Stiftung Tierärztliche Hochschule Hannover
University of Veterinary Medicine Hannover, Foundation

Specific properties of rye –

potentials and benefits in swine feeding/pork production

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KWS – Pig Feeding Seminar, Winnipeg, 17th July 2019

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Bundesministerium für Ernährung und Landwirtschaft
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Contents

- **Recent challenges in pork production**

- **Rye: characterization (literature)**

- **Rye: own experimental studies (start 2017)**
    - **liquid diets (non-fermented vs. fermented)**
    - **physicochemical properties (grinding/soaking)**
    - **nutritive value (in reared/young pigs)**
    - **prececal digestibility/intestinal fermentation**

- **Planned experimental studies (Salmonella/E. coli)**
    - **artificial infections in young reared pigs**

- **Perspectives for rye ("boar taint"/behavior)**

- **Conclusions (based on published/own results)**

Recent challenges in crop production in Germany

Reducing the amounts
of fertilizers (N/P) and herbicides
→ ground water quality

Climatic changes
regarding periods with higher temperatures and/or lack of rainfall

RYE?

CORN?

Suitability of/ competition between different crop species

WHEAT?

BARLEY?

Monocultures
in grain production
- missing diversity
- favoring plant diseases

Contaminations
of cereals by mycotoxins
- Fusarium toxins
- Ergot contamination?

Kamphues et al. 2017

Recent challenges in pork production in Germany

Minimizing the use of antimicrobials!
- ban of growth promoters
- restrictions in therapy

↔

Food safety (zoonoses → Salmonella) and contamination by drug resistant bacteria

↕

Recent challenges in pork production

↕

Environmental pollution
- dietary nutrient surplus (nitrogen, phosphorus)
- emissions in general (air/dust etc.)

↔

Animal welfare
- ban of castration/tail clipping etc.
- abnormal behavior/ cannibalism/tail biting

Kamphues et al. 2017

Goals, intentions of the funding program, in which the „6-R-project“ was considered

(start of funding: 1st of June 2018)

Adaptation on climate change

- efficient use of water plants of high dry tolerance

Reduction of greenhouse gases

- farm own feeds instead of imported ones („region“)

BLE funding program for research activities

Sustainability in food production

- protection of ground water, reduced use of fertilizers, herbizids

Lowering emissions of animal production

- nitrogen, phosphorus and further substances

Participants/focus of the project partners in research activities focused on rye for swine feeding

Animal Nutrition, Hanover

- Project coordination (scientific institutes, economics, pig owners)
- Studies on the **nutritive value**
- **Compound feed optimization** (based on rye and rapeseed or their by-products)
- Determination of **precaecal digestibility**
- **In vitro fermentation experiments**
- **Infection experiments** (Salmonella, E. coli)
- Effects on the behavior of pregnant sows

KWS Lochow

- Securing the "identity" of the hybrid rye
- Creating/organizing integrative relationships for "field trials" (rye cultivation and use)
- Determination of **feed value** (nutrients)
    - **Cereal's safety** (mycotoxin contamination)
- **Economic evaluation** of rye cultivation
- **Evaluation of data from the fattening trials** (field trials and MPA)

Animal Nutrition, Bonn

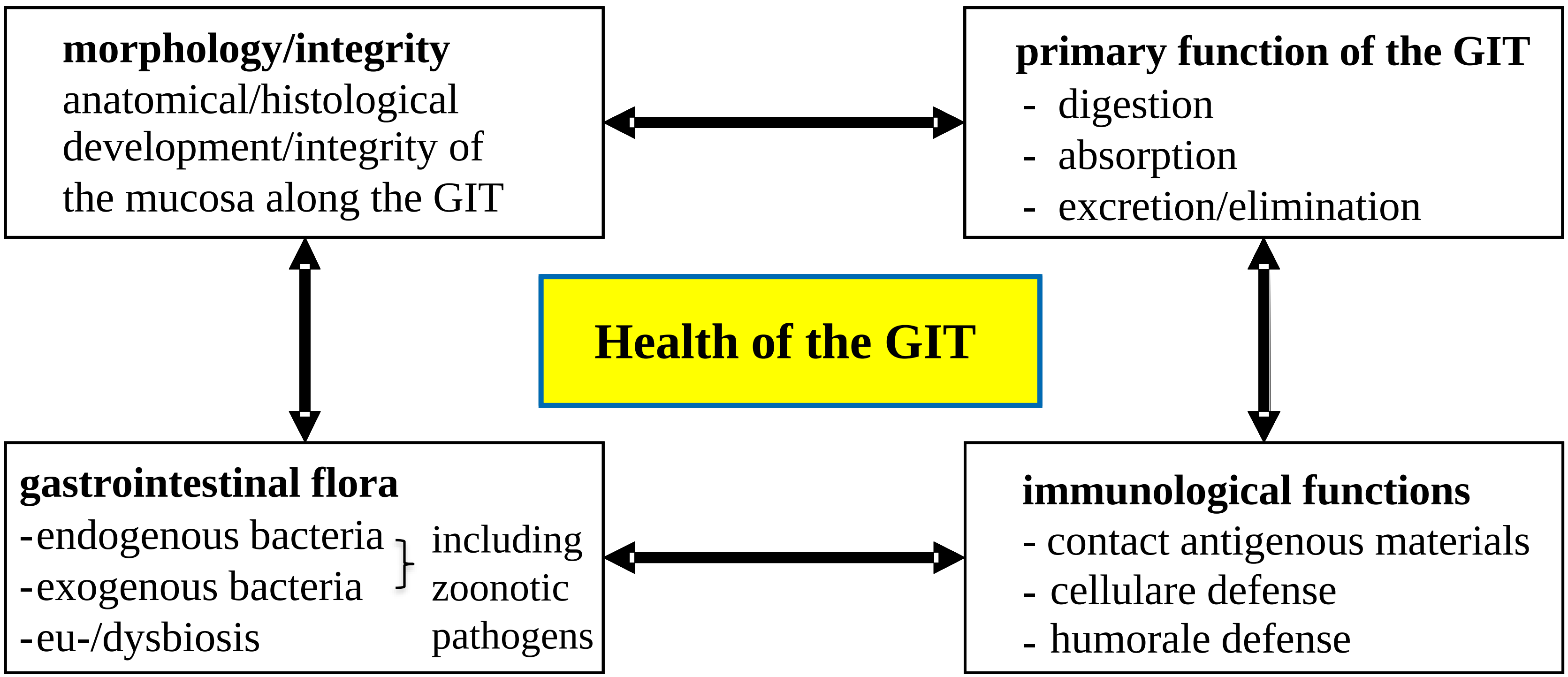
- **Characterization of fiber fractions** in
    - **feed samples**
    - **digesta and faeces samples**
    - **substrate** before/after **fermentation**
- **Determining the metabolizable energy**
- **Determination of P digestibility** (with/without added phytase) from rye and rye-derived products and 6-R compound feeds

Animal Nutrition, Berlin

- Effects in the 6-R concept regarding
    - **intestinal health** (intestinal wall, inflammatory reactions)
    - **Composition of the gastrointestinal microbiome**
    - the **immune system** (local/systemic)

Testing samples from "**institute experiments**" as well as from "**field trials**"

What does it mean: GIT Health/Gut Health?



Kamphues 2011

Rye: Characterization from the traditional point of view of feed science/of animal nutrition

RYE:

- **The cereal of poor/dry/sandy soils**
- **Like wheat "nude cereal" with low levels of fiber (and gluten)**
- **In comparison to wheat: markedly lower protein content**
- **Lower prececal digestibility of protein/amino acids**
- **Welcome: highest phytase activity (rye bran!!)**
- **Inferior palatability compared to wheat (?)**
- **Cereal most prone to ergot contamination**

Rye – from the nutritional point of view

→ values from the recent table on feed composition (DLG 2014) (all values per 1 kg of dry matter)

	ME, MJ	XP, g	pcd XP, %	Lys, g	pcd Lys, %	pcd Lys, g	BFS[1], g
wheat	15.5 (100)	140	90	3.9	88	3.43 (100)	138 (100)
barley	14.3 (92.3)	120	73	4.2	73	3.07 (89.5)	201 (146)
rye	15.1 (97.4)	105	78	4.0	80	3.20 (93.3)	157 (114)

[1] BFS = Bacterially fermentable substances = NfE – (starch + sugar) + crude fiber

The amino acid patterns of rye in comparison to wheat and barley (av. values; RODEHUTSCORD et al. 2016)

→ newest values from the GRAIN UP project

	rye	wheat g/100 g protein	barley
Lys	3.59 (100)	2.72 (75.8)	3.49 (97.2)
Met	1.52	1.47	1.57
Cys	2.10	2.21	2.09
Thr	3.23	2.86	3.39
Trp	1.02	1.15	1.23
pcd of Lys, (%)[1)]	80	88	73

[1)] DLG 2014; pc = prececal; d = digestibility rate

Experimental studies at the Institute for Animal Nutrition, Hanover → focused on the use of rye in feeding of pigs

Author	Focus of the studies
BUNTE 2018	Rye-rapeseed based liquid diets (with/without fermentation)
GRONE 2018	Rye: physicochemical properties/grinding-soaking
WILKE 2019	Rye: substituting wheat (dry pelleted diets) ; RYE: up to 69 % Rapeseed: Substituting soybean in diets based on RYE (60 %)
HARTUNG 2019	Prececal digestibility of wheat- vs. rye based diets In vitro fermentation of rye based diets (→ production of vfa)
N.N. 2020	Experimental infections (Salmonella/E. coli) in young pigs fed wheat- vs. rye based diets
N.N. 2021	Rye in pregnant sows (satiety/behaviour …)

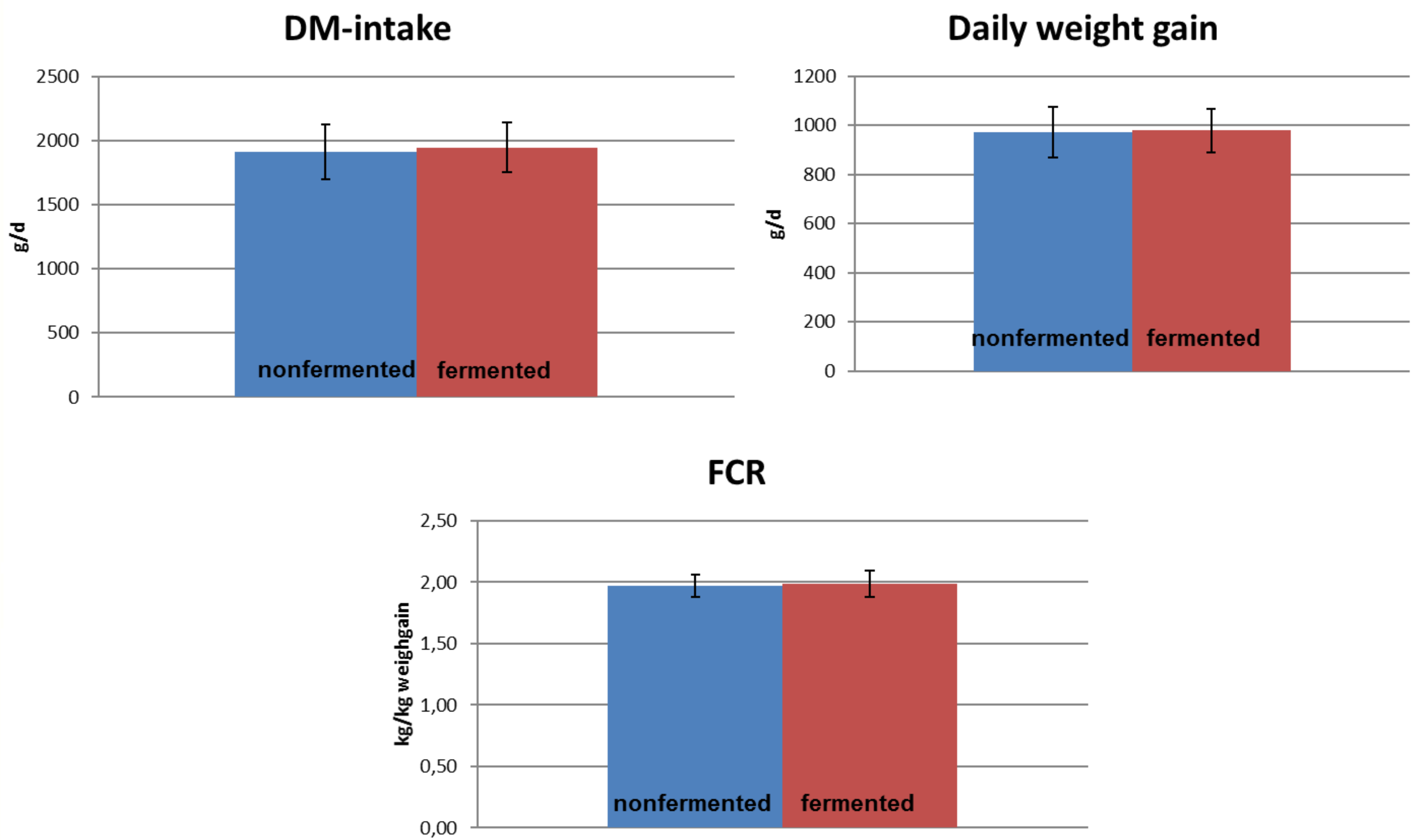
The rye-rapeseed based liquid diet fed with or without fermentation (BUNTE 2018)

