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Review

FIBRE EFFECTS ON NUTRITION AND REPRODUCTION IN PIGS

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ABSTRACT

Dietary fibre (DF) is an indigestible carbohydrate in the form of a non-starch polysaccharide that is a major problem in the use of inexpensive agro-wastes by pigs such as brewer's dry grains, cassava peel, palm kernel cake, rice bran, sorghum spent grain and wheat offal. The DF in a pig's diet can be classified by its solubility as soluble dietary fibre and insoluble dietary fibre, and chemically – as neutral detergent fibre and acid detergent fibre. High DF levels reduced nutrient utilization, growth rate, in terms of pork production and reproductive performance. Pigs' reproductive cycles at different stages and lactation were both greatly impacted by increased DF intake. High DF decreased the number of stillborn piglets at birth and the farrowing duration by sow, while improving colostrum intake in piglets and colostrum yield in sows.
On the other hand, reducing the quantity of DF's hemicellulose in a sow's lactation diet can improve the low-birth-weight piglets' health, post-weaning performance and milk composition. While exogenous enzymes and the extrusion of fibrous feedstuffs enhanced nutrient digestibility and utilisation, other processing methods, including fermentation and extrusion, decreased the DF components and had a beneficial impact on the performance of the pigs. Agro-industrial residues have enormous potential to improve reproductive efficiency and serving as an economically viable DF feeding strategy in the pig industry.

Key words: dietary fibre; pigs; performance; reproduction; blood parameters

INTRODUCTION

The dietary fibre (DF) is an indigestible portion of the feed by pigs, chickens and humans and exerts vital impacts on maintaining normal physiological function and energy metabolism of the animal (Cummings and Stephen, 2007). DF are usually present in unconventional feedstuffs that are mostly agricultural by-products or industrial agro-waste, which are readily available and cheap for pigs feeding. Various plants and agricultural by-products, such as sweet potato peels, yam peels, cassava leaves, rice bran (RB), corn offal, cassava leaf meal, soy bean waste (SBW), sorghum spent grains (SSG), brewer's dry grain (BDG), corn bran, wheat offal and other locally available by-products, are characterized by high fibre content, low nutritional value and used in almost all households for feeding pigs in the developing world.

Agro-wastes in the environment are alternative feed resource usually used in feeding of monogastric animals as a result of continued rise in prices of conventional feedstuffs, such as maize and soya meal (Huang *et al.*, 2021), which are mostly used as sources of dietary energy and protein. Most agro-industrial by products, used in monogastric animal nutrition, contains non-starch polysaccharides (NSPs) in their cell wall that hindered digestibility by endogenous enzymes (Dalolio *et al.*, 2016). Low intake of DF by sows has negative effects on reproductive performance, increased stereotypic behaviour (Ramonet *et al.*, 1999), overweight of pregnant sows resulting in prolonged birth and giving birth to stillborn piglets.

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The gastrointestinal tract of pig has the ability to utilise fibrous feeds of agro-industrial by-products by converting them into animal protein (Tonukari *et al.*, 2016). High fibrous diets increased weight gain (Bertram *et al.*, 2009; Gerritsen *et al.*, 2012), while reduced growth or had no influence on growth performance accompanied by reduced digestibility of nutrients and energy (Jaworski *et al.*, 2017). A higher proportion of crude fibre (CF) in the diet is linked to higher costs, a higher amount of feces and a higher amount of phosphorus excreted (Mpendulo *et al.*, 2018). The fermentation of fibre results in small-chain fatty acids (SCFA) which enhances mucosal epithelial proliferation and villus height (Maswanganye *et al.*, 2021). Nonetheless, supplementing DF to the diet in moderation may result in an increase in gut size, volume, length and morphological structure of pigs. Reproductive efficiency is the major factor that ascertain the sustainability of the pig industry. Fibre content in the diet has been shown to positively influence the reproductive efficiency of sows (Oliviero *et al.*, 2019) through its physical features and influence on the development of the digestive tract (Wenk, 2001) as well as through the reproductive performance and the birth behaviour (Edwards *et al.*, 2019). In sow, inclusion of DF in period prior to farrowing prevents constipation, increases water intake and feed intake during lactation, improves the duration of farrowing as well as milk intake and performance of piglets (Oliviero *et al.*, 2019). This review focused on recent researches on utilisation of DF by swine at all stages of production and the consequences on their nutrition, and reproductive performance. Furthermore, help pig farmers understand alternative feed ingredients of low cost that are critical in reducing the dependence on conventional feed ingredients.

