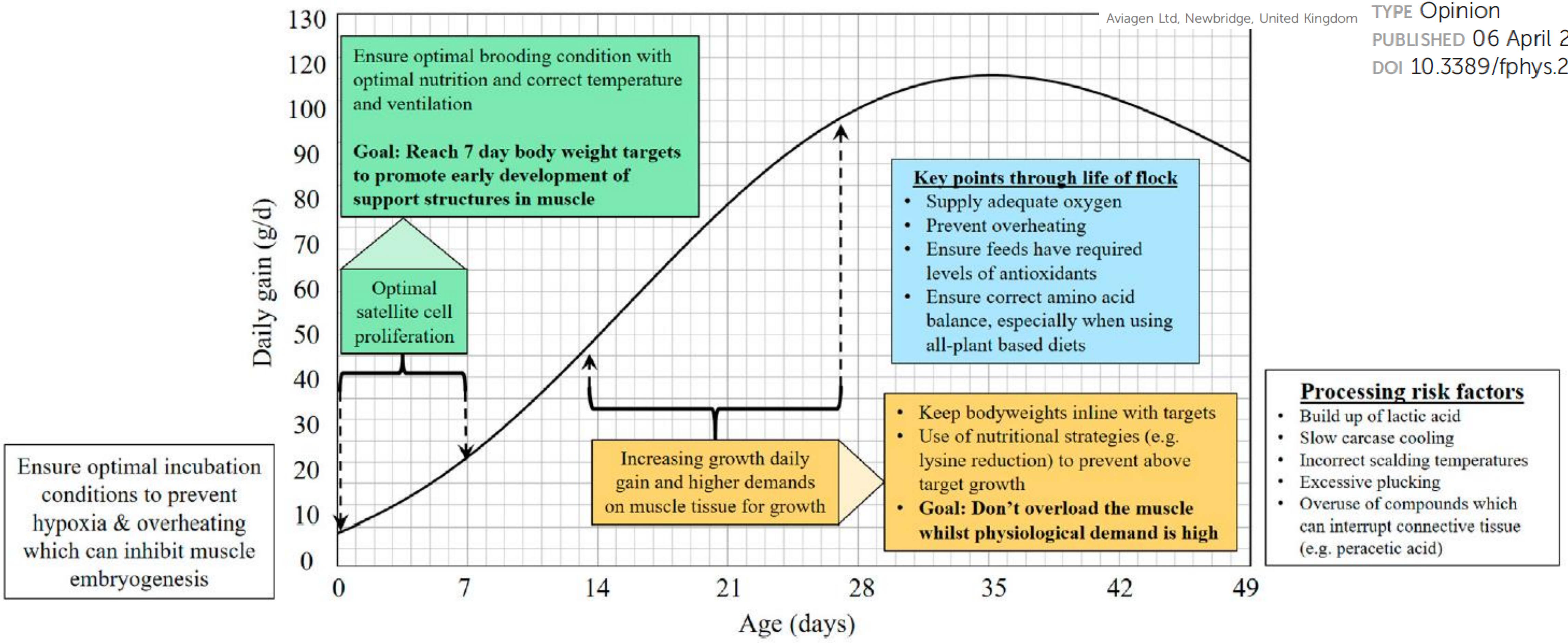


FIGURE 1
Graph proposing critical stages of broiler lifecycle where management may be critical for reducing myopathies.

Defeathering (**plucking**) machines in modern slaughter houses

The vigor of defeathering can vary due to <u>number of machines</u>, position and number and speed of the fingers, and their hardness (indicated by different colors).

<u>Processing risk factors</u>

- Build up of lactic acid
- Slow carcase cooling
- Incorrect scalding temperatures
- Excessive plucking
- Overuse of compounds which can interrupt connective tissue (e.g. peracetic acid)

Each defeathering machine has many of rubber ‘fingers’ mounted on disks arranged in multiple rows. The rapidly rotating fingers remove the feathers by <u>repeatedly beating the shackled broilers</u> (post scalding).

Photos courtesy Koen De Reu

Defeathering in modern slaughter houses (after hot-water scalding)




Carcasses are fully defeathered already after 2-3 machines... Are they doing <u>too much defeathering</u>?