- **Completely fermented**
  - **Rye 48.2 %**
  - **Rapeseed meal 29.4 %**
  - Wheat 9.84 %
  - Barley 9.80 %
- **Added after fermentation**
  - Mineral supplement
    - 2.75 %
    - **without Phytase (!)**

	Control diet	Fermented diet
DM-content (g/kg FM)	213	213
Crude protein (g/kg DM)	199	201
Starch (g/kg DM)	422	425
Sugar (g/kg DM)	**71.2**	**18.4**
Calcium (g/kg DM)	6.69	6.70
Phosphorus (g/kg DM)	6.51	6.64
L-Lactic acid (g/kg DM)	**0.103**	**26.2**
D-Lactic acid (g/kg DM)	**0.052**	**27.5**
Acetic acid (g/kg DM)	0.720	8.28
Butyric acid (mg/kg DM)	11.8	13.2
pH-level	5.95	3.67
Lactic acid producers ($\log_{10}$ cfu/g)	**4.91**	**9.31**

- **Starter culture (Schaumalac Feed Protect XP G)**
  - *Lactobacillus plantarum*, *Pediococcus pentosaceus*, *Lactococcus lactis*
  - 500 g per ton DM ≙ 2.0 x 10^5 cfu/g liquid feed
    → after 24 h: **10^9 cfu/g** fermentate

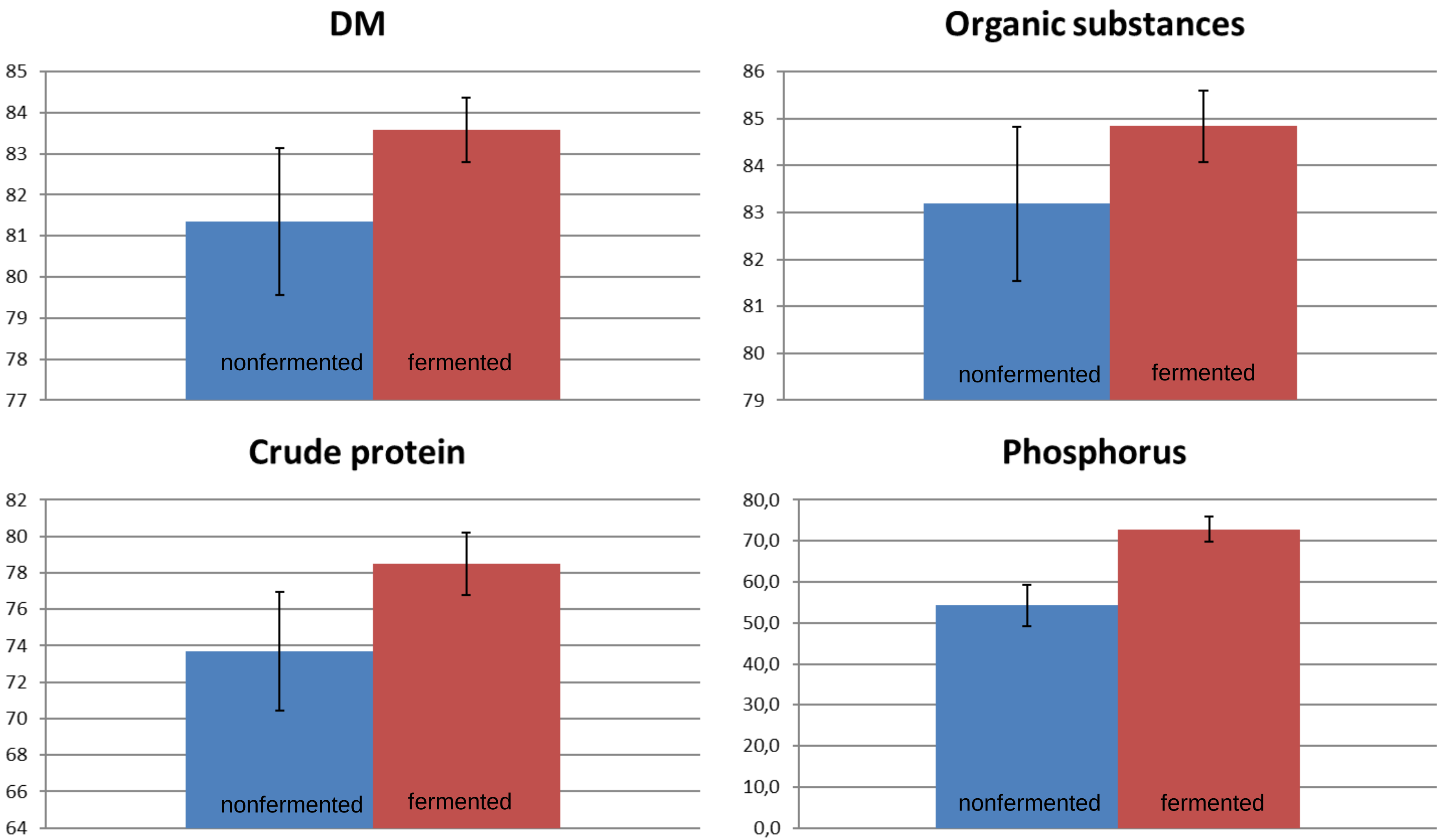
Performance of young fattening pigs fed liquid diets based on rye and rapeseed (with/without fermentation)
BUNTE 2018



Digestibility of liquid diets based on rye and rapeseed in young fattening pigs

Apparent total tract digestibility (%)

BUNTE 2018



High P digestibility in pigs fed rye based, fermented liquid diets – without a phytase additive!

How does it work?

- In cereals and seeds like soybean and rapeseed: P up to 70 % Phytate-P
- Phytate degradation[1)] by phytases (from rye/from the lactic acid producing bacteria) during fermentation of the liquid diet before feeding

	Total-P (g/kg DM)	IP 6 (g/kg DM)	IP 6-P (g/kg DM)	IP 4-P (g/kg DM)	IP 3-P (g/kg DM)
Before fermentation (n = 5)	**5.44 ± 0.164**	**7.34 ± 1.51**	**2.04 ± 0.404**	**< Bg[2)]**	**< Bg**
After 24-h fermentation					
- without starter culture (n = 3)	**5.80 ± 0.100**	**< Bg**	**< Bg**	**< Bg**	**0.201 ± 0.088**
- with starter culture (n = 5)	**5.52 ± 0.084**	**< Bg**	**< Bg**	**< Bg**	**< Bg**

[1)] analyses done by SCHOLLENBERGER and RODEHUTSCORD 2018
[2)] Bg: limit of quantifiable detection (IP < 0.6 g/kg DM)

BUNTE et al. 2019

Rye: Properties regarding the effects of grinding – rye compared to wheat and barley

(GRONE 2018)

Identical conditions of the grinding process in the hammer mill, sieve 3 mm, three different varieties of each crop species

Dry Sieving Results

mass, %	rye	wheat	barley
> 1.0 mm	42.1 ± 3.26	31.3 ± 1.77	40.3 ± 6.61
< 1 – > 0.2 mm	42.4 ± 3.05	50.6 ± 0.69	49.6 ± 4.01
< 0.2 mm	15.5 ± 0.579	18.0 ± 1.08	10.2 ± 2.83

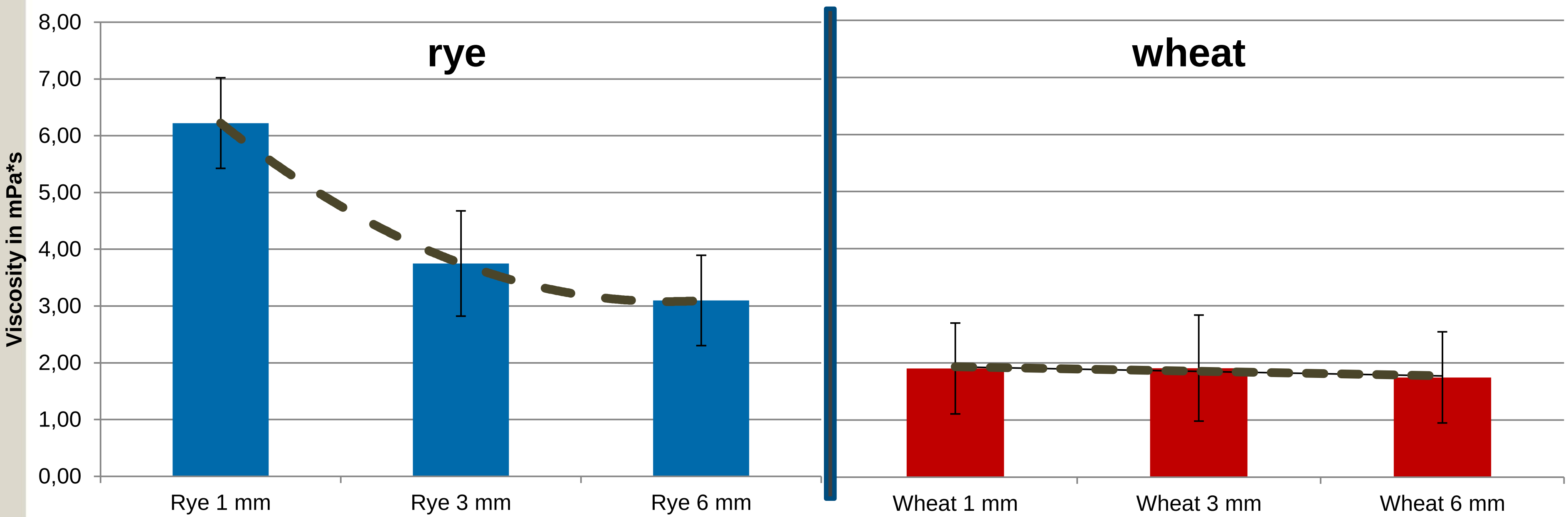
Wet Sieving Results

mass, %	rye	wheat	barley
> 1.0 mm	45.9 ± 3.33	45.8 ± 3.92	52.5 ± 3.44
< 1 – > 0.2 mm	18.5 ± 1.85	22.9 ± 2.51	26.5 ± 2.06
< 0.2 mm	35.6 ± 1.67	31.1 ± 2.02	20.9 ± 1.71

Rye: Viscosity of the supernatant after soaking depending on crop species and grinding intensity
(GRONE 2018)

	grinding intensity		
	1 mm	**3 mm**	**6 mm**
rye values, mPa*s	**6.22** ± 0.797	**3.75** ± 0.928	**3.10** ± 0.797
wheat values, mPa*s	**1.90** ± 0.881	**1.91** ± 0.871	**1.75** ± 0.453

Methods:
- 5 g sample + 20 ml H_2O
- incubation time 30 min (38° C)
- centrifugation (10000 g)
- measurement with Brookfield Viscometer DV-II



