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Alternative ingredients and their feeding in swine and poultry production

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Abstract. With the increase in global human population, people living longer, and relocating from the countryside to urban centres, it is expected that the demand for animal food products will increase. Animal production competes with humans for basic grains. However, humans only consume ~30% of crops directly, therefore animal production is mostly complementary. This overview with a Canadian perspective provides a superficial look at on how we use non-food cereals, oilseeds, pulses and their coproducts and fractions to sustainably convert them into edible protein for human nutrition reducing waste streams. Feeding low-grade grains and coproducts may indeed increase the environmental footprint of animal agriculture. Nonetheless, it is undeniable the role ruminant and monogastric animals play in converting inedible plant material and coproducts into wholesome meat, milk, and eggs. Finding what to feed that is locally grown or sourced, even thought it may be of limited quality and(or) availability, seems a daunting challenge despite that it reduces feed cost and supports the local economy. We should evaluate diets more based on what non-human edible coproducts are included that could become meat, milk, and eggs for human nutrition rather than placing great emphasis on animal performance parameters. Fear of antinutritional factors and mycotoxins on animal performance limits our feed cost advantage. Increased feed and food safety risk is indeed part of getting more out of compromised feedstuffs to reduce waste. Policy changes are required to embrace a circular bioeconomy that would contribute to prevent climate crisis.

Keywords: coproducts, environmental footprint, feedstuffs, fractions, poultry, swine

Ingredientes alternativos y su alimentación en la producción porcina y avícola

Resumen. Con el crecimiento de la población mundial, gente viviendo más años, y relocalización del campo a centros urbanos, se espera que la demanda por productos alimenticios de origen animal va a incrementar. La producción animal compite con humanos por granos básicos. Sin embargo, solo ~30% de las cosechas son utilizadas por humanos en forma relativamente directa, entonces la producción animal es complementaria. Este articulo provee una vista superficial de como nosotros utilizamos granos, coproductos y fracciones para convertirlos de una manera sostenible en alimentos de origen animal para la nutrición humana reduciendo desperdicios en varias fases de la cadena de producción. Producción de granos extras o de calidad no para humanos, sus coproductos y fracciones probablemente incrementan la huella climática de la agricultura animal, pero es imposible argumentar que no contribuyen a la reducción de desperdicios en la cadena alimentaria proviniendo carne, huevos y leche para la nutrición humana. Determinar lo que se produce localmente aun cuando sea de calidad y cantidad limitada y fluctuante parece una tarea monumental aun que reduce el costo de la alimentación animal y soporta la economía local. Nosotros debemos de evaluar dietas basado en que subproductos incluyen en lugar de maximizar el crecimiento de los animales para alcanzar parámetros de producción muy altos. Miedo de como los factores antinutricionales y micotoxinas pueden afectar la producción animal limita ahorros en el costo de alimentación. Incrementos en el riesgo de alimentación animal es parte de extraer más de alimentos comprometidos para reducir desperdicios. Se requieren cambios en política a varios niveles para comenzar a adoptar el concepto de una bioeconomía circular que contribuirá a prevenir una crisis climática.

Palabras clave: aves, cerdos, coproductos, fracciones, huella ecológica, piensos

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Introduction

The world's human population will increase to 9.7 billion by 2050 and it is projected to peak at 11.2 billion by 2100 (un.ordg). India will overtake China as the most populous country (~19% of world's population each). Sub-Saharan African countries will grow the most doubling their populations by 2050. In contrast, the populations of Europe and Japan will decrease by as much as 10 to 15%. World's fertility rate will decline from 2.5 to 2.2 children per woman in 2050. The trend is for life expectancy to increase (77 y by 2050).

For centuries, the primary role of agriculture has been to feed the human population. The future challenge and our utmost responsibility are to support such growth. Dietary needs of some of these populations (e.g., India, Africa) have traditionally relied on crops and vegetables. However, relocation to urban centres with greater food availability and variety in addition to increase in median family income (more family members earn an income) and its consistency throughout the year (not tied to crop cycles), imply greater future demand for animal food products.

Animal production not only requires greater land area, inputs, and water usage, but it also competes with humans when grains are fed. Manure is produced increasing its environmental impact and reducing sustainability. But only ~30% of crops are suitable for human consumption (de Boer and van Ittersum, 2018). Thus, animal production is an integral part of a circular bioeconomy (Figure 1) that utilizes plant coproducts to produce meat, milk, and eggs for human nutrition. Manure can be used to generate energy (biogas) and organic material can replenish soil fertility, increasing crop yield. Waste streams of one supply chain provide raw materials for another.

The objective of this manuscript is to provide a superficial overview with a Canadian perspective, on how we use non-food cereals, oilseeds, and pulses and their coproducts and fractions to sustainably convert them into edible protein for human nutrition reducing waste streams along the production chain. At the same time, we mitigate feed cost in swine and poultry production to increase producers' profitability.

