RESEARCH REPORT

NPB FINAL RESEARCH GRANT REPORT FORMAT

As a requirement of each research grant, a final report detailing the project results must be provided to the National Pork Board. Please write the industry summary with the producer in mind. The remaining content of the report can be written for a scientific audience. *ALL final reports must be submitted in the following format or the report will be returned for correction. PLEASE DO NOT INCLUDE ANY TYPE OF COVER PAGE.*

Project Title and NPB project identification number: *Use of hybrid rye in diets for growing and reproducing pigs: A literature review and determination of green-house gas emissions***.**

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Date Report Submitted: December 20, 2024

Industry Summary:

The objective of this project was to evaluate the nutritional value of hybrid rye as an alternative to corn in pig diets and to assess its impact on greenhouse gas emissions and nitrogen (N) excretion in pig manure. To achieve this, we conducted a detailed literature review and an animal experiment using growing pigs housed in indirect calorimeter chambers to measure gas exchanges and N balance. The published literature was searched for manuscripts about composition of hybrid rye, nutrient digestibility in hybrid rye, and impacts of including hybrid rye for growing and reproducing swine. A total of 54 peer-reveiwed published articles and 7 abstracts were identified in the search and data from these publications were summarized. In the animal experiment, three diets were tested: a control diet containing corn and soybean meal, and two diets where corn was partially (50%) or fully (100%) replaced by hybrid rye. Results showed that increasing hybrid rye in diets did not affect the production of carbon dioxide (CO_2) or methane (CH_4) by pigs, which indicates that increasing hybrid rye in pig diets does not increase or decrease greenhouse gas emissions. Interestingly, the respiratory quotient (RQ), which is a measure of energy utilization in the body and reflects nutrient composition of diets, was reduced when hybrid rye was used, which likely is because hybrid rye contains less starch than corn. Nitrogen excretion in manure and overall N utilization were also not negatively impacted by feeding hybrid rye, even though hybrid rye contains more protein than corn. Because hybrid rye requires less water and fertilizer to grow, it may provide both economic and environmental benefits. Additionally, the need for supplemental amino acids and feed phosphates will be reduced by using more hybrid rye in pig diets because hybrid rye contains more protein and minerals compared with corn. These findings will provide pork producers with a sustainable and cost-effective alternative to corn. Further research is needed to understand the long-term effects of hybrid rye on pig performance and carcass quality. In conclusion, replacing corn with hybrid rye in pig diets can help producers meet growing environmental pressures without compromising production efficiency or sustainability. For more information, please contact Hans Stein, University of Illinois, at hstein@illinois.edu.

Key Findings:

- Hybrid rye has greater digestibility of phosphorus than corn because of greater concentration of intrinsic phytase, and hybrid rye also contains more fermentable fiber than corn.
- Hybrid rye contains less metabolizable energy than corn
- Hybrid rye may replace 65, 100, and 75% of corn in diets for weanling pigs, growing finishing pigs, and sows, respectively.
- Less feed phosphates need to be used if hybrid rye is used instead of corn in diets
- Increasing hybrid rye in diets did not affect the amount of CO_2 and CH_4 produced by growing pigs.
- Increasing hybrid rye in diets reduced respiratory quotient by growing pigs.
- Increasing hybrid rye in diets did not affect N excretion in manure by growing pigs.