Extract viscosity of ground rye samples

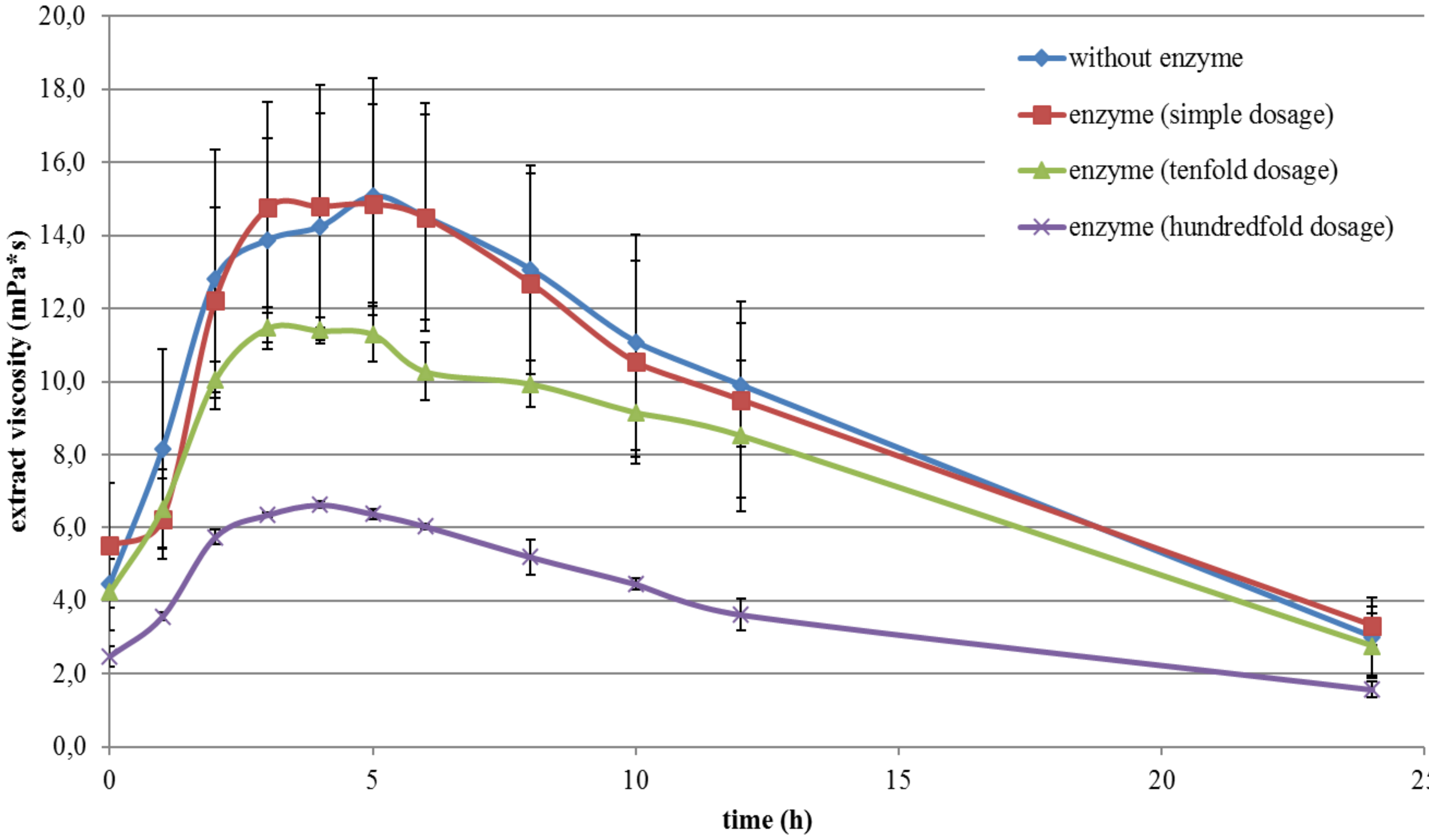
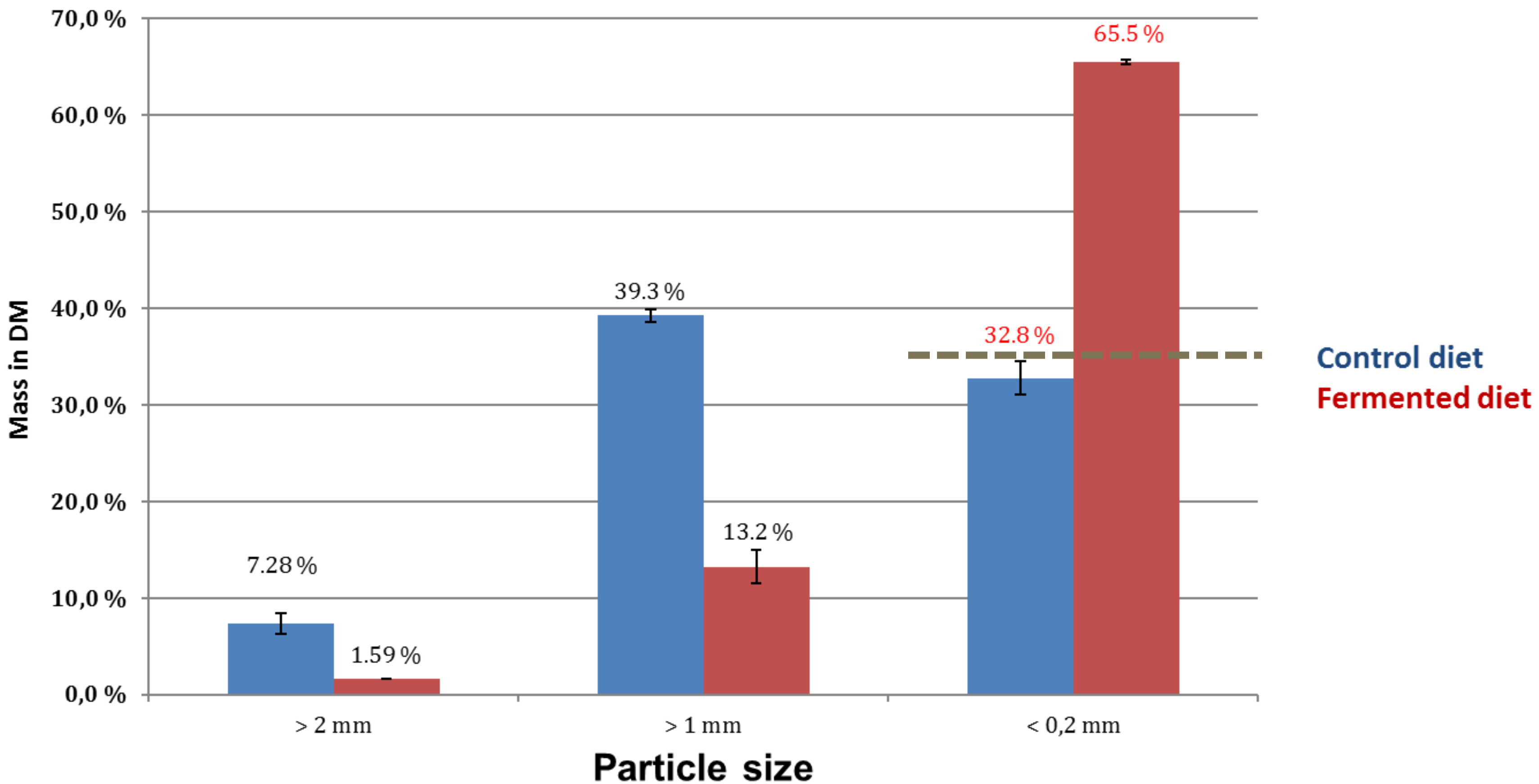


Fig.: Changes in extract viscosity of rye (ground by a hammer mill, sieve: 1 mm) during soaking/fermentation, modified by activity of xylanase (simple enzyme dosage: 2000 FXU/g; GRONE 2018)

Losses of coarse particles in liquid diets exposed to 24 h fermentation (BUNTE 2018)

- **Of special interest: share of particles < 0.2 mm that determines the risk for gastric ulcers in pigs (limit: max. 35 % < 0.2 mm, wet sieve analysis)**

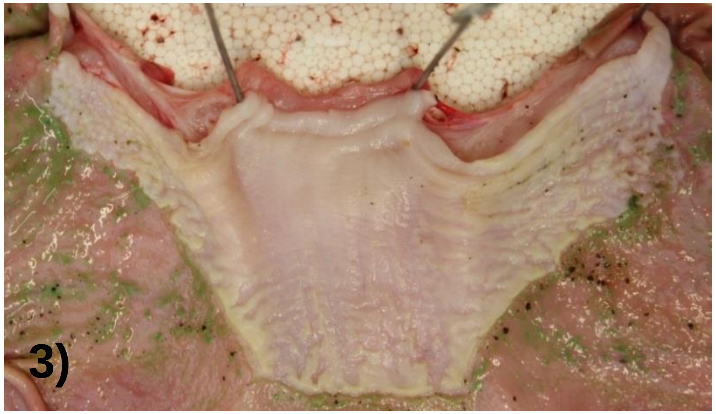


„Rolled“ cereals in the diet for fattening pigs to favor gastric health/to avoid gastric ulcers

GRONE 2018

- fermentate + „crushed“ grain → feed structure ↑
- stomach stratification ↑ → no ulcers

legend:
1) liquid diet (without fermentation)
2) fermented liquid diet (~ 100 %)
3) liquid diet: 60 % of DM fermented
   40 % of DM not fermented
   (including rolled cereals)



The NSP contents in samples of rye – correlated to the extract viscosity[1)] (RODEHUTSCORD et al. 2016)

NSP	g/kg dm	r → NSP-viscosity
arabinoxylans - arabinose - xylose	85.4 34.9 50.5	 r = 0.82 r = 0.72
fructans	29.1	r = - 0.76
ß-glucans - soluble - insoluble	20.1 6.6 13.5	r = 0.46 not calculated
cellulose	11.9	r = 0.46

[1)] estimated as decribed by DUSEL et al. (1997)

Background

CURRENT RECOMMENDATIONS FOR UPPER LEVELS OF RYE IN SWINE DIETS (DLG 2006)

SOWS	PIGLETS	FATTENING-PIGS
25 %	**10 %** < 15 kg BW	**30 %** 28-40 kg KG BW (pre-fattening)
	20 % > 15 kg BW	**40 %** 40-60 kg BW (starter)
		50 % 60-90 kg BW (grower)
		50 % > 90 kg BW (finisher)

https://www.praxis-agrar.de/tier/schweine/kastenstand-fuer-sauen ; https://www.vvg-luedinghausen-selm.de/leistungen-ansprechpartner/ferkel.htm ; https://beckagrar.de/salmonellen

EXPERIMENTAL / FEEDING TRIALS

WILKE, thesis in prep.

20 boxes – individual housing

ad libitum feeding - pellets

trial | experimental design

1.1
- **wheat vs. rye**
- age: **52 ± 2.22** days; BW: **19.5 ± 3.07** kg
- 20 piglets

1.2
- **wheat vs. rye**
- age: **42 ± 0.410** days; BW: **12.7 ± 1.21** kg
- 20 piglets

2.1
- **60 % rye – soy vs. rapeseed**
- age: **47 ± 0.489** days; BW: **15.1 ± 1.57** kg
- 20 piglets

2.2
- **60 % rye – soy vs. rapeseed**
- age: **50 ± 0.00** days; BW: **17.8 ± 2.86** kg
- 20 piglets

in progress

Material and methods

WILKE, thesis in prep.

COMPOUND FEED: INGREDIENTS* (%)

TRIAL 1.1 and 1.2

- **a: wheat vs. rye**

	group 1 DIET Ia	group 2 DIET IIa	group 3 DIET IIIa	group 4 DIET IVa
wheat	**69.0**	**46.0**	**23.0**	
rye		**23.0**	**46.0**	**69.0**
soybean meal	11.5	11.5	11.5	11.5
barley	10.0	10.0	10.0	10.0
potato-protein	5.10	4.95	4.90	4.90

TRIAL 2.1 and 2.2

- **b: soy vs. rapeseed**

	group 1 DIET Ib	group 2 DIET IIb	group 3 DIET IIIb	group 4 DIET IVb
rye	**60.0**	**60.0**	**60.0**	**60.0**
soybean meal	**18.1**	**13.6**	**8.10**	
rapeseed meal		**6.70**	**16.1**	**28.0**
barley	15.1	13.5	10.0	6.50
lignocellulose	2.00	1.50	1.00	0.70

*not listed: minor ingredients / mineral- /vitamin supplement

Material and methods

USED DIETS: THEIR CHEMICAL COMPOSITION

WILKE, thesis in prep.

TRIAL 1.1 and 1.2

- a: wheat vs. rye

	group 1 DIET Ia	group 2 DIET IIa	group 3 DIET IIIa	group 4 DIET IVa
Crude protein (g/kg)	186	185	179	179
Crude fiber (g/kg)	23.7	22.4	26.9	19.9
MJ ME/kg (calculated)	15.5	15.5	15.5	15.4

TRIAL 2.1 and 2.2

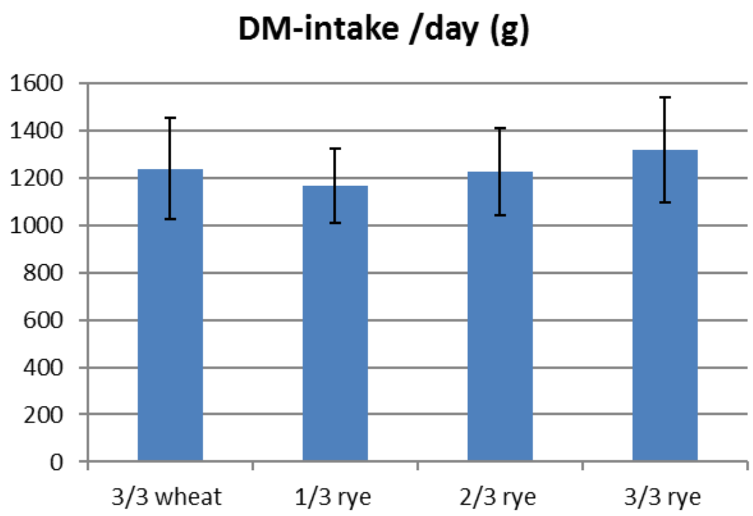
- b: soy vs. rapeseed

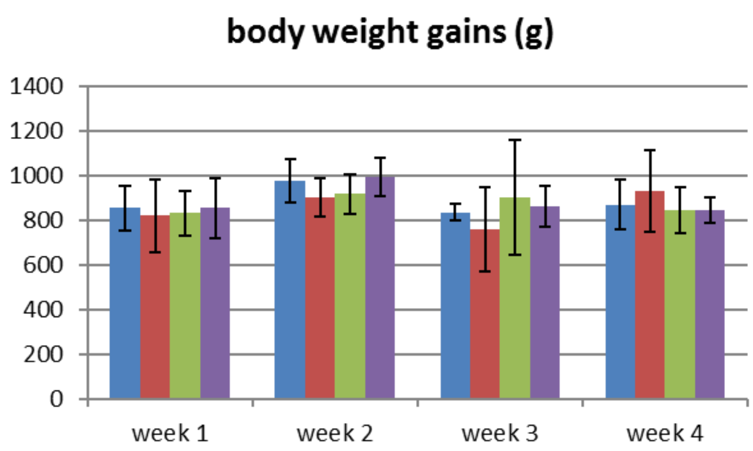
	group 1 DIET Ib	group 2 DIET IIb	group 3 DIET IIIb	group 4 DIET IVb
Crude protein (g/kg)	173	173	173	167
Crude fiber (g/kg)	37.2	38.7	45.2	47.9
MJ ME/kg (calculated)	15.3	15.3	15.4	15.4