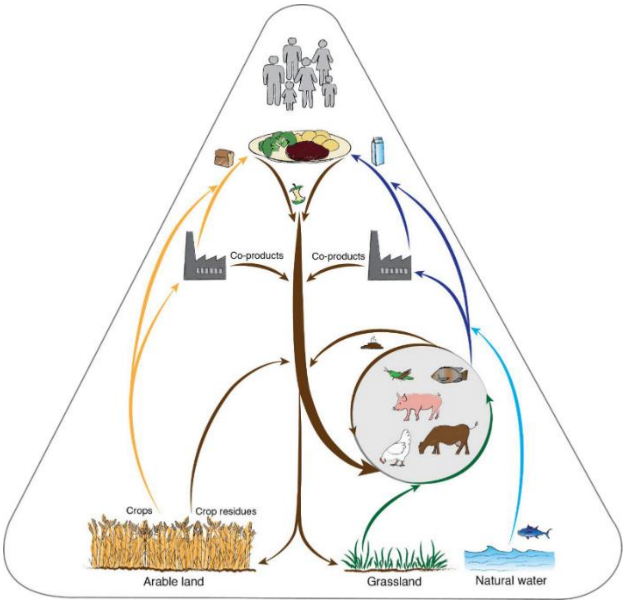


Figure 1. The role of farm animals in a circular food system. Grass (pasture, silage, straw), crops not suitable for direct human consumption, coproducts of food, bioindustrial and fuel production and are fed to production animals that convert them into eggs, meat, milk for human nutrition. Waste streams of one supply chain (crops, food, feed, bioindustrial, biofuel) provide raw materials for another. Water, energy, manure, etc. are managed effectively to minimize effects on climate change (Van Zanten et al., 2019).

Cereals, coproducts, and fractions

Corn grain (~9% CP) is the most common cereal fed as source of starch to poultry and pigs likely followed by wheat (~13% CP). Feeding either cereal to production animals directly competes with human needs unless cereal quality does not meet food grade or there is excess production. Receiving specifications, pest infestation and mycotoxins are the primary culprits to degrade. A level of insect infestation might still be acceptable to feed short-term requiring facility isolation and control. Weed seeds and chaff can be scalped out (novel stream). Ergot too, can also be effectively sieved out.

Mycotoxins is a more concerning health and safety issue. Processing can be used, and feed additives can be included to mitigate that will not be covered here (Boudergue et al., 2009).

Sorghum (milo; 8% CP) is not generally targeted for human consumption. Other than slightly lower protein (~8%) and lipid content, it can readily replace corn grain as main source of starch in animal diets. The astringent taste of tannins in some cultivars can affect feed intake, but cultivar preference data is largely lacking. Harvest moisture content is a challenge in tropical regions where the combination of heated grain (mouldy) and mycotoxin levels can add up to feed refusal.

Barley (~11% CP) that does not meet malting quality can be readily fed to both pigs and poultry. Low-cost dehulling and multi-enzyme inclusion should be a consideration for poultry but typically not swine. Barley's insoluble hull fibre and soluble fibre can both have prebiotic effects in young pigs. Feeding high inclusion barley diets reduces dressing percentage increasing days to market weight compared with corn or wheat grain. Hull-less, high amylose, high ß-glucans cultivars can be fed to pigs (Sánchez Zanatta et al., 2022), but information feeding them to poultry is scarce. Formulating low nutrient dense diets including barley grain reduces feed cost (Beltranena et al., 2022). We fed diets based on either 64.4% wheat or 67.6% barley grain providing 9.6 or 10 MJ NE/kg to weaned pigs. Feeding barley- instead of wheat-based diets reduced dietary energy digestibility but increased growth performance (Figure 2; Zhou et al., 2016b).

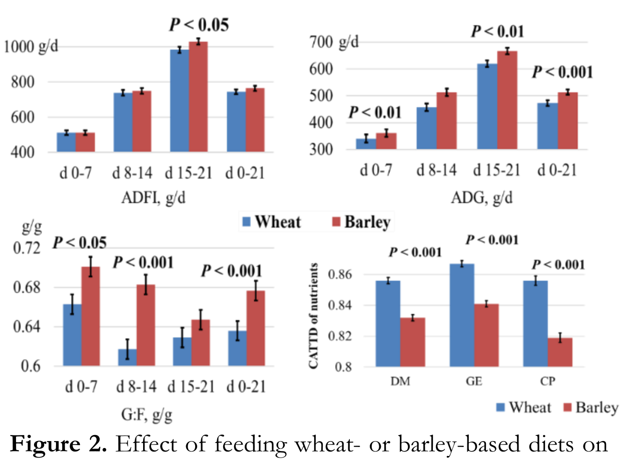


Figure 2. Effect of feeding wheat- or barley-based diets on growth performance of weaned pigs (Zhou et al., 2016b).

Oats (~10.5% CP) is a staple of human breakfasts and bakery products. Excess or lower quality grade go to feed (e.g., horses first). We have included up to 30% whole, ground oats in finishing hog rations to not only lower net energy levels to take advantage of increased feed intake, but also increased revenue over feed cost by as much as $10/hog (Table 1.; Beltranena and Smit, 2015). Restrict-fed gestating sows can handle greater inclusions of oats sparing feeding of more costly cereals. Oats are easily mechanically dehulled or hull-less cultivars exist (AC Gehl). Take advantage of oats' greater lipid content (5 - 8%) feeding weaned pigs. Skip-a-day fed broiler breeders and table egg layers may be fed lower inclusions of rolled, hulled or hull-less oats than pigs but multi-enzyme inclusion is a must.

Table 1. Effect of feeding diets with reduced net energy level on profitability of hog production.

Mcal NE /kg	2.4	2.3	2.2	2.1
Diet cost, $/1000kg	249.51*a*	233.13*b*	216.22*c*	198.81*d*
Feed cost per kg gained, $	0.67*a*	0.63*b*	0.60*c*	0.57*d*
Feed cost per pig, $	62.50*a*	59.58*b*	56.72*c*	54.66*d*
Income per hog after subtracting feed cost, $	61.02*d*	63.50*c*	65.93*b*	71.43*a*

Reducing diet NE by 0.1 Mcal/kg linearly decreased feed cost by $17/tonne, feed cost per kg gained by 3¢, feed cost per hog by $2.6, and increased income over feed cost by $3.5. Feeding 2.1 vs. 2.4 Mcal/kg resulted in over $10 greater profitability per hog (Beltranena and Smit, 2015).