7 defeathering machines, in another slaughter house (<u>high incidence of SM</u>)

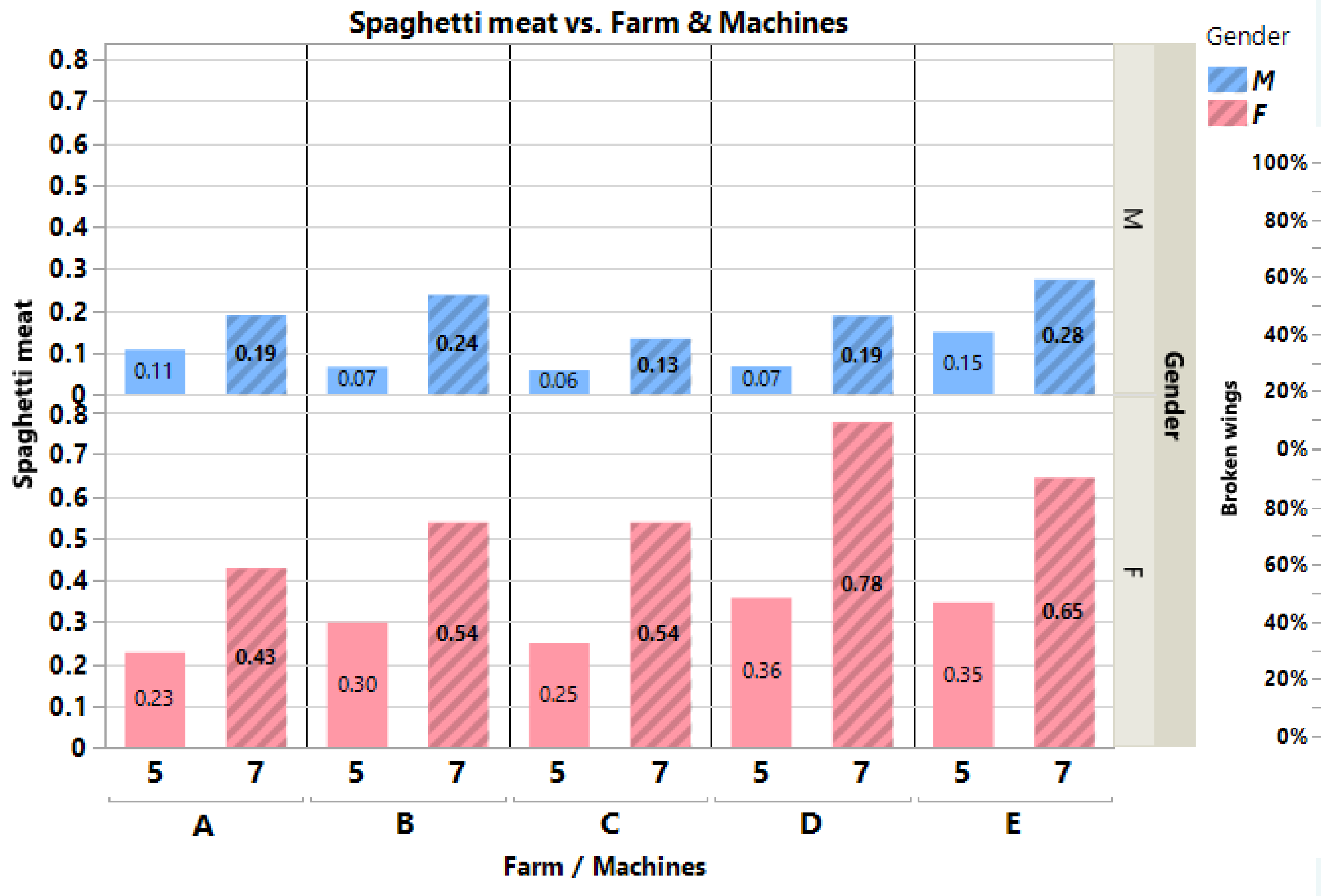
7 6 5 4 3 2 1

Comparing 2 levels of defeathering intensity in <u>Israel</u> *(without hot-water scalding)*