Results (wheat vs. rye)
PERFORMANCE: DM INTAKE/GAINS

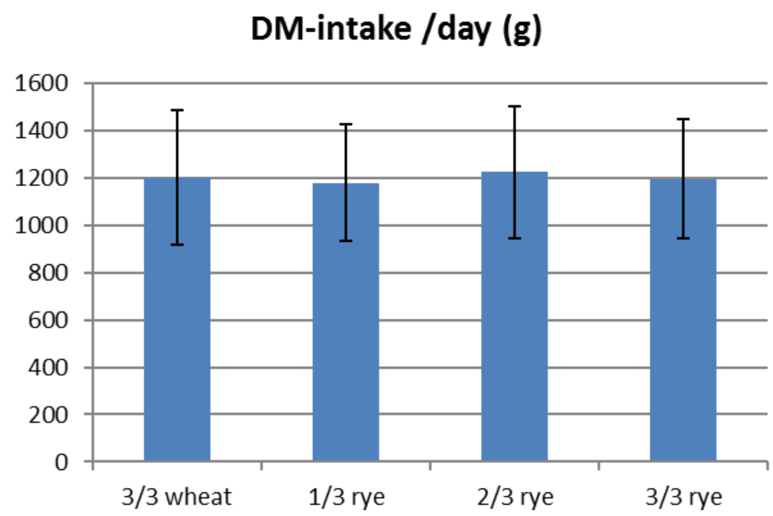
WILKE, thesis in prep.

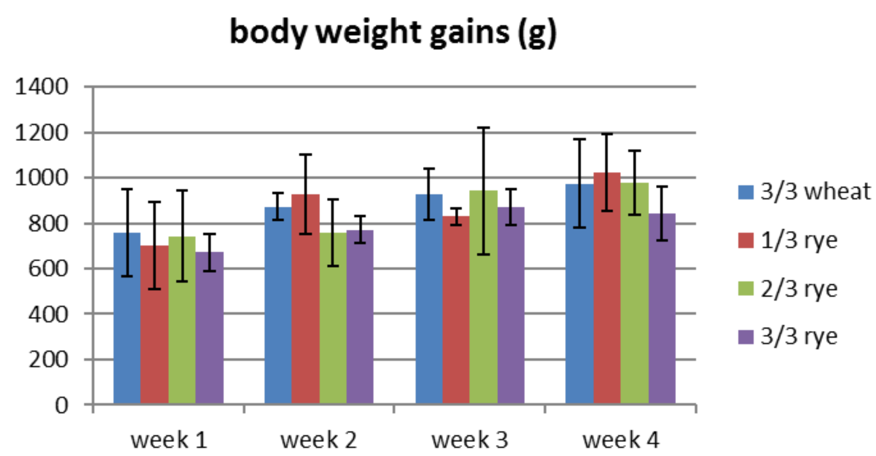
TRIAL 1.1





TRIAL 1.2

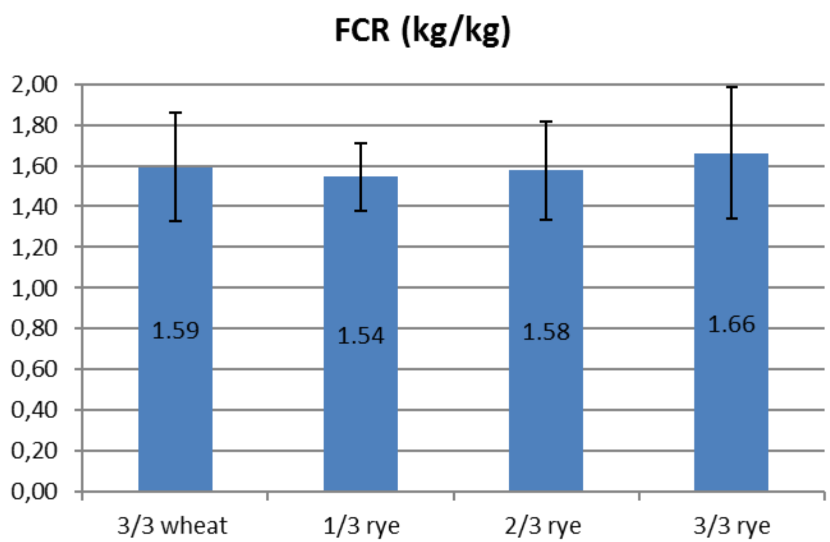




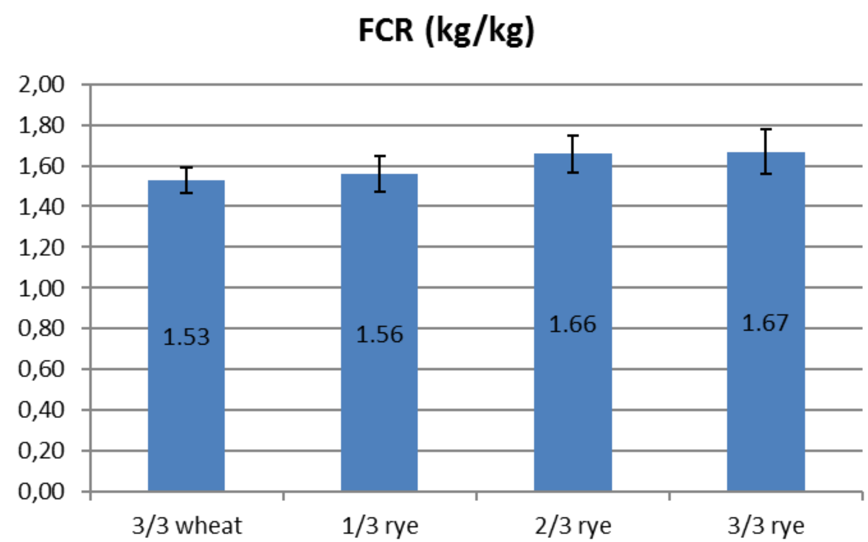
Results (wheat vs. rye)
PERFORMANCE: FEED CONVERSION RATIO

WILKE, thesis in prep.

TRIAL 1.1



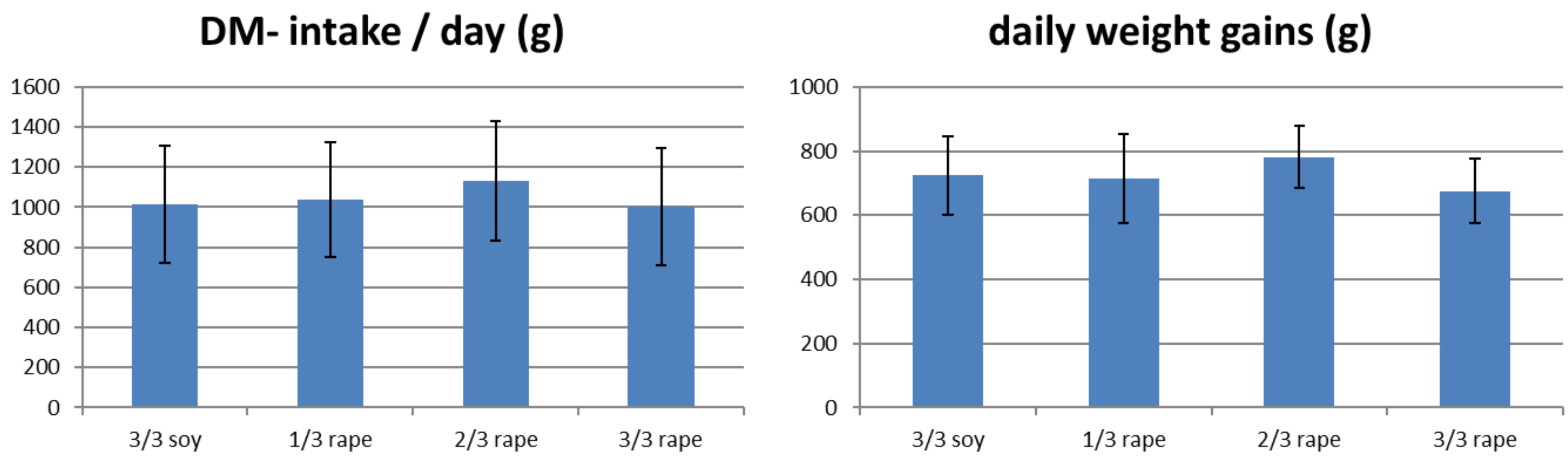
TRIAL 1.2

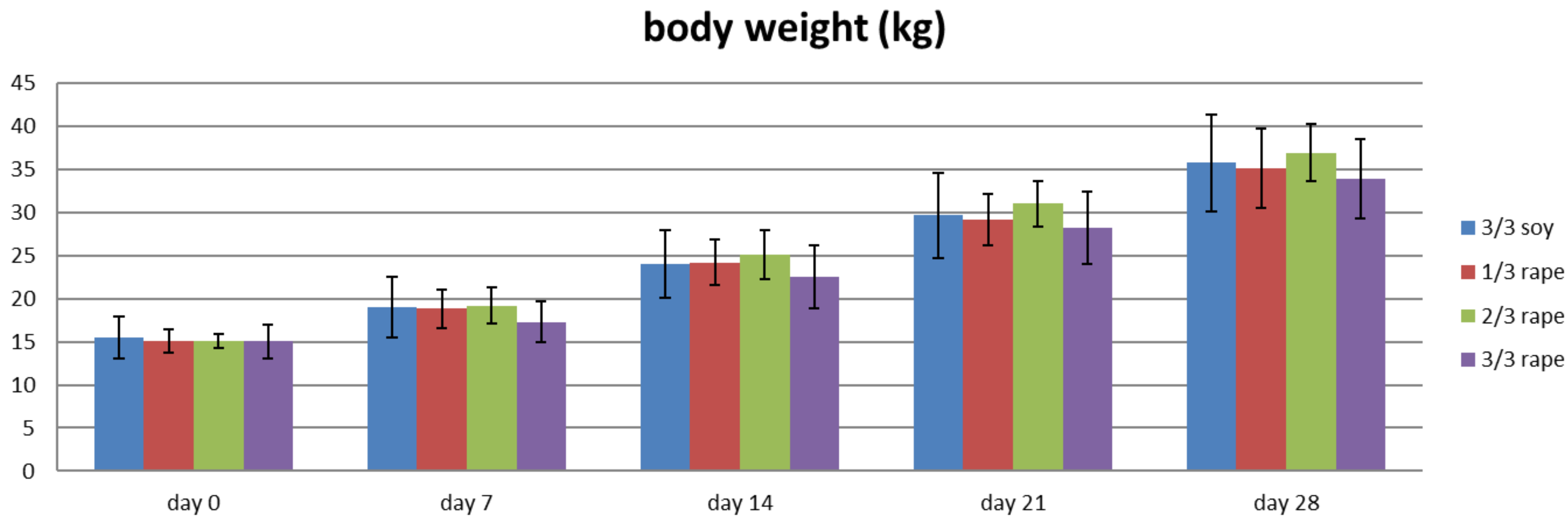


FCR (kg/kg)	3/3 wheat	1/3 rye	2/3 rye	3/3 rye
TRIAL 1.1	1.59 ± 0.269	1.54 ± 0.165	1.58 ± 0.240	1.66 ± 0.322
TRIAL 1.2	1.53 ± 0.063	1.56 ± 0.088	1.66 ± 0.091	1.67 ± 0.110

Results (soy vs. rapeseed)
PERFORMANCE: DM INTAKE/GAINS

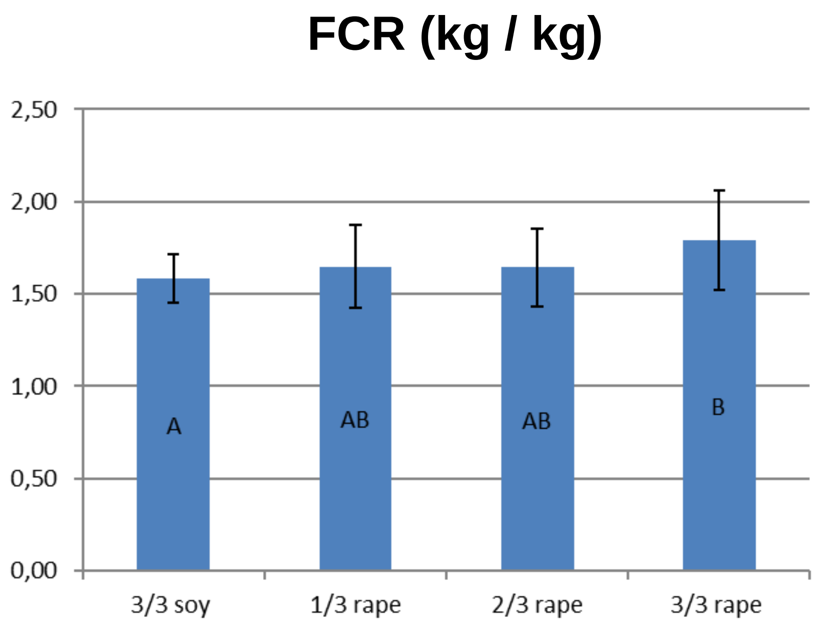
WILKE, thesis in prep.

