

Specific properties of rye – potentials and benefits in swine feeding/pork production



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Gefördert durch:



aufgrund eines Beschlusses
des Deutschen Bundestages

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

CORN?

RYE?

**Suitability of/
competition between
different crop
species**

WHEAT?

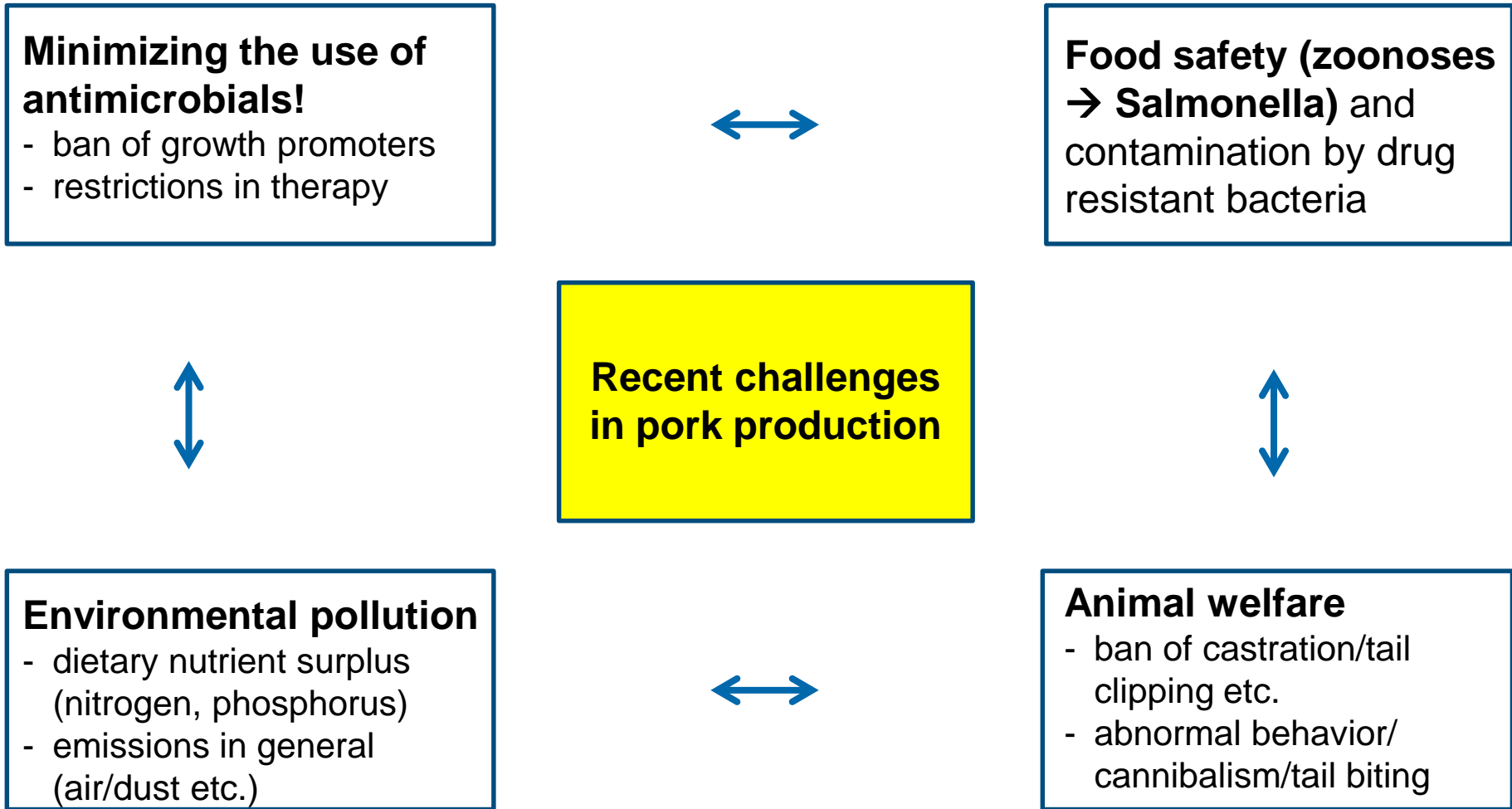
Monocultures
in grain production
- missing diversity
- favoring plant diseases

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

BARLEY?

Kamphues et al. 2017

Recent challenges in pork production in Germany



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, herbicides

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

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

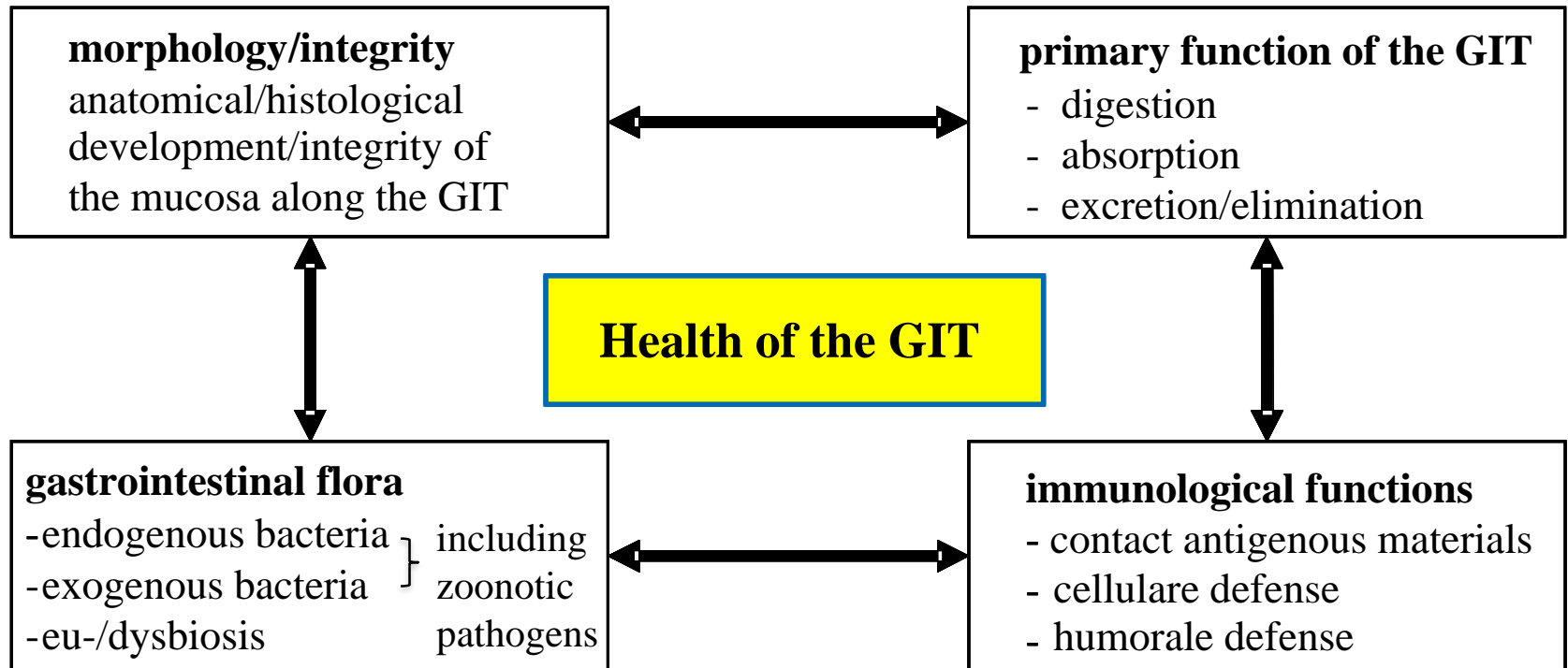
KWS Lochow

- 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, 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)**

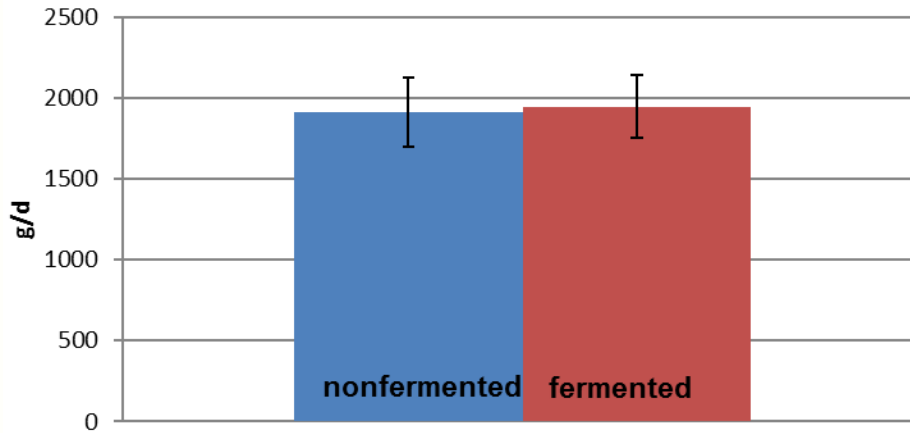
- *Lactobacillus plantarum*, *Pediococcus pentosaceus*, *Lactococcus lactis*
- 500 g per ton DM \cong 2.0×10^5 cfu/g liquid feed
 → after 24 h: **10⁹ cfu/g** fermentate