Triticale (~11% CP) is a hybrid of wheat and rye. Other than niche bakery products, triticale is not commonly directed to human food. It is attractive because of its greater yield than wheat grain (>15%). It can be prone to ergot but affected grain can be easily sieved out. Triticale is also more drought tolerant than wheat and fall-planted cultivars can be dual or even triple purpose (grazing, grain, and forage). As for barley and wheat grain, multi-enzyme inclusion is a must feeding triticale to poultry and perhaps swine because of greater diet viscosity. Digestibility of dry matter, crude protein and amino acid of triticale cultivar was equal of better to that of CPS wheat fed to broilers (Table 2; Oryschak et al., 2011).

Table 2. Apparent ileal nutrient digestibility and calculated AME of 4 Western Canadian triticale cultivars compared with two samples of Canadian Prairie Spring wheat (Oryschak et al., 2011).

	Triticale				CPS wheat			P-value
	Alta	Bunker	Pronghorn	Tyndall	Sample 1	Sample 2	SEM	Triticale vs. CPS wheat
Dry matter	71.32[ab]	72.34[a]	72.10[a]	73.05[a]	63.94[c]	65.96[bc]	1.80	0.0001
AME, kcal/kg	2975[ab]	2831[b]	2981[ab]	2988[ab]	2191[c]	3178[a]	95	0.0032
Crude protein	79.90[a]	84.32[a]	83.22[a]	82.45[a]	67.89[b]	81.39[a]	1.88	0.0001
Indispensable AA								
Lysine	76.44[bc]	82.85[a]	81.95[ab]	80.30[abc]	63.63[d]	74.77[c]	2.19	0.0001
Methionine	85.10[a]	90.28[a]	87.50[a]	88.39[a]	74.26[b]	87.78[a]	2.07	0.0009
TSAA	81.90[a]	86.37[a]	84.29[a]	84.73[a]	68.86[b]	86.11[a]	2.42	0.0031
Threonine	69.85[b]	77.24[a]	75.09[ab]	73.04[ab]	56.71[c]	73.61[ab]	2.57	0.0005
Tryptophan	88.10[b]	86.93[bc]	86.45[bc]	86.75[bc]	84.21[c]	91.82[a]	1.22	0.3825
Total AA	84.10[a]	88.00[a]	86.66[a]	86.46[a]	73.07[b]	86.51[a]	1.85	0.0004

Rye (~11% CP) is a classic component of Scandinavian bread. In North America, a large proportion of rye grain is fermented to produce spirits. Novel hybrid cultivars exist that yield more than wheat grain and are not so affected by ergot. Fall planting of hybrid rye maximizes the utilization of crop land, ensures winter soil coverage, and results in an earlier crop than spring-planted cultivars. Hogs responded to xylanase and ß-glucanase inclusion when hybrid rye replaced wheat grain in growout rations (Figure 3; Smit et al., 2019).

Distillers' grain (and solubles if included) resulting from ethanol and distillery production is the most common worldwide cereal coproduct fed to domestic animals. Fermentation of corn, wheat, sorghum, barley, triticale, or rye by yeast yields ~1/3 ethanol for inclusion in gasoline, ~1/3 distillers with solubles for animal feeding, and ~1/3 CO_2 that it is typically not captured. It is considered a high fibre (~12% ADF) coproduct, which limits its inclusion in poultry diets and reduces dressing percentage fed to hogs. Yeast increases its phosphorus availability and act as probiotic (de Vries et al., 2020). Flash drying reduces amino acid digestibility by scorching the protein. Modern processing involves oil removal lowering its energy value (Kerr et al., 2013). We have effectively reduced the fibre content of DDGS by dry fractionation (Yáñez et al., 2014).

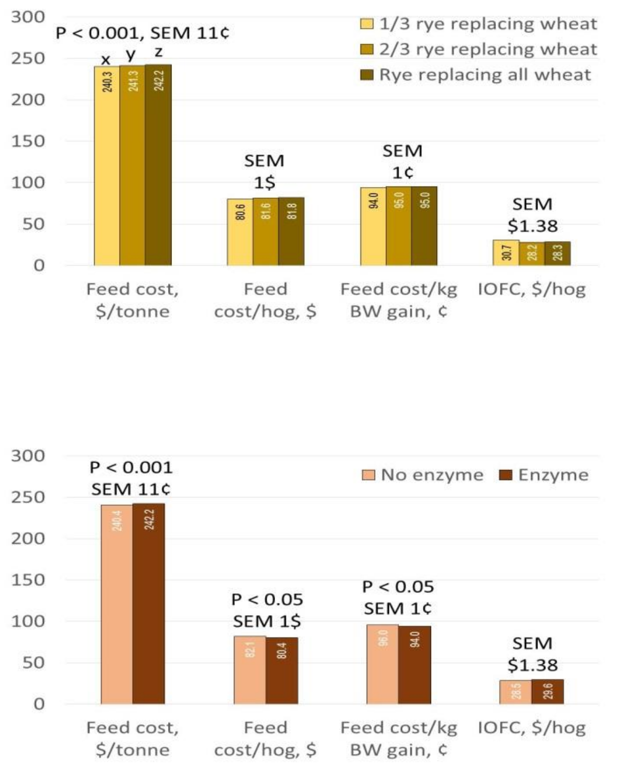


Figure 3. Cost vs. benefit of feeding increasing hybrid rye level replacing wheat grain with or without enzyme to hogs. Income over feed cost (IOFC) calculated as gross carcass revenue minus feed cost (Smit et al., 2019).