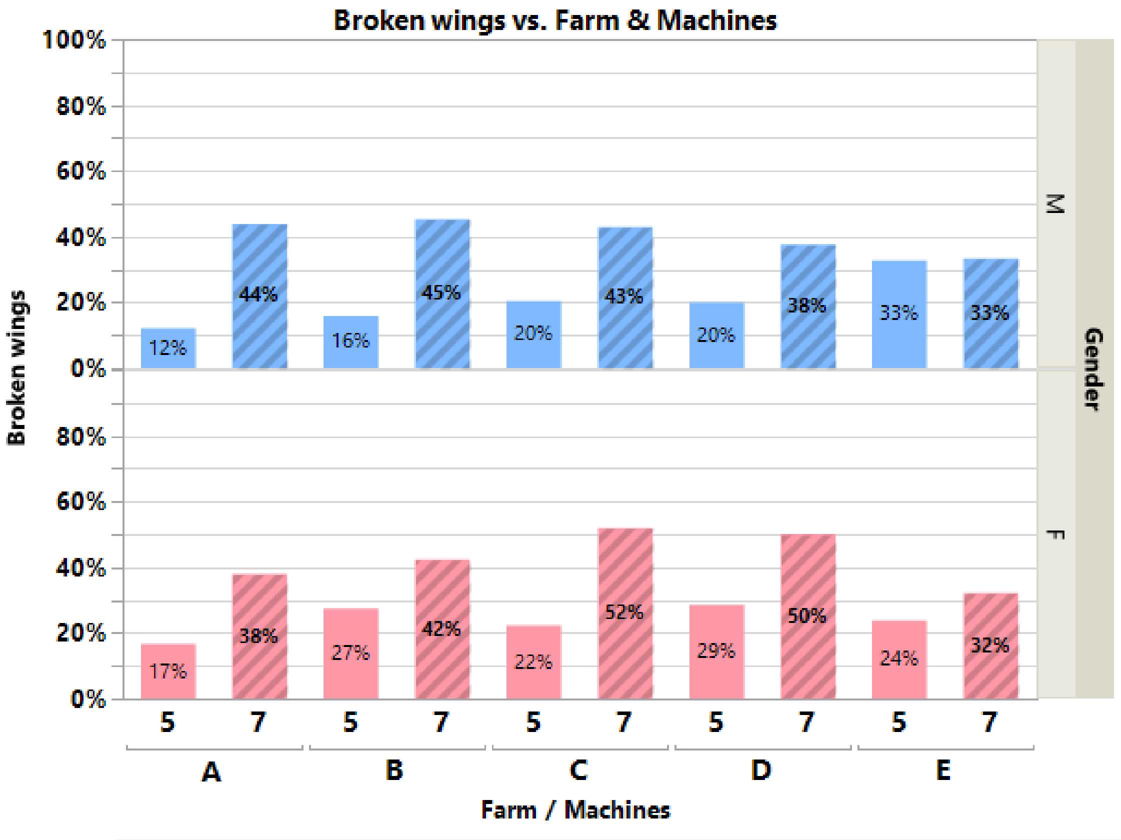
5 farms, total of 300 broilers (150/gender) defeathered by either **5 machines** or **7 machines**

Spaghetti Meat was scored on individual broilers using 5-levels gradual scale: **0** / **0.25** / **0.50** / **0.75** / **1** *(from none to severe)*

Group's **SM score**: averaging the individual scores; approximates the group's percentage of SM-related losses of breast meat



The percentage of broken wings



Conclusions

Similar to the genetic mitigation of previous growth-related defects (excessive fatness, TD, ascites), **breast muscle myopathies** are also a-symmetrically associated with rapid growth, hence they were expected to be genetically mitigated, once 'susceptible' individuals (or families) are identified and culled.

White Striping (WS) and **Wooden Breast** (WB) were integrated into balanced broiler breeding programs in the early 2010's, and by now their prevalence and negative economic impacts are been significantly mitigated.

Spaghetti Meat (SM), due to its later emergence, and due to the difficulty to identify 'Low-SM' individuals or families, has not been mitigated yet, but genetic mitigation can be expected within several years.

Meanwhile, the incidence and severity of Spaghetti Meat can be substantially reduced by less aggressive defeathering, (mainly of females above 2 kg). **And more aggressive defeathering can help the identification of 'Low-SM' families**.

In summary: the observed (and expected) genetic reductions in incidence of breast muscle myopathies, indicate that the breeding of fast-growing high-yielding broilers has not reached yet a biological limit.

Thank you!

Contact:
avigdor.cahaner@mail.huji.ac.il