DIETARY FIBRE

The DF is the major component of fiber-rich feed, accounting for about more than 40 % of the total dry matter (DM) (Woyengo *et al.*, 2014). Fibre is defined as all carbohydrates that resist digestion in the upper gut of pigs. Carbohydrates of plants are divided into storage carbohydrates or starch and structural carbohydrates or non-starch polysaccharides (NSP). NSP can be grouped into soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) based on their solubility in water. SDF includes pectins, gums, and mucilages (Dhingra *et al.*, 2011).

Utilisation of fibrous feed ingredients by swine depends upon nature of the NSP. The main source of energy in pig diet is starch and digestion in the upper gut produces glucose. Source of DF in pigs include NSP which resist digestion in the upper gut and subsequently subjected to fermentation by gut microflora in the hindgut to produce volatile fatty acids (VFA) (Kerr and Shurson, 2013). DF can be fermented by intestinal microbes and provides 5 % – 28 % energy for pigs (Kass *et al.*, 1980).

Similarly, Yang and Zhao (2021), defined DF as neutral detergent fibre (NDF) and acid detergent fibre (ADF), which are commonly used in pig nutrition due to high cost of SDF and IDF analysis. The authors however, noted that NDF and ADF primarily contain cellulose, lignin, and insoluble hemicellulose, but SDF components are not measured. NDF and ADF are generally used analytical methods for the estimation of the nutritive qualities of feed. They were originally proposed by Van Soest and Wine (1968), but have undergone significant changes over the years (Mertens, 2003).

NDF was designed to isolate IDF components of plant cell walls like cellulose, hemicellulose, and lignin, whereas ADF is used to quantify cellulose and lignin (Dhingra *et al.*, 2011). SDF and IDF are dietary components usually recommended in application of pig production in order to achieve accurate feeding rather than ADF and NDF. Knudsen (2001) also recommended the use of IDF and SDF based on the physical properties of solubility in evaluating roles of DF in regulating pig nutrition accurately. SDF can be determined using high-performance liquid chromatography, or gravimetrically with ash and protein corrections (McCleary *et al.*, 2010).

Total dietary fibre (TDF) in feed ingredient contains IDF as the major component and SDF as a minor component (Jaworski *et al.*, 2015). The TDF, SDF and IDF can be determined using by the methods of Asp *et al.* (1983) with the use of the FIBERTEC machine by Tecator. Alternatively, SDF can be calculated as follows: organic matter – (protein + fat + soluble sugars + starch + NDF).

Sources of dietary fibre in pigs' diets

Several agro-industrial wastes have been used in formulating diets for pigs especially in the tropics. Examples of non-conventional feed ingredients commonly used in swine nutrition; readily available and are relatively cheap are presented in Table 1. Corn bran consists of insoluble fibre with 280 g.kg^{-1} cellulose and 700 g.kg^{-1} hemicellulose comprising of bioactive components like corn fibre gum, cellulosic fibre gel, and xylo-oligo-saccharides (Rose *et al.*, 2010). By-products from cassava tuber processing are usually high in starch (Régnier *et al.* 2010) and low in protein (Oguntimein, 1992) and, which are often use in replacement of maize at a least cost feed formulation.

The chemical and physical characteristics of DF can determine the rate of fermentation and VFA absorption. The negative impact of DF can vary considerably between fibre sources (Dunmire *et al.*, 2018). The crude protein (CP), ether extract (EE), CF, ADF, NDF, SDF and IDF of fibrous feedstuff were shown in Table 1. The CP value of 37.90 % of Dried brewers' grains (DBG) was shown to be the highest whereas, maize cobs (2.02 %) which is quite low in CP and highest in CF (28.69 %), ADF (51.58 %), NDF (70.63 %) when compared to other non-convention feed ingredients suggesting maize cob as a potential source of DF in pig's nutrition. Szyszkowska *et al.*, (2007) observed that nutrient profile of maize cobs is affected by stage of maturity, cultivar, climate, soils and production methods. Mature cobs have higher NDF, ADF and lower CP than less mature cobs.

Fermentation of feeds have been a useful tool in improving the nutritive qualities of feeds for mono-gastrics (Apata and Atteh, 2016; Aladi, 2016). The microbial fermented feeds contains useful bacteria and animal digestive enzymes, helping the balance of intestinal flora and better digestion of nutrients (Le *et al.*, 2016). Fermentation of feed components resulted in an increase in crude protein while decreasing the amount of CF, ADF, and NDF in fibrous feedstuffs, as shown in Table 1. The decreased in the various fibre components of fermented ingredients are due to the activities of enzymes released by microbes during the process of fermenting the feedstuff that brought about degradation of the non-cellulosic wall polysaccharides. The CP, SDF and IDF of corn bran fermented increased by 69.36 %, 53 % and 23 % respectively.