Wheat milling to produce flour for human bakery products involves upfront removal of testa components resulting in various coproducts: middlings, shorts, and millrun with proportionally increasing insoluble fibre content. Corn milling also produces several coproducts (bran, gluten, hominy, etc.). Oat hulls can also be included in sow and finishing hog diets to reduce dietary energy. These low-cost milling coproducts can be included in swine and poultry diets tailoring fibre content to production stage and objective. Multi-enzyme inclusion and feeding equipment should be a consideration for both poultry and swine feeding. Increasing inclusions (0, 5, 10, 15, 20%) of wheat millrun in substitution for up to 15% SBM and 5% wheat grain reduced diet digestibility but did not affect ADFD and ADG over 21 d starting 2 weeks after weaning (Figure 4; García et al., 2015).

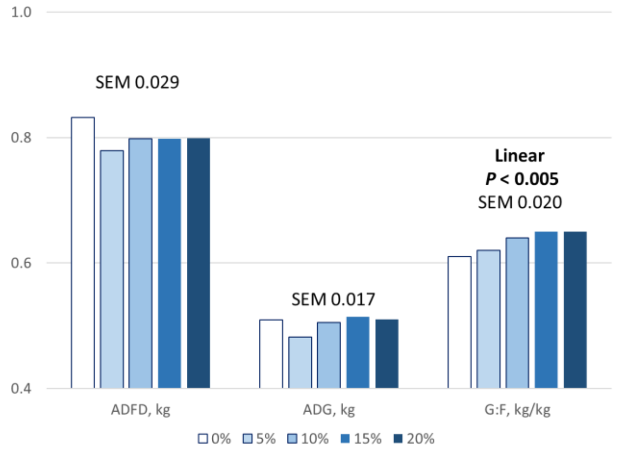


Figure 4. Growth performance of weaned pigs fed 0, 5, 10, 15 y 20% millrun for 21 d (García et al., 2015).

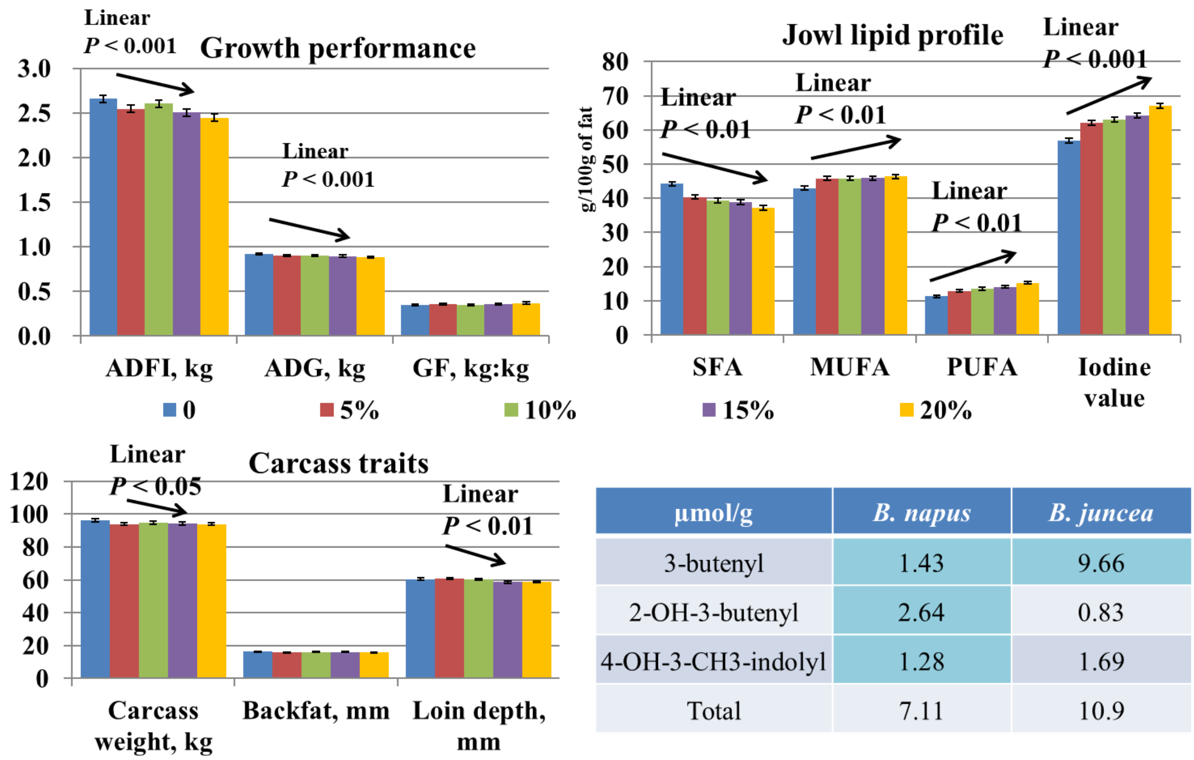
Oilseeds, coproducts, and fractions

Oilseeds are mostly fed as coproducts rather than full-fat seed to production animals. The oil, which has the highest value is directed to humans, even though it makes up the smaller component of the seed. Demand for culinary oil seems to never reach a plateau; thus, oilseed coproduct tonnage keeps increasing while pricing remains strong.

Soybean meal (44 – 48% CP) is the worldwide most relevant coproduct of dehulling, flaking, and solvent-extracting oil out of soybean. Similar processing excluding dehulling applies to canola or modern European rapeseed making it the second most relevant oilseed coproduct worldwide. Robust human demand for oil implies that all must be washed out. However, small regional plants with lower-cost plant infrastructure (no solvent extraction) crush lower quality seed (e.g., green; Woyengo et al. 2014b) producing cold-pressed, expeller or extruded-pressed cake with remaining oil content (>15%, <10%, respectively). Other small plants merely toast soybean to reduce trypsin inhibitors, grind, and feed. We routinely feed merely rolled full-fat canola seed to broilers (Cho et al., 2019; Smit et al., 2021a,b). The more oil remains in cake or full-fat seed, the greater its energy value (Grageola et al., 2013) and the lower the processing and transportation footprint as oilseeds are grown, processed, and fed locally. Crude oil is chiefly directed to biodiesel production instead of human food.