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

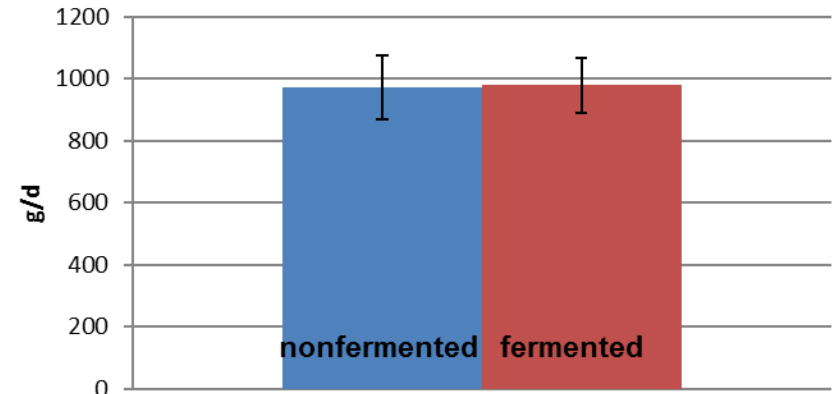
BUNTE 2018



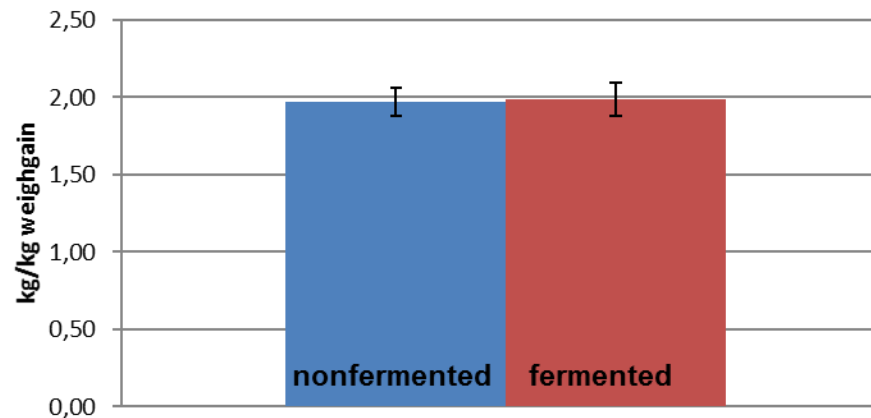
DM-intake



Daily weight gain



FCR



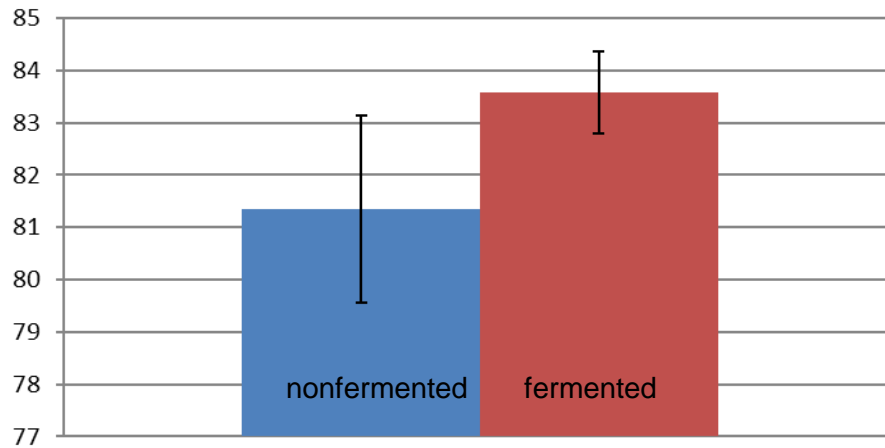
Digestibility of liquid diets based on rye and rapeseed in young fattening pigs



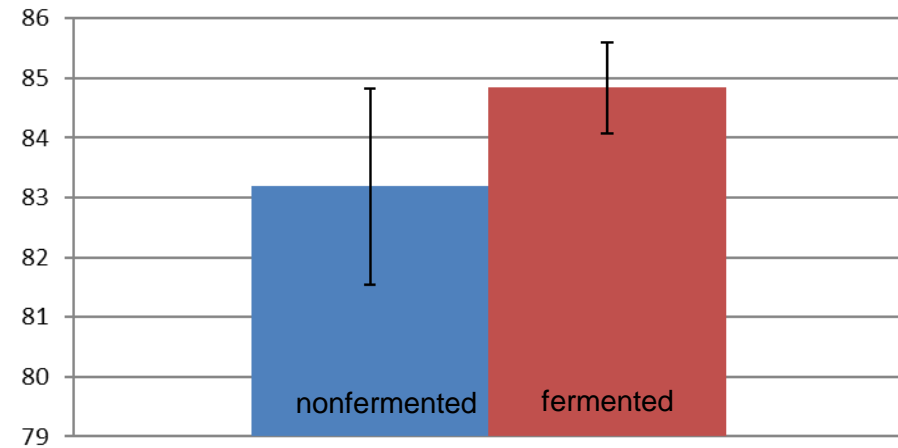
Apparent total tract digestibility (%)

BUNTE 2018

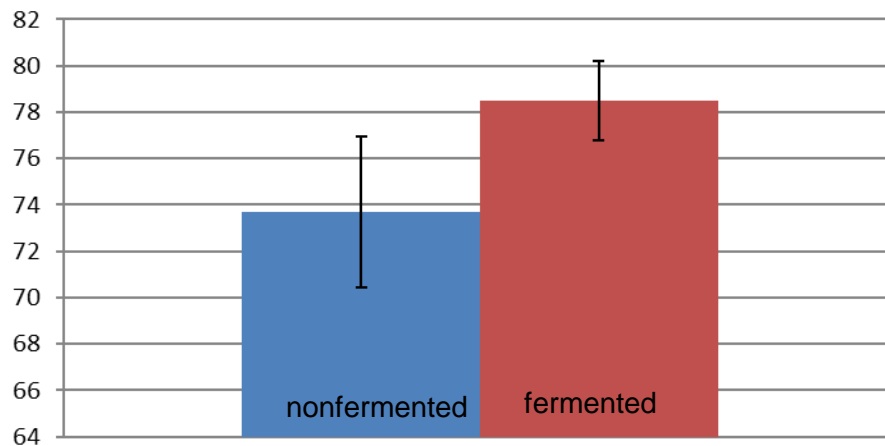
DM



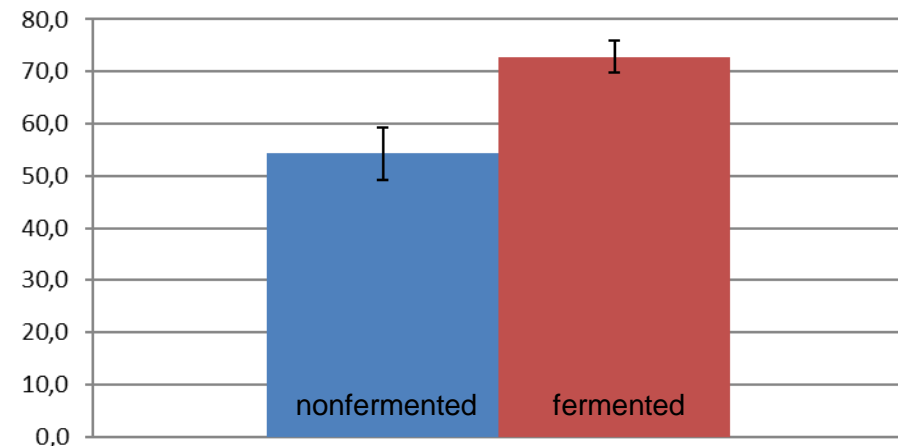
Organic substances



Crude protein



Phosphorus



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 degradation¹⁾ 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 |



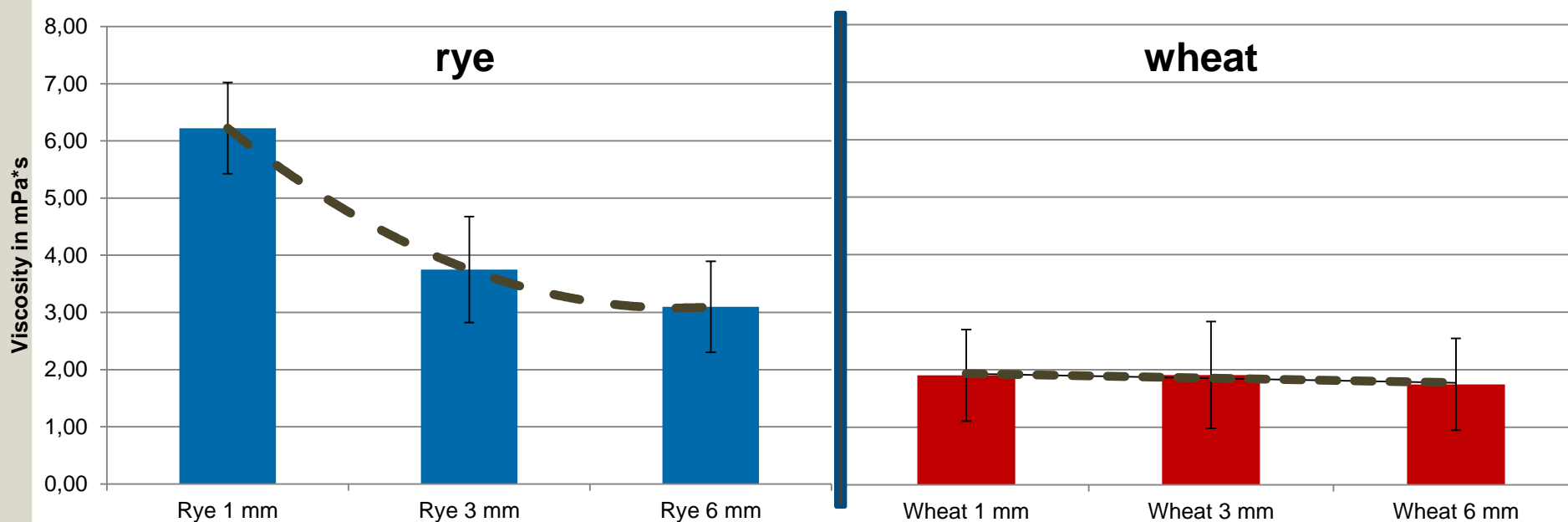
Rye: Viscosity of the supernatant after soaking depending on crop species and grinding intensity (GRONE 2018)



| | 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 H₂O
- incubation time 30 min (38° C)
- centrifugation (10000 g)
- measurement with Brookfield Viscometer DV-II