Table 1. Chemical composition of fibrous feed ingredients in pig diet

Ingredients	CP (%)	EE (%)	CF (%)	ADF	NDF	SDF	IDF
BDG[a]	25.04	9.02	18.00	21.00	37.55		
Corn offal[b]	11.16	6.50	8.76	28.50			
CPM[c]	4.20	1.40	12.70	15.20	48.10		
CPLM[d]	18.93	2.67	16.78	32.97	43.28		
CW[e]	3.40	0.40	18.40	24.40	41.70		
CWF[e]	11.10	0.70	13.70	22.70	39.20		
DBG[f]	37.90	8.10		22.10	51.70		
DDGS[g]	31.10	7.90	8.50	12.00	27.90		
Maize cobs[h]	2.02	0.80	28.69	51.58	70.63		
Maize offal[i]	11.16	6.50	8.76	28.50			
PKC[j]	15.56	3.90		24.60	44.80	3.90	46.20
PKC[k]	17.50	10.70	16.80	46.80	12.40	79.00	45.90
PKC[k]	24.70	4.10	14.50	35.80	14.30	50.30	42.20
RB[e]	15.20	12.00	13.60	14.60	39.30		
RBF[e]	17.80	20.50	10.30	13.70	33.40		
SBP[j]	8.70	0.40	17.90	37.70	21.20	27.40	42.50
SSG[a]	25.59	8.00	14.00	21.00	42.88		
Wheat offal[l]	11.43	13.00	10.00				

CP: Crude protein; EE: Ether extract; CF: Crude fibre; ADF: acid detergent fibre; NDF: neutral detergent fibre; SDF: soluble dietary fibre; IDF: insoluble dietary fibre; BDG: brewer's dried grains; CPM: cassava peel meal; CPLM: cassava peel leaf meal; CW: cassava waste; CWF: cassava waste fermented; DBG: dried brewers' grains; DDGS: dried distillers grains with solubles; PKC: palm kernel cake; RB: rice bran; RBF: rice bran fermented; SBP: sugar beet pulp; SSG: sorghum spent grains
[a]Babarinde *et al.* (2020); [b]Makinde and Sonaiya (2011); [c]Dayal *et al.* (2018); [d]Kehinde *et al.* (2020); [e]Hong *et al.* (2016); [f-g]Dunmire *et al.* (2018, 2010); [i]Olukayode *et al.* (2011); [j]Lv *et al.* (2022); [k]Marini *et al.* (2008); [l]Alikwe *et al.* (2012)

UTILISATION OF DIETARY FIBRE BY PIGS

Digestibility of fibre by pigs

Effects of fibre source on nutrient digestibility and fibre fermentability in pigs depends on the physio-chemical properties of various fibre-rich ingredients (Mpendulo *et al.*, 2018), age of the animal as a result of differences in physiological stage of pigs. The digestibility of DF differs (40 % – 60 %) and very lower than other nutrients such as starch and sugars (above 80 %) (Berrocoso *et al.*, 2015), its digestibility was affected by the amount and the source of DF in the diet. DF in diets of pigs exhibited lower digestibility of dry matter, CP, gross energy, non-fibrous carbohydrates, and organic matter (Holt *et al.*, 2006; Feyera *et al.*, 2017). There is a high rate of degradation of DF in the hind gut of adult sows than in growing pigs due to longer retention time consecutive to their higher gastro intestinal tract volume combined with a lower feed intake per live weight (Jha and Berrocoso *et al.*, 2015).

According to studies by Kil *et al.* (2013) and Zhao *et al.* (2018), nutritional digestibility in growing pigs improves with age and breed and is largely affected by dietary management. The positive effect of increased fibre concentration on its digestibility is because more substrates went into the large intestine to be fermented.

Table 2. Effects of dietary fibre on nutrition of pigs

Basal diets	Pig category/ phase	Inclusion level (%)	Effect	References
BDG	Weaner	30	Decreased performance	Imonikebe & Kperegbeyi (2014)
GSM	Piglets	15	Not significant ADFI, DWG & FCR	Martins *et al.* (2021)
SBP	Grower	15 – 55	Decreased apparent total tract digestibility of dry matter, crude protein and gross energy	Zhang *et al*. (2013)
Alfalfa meal	Weaner	60	Depressed daily gain and efficiency of feed utilization	Kass *et al*. (1980)
Maize cobs	Finisher	7.5 – 15	Reduced weight gain & feed intake	Frank *et al.*, (1983)
BSH	Finisher	58.50	Not significant	Olajide *et al.* (2019)
Maize cobs	Finisher	30	Reduced weight gain & feed intake	Kanengoni *et al*. (2004)
BDG	Weaner	10	Improved performance	Amaefule *et al*. (2006)
DDGS	All pigs	30	Improved performance	Stein and Shurson (2009)
Maize bran	Growing	25	Improved performance	Akinfala *et al*., (2017)
BNWM	Weaner pigs	40	Improved performance	Nwakpu *et al*.(2010)
FCSM	Weaners	6	Improved performance	Gu *et al*. (2021)
CP	Weaners	50	Improved performance	Oboh (2016)
PKC	Grower	30	Improved performance	Adesehinwa, 2007
CRP:PKC (3:1)	Weaner	55	Improved performance and cost effective	Obongekpe (2020)
BDG	Weaners & grower	35 and 40	Improved performance at 40 % weaners and 35 % for grower	Amaefule *et al.* (2006)
BDG	Grower	40	Improved digestibility	Amaefule *et al.* (2006)
CP + PKC	Grower	55	Improved performance	Oboh *et al.* (2018)
RB	Weaner	30	Improved performance	Adebiyi *et al.* 2018
RBF, CWF	Grower and finisher	25	Reduced cost per kg, reduced ADFI & ADWG	Hong *et al.* (2016)
DDGS	Finishing pigs		Poor feed to gain ratio	Dunmire *et al.* (2018)