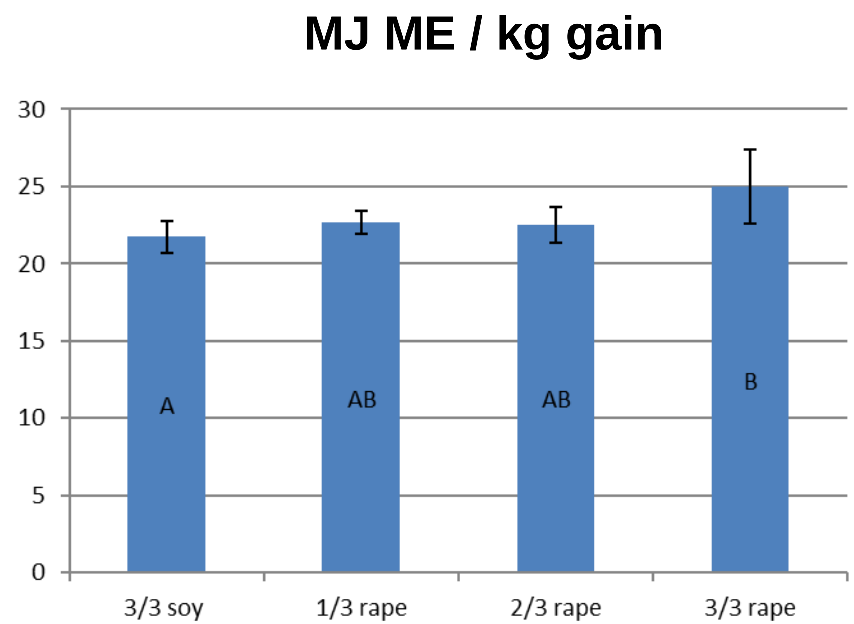




Results (soy vs. rapeseed)
PERFORMANCE: FEED CONVERSION RATIO

WILKE, thesis in prep.





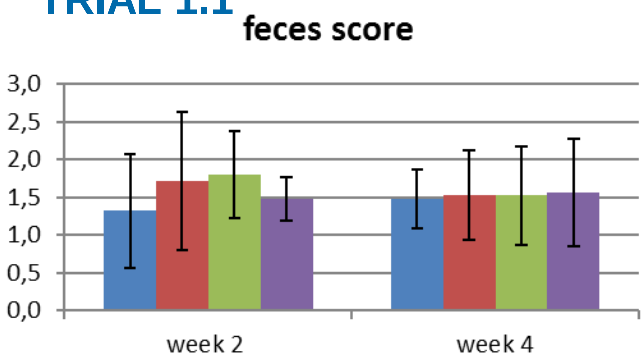
	3/3 soy	1/3 rape	2/3 rape	3/3 rape
FCR (kg / kg)	1.58 ± 0.129	1.65 ± 0.224	1.64 ± 0.212	1.79 ± 0.269
MJ ME / kg gain	21.7 ± 1.03	22.7 ± 0.758	22.5 ± 1.15	25.0 ± 2.38

Results (wheat vs. rye)
FECES COMPOSITION/QUALITY

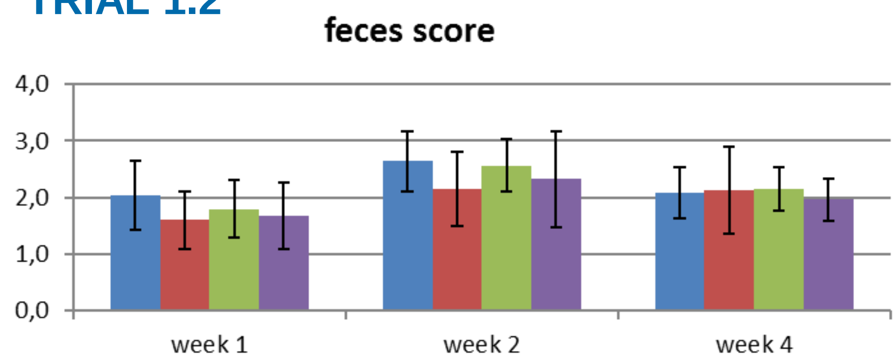
WILKE, thesis in prep.

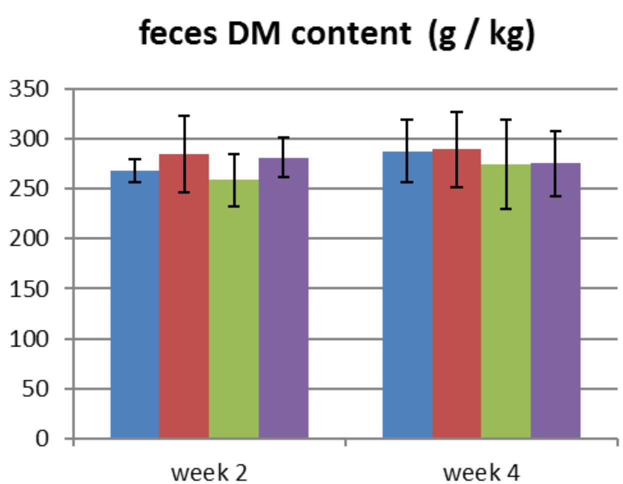
feces score	consistency
1	firm, formed
2	pulpy, formed
3	pulpy, unformed
4	soupy
5	watery

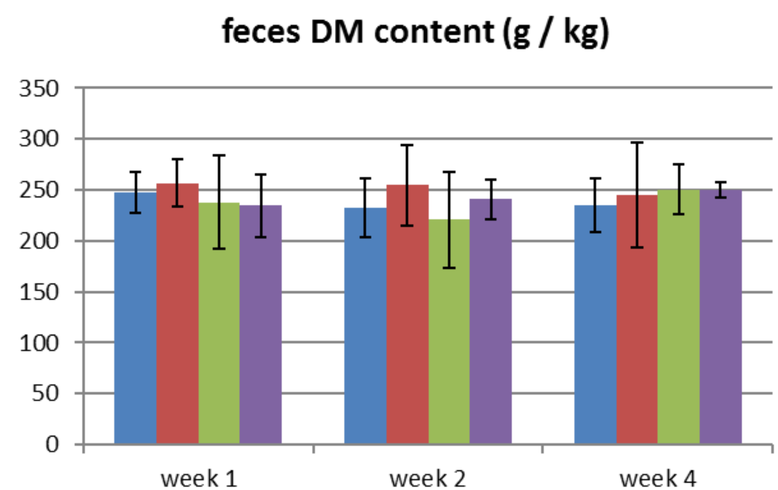
TRIAL 1.1



TRIAL 1.2

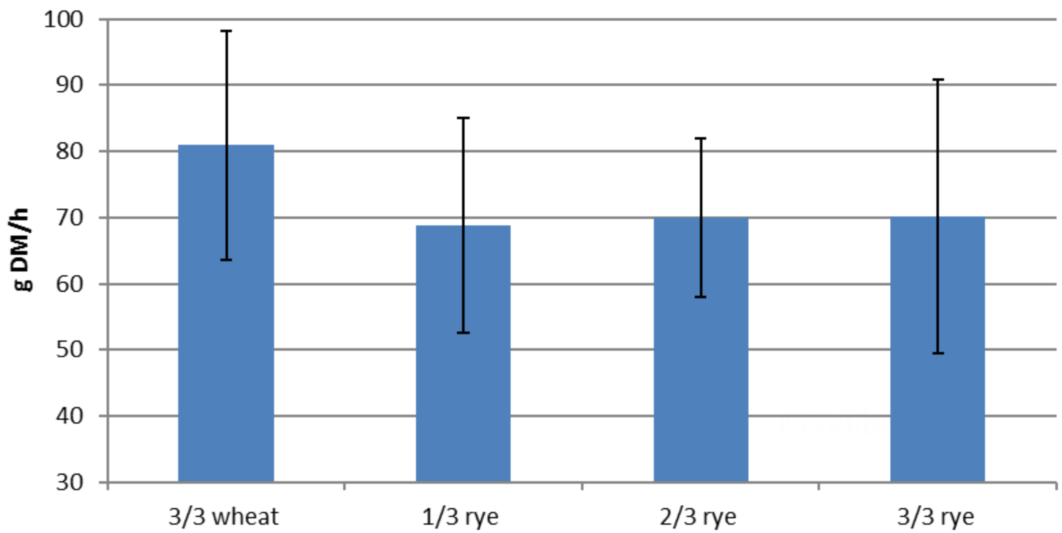






Results (wheat vs. rye)
STOMACH-DIGESTA-PASSAGE

WILKE, thesis in prep.



DM outflow (g) / hour*	
3/3 wheat	80.9 ± 17.3
1/3 rye	68.7 ± 16.2
2/3 rye	70.0 ± 12.0
3/3 rye	70.1 ± 20.7

***calculated:**
DM intake (g) minus DM amount (g) in the stomach divided by the time (h) between offering the diet and necropsy. Diet's availability for / during 4 hours. Pigs sacrificed between 4 and 7,5 h after the diets were offered.

- **"dough-balls / clumps" found**

Results (wheat vs. rye)
DOUGH-BALLS / CLUMPS

WILKE, thesis in prep.

Fig: doughballs / clumps found during dissection

Wilke 2019 (thesis in prep.):

- all feeds were pelleted (»effect of rye?!)

group	diets	occurrence of "dough-balls" (n / n)
1	**3/3 wheat**	**1 of 10**
2	**1/3 rye**	**2 of 10**
3	**2/3 rye**	**5 of 10**
4	**3/3 rye**	**9 of 10**

Liermann et al. (2015):

- "dough-balls / clumps" only found, when feed was thermally treated (composition: ~ 25 % each barley / rye / triticale)

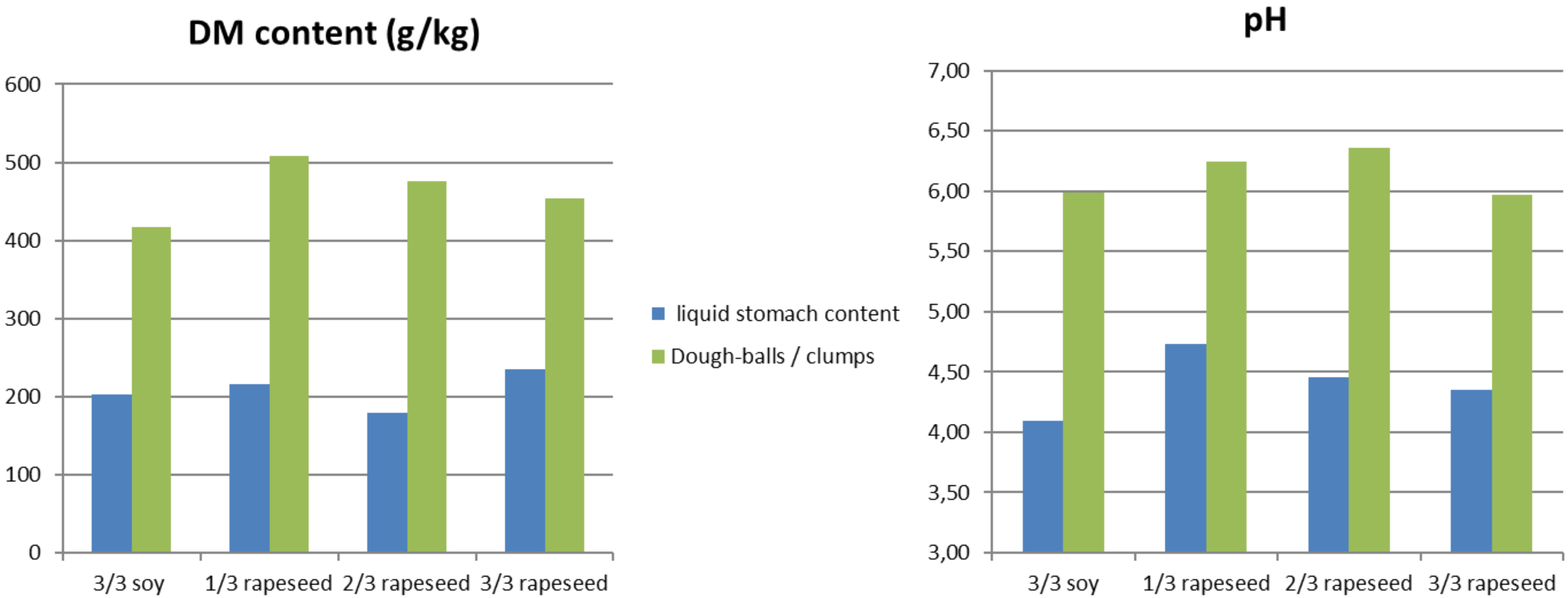
group	temperature	occurrence of "dough-balls" (n / n)
without thermal treatment	**-**	**0 of 24**
pelleted	**165°F**	**9 of 24**
extruded	**235°F**	**15 of 24**
pelleted and extruded	**235/189°F**	**12 of 23**

Results (soy vs. rapeseed)
DOUGH-BALLS / CLUMPS: DEEPER CHARACTERIZATION

WILKE, thesis in prep.