Extract viscosity of ground rye samples

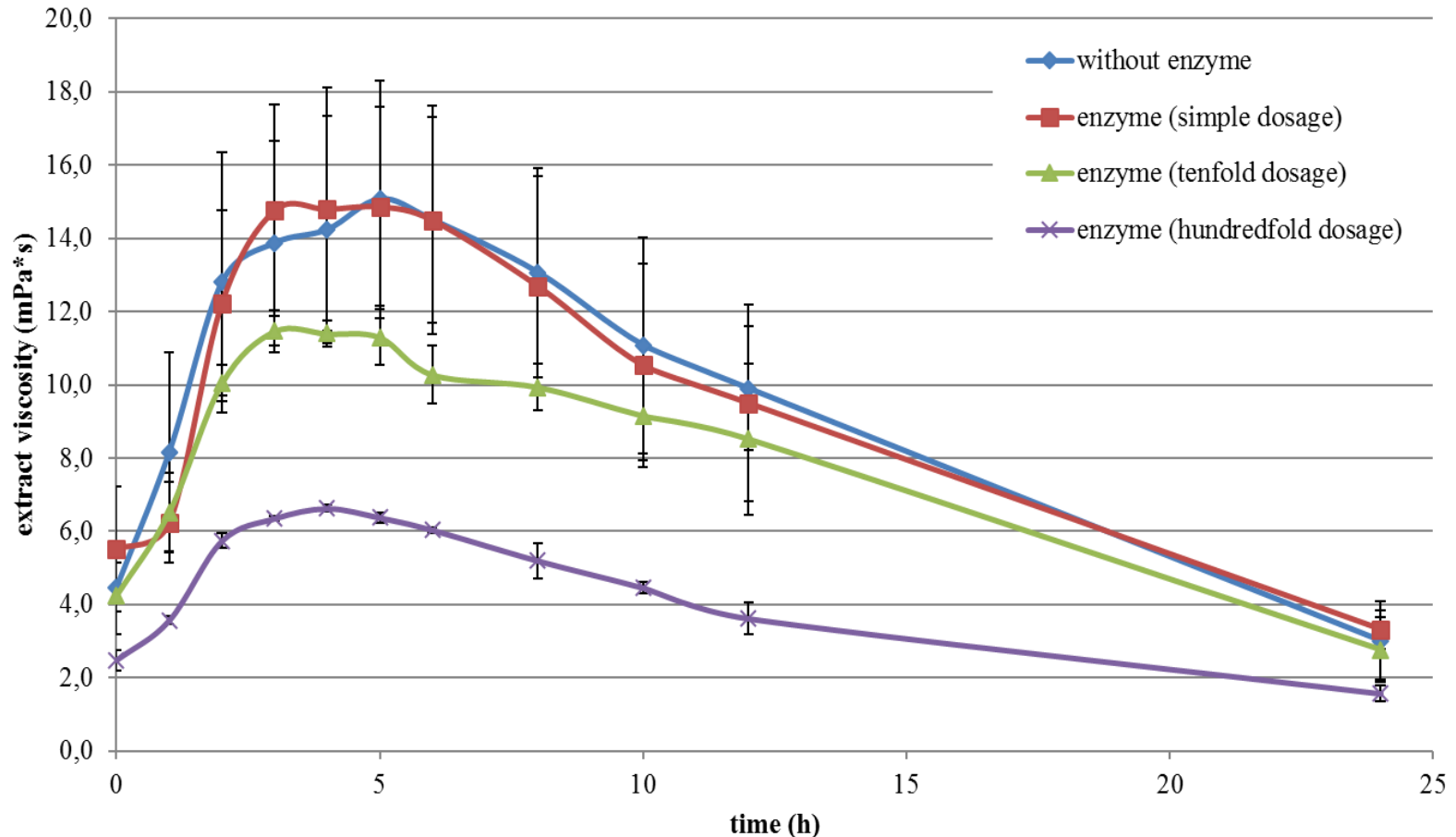
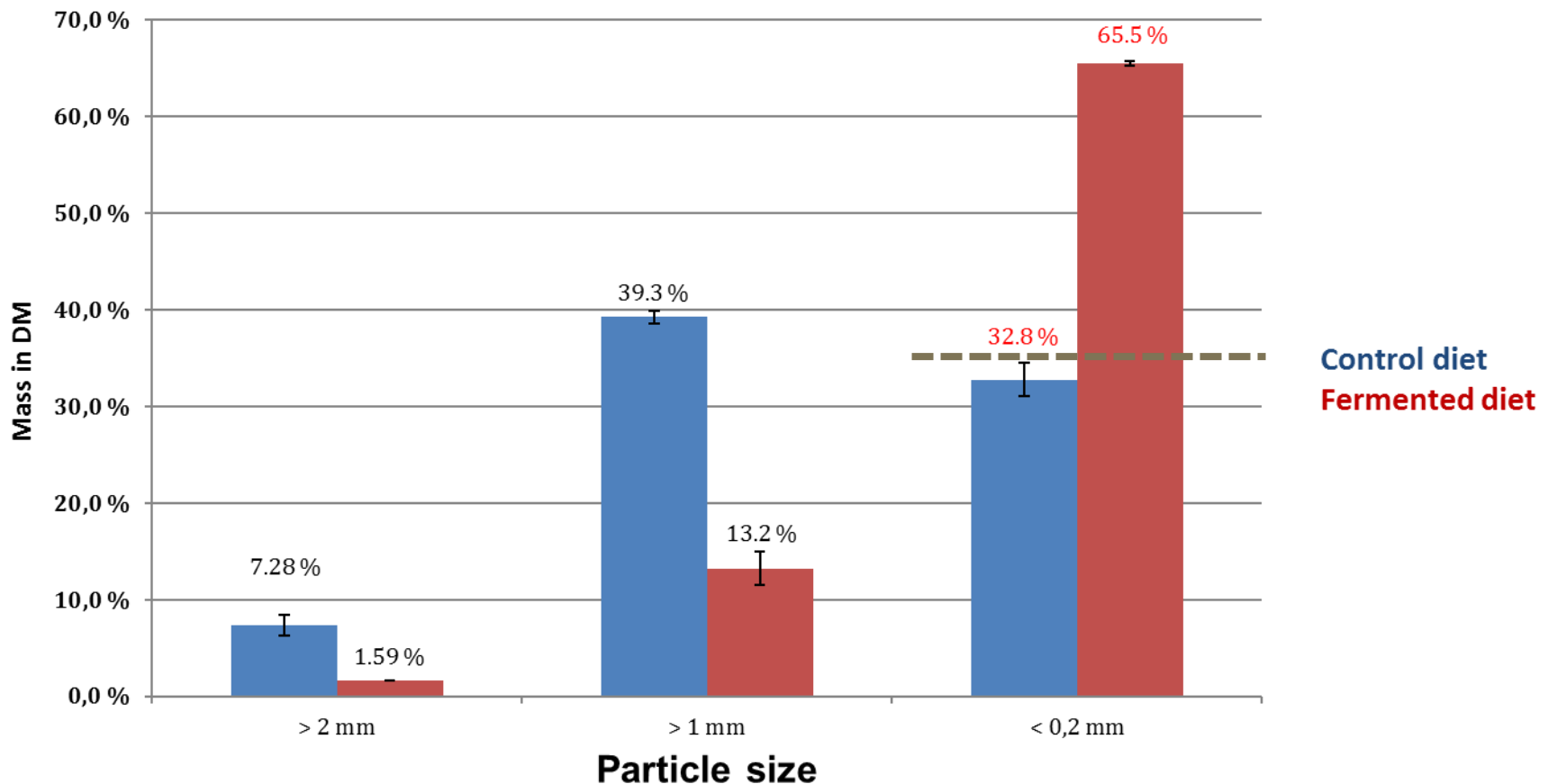


Fig.: Changes in extract viscosity of rye (ground by a hammer mill, sieve: 1 mm) during soaking/fermentation, modified by activity of xylanase (simple enzyme dosage: 2000 FXU/g; GRONE 2018)

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

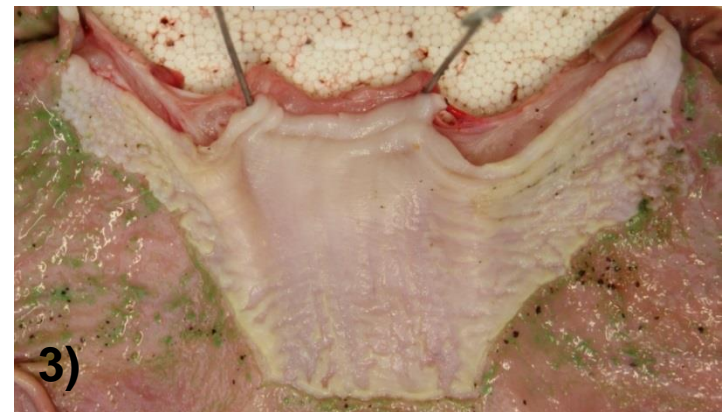
GRONE 2018

- 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 viscosity¹⁾ (RODEHUTSCORD et al. 2016)



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

¹⁾ estimated as described by DUSEL et al. (1997)

Background

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



SOWS

25 %



PIGLETS

10 %
< 15 kg BW

20 %
> 15 kg BW



FATTENING-PIGS

30 %
28-40 kg KG BW (pre-fattening)

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>

21.08.2019

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)