ADFI: average daily feed intake; ADWG: average daily weight gain; BNWM: Bambara nut waste meal; BDG: Brewer's dry grains; BSH: CP: cassava peel; CRP: cassava root pulp; CWF: cassava waste fermented; DDGS: dried distillers grain with solubles; DWG: daily weight gain; FCSM: fermented cotton seed meal; FCR: feed conversion ratio; GSM: guava seed meal; PKC: Palm kernel cake; RB: rice bran; RBF: rice bran fermented ; SBP: sugar beet pulp

Increasing dietary lipid content result to depressed fiber digestibility and more prominent at the faecal level than at the end of the ileum (Dégen *et al.*, 2007). In a feeding trial by Wafar *et al.* (2020) different milling by-products using maize offal, wheat offal, sorghum offal, millet offal and rice offal respectively (Table 2). The result of growth performance and nutrient digestibility showed that average feed intake, final body weight as well as digestibility of dry matter, CF, EE, CP and ash were higher for pigs fed maize offal, wheat offal, sorghum offal and millet offal, while rice offal had the lowest growth and nutrient digestibility. It was concluded that maize offal, wheat offal, sorghum offal, millet offal can be used in weaned pigs' diet. Low nutrient digestibility in rice offal was attributed to the decrease in the mean retention time of this diet in the gastro-intestinal tract (Bindelle *et al.*, 2008), depresses apparent digestibility of dry matter and nitrogen, decreases daily body weight and increase feed to gain ratio. The higher fibre digestibility observed for other cereal by-products were because of fermentation of DF in the hind gut with the VFA produced contributing the net energy requirement of the pigs. Yen *et al.* (1991) reported VFA contributing 5 – 28 % of energy required for maintenance in growing pigs resulted from fermentation of DF in the gastrointestinal.

Zhang *et al.* (2013) in their investigation observed that apparent total tract digestibility of dry matter, CP and gross energy decreased when TDF increased but the digestibility of SDF and IDF increased. The digestible energy (DE) and metabolisable energy (ME) content of diets decreased as the TDF increased and subsequently the amounts of nitrogen and energy excreted from feces were increased as DF level increased, while the amounts of energy excreted from urine was decreased. The DE and ME content of the diets decreased when the level of sugar beet pulp increased from 15.0 to 55.0 %.

Performance and cost benefits of utilisation of fibre in pigs diet

Growing pigs with higher body weight have greater capacity to digest DF components than lower body weight of pigs. Many researchers have investigated the inclusion of DF at various growth stages of pigs (Table 2). Majority of research had focused on finding alternative to maize utilisation in the diets of pigs, leading to the use of fibrous feedstuff which tends to be cheaper and readily available. Le Goff and Noblet (2001) stated that greater capacity of heavy pigs and adult sows to digest DF is due primarily to more advanced development of pig intestine, rather than enhanced intrinsic ability of gut microbiota to degrade DF. Adesehinwa *et al.* (2017) conducted a feeding trial with weaned crossbred (Large white Landrace) pigs to determine the replacement value of cassava peel fine mash for maize. The result demonstrated the potential for replacement of up to 15 % of the 40 % maize inclusion in the diet.