“Dough-balls / clumps“: data on amounts / DM content and pH

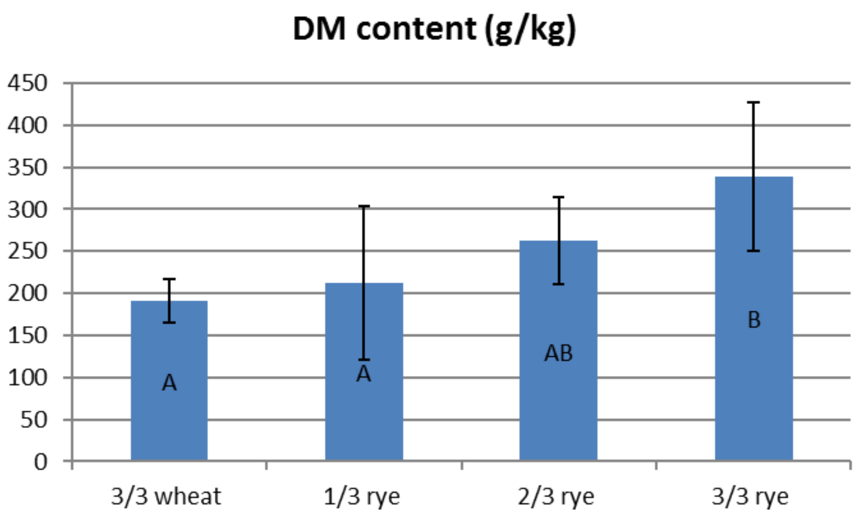
mass (%)		DM content (g/kg)		pH	
liquid stomach content	dough-balls	liquid stomach content	dough-balls	liquid stomach content	dough-balls
46.4	53.6	191	464	4.41	6.14

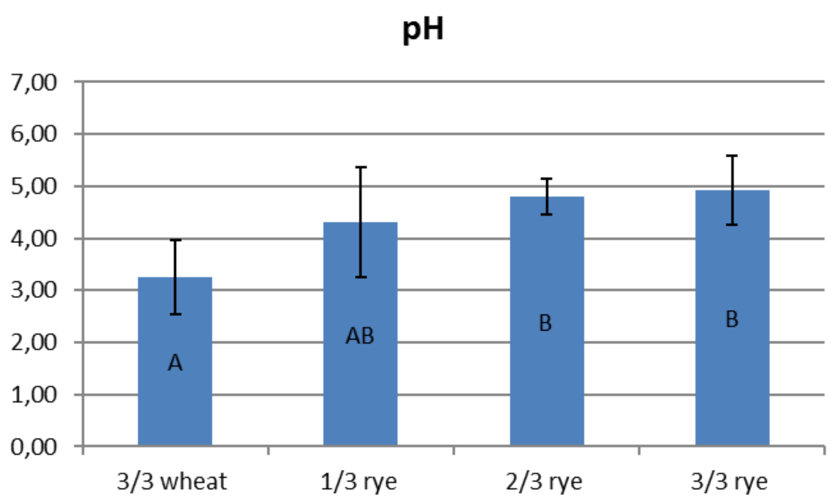


Results (wheat vs. rye)
STOMACH DIGESTA: DM CONTENT AND pH

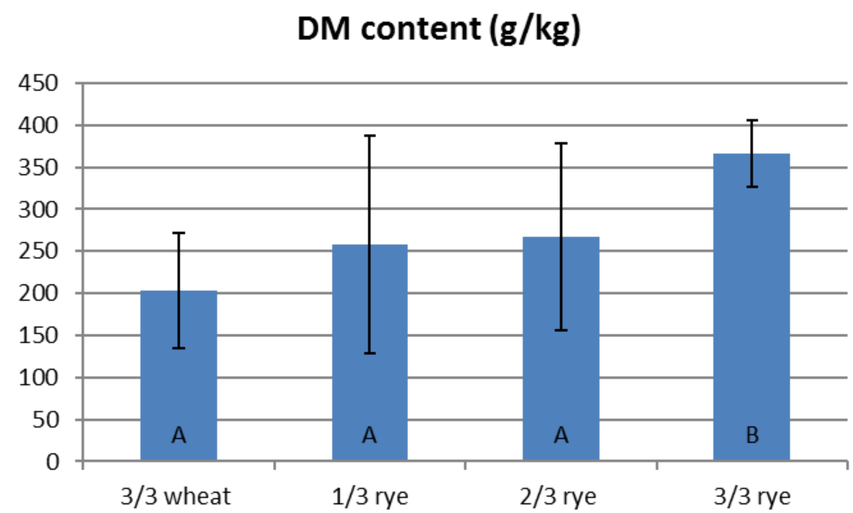
WILKE, thesis in prep.

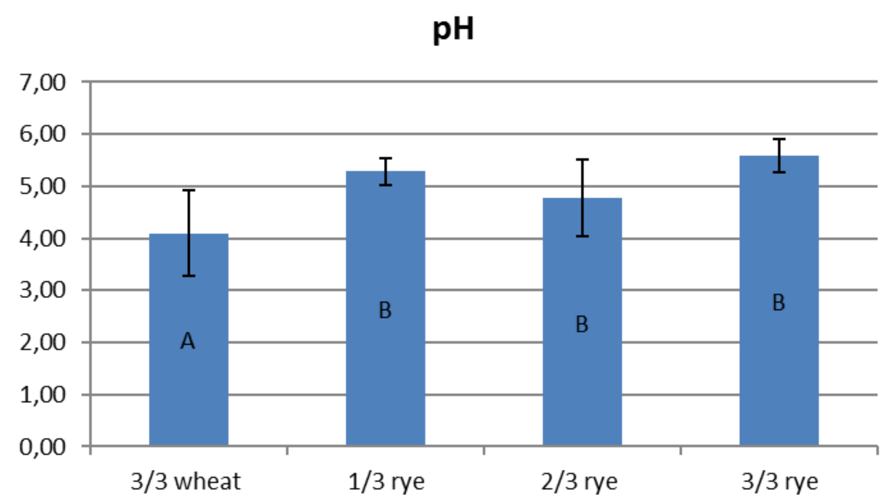
TRIAL 1.1





TRIAL 1.2





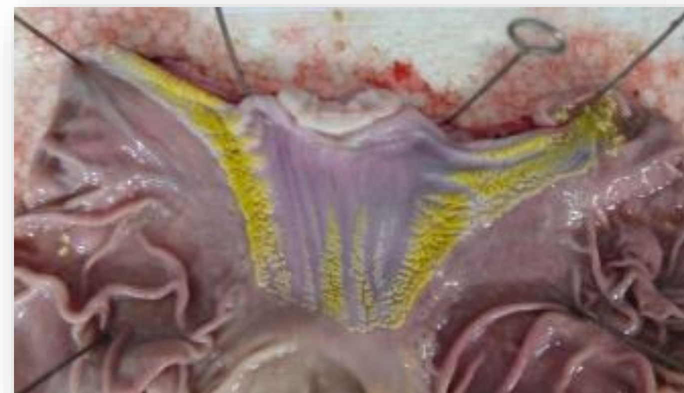
Results (wheat vs. rye)
STOMACH‘S ULCERS: SCORE / DESCRIPTION

WILKE, thesis in prep.

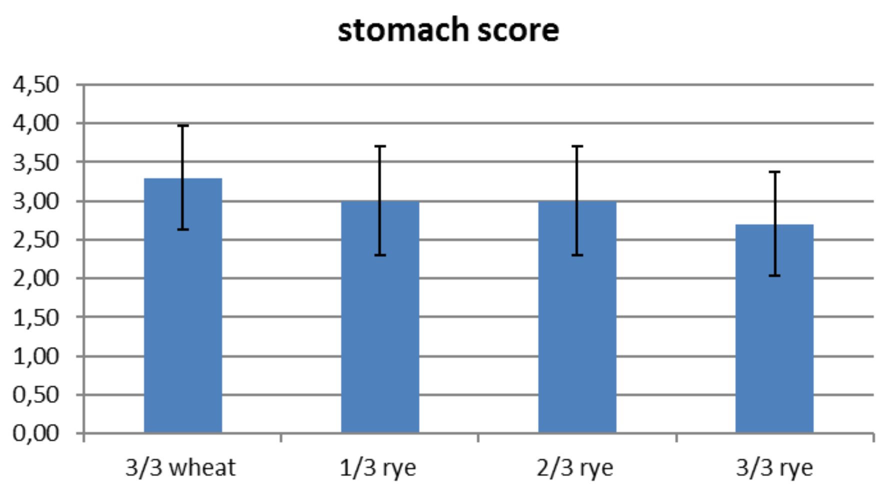
Score for describing stomach health

0	no changes / alterations
1	slight hyperkeratosis
2	moderate hyperkeratosis
3	high hyperkeratosis
4	erosion
5	ulcer

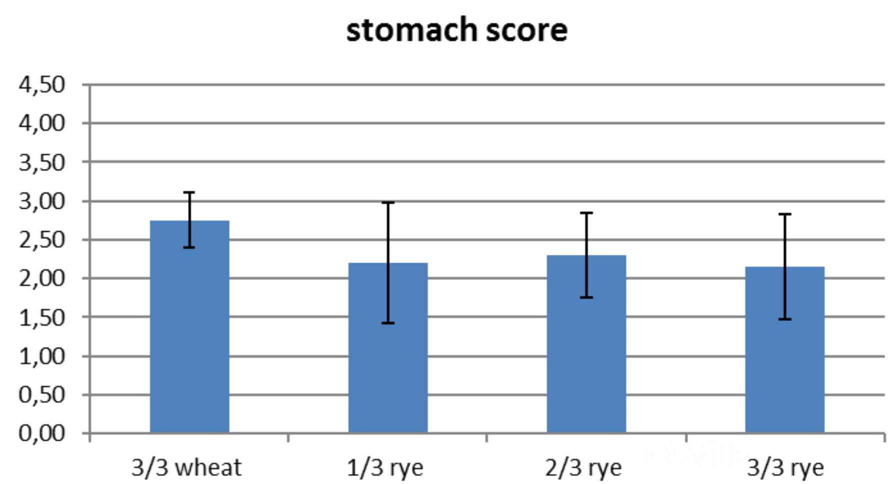
Stomach with moderate hyperkeratosis



Trial 1.1



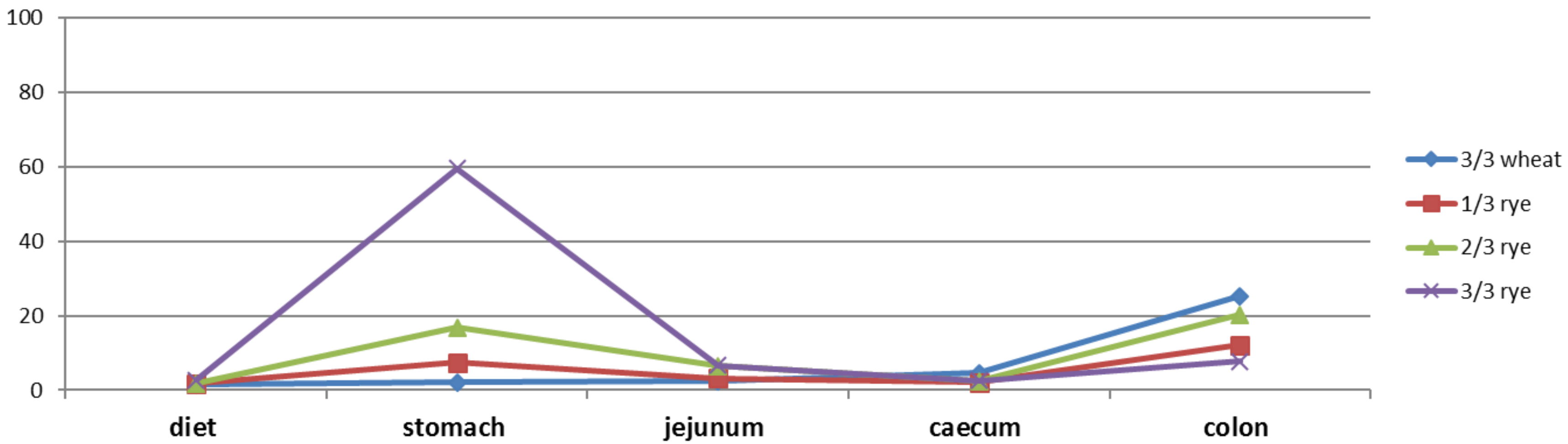
Trial 1.2



Results (wheat vs. rye)
CHARACTERISATION OF THE DIGESTA REGARDING THE VISCOSITY

Marked differences regarding digesta viscosity in pigs fed rye-based diets. [Grone 2018; Wilke 2019 (thesis in prep.)]