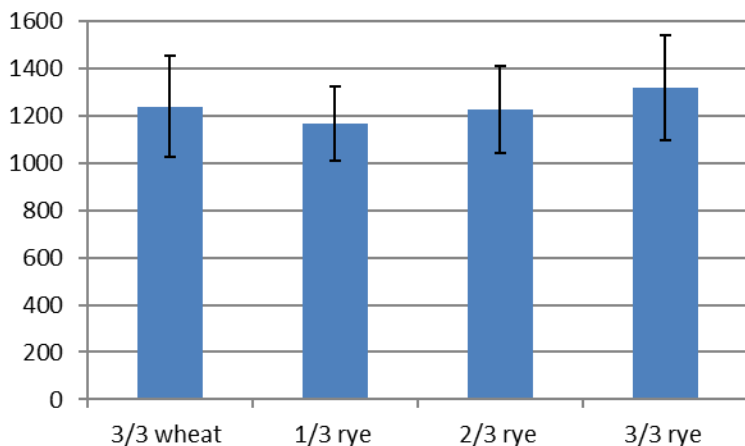
PERFORMANCE: DM INTAKE/GAINS



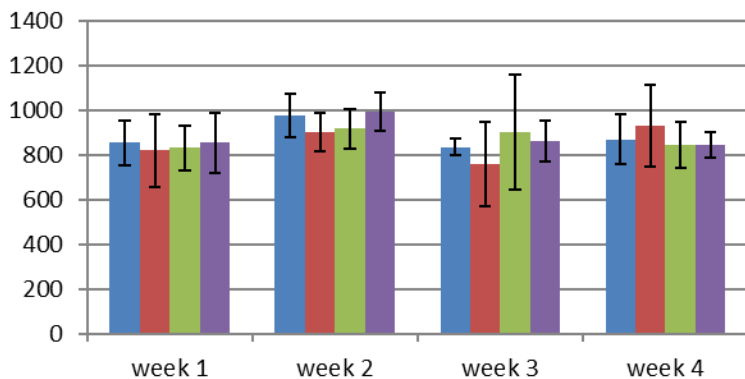
WILKE, thesis in prep.

TRIAL 1.1

DM-intake /day (g)



body weight gains (g)

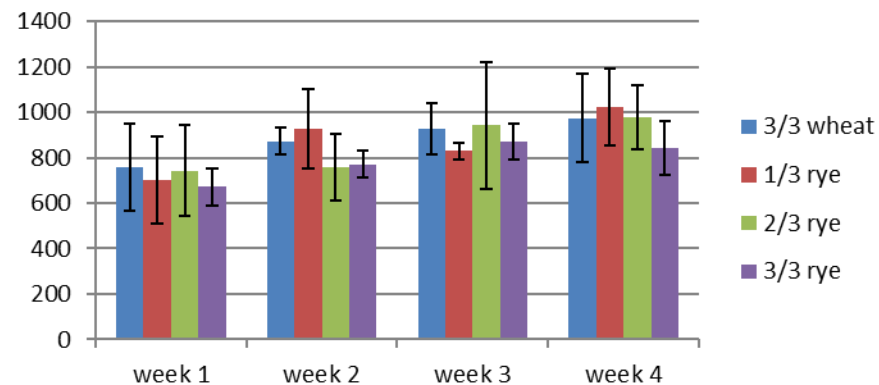


TRIAL 1.2

DM-intake /day (g)



body weight gains (g)



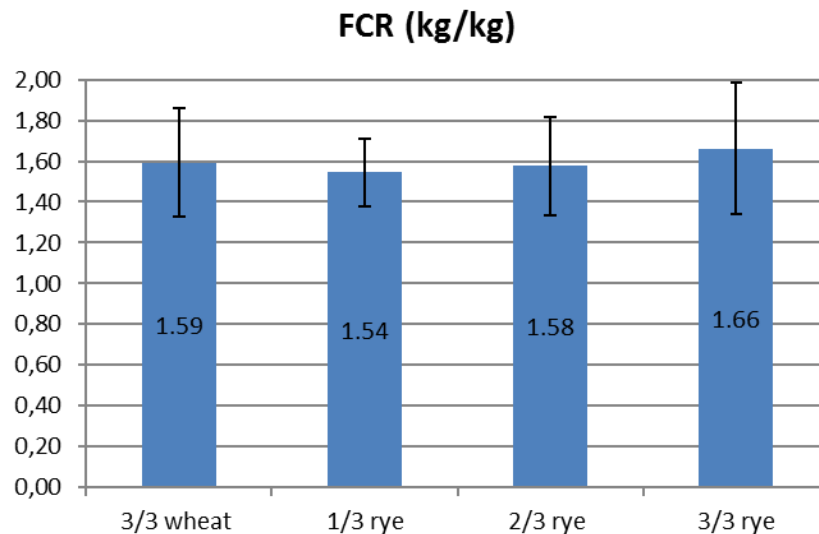
Results (wheat vs. rye)

PERFORMANCE: FEED CONVERSION RATIO

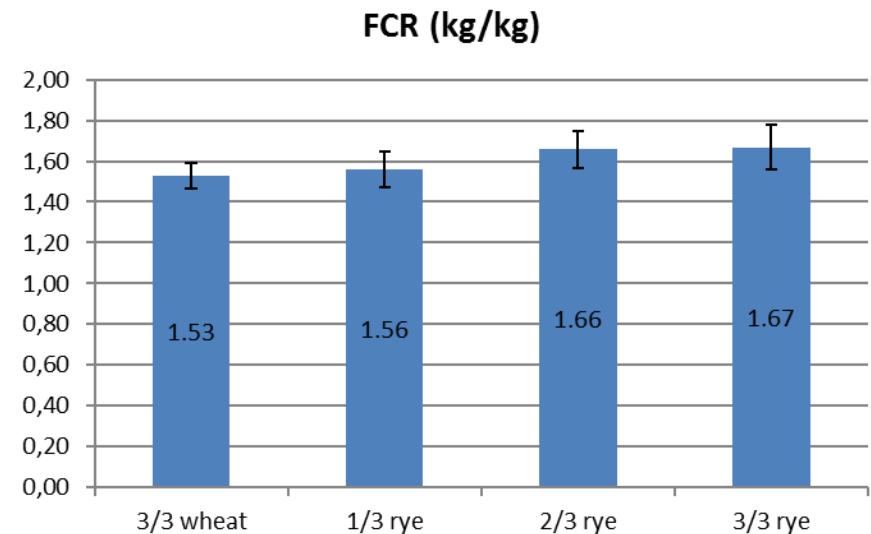


WILKE, thesis in prep.

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 |

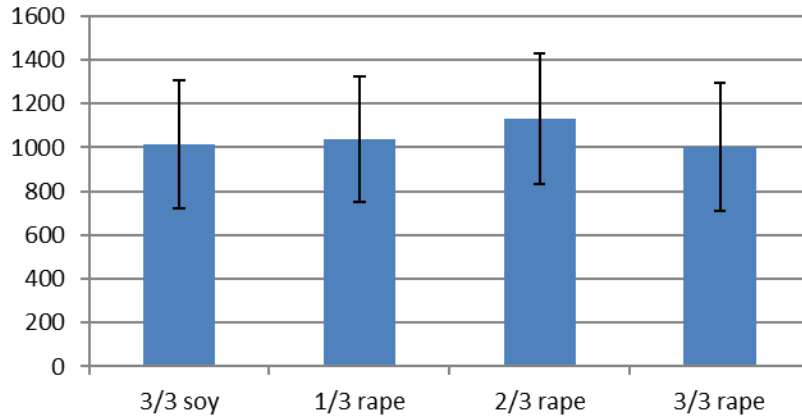
Results (soy vs. rapeseed)

PERFORMANCE: DM INTAKE/GAINS

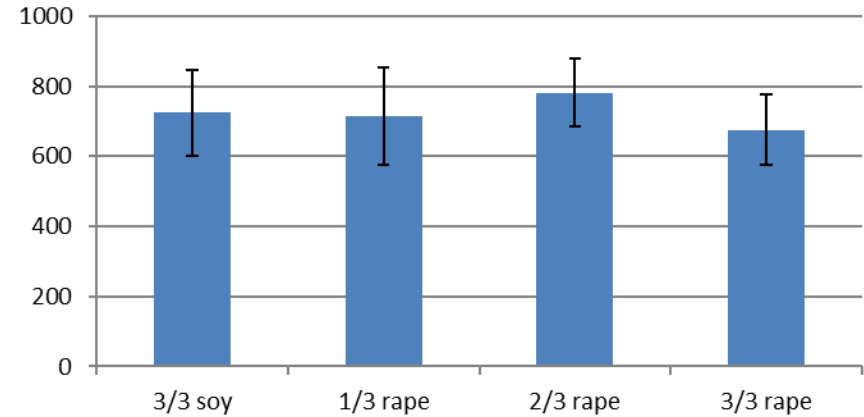


WILKE, thesis in prep.