Keywords: hybrid rye, literature review, green-house gas

Scientific Abstract: The first objective of the current work was to conduct a literature review of all published information related to the feeding value to pigs of hybrid rye for swine and to provide feeding recommendations based on the summarized data. The second objective was to conduct an animal experiment to determine greenhouse gas emission from pigs fed diets based on hybrid rye and compare those values to diets containing corn. In the literature review, 54 peer-reviewed manuscripts and 7 abstracts were used to summarize current knowledge about chemical composition and nutrient and energy digestibility in hybrid rye, and conclusions about recommended inclusion levels were also identified. In the animal experiment, a total of 24 pigs (initial body weight: 52.38 ± 2.52 kg) were assigned to 6 calorimeter chambers with 4 pigs per chamber. Chambers were allotted to a replicated 3 × 3 Latin square design with 3 diets, 6 chambers, and 3 periods. Therefore, there were a total of 6 replicates for each diet. Each chamber was equipped with a stainless steel wet-dry feeder, and an auxiliary nipple waterer was in each chamber to ensure free access to water. Fecal and urine materials were quantitatively collected, and gas exchanges were recorded. The statistical model included diet as the fixed effect and chamber and period as the random effects. Linear effects of increasing hybrid rye were analyzed using contrast coefficients. Results of the literature review indicated that the digestibility of phosphorus is greater in hybrid rye than in other cereal grains because of a much greater concentration of intrinsic phytase, but the concentration of digestible energy is less in hybrid rye than in corn and wheat due to a greater concentration of fiber. Hybrid rye can replace up to 65% of corn in diets for weanling pigs, and all corn in growing-finishing diets can be replaced by hybrid rye without negative impacts on growth performance. However, hybrid rye can only replace up to 75% of corn in diets for gestating or lactating sows. Results of the animal experiment indicated that respiratory quotient (**RQ**) of pigs during the fasted period was not affected, but RQ of pigs during the fed period was reduced (linear; $P = 0.047$) by increasing hybrid rye in diets. Consumption of O_2 and productions of CO_2 and CH_4 were not affected by dietary treatment. Nitrogen intake was not affected by dietary treatment, but concentration of N in feces was greater ($P < 0.020$) when corn was completely replaced by hybrid rye. However, digestibility and retention of N and excretion of N in feces and urine were not affected by increasing hybrid rye in diets.

Introduction: Feeding of hybrid rye to pigs is unfamiliar to most pork producers in the U.S. and there is relatively little applied information about feeding rye to swine. However, during the last few years, a number of peer-reviewed publications and abstracts related to nutritional values of hybrid rye fed to pigs have been published. There is, therefore, a body of literature available that can be used to make conclusions about the impact of using hybrid rye in diets for swine. However, at this time, no reviews in which the literature were systematically been summarized to produce an easy-to-use overview over the nutritional characteristics of hybrid and no general recommendations (based on published literature) for use of hybrid rye in diets for swine were available. Likewise, whereas the nutritional value of rye had been documented, there was no information about how hybrid rye influences production of green-house gases (i.e., carbon dioxide and methane) when fed to growing pigs. It was, therefore, not known if a change from using corn to using hybrid rye would result in a change in production of green-house gases.

Objectives:

There were two objectives of this work:

1. To conduct an exhaustive literature review of all published information related to the feeding value to pigs of hybrid rye for swine and to provide feeding recommendations based on the summarized data.
2. To conduct an animal experiment to determine greenhouse gas emission from pigs fed diets based on hybrid rye and compare those values to diets containing corn.

Specific aims of this work included:

a. Summary of all data related to the chemical composition of hybrid rye.
b. Summary of all data related to the digestibility of energy and nutrients in hybrid rye.
c. Summary of results of growth performance experiments and experiments with gestating and lactating sows.
d. Recommendations for using hybrid rye in diets for pigs.
e. Determination of the impact of hybrid rye on greenhouse gas emission from growing pigs.

Materials & Methods:

Objective 1: Literature review

The literature review utilized a literature search to compile previously published peer-reviewed journal articles and abstracts to summarize energy and nutrient composition, digestibility, characteristics, and utilization of hybrid rye in swine. The search was performed via the PubMed database, Web of Science of the University of Illinois at Urbana Champaign Library, and Google Scholar. Search terms including (RYE, HYBRID RYE) AND (PIGS OR SWINE) AND the respective search item of interest (protein, amino acids, phosphorus, energy, digestibility, growth performance, nursery, finishing, sows, carcass, mycotoxin, ergot alkaloids, fiber, starch, gastrointestinal, microbiome, and intestinal). Articles were not restricted based on region but were restricted to the English language. Once relative articles were identified, they were filed and categorized according to topic for further evaluation. Data were collected from 54 published peer-reviewed journal articles and 7 abstracts.

Objective 2: Animal experiment

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment. Pigs were the offspring of Line 800 boars and Camborough females (Pig Improvement Company, Hendersonville, TN, USA).

Diets

Three diets were formulated (Table 1). A control diet contained corn and soybean meal as energy sources (Table 2). Two additional diets were formulated by replacing 50% or 100% of the corn in the control diet by hybrid rye. All diets contained amino acids, minerals, and vitamins at or above the requirements of pigs (NRC, 2012).