Adesehinwa *et al.* (2011) reported that feeding an enzyme-supplemented cassava peel-based diet to growing pigs reduced the cost per kilogram of weight gain. Ekpo (2015) replaced maize with composite cassava tuber meal (C), BDG (B), and palm oil (P) mixed thoroughly at 65 %, 25 %, and 10 %, respectively, to produce CBP mixture in pig diets. The cost of producing a unit weight of pig was substantially reduced by replacing maize with CBP. CBP therefore may be utilised instead of maize in pig diets to reduce feed costs and total dependence on maize. Thus increase the farmer's profit when 50 kg of maize is replaced. Nwakpu *et al.* (2010) in an experiment using weaned piglets and recommend that it was cost effective in replacing 100 % maize with raw Bambara nut waste in the diets resulted to increased feed intake, increased daily weight gain when compared with the control diet and significantly reduced daily feed cost of feed per kg weight gain of pigs. Adesehinwa (2007) in replacing maize with palm kernel cake (PKC) on the performance and economy of production of growing pigs, concluded that maize when substituted with PKC (30 kg/100 kg of diet) improved performance characteristics and 50 % PKC replacement was the cheapest cost of production in diets of growing pigs. Adesehinwa *et al.* (2016) fed 30 % of cassava peel in replacement for 75 % of maize in growing pigs and discovered that there was no significant difference in body weight, feed intake and feed conversion ratio of between treatments and that it reduced 4 % in cost per kg of weight gain. They reported PKC as a high energy source and cost-effective ingredient for ration formulation.

In a contrary view, Igene (2006) observed that feeding cassava peels to weaner pigs at level higher than 50 % decreased live weight and feed conversion efficiency. Similar observation was made by Amaefule *et al.*, (2006) replaced maize with BDG at 0, 30, 35 and 40 % BDG in pigs. Their results indicated that weaned pigs fed 40 % BDG diet had significantly higher protein intake (113.65 g) than others, while increasing levels of BDG in the diets significantly decreased feed cost at the weaned stage. And recommended 35 % of BDG at the grower stage for optimum performance. Frank *et al.* (1983) observed individual variability in ability of pigs to utilize the higher level of maize cob in their diets. The differences in responses to high fiber diets was attributed to genetic and physiological determinants of feed intake. Kanengoni *et al.* (2004) observed that in a growth performance experiment, growth rate decreased by 26 % and the Mukota pigs by 19 % as maize cobs increased from 0 to 300 g/kg in the diet.

Extrusion process inactivate the enzymes and subsequently prevent rancidity (Adebiyi *et al*., 2018). The temperature reached by the feed during extrusion cooking can be as high as 200 °C but the exposure time at this elevated temperature is very short (5 s to 10 s). Adebiyi *et al.* (2018) observed that extrusion processing of rice bran at 100 °C and 120 °C had a significant effect on weight gain and feed conversion ratio of weaner pigs when compared to those fed raw rice bran. This was attested to be as a result of the improvement in the crude protein, increased fibre digestibility. Adebiyi *et al.* (2018) concluded that extrusion treatment of rice bran increased the quality of rice bran for swine nutrition by feeding extruded rice bran at 120 °C up to 30 % inclusion improved weaner pigs' performance.

Interaction of dietary fibre on intestinal mucosal of pigs

The gastrointestinal tract (GIT) help to digest and absorb nutrients from the diet. The GIT serves as a physical barrier that prevent the translocation of luminal toxins and antigens into epithelial immune cells. It also plays a major role in regulating epithelial and immune functions which are important for normal biological functioning and maintaining homeostasis in both the GIT and the body (Zhao *et al.*, 2018). The GIT tract has its origin from the esophagus to the anus, composed of four concentric layers that constitute the wall of the tract: serosa, muscularis external, submucosa, muscularis mucosae and mucosa (Gartner and Hiatt, 2014). Intestinal mucin is the main constituent of the mucus protecting the gastrointestinal tract. For optimal mucosal protection, both the quantitative and qualitative characteristics of mucin are essential.

The intestinal mucosa is composed of epithelium, the gut-associated lymphoid tissue (GALT), and the mucus overlying the epithelium. A delicate and dynamic equilibrium, which is crucial to a streamlined functioning and absorption capacity of the digestive system, is formed as a result of the interaction between the GALT, the intestinal mucus, host epithelial cells and microbiome (Maswanganye *et al.,* 2021). Mucosa morphology reflects intestinal capacity of nutrient absorptions and digestion. Pigs hydrolyses and breaks down the ingredients of feed into tinier compounds; amino acids, peptides from proteins, fatty acids, monoglycerol from lipids and starch all contain glucose which is obtained by the mucosa. DF stimulate intestinal epithelial cells to secret mucosal protein and produce growth factors and metabolites such as arachidonic acid, all of which are beneficial to goblet cell proliferation and mucosal protein secretion (Yang and Zhao, 2021).