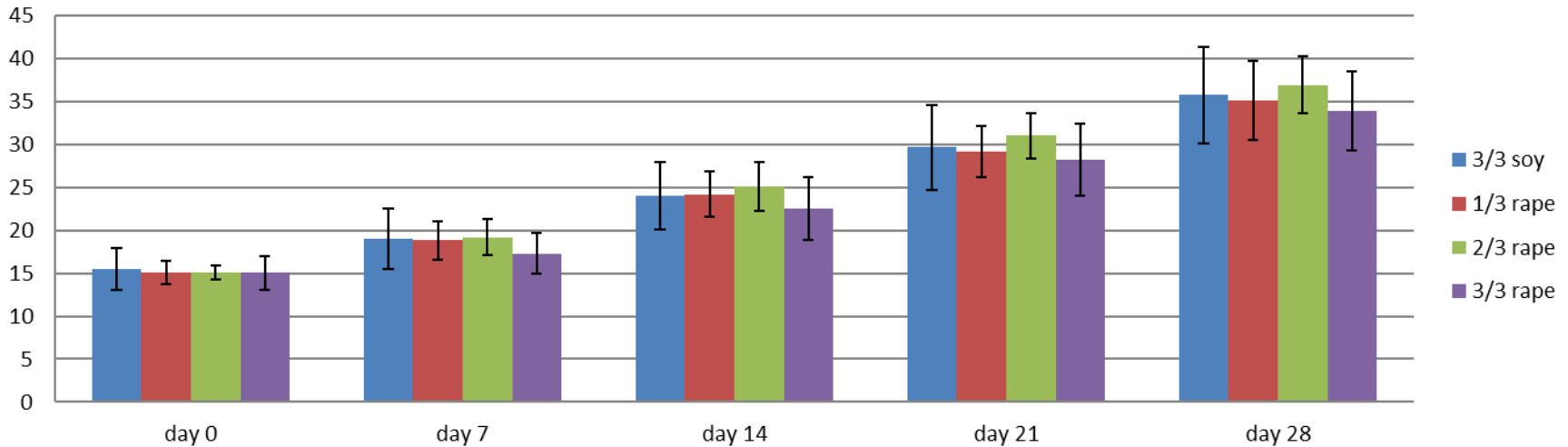
DM- intake / day (g)



daily weight gains (g)



body weight (kg)



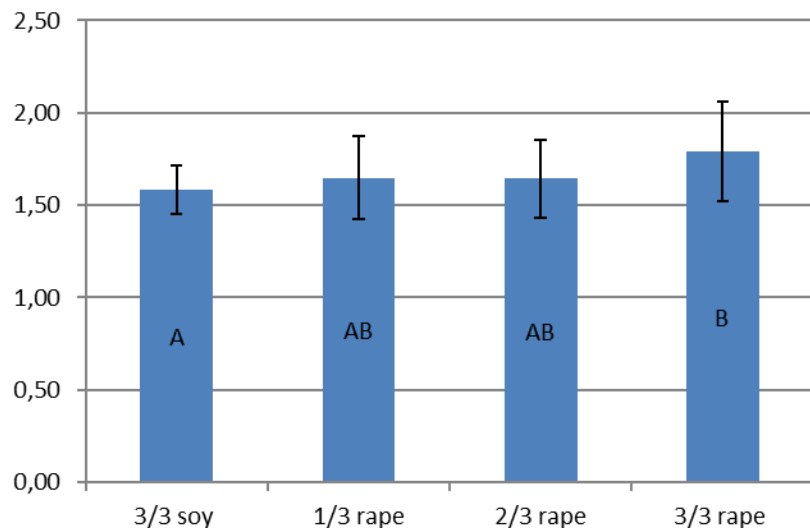
Results (soy vs. rapeseed)

PERFORMANCE: FEED CONVERSION RATIO

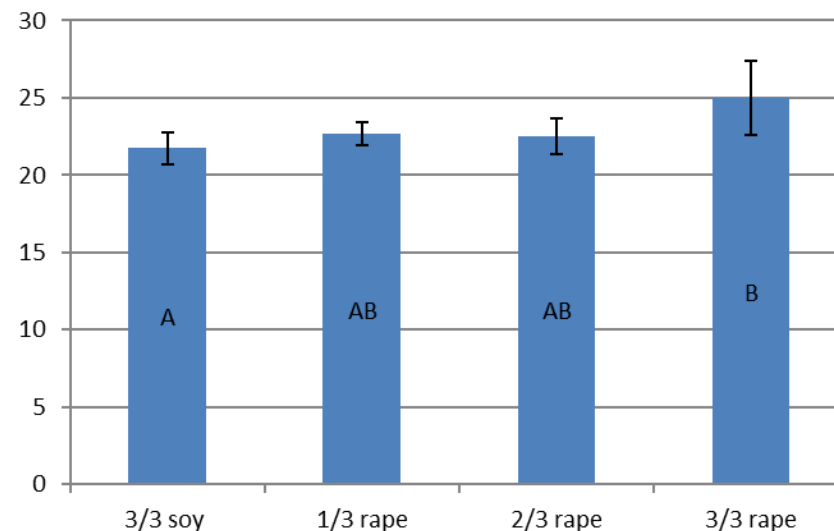
WILKE, thesis in prep.



FCR (kg / kg)



MJ ME / kg gain



| | 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

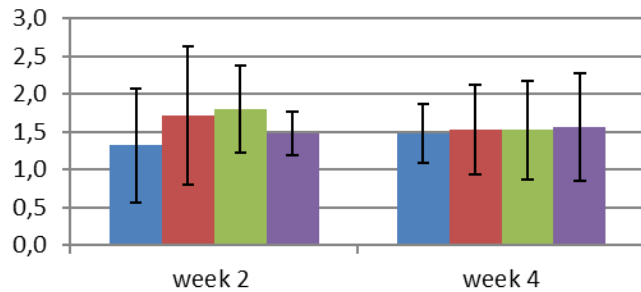
WILKE, thesis in prep.

| feces score | consistency |
|-------------|---------------|
| 1 | firm, formed |
| 2 | pulpy, formed |

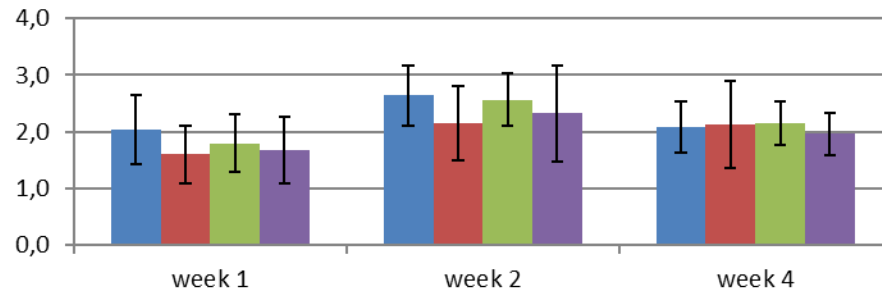
| | |
|---|-----------------|
| 3 | pulpy, unformed |
| 4 | soupy |
| 5 | watery |

■ 3/3 wheat
■ 1/3 rye
■ 2/3 rye
■ 3/3 rye

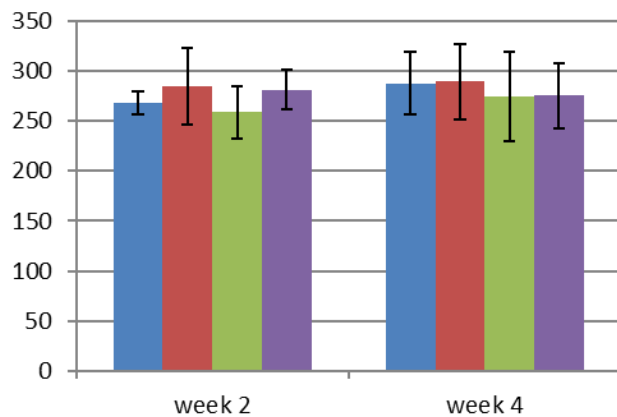
TRIAL 1.1 feces score



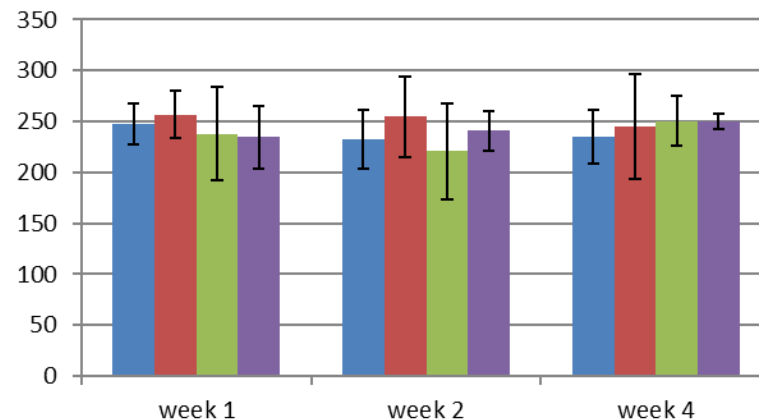
TRIAL 1.2 feces score



feces DM content (g / kg)

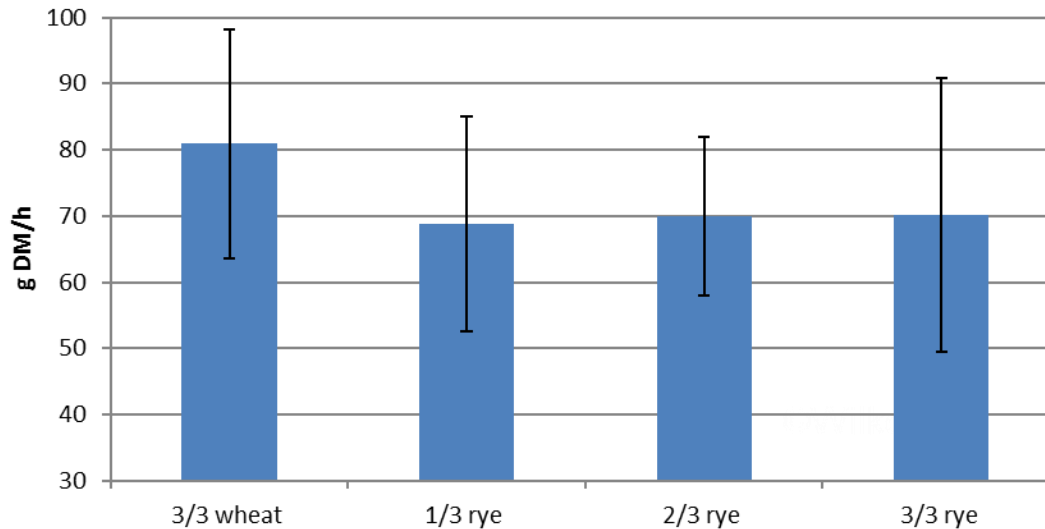


feces DM content (g / kg)



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

WILKE, thesis in prep.