Animals, housing, and sample collection

A total of 24 pigs (initial body weight: 52.38 ± 2.52 kg) were used. The 24 pigs were assigned to 6 calorimeter chambers with 4 pigs per chamber. Chambers were allotted to a replicated 3 × 3 Latin square design with 3 diets, 6 chambers, and 3 periods. Therefore, there were a total of 6 replicates for each diet. Each chamber was equipped with a stainless steel wet-dry feeder, and an auxiliary nipple waterer was installed in each chamber to ensure free access to water. Each chamber was equipped with a slatted floor, 4 stainless steel fecal screens, and 2 urine pans for total, but separate, collection of fecal and urine materials. The temperature and relative humidity inside the chambers were controlled by a temperature and humidity control unit, and the air velocity was controlled using an airflow meter (AccuValve; Accutrol, LLC, Danbury, CT, USA). Throughout the experiment, pigs were allowed ad libitum access to feed. Diets were fed for 13 days, where the initial 7 days were considered the adaptation period to the diet. At 0700 h on d 8, the gas analyzers started measuring O_2 consumption and CO_2 and CH_4 productions. Fecal and urine samples were also collected from d 8 to d 13. During the collection period and to avoid nitrogen (**N**) loss in the urine, 100 ml of 6 *N* HCl was added to each urine pan every day, for a total of 200 ml of 6 *N* HCl per chamber. Chambers were opened every day to check feeders, and for collection of fecal and urine materials from the chambers. Data from the gas analyzers obtained during the period that the chambers were open and until they reached the condition set by the temperature and humidity control unit was disregarded in the calculation of gas exchanges. Fecal samples and 5% of the urine were stored at −20 °C immediately after collection.

Chemical analysis

At the conclusion of the experiment, urine samples were thawed and mixed within chamber and diet, and a sub-sample was stored. Fecal samples were thawed and mixed within pig and diet, and then dried in a 50 °C forced air drying oven prior to analysis (Heratherm OMH750, Thermo Fisher Scientific, Pittsburgh, PA, USA). Fecal samples were ground through a 1-mm screen using a hammermill (model: MM4; Schutte Buffalo, NY, USA). Diets and ingredient samples were analyzed for gross energy (**GE**) using bomb calorimetry (Model 6400; Parr Instruments, Moline, IL, USA). Diets, ingredients, and fecal samples were analyzed for dry matter (**DM**; method 930.15; AOAC Int., 2019) and ash (method 942.05; AOAC Int., 2019) was analyzed in diet and ingredients samples. Acid-hydrolyzed ether extract in diets and ingredients was determined by acid hydrolysis using 3 *N* HCl (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY, USA) followed by fat extraction (Ankom XT-15 Extractor, Ankom Technology, Macedon, NY, USA). Nitrogen in ingredient, diet, and fecal samples were analyzed using the combustion procedure (method 990.03; AOAC Int., 2019) on a LECO FP628 (LECO Corp., Saint Joseph, MI, USA). However, N in urine was analyzed on a Kjeldahl apparatus. Crude protein was calculated as analyzed N × 6.25. Diet and ingredient samples were analyzed for insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**) according to method 991.43 (AOAC Int., 2019) using the Ankom TDF Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber (**TDF**) was calculated as the sum of IDF and SDF.

Calculations

The concentrations of O_2, CO_2, and CH_4 were averaged within the collection period. Consumption of O_2 and productions of CO_2, and CH_4 were expressed as *l*/d/pig, *l*/d/body weight, *l*/d/metabolic body weight, and *l*/d/g of N intake. Respiratory quotient (**RQ**) was calculated by dividing CO_2 produced by O_2 consumed. Nitrogen excretion and N balance were also calculated using analyzed N in diets, feces, and urine and weights of feces and urine.

Statistical analysis

Homogeneity of the variances and normality were confirmed and data were analyzed using the PROC MIXED in SAS. The statistical model included diet the fixed effects and chamber and period as the random effects. Mean values were calculated using the LSMeans statement. Linear effects of increasing hybrid rye were analyzed using contrast coefficients. Calorimeter chamber was the experimental unit. Results were considered significant at $P < 0.05$ and considered a trend at $P < 0.10$.