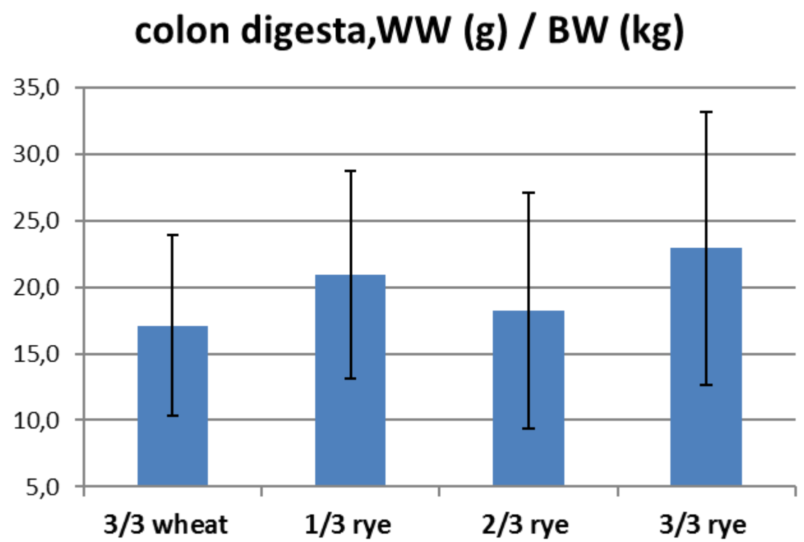
Average viscosity (mPa*s) in the extract of the diets and digesta

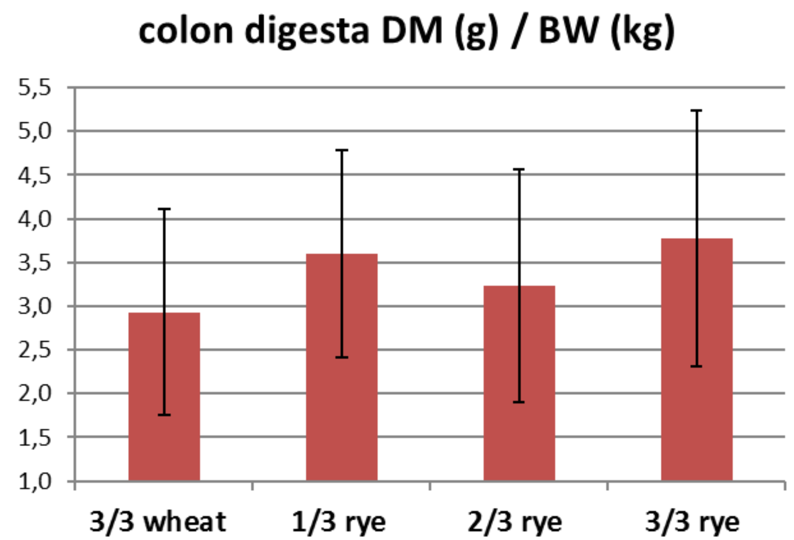


group/diet	diet	stomach	jejunum	caecum	colon
3/3 wheat	1.47 ± 0.138	2.02 ± 0.665	2.33 ± 0.959	4.54 ± 4.97	25.2 ± 30.5
1/3 rye	1.81 ± 0.216	7.47 ± 7.28	3.23 ± 1.65	2.15 ± 0.433	12.1 ± 9.45
2/3 rye	1.83 ± 0.358	16.8 ± 15.6	6.52 ± 8.19	2.35 ± 0.285	20.4 ± 18.4
3/3 rye	2.78 ± 0.659	59.5 ± 41.2	6.55 ± 5.02	2.61 ± 1.09	7.79 ± 5.94

Results (wheat vs. rye)
"GUT FILL": AMOUNTS OF COLONAL DIGESTA

Amounts of digesta in the colon [wet weight (WW) / dry matter] per kg BW





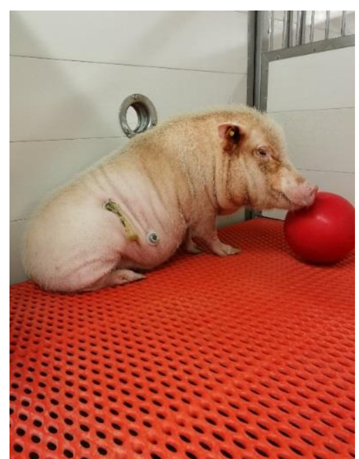
relative:	**100**	**122**	**107**	**134**	**100**	**123**	**110**	**129**

WILKE, thesis in prep.

Studies on prececal digestibility (pc VQ) of diets based on wheat vs. rye in ileocecally fistulated minipigs (HARTUNG, thesis in prep.)

Prececal and postileal digestibility of complete feed with high shares of either wheat (F1) or rye (F2)

- Minipigs with an ileo-caecal fistula
- Marker method



Prececal digestibility (pc VQ) of wheat- vs. rye-based diets in adult minipigs (HARTUNG, thesis in prep.)

Prececal digestibility of diet 1 (69 % wheat) and diet 2 (69 % rye) respectively

feed	OM[1]	NfE[2]	CP[3]	EE[4]	Lys	Cys	Met
diet 1 (wheat)	78.4±1.11[a]	81.5±0.98[a]	77.5±2.23[a]	75.7±1.87[a]	87.3±2.20[a]	78.3±3.40[a]	91.9±0.88[a]
diet 2 (rye)	74.7±1.84[b]	76.8±1.88[b]	75.8±3.12[a]	72.7±5.59[a]	87.9±1.32[a]	73.3±3.63[a]	92.4±0.69[a]

[1]organic matter, [2]N-free extractive, [3]crude protein, [4]ether extract

- Significant differences only found for organic matter and NfE
- Higher amounts of these nutrients (compared to diet 1) reached the large intestine (1.25 times higher for NfE, 1.17 times higher for OM)

Total tract digestibility of wheat- vs. rye-based diets in adult minipigs (HARTUNG, thesis in prep.)

Total tract digestibility of diet 1 (69 % wheat) and diet 2 (69 % rye)

Feed	OM	NfE	CP	EE
diet 1 (wheat)	91.2 ± 0.62	93.9 ± 0.42	91.0 ± 1.55	74.9 ± 2.91
diet 2 (rye)	90.1 ± 0.64	93.2 ± 0.25	89.2 ± 2.51	64.2 ± 2.18

➡ **No significance for NfE and organic matter → increased influx of fermentable substances into the hindgut → favoured fermentation**

➡ **Consequences: adequate supplementation of amino acids**

Comparing with published data

Data of MCGHEE and STEIN (2018):

1.6 – 1.7 times higher influx of DM into the hindgut of pigs fed rye instead of wheat

Data of HARTUNG (2019, thesis in prep.):

- **Extrapolation on a fictive diet containing 100 % of wheat or rye resulted in**

  1.81 times higher influx of OM and 1.62 times higher influx of DM into the hindgut of pigs

Similar values were found!

Planned studies on in vitro fermentation of diets based on wheat or rye (HARTUNG, thesis in prep.)

Daisy Incubator

© ANKOM Technologies

Dry matter-“disappearance rate“
- Microbial degradation of the substrate

- **Inoculum: ileal digesta or feces of the minipigs**
- **Substrates: diets and ingredients like bran or DDGS**

No absorption of the vfa produced during fermentation in the incubation jars
- Calculation of **production rates instead** of **concentrations** of vfa etc. from each substrate

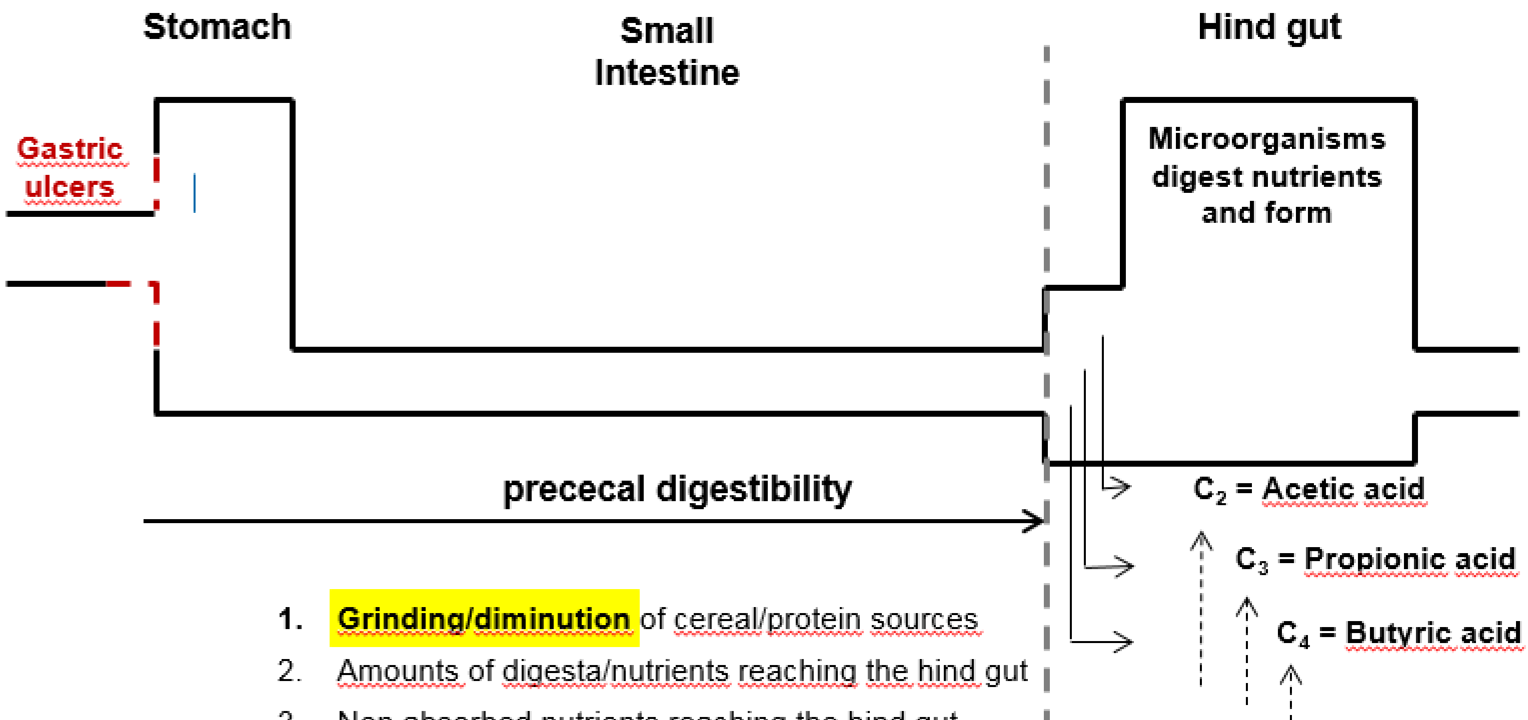
Gas Production System („GPS“)

© ANKOM Technologies

Measuring of
- Gasproduction
- pH changes
- Production of vfa (esp. butyrate!)
- Lactate

The Alimentary Tract of Pigs – a Model

Kamphues et al. 2017



1. **Grinding/diminution** of cereal/protein sources
2. Amounts of digesta/nutrients reaching the hind gut
3. Non absorbed nutrients reaching the hind gut
   - Cellulose, pectin → Acetic acid (C_2) ↑
   - Starch → Propionic Acid (C_3) + Butyric acid ↑
   - Inulin[1], Polyfructans[1], Arabinoxylans[1] → Butyric acid (C_4) ↑↑

[1] specifically high amounts in rye

Is there a special need for high butyric acid levels in pig's digesta?