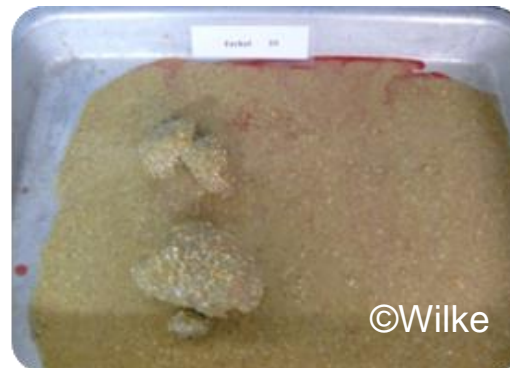


| DM outflow (g) / hour* | |
|------------------------|-------------|
| 3/3 wheat | 80.9 ± 17.3 |
| 1/3 rye | 68.7 ± 16.2 |
| 2/3 rye | 70.0 ± 12.0 |
| 3/3 rye | 70.1 ± 20.7 |

***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

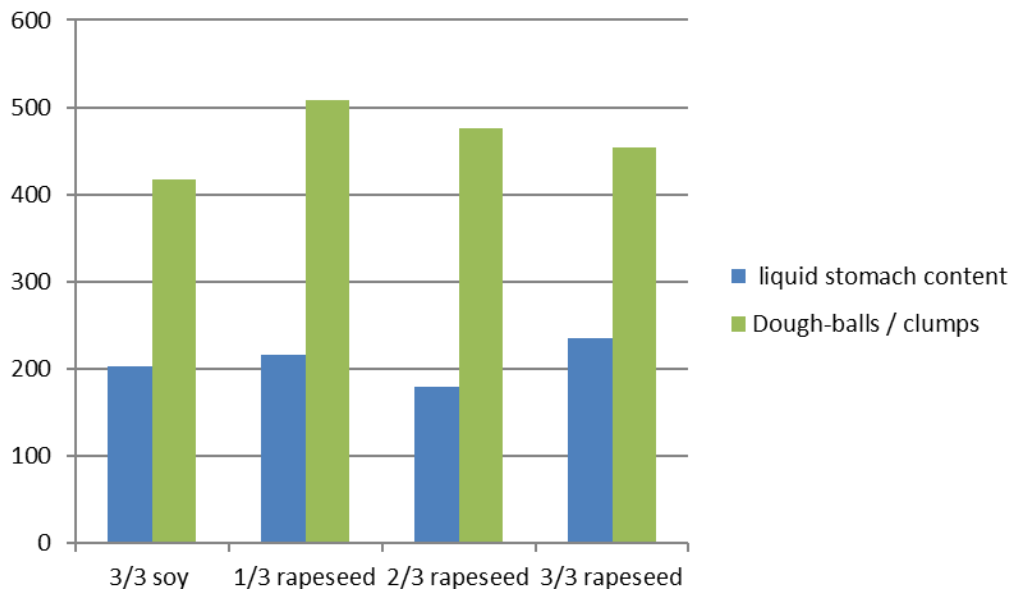
WILKE, thesis in prep.



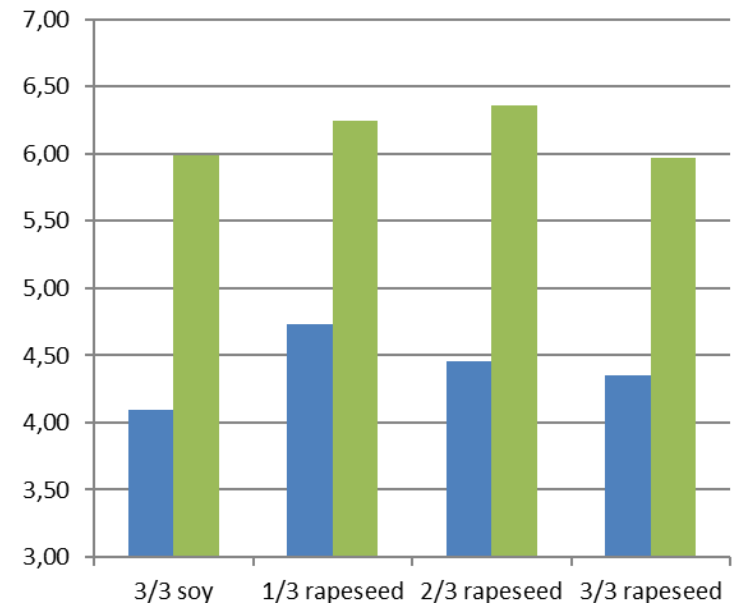
“Dough-balls / clumps“: data on amounts / DM content and pH

| 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 |

DM content (g/kg)



pH



Results (wheat vs. rye)

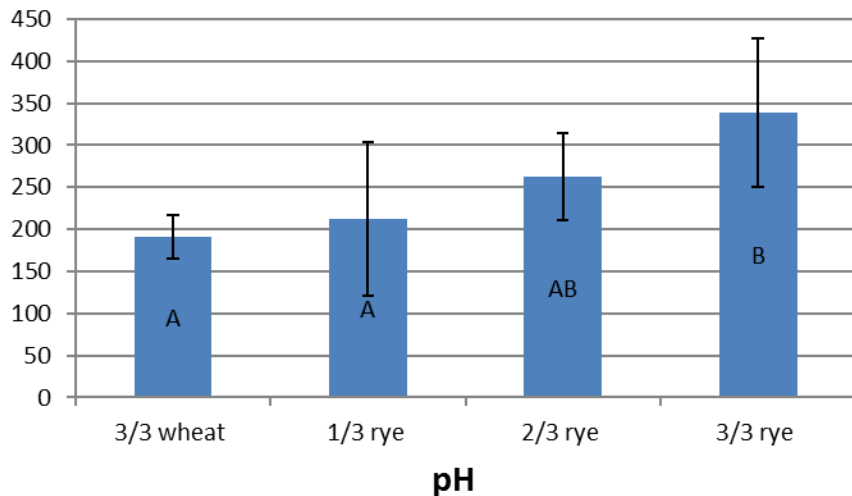
STOMACH DIGESTA: DM CONTENT AND pH

WILKE, thesis in prep.



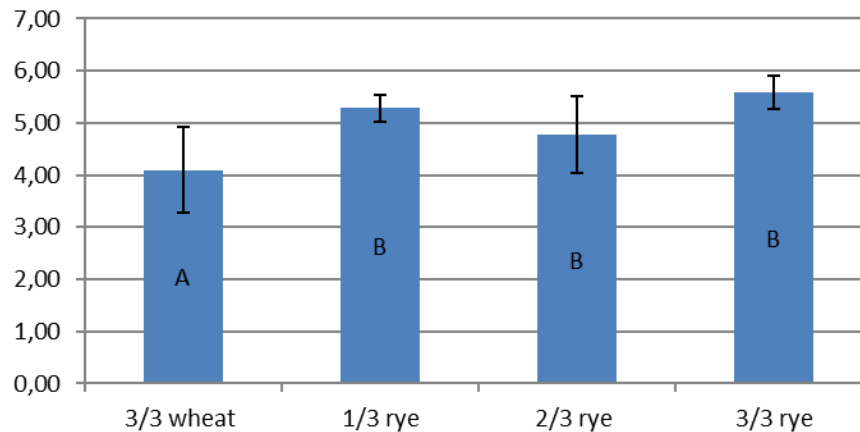
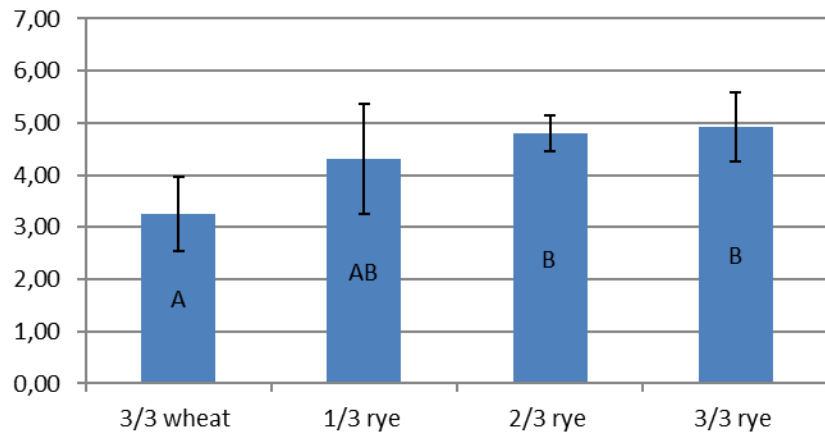
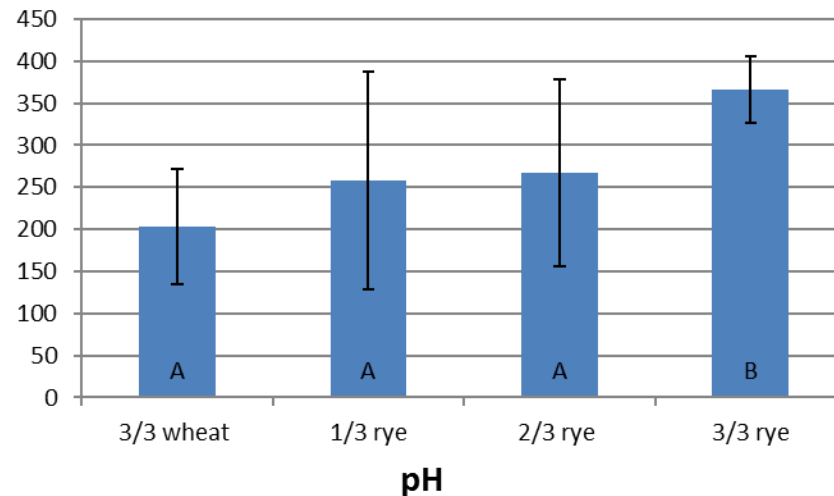
TRIAL 1.1

DM content (g/kg)



TRIAL 1.2

DM content (g/kg)



Results (wheat vs. rye)

STOMACH'S ULCERS: SCORE / DESCRIPTION

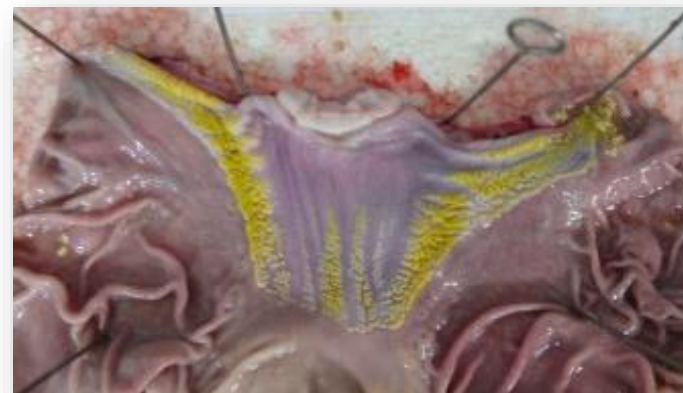
WILKE, thesis in prep.