Results:

Objective 1: Literature review

Results of the literature review are attached in Appendix 1.

Objective 2: Animal experiment

Results indicated that RQ of pigs during the fasted period was not affected, but RQ of pigs during the fed period was reduced (linear; $P = 0.047$) by increasing hybrid rye in diets (Table 3). Consumption of O_2 and productions of CO_2 and CH_4 were not affected by dietary treatment. Nitrogen intake was not affected by dietary treatment, but concentration of N in feces was greater ($P < 0.020$) when corn was completely replaced by hybrid rye (Table 4). However, the apparent total tract digestibility (**ATTD**) of N, retention of N, and excretion of N in feces and urine were not affected by increasing hybrid rye in diets.

Discussion:

Objective 1: Literature review

The conclusions from the literature review demonstrated that hybrid rye is a suitable feed ingredient for growing and reproducing swine. As a cereal grain, hybrid rye provides similar quantities of standardized ileal digestible amino acids, slightly less metabolizable energy, and a greater amount of fermentable dietary fiber to diets compared with other cereal grains. These changes may result in a slightly reduced gain to feed ratio by growing-finishing pigs, but this has not been observed in all experiments, which may be because the fermentable fiber in hydrid rye have positive impacts on intestinal health. The increased digestibility of phosphorus is a clear advantage for hybrid rye, which will result in reduced usage of feed phosphates in diets containing hybrid rye. The observation that preweaning mortality is reduced if lactating sows are fed diets containing hybrid rye may be a result of sows being calmer due to the increased fermentable fiber in hybrid rye, which in turn results in fewer crushed pigs from these sows. The conclusion that hybrid rye may replace up to 65% of barley, wheat, or corn in diets for weanling pigs, up to 100% in diets for growing-finishing pigs, and up to 75% in diets for reproductive sows without negatively impacting growth and reproductive performance indicate that large quantities of hybrid rye can be used in the diets.

Objective 2: Animal experiment

Concentrations of fat and protein in hybrid rye were less, but concentrations of TDF, SDF, IDF, and GE were within the range of values reported in the literature. Concentrations of nutrients and GE in corn and soybean meal agreed with reported values (NRC, 2012). Using hybrid rye in swine diets may reduce diet cost and carbon footprint because producing hybrid rye requires less water and fertilizers (Miedaner and Laidig, 2019). By replacing corn with hybrid rye in diets, less feed phosphates were used in the experimental diets because hybrid rye contained more protein and minerals compared with corn, which also reduces diet cost. However, to our knowledge, there are no data for effects of using hybrid rye on green-house gas emissions from pigs. Even though O_2 consumption and CO_2 production were not affected by dietary treatment, the RQ was reduced by increasing hybrid rye in the diets because CO_2 production was numerically decreased with the relatively consistent O_2 consumption. This indicates that using hybrid rye in pig diets results in reduced CO_2 production relative to O_2 consumption. A lower RQ is associated with reduced carbohydrate utilization as an energy source in the body (Richardson, 1929). This aligns with the observation from the literature review that hybrid rye contains less starch than corn, which resulted in reduced starch in diets when more hybrid rye was used instead of corn. The lack of effects on the amount of green-house gas emissions indicates that nutrient utilization and metabolic efficiency were not changed by the substitution of corn with hybrid rye. Even though concentration of protein in hybrid rye is greater than in corn, N excretion in feces and urine and N utilization in the body were also not affected by increasing hybrid rye in diets. This indicates that hybrid rye can be used as an alternative to corn without negatively impacting the environmental footprint of pig production systems.

The pork industry is under growing pressure to reduce the carbon and N footprints. Result from this experiment will provide pork producers with an opportunity to adopt sustainable and cost-effective feeding strategies without compromising environmental outcomes. However, further research is needed to evaluate the long-term impact of hybrid rye on growth performance, carcass characteristics, and manure composition. This will also help pork producers make well-informed decisions about using hybrid rye in commercial feeding programs for pigs.