The fermentation of DF results in SCFA which enhances mucosal epithelial proliferation and villus height (Johnston *et al.*, 2003). DF in wheat bran, pea fibre, cellulose have been shown to increase the excretion of intestinal mucin by stimulating the capacity of mucosal protein synthesis (Chen *et al.*, 2013). Pea fibre (pea hulls and pea inner fibre) improved intestinal health in animals by reducing the adhesion and increasing the excretion of enterotoxigenic *E. coli* (Becker *et al.*, 2009). A decreased ratio of villus height to crypt depth usually relates to impaired digestion and absorption of nutrients by intestinal mucosa. Yang and Zhao (2021) noted that DF directly disrupt surface structure of the mucosal layer resulting to increased speed of cell shedding, which causes compensatory growth of mucosal. And similarly, high inclusion of DF decreased energy density in diets, leading to an increase in feed intake and greater digesta flow in the intestine, which promotes renewal of mucosal protein, thus affecting intestinal mucosal layer. Addition of 10 % DF in the diets of growing pigs for a period of 14 days resulted in an increase in villi width and crypts depth in the ileum and jejunum which elevated rates of cell proliferation and crypt depth in the large intestines, as opposed to the same diet devoid of straw (Bach Knudsen, 2001).

Montagne *et al.* (2003) in their investigation observed that gut bacteria play a key role in interactive relationships between DF and mucosal layer or intestinal epithelium. But, DF have discrete structures, such as monosaccharide type, glycosidic bond, and physicochemical property, thus exerting different impacts on intestinal barrier in pigs. Nevertheless, moderate supplementation of DF to the diet resulted to an increase in gut size, volume, length and morphological structure of pigs (Maswanganye *et al.*, 2021). Feeding pigs with high IDF diets might be better protected against pathogenic bacteria by increasing the villous length (Hedemann *et al.*, 2006) and similar observation was made by Chen *et al.* (2013), who observed that DF elevated ileal mucosal integrity by improving ileal villous height and the villous height: crypt depth ratio. Feeding of pigs with IDF and SDF had more goblet cells in the ileum than those in a fibre-free group (Hino, S. *et al.*, 2012). The mechanisms of the negative impact of high DF diets on nutrient digestibility could be as a result of soluble fibre that impair bile salt recycling and mixing and transport of micelles, which limits the effectiveness of the emulsification process and mass transfer of lipolytic products to the mucosal surface, thereby causing decreased nutrient digestion.

In addition, DF in pigs diets increase endogenous loss of nitrogen and amino acids due to enhanced secretion of digestive enzymes, mucin, and sloughed epithelial cells in the small intestine (Schulze *et al.*, 1994). Bikker *et al.* (2006) reported that feeding neonatal piglets high concentrations of SDF derived from wheat middlings, sunflower meal, and sugar beet pulp increased the length of the small intestine and improved amylase activity in the small intestinal brush border.

Effect of dietary fibre on blood components of pigs

The haematology and serum biochemistry have been a useful assessment in predicting the nutritional condition of livestock. Several leaf meals of plant have been fed to pigs without being detrimental on blood parameters *Microdesmis puberula* leaves (Obua, 2013), cassava, Manihot (Iyayi, 2001), *Gmelina arborea* (Nkwocha *et al.*, 2008) and water hyacinth (Akovbovbo *et al.*, 2014). Olayemi *et al.*, (2006) opined that test ingredients have the ability to provide and maintain the essential amino acids and minerals in the diets which are necessary for the normal functioning of the blood cells producing tissues and organs.

Table 3 shows effects of feeding fibrous feedstuffs on blood parameters of pigs at different stages of their growth. High serum urea has been reported as an indicator of muscular wastage in animals (Adesehinwa, 2008). Ziemer *et al.* (2012) hypothesized that pigs feeding of fibrous feeds are likely to have high serum glucose concentrations resulting from increased availability of sugars from the fermentation of fibre. Nwakpu *et al.* (2010) fed raw bambara nut to weaned piglets in replacement for maize at 0, 10, 20, 30 and 40 and observed that all haematological indices had no negative effect on the animals (Table 3).

Obua (2013) fed *Microdesmis puberula* leaves that was harvested green, sun dried and ground into a meal and was subsequently fed to weaner pigs in replacement for soya bean meal. The study revealed that the RBC and Hb values of the pigs increased with increasing dietary inclusion of the leaf meal. The packed cell volume, haemoglobin and red blood cells were relatively high and best at 15 % dietary level showed enhanced quality of blood. Frank *et al.* (1983) reported a linear decrease in plasma glucose and an increase in plasma urea concentrations in cross-bred pigs fed diets with incremental levels of 7.5 % and 15 % maize cobs as fibre sources. The glucose decrease was attributed to less starch in the diet because maize cobs were incorporated in the diet at the expense of grain, while the high urea was because of increased ammonia production by intestinal microbes.