Canola meal or cake at >2/3 or full-fat seed at >1/3 replacing soybean meal inclusion may reduce growth performance. The main constrain is the insoluble hull fibre of canola vs. feeding dehulled soybean meal. Glucosinolates and synapin content are no longer antinutrional factors concerning canola inclusion even in coloured-egg layer diets. Back in 1970s, to be named canola, it had to contain <35 ppm glucosinolates. Modern canola cultivars hardly reach 10 with 3 to 6 ppm being common in meal (Dyck and Evans, 2017). Canola coproducts generally have lower amino acid content and digestibility but somewhat greater phosphorus content than soybean meal. Least-cost complementing is therefore the best feed strategy. Modern canola cultivars (e.g., ProPound™, Dow AgroSciences LLC.) can have as high a protein content as soybean meal and reduced fibre (44% CP, 19% NDF; Pedersen et al., 2016). Up to 24% of either conventional or high protein canola meal fed to broiler chickens during the grower phase resulted in no difference in performance (Gorski et. al. 2017).

We fed up to 20% canola press-cake replacing 25% soybean meal and canola oil in diets to weaned pigs. Increasing inclusion of canola press-cake reduced dietary energy digestibility but did not affect ADFD and ADG over 35 d starting 1 week after weaning (Figure 5; Zhou et al., 2016a).



µmol/g	*B. napus*	*B. juncea*
3-butenyl	1.43	9.66
2-OH-3-butenyl	2.64	0.83
4-OH-3-CH3-indolyl	1.28	1.69
Total	7.11	10.9

Figure 5. Effects of feeding increasing dietary inclusions of extruded *Brassica juncea* canola expeller-pressed cake on growth performance, carcass characteristics, and jowl fatty acids of growing-finishing pigs (Zhou et al., 2016a).

Flax or linseed should be first directed to human food. Both table eggs and pork can be enriched with ω-3 fatty acids feeding rolled flax seed or cake. While that is highly desirable in eggs, flax oil affects pork quality by reducing fat firmness. Because of high content of unsaturated fatty acids, flax meal goes rancid soon. It must be rolled in small quantities and fed promptly according to ambient temperature (Table 3; Oryschak and Beltranena, 2019). The main practical issue with flax is not its mucilaginous NSP or cyanogenic glycosides but its low lysine content. It simply does not price in rations unless forced to with the objective to enrich egg or meat ω-3 content.

Table 3. Effect of feeding whole or rolled camelina or flax seed to layers on table egg fatty acid profile (Oryschak and Beltranena, 2019).

	Seed			Processig				
	Camelina	Flax	SEM	Whole	Rolled	SEM	Seed	Processing
Linolenic C18:3	2.29b	3.15a	0.10	2.20b	3.24a	0.10	<0.001	<0.001
EPA C20:5	0.06b	0.09a	0.00	0.06b	0.09a	0.00	<0.001	<0.001
DHA C22:6	1.55	1.55	0.02	1.49b	1.61a	0.02	0.944	0.002
Total n-3	4.18b	5.06a	0.11	3.99b	5.25a	0.11	<0.001	<0.001
Total long chain n-3	1.86	1.89	0.03	1.78b	1.98a	0.03	0.404	<0.001
n6:n3	2.57a	2.11b	0.05	2.63a	2.05b	0.05	<0.001	<0.001
Saturated	25.54	25.39	0.40	25.53	25.40	0.40	0.789	0.808
Monounsaturated	41.84	40.60	0.61	41.67	40.76	0.61	0.123	0.257
Polyunsaturated	16.49b	17.34a	0.27	16.15b	17.67a	0.27	0.033	<0.001

Sunflower is destined to human snacks and culinary oil. Lower grade seed can be rolled to dehulled. Cake of non-GMO cultivars is popular for organic egg production. Remaining oil in cake is cherished because of its differing content of oleic and linoleic fatty acids.

Camelina (categorized as a weed!) is indeed the oilseed for marginal agricultural land. Its oil is mostly cold pressed for niche culinary markets and highly treasured as partial substitute of kerosene to blend in aviation fuel. Its oil is approximately 1/3 α-linolenic acid and has far greater lysine content than flax. It can therefore replace at least 1/3 imported soybean meal or cake in layer rations enriching table eggs (Table 3; Oryschak and Beltranena, 2019) and broiler meat (Nain et al., 2015). We have proven ω-3 enrichment of pork feeding camelina cake but including Celine cake in hog diets resulted in ~4 weeks delay to market weight (Smit et al., 2017a). In contrast, we have fed other cultivars that limited to 15% cake inclusion did not affect growth performance or days to market. We never had the funding to figure out what in camelina cake makes hogs run away from the feeder.

Further processing of soybean and canola meal results in protein concentrates (60% CP; Maenz, 2007) and isolates (>80% CP), which can sustainably replace fish meal from depleted ocean stocks in chick and pig starter diets. Solvent-extracted canola meal can be cost-effectively sieved or air-classified as tail-end processing (Beltranena, 2011). The fractions concomitantly increasing in protein and AA and decreasing in fibre content can be fed to monogastrics and ruminants, respectively (Mejicanos et al., 2017). The fibre-rich hull of canola is denser than the oil-free cotyledons, so these seed components fractionate in a stream of air. Air classification thus separates canola meal into a low-fibre, light-particle fraction and a high-fibre, heavy-particle fraction. Feeding weaned pigs the light-particle fraction did not affect ADFD, increased G:F, and tended to increase ADG compared with parent meal. Air classification of canola meal increased diet nutrient digestibility, but only modestly increased G:F of weaned pigs because of dietary fibre reduction (Table 4; Zhou et al., 2013).