- **Favoring gut health due to "trophic effects" regarding the mucosa**
  - life time/renewing/regeneration/maturation
  - ➢ improved health/reduced amounts of antibiotics
- **Reducing Salmonella prevalence at individuals'/herd level**
  - at high butyric acid levels: down regulation of invasion genes in Salmonella
  - ➢ improved food safety and favored consumers' protection
- **Lowering the "boar taint" prevalence in fattening boars**
  - polyfructanes (inulin) highest efficacy against "boar taint"
  - ➢ rate of condemnation of carcasses due to sensorial deviations ↓
- **Fostering the feeling of satiety/avoiding behavioral disorders**
  - mass of digesta, more continuous serum levels of glucose/insulin
  - ➢ improved animal welfare/wellbeing/image of pork production

Kamphues et al. 2017

Amounts of dry matter entering the hindgut in pigs fed 1 kg DM of a diet consisting for 94 % of the distinct grain (according to data from MCGHEE and STEIN; 2018)[1)]

Type of cereals	Amounts of dry matter entering the hind gut		
	absolute	relative	relative
corn	**181**	100	-
wheat	**202**	112	100
barley*	**241**	133	120
hybrid rye 1	**323**	178	160
hybrid rye 2	**327**	181	162
hybrid rye 3	**342**	189	169

* "dehulled barley"

[1)] diet containing in general 94 % of the distinct grain type

Butyrate: diverse relationships to the immunological capacity of individuals, selected recent literature

Intestinal barrier ↑
(tight junction protein ↑, protection against LPS-induced damage; (Yan and Ajuwon 2015)

Host defense peptides ↑ (via blocking the histondeacetylase)
(XIong et al. 2016)

Activation of pro-inflammatoric cytokines like TNFα, IL-1β, IL-6;
(Liu 2016)

Bacteriostatic effects
(Moquet et al. 2016)

Butyrate

Inflammatory reactions↓, forced mucin production, secretion of antimicrobial peptides
(Onrust et al. 2015)

Infectious agents ↓
reduction of colonization and faecal Salmonella excretion
(Barba-Vitel et al. 2017)

Oxidative stress ↓
inhibition of forced apoptosis
(Jiang et al. 2016)

Antibody secretion ↑
sow feeding: higher IgG and IgA in colostrum and milk
(Jang et al. 2014)

Kamphues et al. 2017

LAWHON et al. 2002:
(Molecular Microbiology 46, 1451 – 1464)

„It is likely then that Salmonella can use the SCFA conditions of the mammalian intestinal tract as **a signal for invasion**.

- **Low total SCFAs** (~ 30 mmol) with a predominance of acetate induce invasion

  whereas

- **high total SCFAs** (~ 200 mmol) with greater concentrations of **propionate and butyrate** suppress it.“ **!**

→ in the distal small intestine: Acetate ⇑ → Invasion ⇑⇑⇑

→ in the cecum/colon: Propionate, Butyrate ⇑ → Invasion ⇓⇓⇓

Favoring the intestinal butyrate production for dietetic reasons in human nutrition – experiments in pigs (rye bread instead of wheat bread)

BACH-KNUDSEN et al. 2005; J. Nutrition, 135, 1696 - 1704

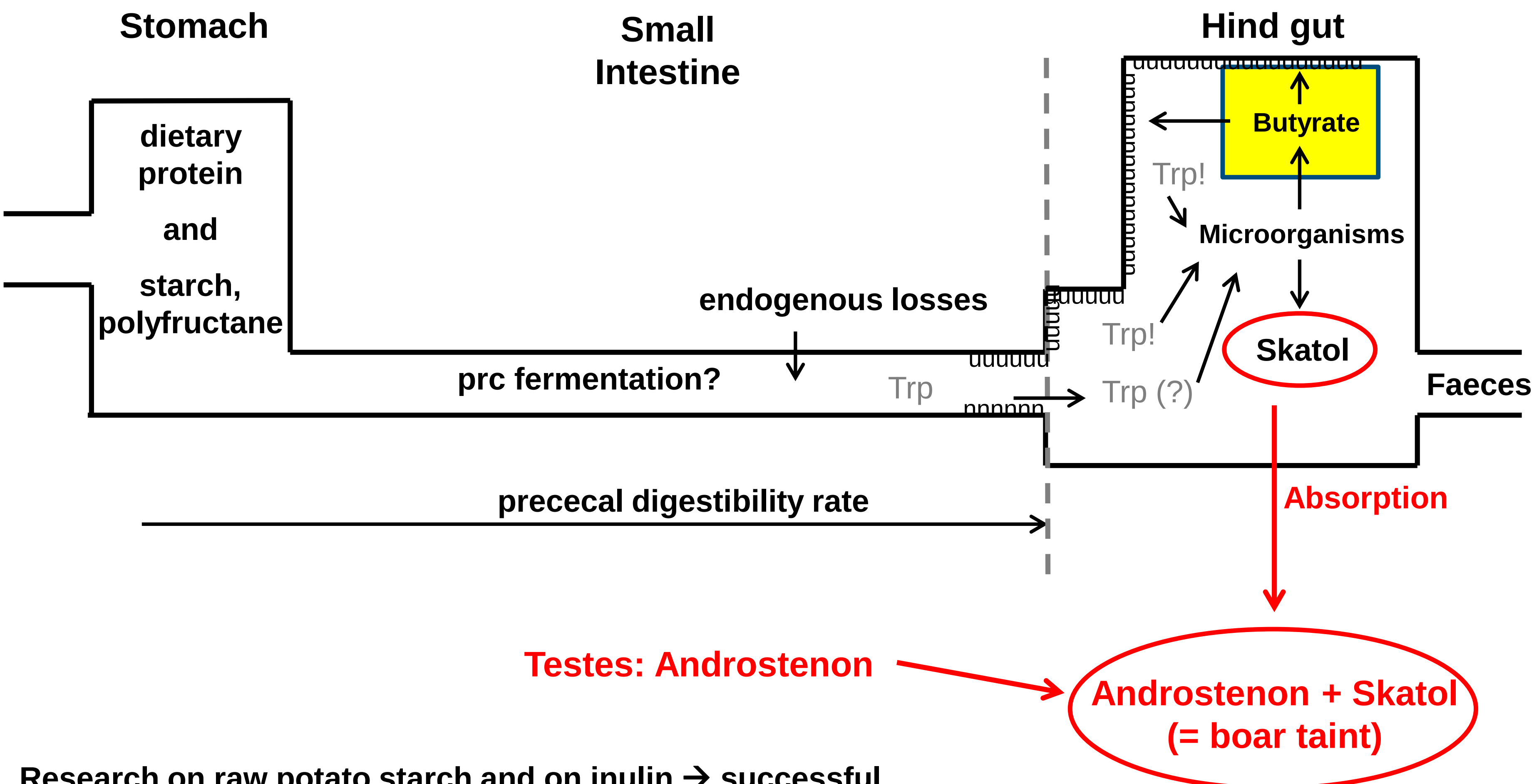
„**Dietary fiber**“:	wheat: determined mainly by cellulose rye: determined by arabinoxylans/polyfructans!
Experiments in pigs:	**rye** bread instead of **wheat** bread catheterization of draining vessels fistulation at the terminal ileum

Blood (portal vein):	**wheat bread**	**rye bread**	(factor)
Butyrate level	52.6 µmol/L	141.2 µmol/L***	(2.68)
Butyrate absorption/d	91 ± 18 mmol	242 ± 32 mmol***	(2.66)

Blood (mesenteric arteries):			
Butyrate level	9.6 ± 0.6 µmol/L	25.4 ± 1.1 µmol/L***	(2.65)

→ Chances for modulating the butyrate level in peripheral vessels!

Effects of rye based diets on the „boar taint“ in fattening male pigs (Kamphues and Betscher 2011, modified)



Research on raw potato starch and on inulin → successful reduction of the skatol formation and the “boar taint“

Feeding Jerusalem artichoke to entire male pigs for 1 week before slaughter

→ To reduce skatole level in adipose tissue! → boar taint ↓ (VHILE et al. 2012)

Diet	basal diet				
Added (percentage)	Control — (0)	Chicory inulin[1] (9)	Jerusalem artichoke[2] 4.1	Jerusalem artichoke[2] 8.1	Jerusalem artichoke[2] 12.2
Skatole contents (mg/kg DM)					
- Colon digesta	4.6[ab]	1.3[b]	7.4[a]	1.8[b]	0.5[b]
- Faeces	13.0[ab]	9.7[ab]	15.6[a]	7.6[ab]	4.7[b]
- Adipose tissue (mg/kg)	37.0	17.0	55	15	10
Cl. perfringens (log CFU/g)	6.09	5.42	5.92	5.08	4.98[3]

[1] 75% fructans, [2] 50.6% fructans, [3] significant effects when positive control – 9% inulin – was omitted

→ For comparison: in rye ~ 6% fructans!

Type of microbial fermentation in the hindgut of pigs

→ Do fermentation rates and/or patterns affect behavior?

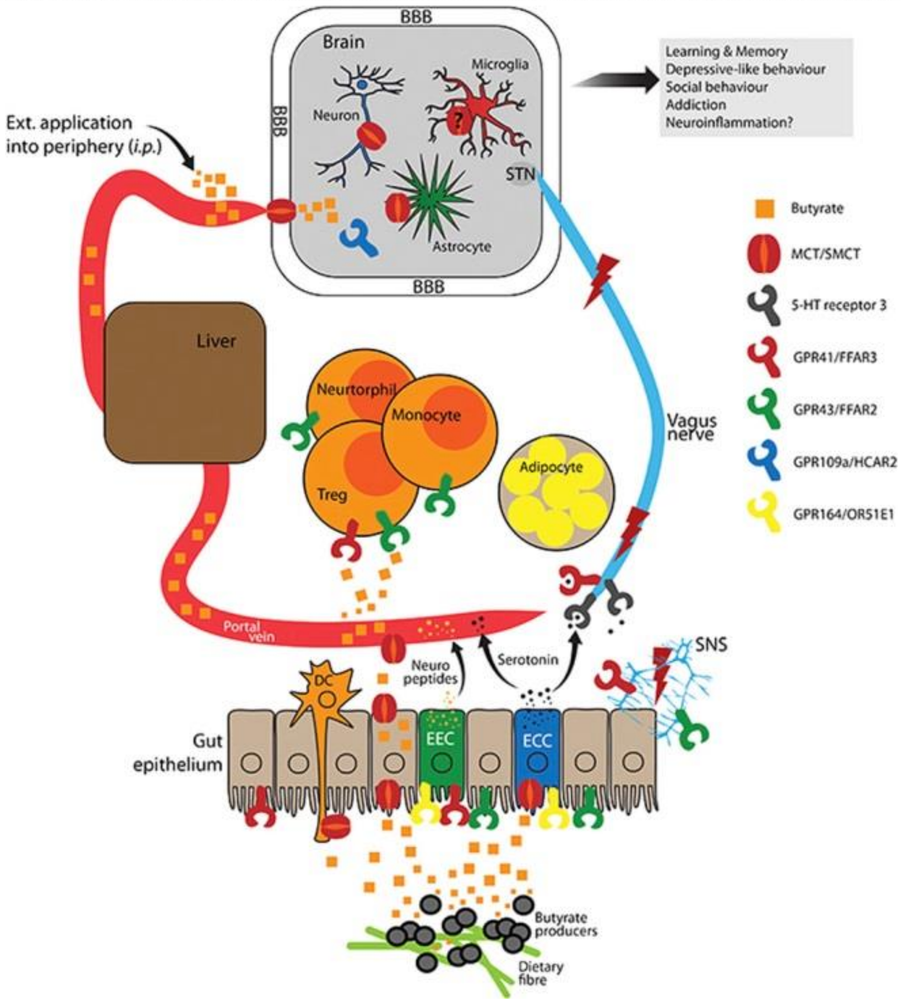
- **Non-directional moving activity** related to
  - physical effects of higher gut fill due to non digestible feed constituents?
  - chemical effects of rate/type of produced volatile fatty acids?

  ➡ experimental studies in sows:
  - "**resistant starch**" more effective than crude fiber!
- **Kinetics** of postprandial glucose/insulin levels in human beings?
  - diurnal curves in individuals consuming **wheat** or **rye** bread?
  - delayed absorption of nutrients in individuals consuming **rye**?

- **Experiments** in small rodents regarding treatment of depressive symptoms via diets/probiotics/butyrate?

➡ **"microbiome-gut-brain axis"** (CRYAN & O'MAHONY 2011)

Schematic summary of butyrate effects on host physiology and brain function (STILLING et al. 2016)



Learning & Memory
Depressive-like behaviour
Social behaviour
Addiction
Neuroinflammation?

Key:

STN: Solitary tract nucleus; BBB: Blood brain barrier; SNS: Sympathetic nervous system;
EEC: Enteroendocrine cell; ECC: Enterochromaffin cell; DC: Dendritic cell; Treg: T-regulatory cell

Summary/Conclusions

- **Rye as crop**
  - highest efficiency regarding the utilization of water, nitrogen, phosphorus
  - low contamination by Fusarium spp. (e. g. DON, ZEA)
- **Rye as feed**
  - highest “dietary fiber“ contents stimulating butyrate production due to arabinoxylan and fructan fermentations (“natural prebiotic“)
- **Rye for dietetic reasons**
  - benefits for mucosa health and regeneration
  - fostering the barrier function of the GIT (tight junctions!)
- **Rye: positive “side effects”**
  - reducing Salmonella prevalence (“signal function“)
  - lowering risk for “boar taint“ in fattening entire males
  - enabling wellbeing/avoiding disturbed behavior (?)
- **Rye: drawbacks?**
  - increased risk for gastric ulcers (grinding technique?)
  - enhanced toxin production (?) in distinct bacteria (e. g. EHEC)
  - ergot contamination in low pollen shedding cultivares (⟹ PollenPlus KWS)