Literature cited

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Table 1. Ingredient and nutrient compositions of experimental diets, as-is basis

Item, %	Hybrid rye replacement, %		
	0	50	100
Ingredient			
Corn	77.08	38.57	-
Hybrid rye	-	38.58	77.25
Soybean meal	20.00	20.00	20.00
L-Lys·HCl, 78% Lys	0.26	0.22	0.17
DL-Met, 99% Met	0.03	0.03	0.03
L-Thr, 99% Thr	0.05	0.05	0.06
Limestone	0.77	0.88	0.97
Dicalcium phosphate	0.91	0.77	0.62
Salt	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.50	0.50	0.50
Analyzed nutrients, %			
Dry matter	88.53	89.80	90.41
Ash	3.65	4.00	4.41
Gross energy, kcal/kg	3,887	3,876	3,875
Crude protein	15.32	15.65	17.20
Acid hydrolyzed ether extract	2.78	2.12	1.58
Total dietary fiber	11.4	14.4	18.9
Soluble dietary fiber	1.9	3.6	6.9
Insoluble dietary fiber	9.5	10.8	12.0

Table 2. Nutrient composition of hybrid rye, corn, and soybean meal, as-is basis

Item, %	Hybrid rye	Corn	Soybean meal
Dry matter	90.09	88.30	90.27
Ash	1.68	1.29	6.33
Gross energy, kcal/kg	3,867	3,911	4,271
Crude protein	8.20	7.46	45.25
Acid hydrolyzed ether extract	0.70	3.06	2.37
Total dietary fiber	17.8	9.9	18.6
Soluble dietary fiber	4.8	1.2	3.3
Insoluble dietary fiber	13.0	8.7	15.3

Table 3. Green-house gas emissions from growing pigs fed experimental diets[1]

Item[2] (per one pig)	Hybrid rye replacement, %			SEM	Linearity[3]
	0	50	100		
Respiratory quotient, fasted	0.69	0.68	0.68	0.02	0.957
Respiratory quotient, fed	1.11	1.07	1.08	0.04	0.047
Gas exchanges, *l*/d					
O_2 consumption	871.24	878.38	875.49	38.89	0.860
CO_2 production	960.87	945.06	940.50	65.16	0.432
CH_4 production	-0.07	0.36	0.26	1.10	0.414
Gas exchanges, *l*/d/kg BW					
O_2 consumption	12.18	12.16	12.14	0.97	0.925
CO_2 production	13.38	13.00	12.97	0.81	0.261
CH_4 production	-0.001	0.005	0.003	0.02	0.442
Gas exchanges, *l*/d/kg $BW^{0.60}$					
O_2 consumption	66.98	67.14	67.00	2.50	0.991
CO_2 production	73.70	71.96	71.73	2.47	0.313
CH_4 production	-0.01	0.03	0.02	0.08	0.466
Gas exchanges, *l*/d/g N intake					
O_2 consumption	8.89	8.35	8.52	0.63	0.605
CO_2 production	9.79	8.92	9.11	0.57	0.349
CH_4 production	-0.0002	0.0033	0.0031	0.0104	0.469

[1]Least mean squares represent 6 replicates per dietary treatment except for CH_4 production data (n = 5).
[2]BW = body weight.
[3]Linear effects (*P*-value) of increasing hybrid rye in diets.

Table 4. Nitrogen (N) excretion and N balance in diets fed to growing pigs (n = 6)

Item (per one pig)	Hybrid rye replacement, %			SEM	Linearity[2]
	0	50	100		
N intake, g/d	98.80	110.46	103.27	9.75	0.574
N in feces, %	4.09	3.78	4.26	0.11	0.020
Fecal N excretion, g/d	17.63	16.86	16.80	0.89	0.164
ATTD[1] of N, %	81.93	83.96	83.63	1.56	0.312
Absorbed N, g/d	81.17	93.59	86.46	9.61	0.511
N in urine, %	0.25	0.25	0.25	0.05	0.951
Urine N excretion, g/d	21.90	24.07	23.87	4.27	0.366
Retained N, g/d	59.27	69.52	62.59	6.56	0.683
Retention of N, % intake	60.00	62.20	60.70	2.50	0.845

Retention of N, % absorbed	73.15	74.04	72.64	3.13	0.881

[1]ATTD = apparent total tract digestibility.

[2]Linear effects (*P*-value) of increasing hybrid rye in diets.