Table 4. Effect of feeding parent *Brassica napus or Brassica juncea* solvent-extracted canola meal or their air-classified fractions to weaned pigs (Zhou et al., 2013).

	Species			Fractions				P value	
	B. napus	B. juncea	SEM	Parent	Light	Heavy	SEM	Species	Fraction
ADFD, g/d	755.6	722.9	5.6	736.3	740.8	740.7	6.8	<0.001	0.866
ADG, g/d	513.8	503.4	4.7	501.3	519.2	505.4	5.7	0.121	0.070
G:F, g/g	0.718	0.735	0.005	0.721[b]	0.739[a]	0.720[b]	0.006	0.013	0.034

Glycerol is a coproduct of biodiesel production. Pressed, raw oilseed oil is hydrolyzed using an alcohol and a catalyst producing methyl esters (biodiesel) and crude glycerol. The latter is a simple sugar alcohol, so easily digested.

Glycerol has a similar energy value to corn and wheat grain that it substitutes in diets. Feeding weaned pigs increasing levels (0, 4, 8%) of glycerol replacing wheat grain for 28 d linearly increased trial end weight (1.1 kg heavier 8 vs. 0%), ADG, and ADFI, but not G:F (Figure 6; Zijlstra et al., 2019).

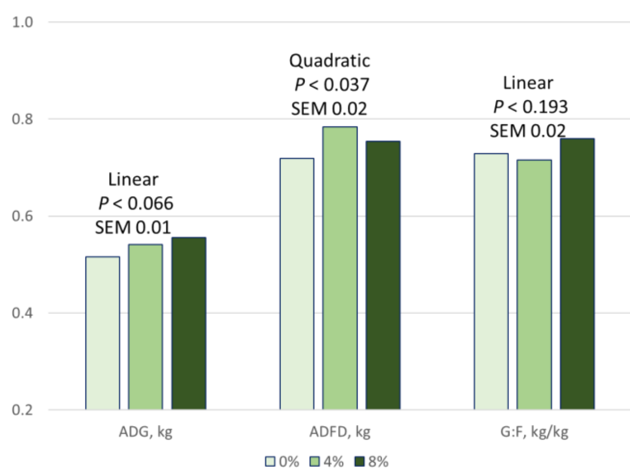


Figure 6. Effect of feeding 0, 4 or 8% crude glycerol on growth performance of weaned pigs (Zijlstra et al., 2009).

Pulses, coproducts, and fractions

Perhaps the least fed group of feedstuffs to poultry and swine are pulses (low fat legumes). Field pea, lentil, faba bean, chickpea typically go first to food export. Excess production, splits or frost-damaged beans can be fed to poultry and swine. Sometimes pulses price into diets more readily than cereals or oilseed meals or cakes because they contribute ~2x more starch than protein. Most remarkable of legumes (includes soy) is their ability to fixate atmospheric nitrogen in symbiosis with root rhizobia. Nodules remain in soil for up to 3 years bumping up yield of cereal or oilseed crops planted subsequently.

Field pea either green or yellow (20 – 23% CP) harvested with low moisture content easily split so become feed grade rather than export quality. We have fed as much as 70% field pea to layers, but it is far from optimal. Field pea is relatively high in lysine but low in sulfur AA, therefore avidly complements canola meal or cake in monogastric rations. Field pea is somewhat drought tolerant but withstand no hail. Field pea is hard to grind, nearly impossible to roll, thus increasing power consumption. Because of its starch content, field pea meal is a great pellet and extrudate binder (dog food). Weaned pigs fed 40% raw or heat-processed field pea: cold-pelleted (70–75°C), steam-pelleted (80–85°C) or extruded (115°C), to replace 30% soybean meal and 10% wheat grain in a 21-d trial had no different ADG, but greater ADFD, thus poorer G:F. Heat processing did not improve feed conversion or nutrient digestibility. Pigs fed such diets had similar final body weight (Figure 7; Hugman et al., 2020).

Faba bean (28 - 30% CP) fixates the most nitrogen compared to any legume crop, requires low crop inputs, and due to their large biomass below and above ground may fixate more CO_2 than that emitted. It also outyields field pea by >1 tonne/ha where cool growing conditions prevail and rainfall is not limiting. Tannin cultivars are very appealing to Egyptians who cherish their brown-orange shiny coat. Tannins that concentrate on the outer bean hull, protect beans from fall frost around the time of harvest. We fed broilers hulled and dehulled faba bean to reduce dietary tannin content and performance was comparable (Cho et al., 2019). Vicine and covicine that concentrate in the cotyledons, which cause favism in humans with a recessive erythrocyte enzymatic deficiency (G6DP), may affect hepatic redox status, and thus their content might be more relevant than tannins to pigs and poultry. Double-low cultivars are being developed with low content of both tannins and vicine and covicine. Because of late spring planting or early fall frost, immature frost-damaged faba bean do not meet export food grade and become available for feeding. These grayish to blacken hull beans can be expediently colour sorted by optical sorters and fed to poultry. We discovered that immature, green-cotyledon, blacken-hull beans have both greater energy and amino acid digestibility than ripen, mature beans (Smit et al., 2021a). Thus, immature, frost-damaged beans were of no concern feeding to broilers on growth performance and yield or saleable meat cuts (Table 5; Smit et al., 2021b).