Blood urea is a principal product of the catabolism of protein and its concentration can act as an indicator of body protein status (Kohn *et al.*, 2005). Serum energy metabolite concentrations depends on breed of pig and level of maize cobs in the same way their concentrations vary in response to type of fiber as reported by Weber and Kerr (2012). Mashatise *et al.* (2005) reported no differences in plasma glucose, urea and creatinine levels in Mukota and Mukota×Large White gilts fed a control and a high fiber diet with 20 % maize cobs. Adesehinwa *et al.* (2016) fed graded levels of high-quality cassava peel (HQCP) mash to growing pigs. Though the HDL-cholesterol and superoxide dismutase (SOD), was significantly different in the haematological and serum biochemical parameters among treatments, but all the values were within the normal range for healthy pigs and concluded that HQCP fine mash can effectively replace 75 % of the maize in the diet of growing pigs with no adverse effect on serum biochemical and haematological indices. The use of exogenous enzymes in fibrous feeds have been investigated by several authors on haematological and serum constituents of pigs. Adesinwa *et al.* (2008a) observed that 100 g Avizyme® 1300 inclusion in 100 kg of 45 % – CPM based diet as ideal for growing pig. Similarly, Adesehinwa *et al.* (2011) included Farmazyme which resulted in better utilisation of cassava peel meal. They observed that the protein levels of the maize-based diet and the CPM based diet supplemented with Farmazyme®

Table 3. Effects of feeding dietary fibre on haematology and serum of pigs

Feed ingredient	Pig category/ phase	Optimum inclusion level	Effect	References
BNWM	Weaner	40	Haematological data not significant	Nwakpu *et al.* (2010)
MPLM	Weaner	15	Normal haematology and serum biochemistry	Obua (2013)
IALM	Grower	15	Normal haematology and serum biochemistry	Ekenyem & Madubuike (2007)
CPM	Grower	30	no significant effect on serum metabolites, haematological parameters and serum electrolytes but for slight variations observed in the values of MCHC and $PO4^{2-}$	Adesehinwa *et al.* (2008)
PBSM	Weaner	11 – 15	Negative effect on haematology and serum components	Ogunbode *et al.* (2016)
CPM	Grower	40	Normal haematology and serum biochemistry	Irekhore *et al.* (2015)
HQCP		30	Haematology and serum were positively correlated	Adesehinwa *et al.* (2016)
CRP:PKC (3:1)	Weaner	55		Obongekpe (2020)
Maize offals	weaners	26.45	Serum not significantly different from control	Adesehinwa *et al.* (1999)
TDLM	Growers	21 – 30	Negative effect on haematology and serum components	Fasuyi *et al.* (2013)

BNWM: Bambara nut waste meal; CPM: Cassava peel meal; CRP: cassava root pulp; HQCP: high quality cassava peel; IALM: *Ipomoea asarifolia* leaf meal; MPLM: *Microdesmis puberula* leaf meal; PBSM: Pride of barbados seed meal; PKC: palm kernel cake; PBSM: pride of barbados seed meal; TDLM: *Tithonia diversifolia* (wild sunflower) leaf meal

was able to support the protein reserves of the pigs across the groups and that CPM was efficiently utilised leading to high tissue deposition.

Effect of dietary fibre on reproductive performance of pigs

In large-scale pig production, sows and piglets are crucial to determining production levels and the economic benefits of pig farms, and the gestational, lactation, and newborn periods are critical stages for feed management of sows and piglets in large-scale pig production (Kim *et al.*, 2013). Feeding of fibrous feeds to pigs improved their reproductive performance at different stages. Proper feeding of pregnant sows improved feed intake which can help to prevent constipation thus enhancing their reproductive performance. Origin and type of DF determine the reproductive effects on the animals. DF improved oocyte quality and early embryo survival rate, increased litter size, prevent gestation and miscarriage, and improved the reproductive performance of sows (Loisel *et al.*, 2013; Yin *et al.*, 2016). DF reduced estrogen during follicular development that could improve the survival rate of early embryos and reduced intrauterine growth retardation of fetal pigs, even stimulated the immune system, and reduced diarrhea rate and mortality (Ferguson *et al.*, 2007). Feeding a high DF prior to mating also improved the outcome of pregnancy. Proper feeding of pregnant sows improved feed intake which can help to prevent constipation thus enhancing their reproductive performance.

The type of DF fed to pregnant sows helps to determine the reduction farrowing length and stillborn piglets. DF influence the energy metabolism of the sow (Le Goff and Noblet 2001), inclusion of exogenous enzymes helps to improve the energy digestibility of the diet (Zhou *et al.*, 2009) and consequently allow a coarser diet, which is central in order to avoid stomach ulcers. High DF diets intake during the perinatal period were documented to reduced prolonged farrowing duration by softening the faeces and supplying energy from the hindgut (Loisel *et al.*, 2013; Feyera *et al.*, 2017). Meunier-Salaün *et al.* (2001) observed that energy requirement of sows' increases at last weeks of gestation which justifies reasons why the raw fibre requirement for gestating sows is reduced to a minimum. Feeding sows a diet high in fermentable NSP during the weaning to oestrus interval and the subsequent pregnancy over three successive parities, resulted in an increase in the total number of piglets born and the number of live born piglets (Van der Peet-schwering *et al.*, 2003).