Score for describing stomach health

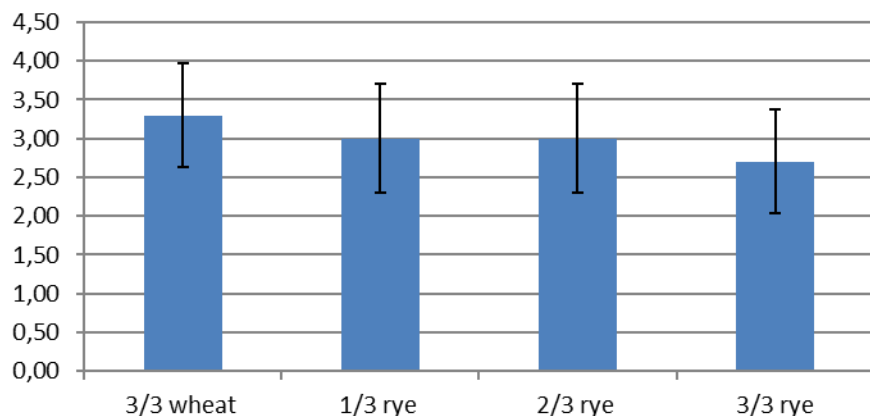
| | |
|---|--------------------------|
| 0 | no changes / alterations |
| 1 | slight hyperkeratosis |
| 2 | moderate hyperkeratosis |
| 3 | high hyperkeratosis |
| 4 | erosion |
| 5 | ulcer |

Stomach with moderate hyperkeratosis



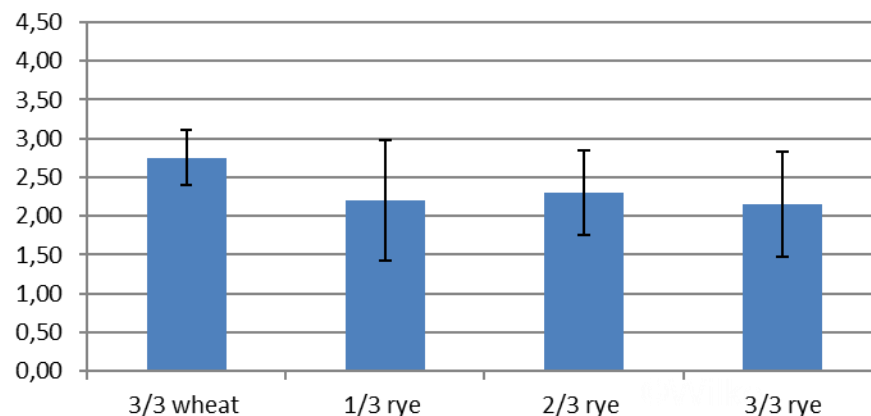
Trial 1.1

stomach score



Trial 1.2

stomach score



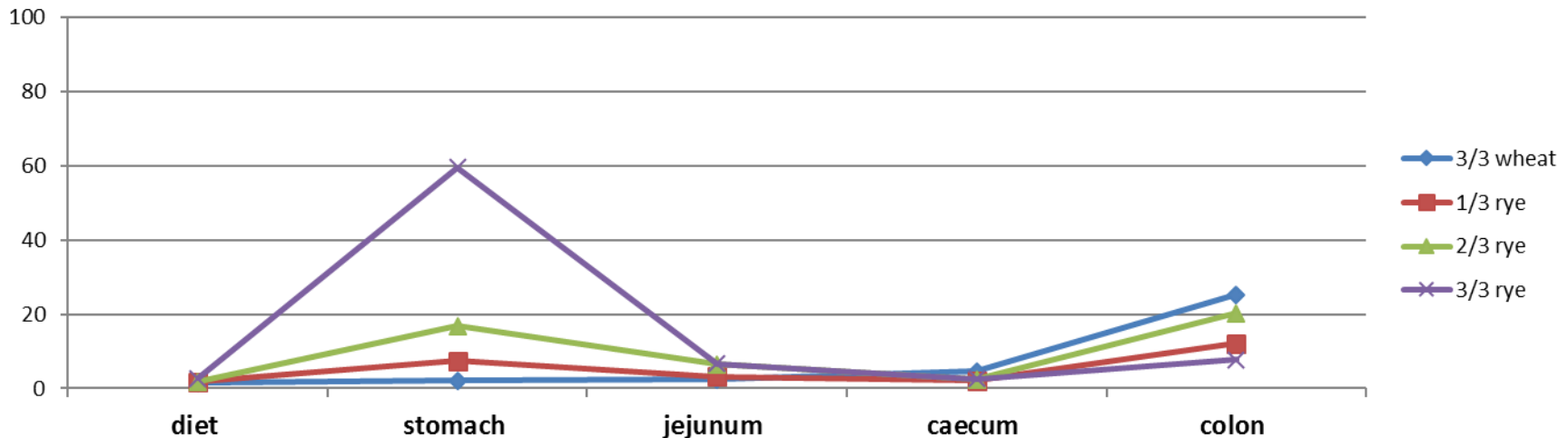
Results (wheat vs. rye)

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 |

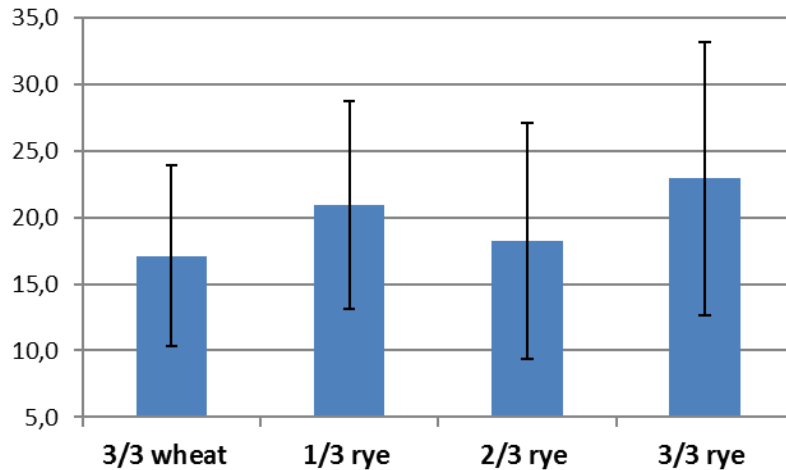
Results (wheat vs. rye)

“GUT FILL“: AMOUNTS OF COLONAL DIGESTA



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

colon digesta, WW (g) / BW (kg)



colon digesta DM (g) / BW (kg)



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 |

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

- **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

Dry matter-
“disappearance rate“

- Microbial degradation of the substrate

Gas Production System („GPS“)