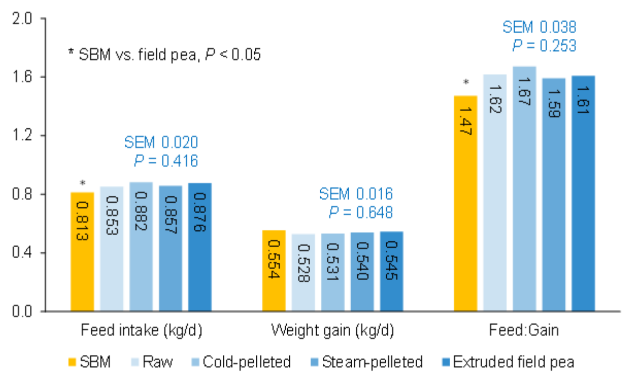


Figure 7. Effect of feeding 40% ground field pea, cold-pelleted, steam-pelleted, or extruded in substitution of 30% soybean meal and 10% wheat grain to weaned pigs (Hugman et al., 2020).

Lentil become available for feeding from time to time as export demand from India-Pakistan region is steadily strong. Little information is available regarding antinutrional factors content in lentil. Red and orange cultivars may have greater tannin content than green or yellow cultivars. Weaned pigs fed 7.5 to 22.5% green lentil had no different ADG and G:F than pigs fed soybean meal, whilst inclusion of 30% lentil, reduced both ADG and G:F by 10% (Table 6; Landero et al., 2012).

Chickpea in excess of food export demand also become available from time to time. Weaned pigs fed 7.5, 15, 22.5, or 30% Kabuli chickpea mixed cultivars in substitution for up to 20% soybean meal and 10% wheat quadratically increased ADFI, quadratically increased then decreased ADG, and quadratically decreased G:F and final BW; 15% Kabuli inclusion was optimal (Table 7; Wang et al., 2017).

Table 5. Effect of feeding diets including 3 different faba bean cultivars of 2 quality levels on growth performance of broiler chickens (Smit et al., 2021).

Cultivar				Quality			P value		
Snowbird	Snowdrop	Fabelle	SEM	High	Low	SEM	Cultivar	Quality	C × Q
2.844	2.892	2.899	0.031	2.880	2.877	0.026	0.3968	0.9246	0.2098
68.98	70.40	71.05	0.94	69.78	70.51	0.78	0.2691	0.4947	0.3651
111.06	112.21	111.84	1.39	112.15	111.26	1.16	0.8247	0.5672	0.0151
0.621	0.628	0.635	0.004	0.622	0.634	0.003	0.0694	0.0168	0.0300

Table 6. Effect of feeding 0, 7.5, 15, 22.5, and 30% lentil in substitution for soybean meal and wheat grain on growth performance of weaned pigs (Landero et al., 2012).

	Inclusion level of lentil, %						P value	
	0	7.5	15	22.5	30	SEM	Linear	Quadratic
ADFD, g/d	831	814	827	835	830	17	0.737	0.746
ADG, g/d	523	507	511	532	472	12	0.049	0.125
G:F, g/g	0.64	0.63	0.64	0.65	0.58	0.01	0.001	0.002

Table 7. Effect of feeding 0, 7.5, 15, 22.5, or 30% chickpea in substitution for soybean meal and wheat grain on growth performance of weaned pigs (Wang et al., 2017).

	Inclusion level of chickpea, %						P value	
	0	7.5	15	22.5	30	SEM	Linear	Quadratic
ADFD, g/d	784	794	849	797	795	22	0.602	0.030
ADG, g/d	543	535	596	532	497	16	0.014	<0.001
G:F, g/g	0.69	0.67	0.70	0.67	0.63	0.01	<0.001	<0.001

Lupin, with little starch but greater lipid content than most pulses, is a new crop introduction to America. It has been long fed to production animals in Australia and Europe (<0.05% bitter alkaloids). It must be first dehulled (20-30% of seed), but the cotyledon meal with greater protein (30-35%) and lipid content (6-10%) is attractive due to amino acid balance and higher energy value. We fed 0, 10, 20, 30% dehulled narrow-leafed lupin meal substituting soybean meal to weaned pigs for 28 d. Overall ADG and G:F were not different from pigs fed the control diet but ADFI was lower (Beltranena, unpublished results).

Fractionation of pulses allows value adding their two main components: starch and protein. Dehulled field pea, faba bean, lentil, or chickpea are finely ground and suspended in a rotating cloud of air. The heavy particles (mostly starch granules) fall and a high-speed spinning wheel at the top removes the light particles (mostly protein). Air classification is a continuous, cost-effective process to produce concentrates reaching up to 75% CP or up to 94% starch fraction. Pulse concentrates are primarily targeted to the food industry, but excess production diverts to higher profit pet and fish food. At ~3x the yield of protein fraction, there is generally excess pulse starch that is directed to the feed market. Being ~50% resistant (Tan et al., 2021), pulse starch complements fast-digestible cereal starch in nursery, pullet and broiler diets greatly improving pellet quality (Gunawardena et al., 2010a, b). At commercial scale, we have used faba starch as replacement for mycotoxin contaminated wheat grain in growout hog rations. Pulse protein concentrates can totally replace fish, plasma, blood cells in starter diets preventing depletion of ocean stocks and prevent the potential introduction of viral diseases into herds and flocks (e.g., Porcine Epidemic Diarrhea). We are just starting to scratch the potential of pulse fractions in animal feeding.