Higher proportion of SDF to IDF in the pregnant diet of sows improved the antioxidant capacity and inhibited the inflammation of the colon for piglets (Li *et al.*, 2020). SDF intake promote neonatal intestinal health through maternal inulin intake during late pregnancy and lactation changed the intestinal microbiota for their suckling piglets (Paßlack *et al.*, 2015). Research on maternal SDF intake by pregnant sows needed to be explore because of its beneficial effect to the intestinal health of piglets. Collaborating this, Holt *et al.* (2006) observed that DF for gestating sows during transition reduced the proportion of stillborn piglets and mortality of total born piglets. According to the Animal Welfare and Animal Husbandry Ordinance, in Germany breeding sows must be fed with at least 8 % or 200 g CF per day per animal up until one week before the expected farrowing date (Ernährung, 2006).

Che *et al.* (2011) reported the effect of feeding DF on reproductive performance during the first two parities. The authors discovered that at first parities; sows fed low DF diet in parity 1 gained more backfat during gestation but lost more during lactation than sows fed high DF diet; sows fed low DF diet farrowed more pigs (+0.7-1.1 pigs) and pigs born alive (+1.0 pigs) relative to sows fed high DF diet. Similarly, sows fed Low DF diets had greater litter weights at parturition (both $p = 0.06$) and day 22 after lactation. In parity 2, after 22 d of lactation, sows fed high DF diet had most pigs alive and heavier litter weight, increased internal organs weight of newborns. Papatsiros *et al.* (2021) reported that feeding of sows with high DF lead to a decrease of the number of stillborn piglets at birth, increase of the number of live born and weaned piglets and reduced farrowing time. Darroch *et al.* (2008) added 20 % soybean hulls and 0.3 % psyllium to the diets of pregnant sows. Their results showed that soybean hull was more conducive to physical health maintenance in pregnant sows but had little effect on litter size.

Beneficial bacteria in the intestine with functional SDF help improve the metabolic syndrome in the way of "microbiota remodeling", thereby alleviating inflammation and oxidative stress in sows, which effectively increased the ADFI of sows during lactation (Tan *et al.*, 2016; Li *et al.*, 2020; Xu *et al.*, 2020). Zhuo *et al.* (2020) found that IDF of oat bran mixed with corn or soybean meal produced more SCFA by gut fermentation, which improved pig behaviors and reproductive performance. Cheng *et al.* (2018) added combined SDF from pregelatinized waxy corn starch and guar gum to the sows' pregnancy diet, which significantly improved the developmental growth performance and gut function of 14-day-old suckling piglets. Research on effect of feeding DF during lactation on the performance of suckling piglets is scanty because of the ability of fibrous ingredients to reduce feed intake. The number of piglets weaned was affected by feeding DF during gestation.

Researchers have shown that the nutritional composition of colostrum can be changed with additives or types of DF in the diet of pregnant and lactating sows, thereby regulating the growth performance and immunity of offspring piglets (Grela *et al.*, 2019; Tan *et al.*, 2021; Zhang *et al.*, 2020). DF reduced the concentration of dietary energy, but improved the colostrum intake by piglets and colostrum yield of gestating sows (Theil *et al.*, 2014). Luo *et al.* (2021) fermented *Radix puerariae* residue (FRPR), their results showed that dietary FRPR had no effects on litter size and the number of total alive piglet, and that the number of weaned piglets and weaning weight of litter were increased in sows with 4 % FRPR treatment compared with control treatment. The addition of guar gum to maternal diets increased the population of beneficial microbiota in the intestine and reduced the diarrhea rate of piglets (Cheng *et al.*, 2018).

CONCLUSION

The current review demonstrated that feeding DF to pigs at all stages of growth, especially during the growing and finishing periods, is nutritionally beneficial. CPM, PKC, and RB improved the productive performance and economic efficiency of growing pigs; SDF in SBP improved enzyme activities in the small intestinal walls; fermentation of CW and rice bran improved crude protein while reducing ADF and NDF; enzyme supplementation resulted in high tissue deposition; extrusion of RB at 120 °C improved performance of weaned pigs, and DF reduced piglet stillbirth and mortality. Agro-industrial residues have major potential as economically viable DF feeding strategies in pig production, as well as for improving reproductive efficiency.

AUTHOR'S CONTRIBUTIONS

Conceptualization: Atteh, O. M.

Methodology: Apata, D. F.

Investigation: Atteh, O. M.

Data curation: Apata, D. F.

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Writing-review and editing: Atteh, O. M.

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All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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