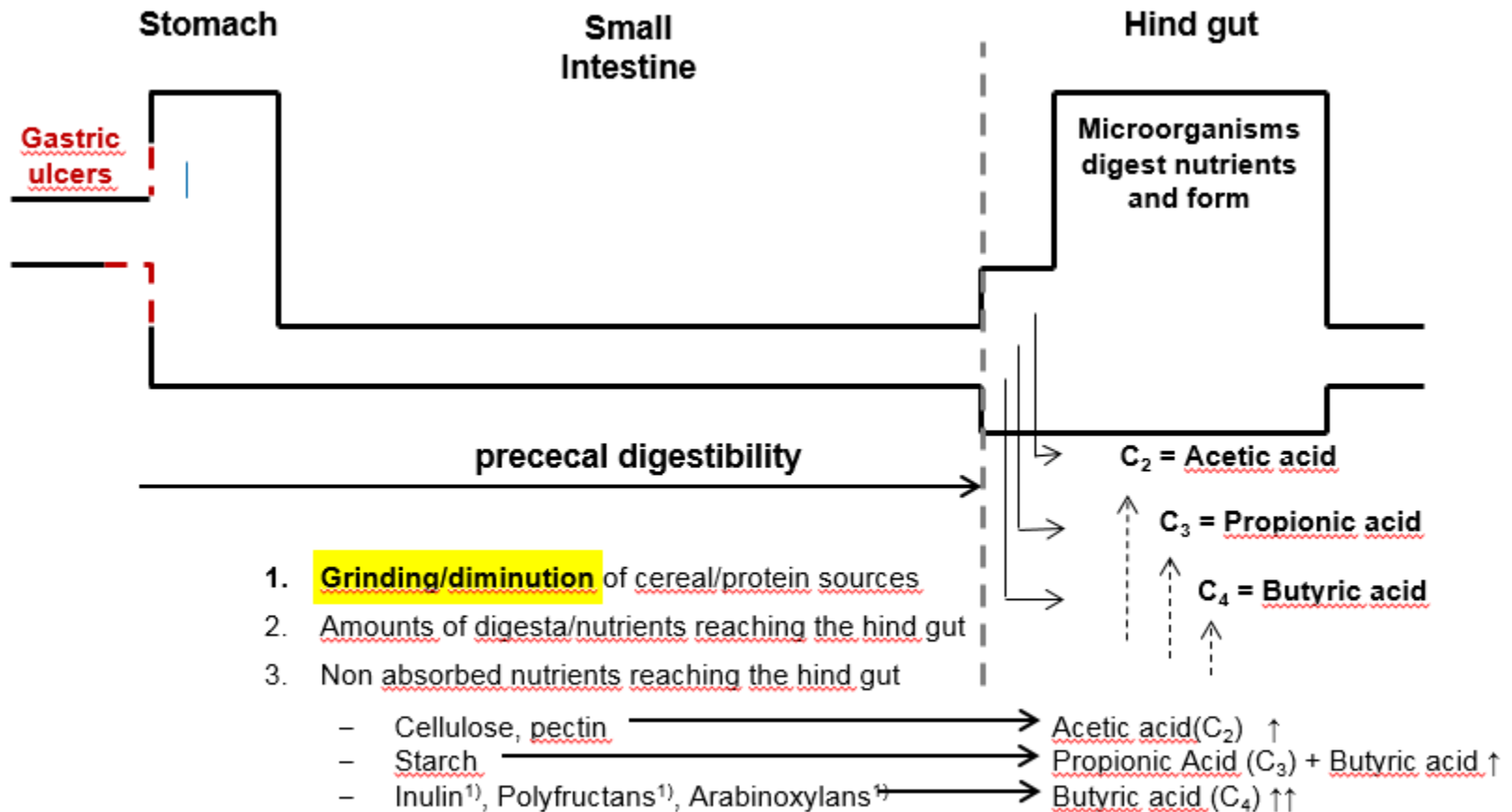
© ANKOM Technologies

Measuring of

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

The Alimentary Tract of Pigs – a Model

Kamphues et al. 2017



¹⁾ 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 histone deacetylase)
(Xlong et al. 2016)

Activation of pro-
inflammatory cytokines
like $\text{TNF}\alpha$, $\text{IL-1}\beta$, 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!

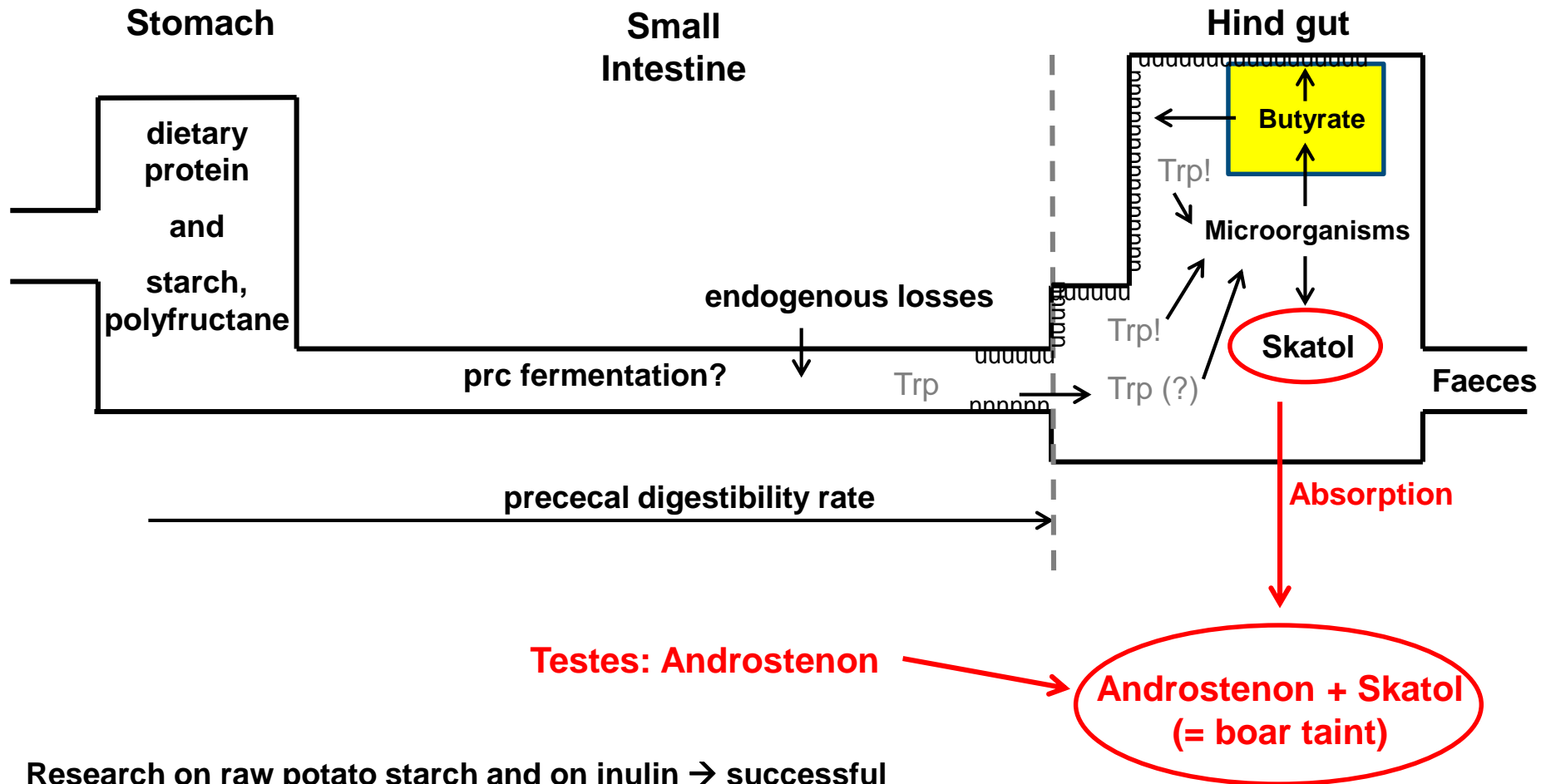
Experiments in pigs: rye bread instead of wheat bread
catheterization of draining vessels
fistulation at the terminal ileum

| 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): | wheat bread | rye bread | (factor) |
|------------------------------|------------------|----------------------------------|----------|
| 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 | Chicory inulin ¹⁾ | Jerusalem artichoke ²⁾ | | |
|--|--------------------|---------------------------------|--------------------------------------|-------------------|--------------------|
| | — (0) | (9) | 4.1 | 8.1 | 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

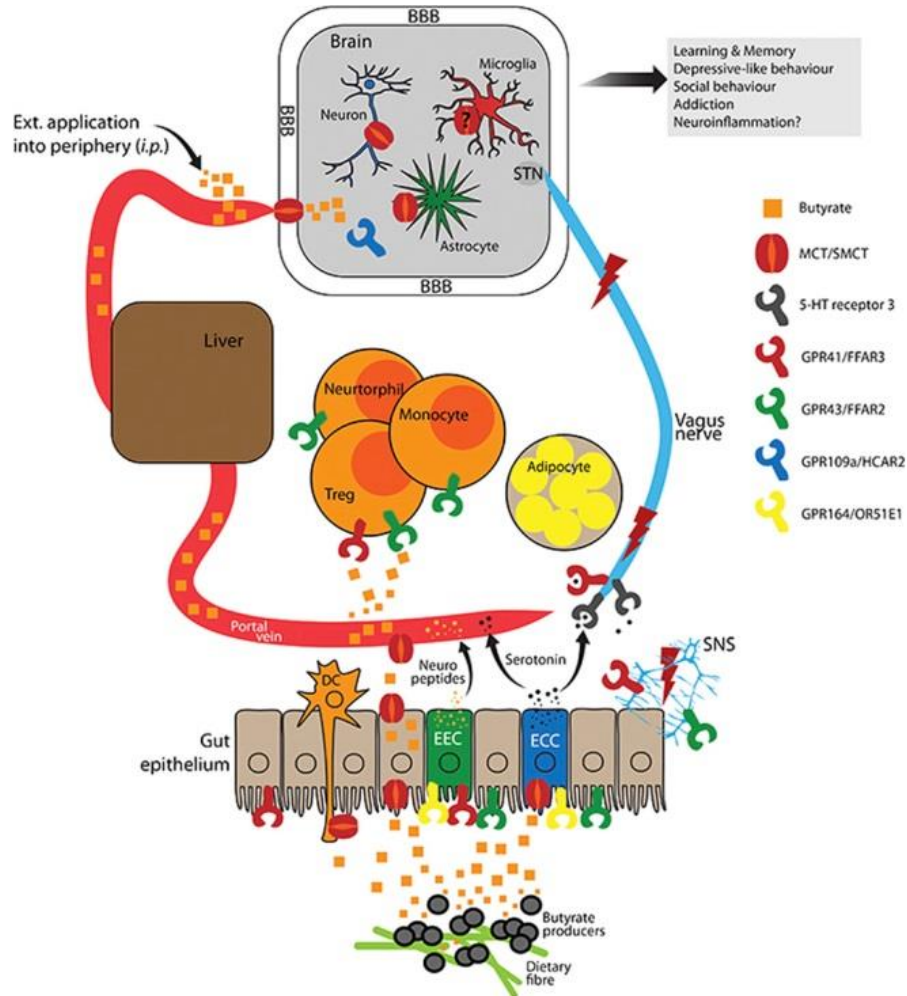
→ Do fermentation rates and/or patterns affect behavior?

- **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)