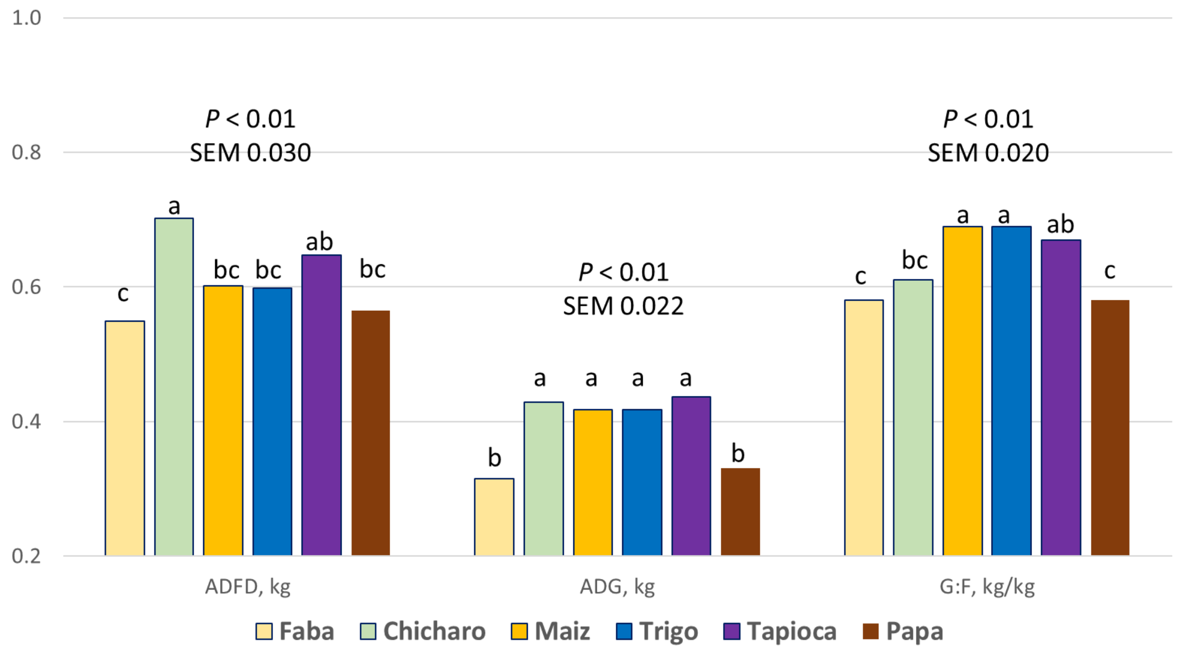


Figure 8. Growth of weaned pigs fed air-classified faba bean and field pea starch concentrates compared to native corn, wheat, tapioca, and potato starch for 14 d after weaning at 20 d of age (Gunawardena et al., 2010).

Concluding remarks

Feeding low-grade grains, coproducts and fractions may indeed increase the environmental footprint of animal agriculture (Jaworski et al., 2022). Nonetheless, it is undeniable the role ruminant and monogastric animals play in converting inedible plant material and coproducts into wholesome meat, milk, and eggs for human nutrition (Zijlstra and Beltranena, 2013). Furthermore, animal production does not directly compete but rather complements human food production by utilizing previously classified 'waste' byproducts (husks, beet pulp, sugarcane bagasse, etc.) as coproducts that are thus value-added simply by feeding them to animals (Zijlstra and Beltranena, 2019). Similar analogies to the food industry (Fondevila et al. 2021) apply to bio-industrial goods and biofuel production required for human activities where 'waste' stream products are fed to production animals (e.g., starch, DDGS) instead of ending in landfills (Zijlstra and Beltranena, 2022).

Sourcing quality grains from other regions instead of identifying what is available locally has grown in popularity. We pay for the convenience of comfortably looking at computer screens to shop in far away commodity jurisdictions, pay brokers, customs, and distributors fees. Plus, there is a transportation cost and associated emissions to have it brought in. Finding what to feed that is locally grown or sourced, even thought it may be of limited quality and(or) available only during a specific time of the year, seems a daunting challenge despite that it reduces feed cost (Woyengo et al. 2014a) and supports the local economy. Importing feed commodities also carries implicit health risks that we rather entirely avoid (African Swine Fever, Avian Influenza, Porcine Epidemic Diarrhea). Feeding food waste and animal tissues to a greater extent while protecting human and animal health in food producing animals has been reviewed recently (Shurson, 2020).

Too much emphasis on animal performance parameters is a paradigm that should be tuned. We should instead evaluate diets more based on what non-human edible coproducts are included that could become meat, milk, and eggs for human nutrition. Instead, we brag about how fast and heavy production animals grow with little good feed. Indeed, mortality can be reduced by not pushing broilers to grown so fast or transitioning weaner pigs more progressively from liquid milk to dry feed. Not only gestating sows and broilers breeders would benefit feeding more fibre coproducts if we just tuned back a bit our standards. More fibre in sow diets during pregnancy, and prior to farrowing, prevents constipation, increases water intake around parturition, increases milk yield and performance of piglets (Peltoniemi et al. 2016). Moderate levels of insoluble fibre chiefly as coarse particle size and when pigs have a compromised health status, might have positive effects promoting gut health after weaning (Molist, et al. 2014). Pigs fed a highly fermentable fibre diet had improved growth performance compared with those fed diets of lower fermentability and nearly had absence of swine dysentery (*Brachyspira hyodysenteriae*; Helm et al., 2021). Best feed efficiency and greatest profit margin are not synonymous. Let us focus more on the optimisation of the whole system all the way to consumer streams instead of maximal productivity of just crop land and animals.

How often the fear of antinutritional factors or mycotoxins on animal performance have limited our feed cost advantage? These may affect production species differently according to age and stage of production. Are we using feed additives and processing effectively to mitigate their health risks? Perhaps there are millions in feed cost savings that we have been passing on by not taking calculated risks (*E. coli* fertilizing with human waste).

Increased feed and food safety risk is indeed part of getting more out of compromised feedstuffs. Policy changes are required to safely embrace a circular bioeconomy that reduces waste preventing climate crisis.

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