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Effect of liquid-fermented potato hash, with or without exogenous enzymes, on carcass characteristics of growing pigs

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Abstract

The objective of the current study was to determine the effect of the dietary inclusion of liquid-fermented potato hash with or without exogenous enzyme on fermentation characteristics and carcass characteristics of pigs. Forty-two crossbred, male pigs (Large White × Landrace) aged 55 d with an average body weight of 25.5 ± 3 kg (mean ± standard deviation) were selected. Six pigs were randomly allocated to seven experimental dietary treatments. The dietary treatments included dry standard feed; liquid-fermented standard feed; liquid-fermented potato hash, 200 g/kg (as fed), with and without exogenous enzymes; and liquid-fermented potato hash, 400 g/kg (as fed), with and without exogenous enzymes. The back-slopping fermentation approach was followed to prepare experimental diets. Diets were formulated to provide 14 MJ/kg digestible energy (DE), 180 g crude protein (CP)/kg and 11.6 g lysine /kg. Lactic acid bacteria (LAB), Enterobacteriaceae, yeast, moulds, and *Escherichia coli* in the liquid-fermented diet with or without potato hash were influenced by the addition of enzymes. An effect of diet and enzymes was observed on lactic acid and water-soluble carbohydrates. The low and high liquid-fermented potato hash diets without enzymes had a higher pH than the low and high liquid-fermented potato hash diets with enzymes after 8 and 24 hr. Fermented potato hash with or without enzymes led to high drip loss and lean percentage. Carcass traits improved in pigs fed less liquid-fermented potato hash with or without enzymes.

Keywords: backfat thickness, bulkiness, feed processing, lactic acid, potato by-products
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Introduction

Waste from the food-processing industry can be used as food, feed, and fodder (Khedkar & Signh, 2018). Food waste can be partially incorporated into animal feed to reduce food wastage without compromising animal health and growth (Ncobela *et al*., 2017). A major challenge for the pig industry is the limited availability of energy sources, such as yellow maize, due to competition and harsh climatic conditions. Consequently, the use of by-products from the food processing industry as energy sources for pigs is gaining substantial momentum because is both economical and eco-friendly, since it can reduce waste disposal costs and pollution. By-products from the food processing industry are high in moisture and difficult to use without processing (Khedkar & Singh, 2018). They therefore decay readily, leading to nutrient losses and contamination with microorganisms and toxins in the process.

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Potato hash, a mixture of potato skins, fats, and yellow maize obtained after the production of snacks, is an agro-industrial by-products that is available in appreciable quantities in South Africa (Ncobela *et al*., 2017). Nkosi & Meeske (2010) reported that potato hash contains 150 g DM/kg, 700 g starch/kg DM, 11.16 MJ ME/kg DM, 105 g CP/kg DM, 369.6 g NDF/kg DM, and 162.5 g ADF/kg DM. Incremental levels of unfermented potato hash increase rates of digesta passage, reduce nutrient digestibility, and compromise growth performance in pigs (Ncobela *et al*., 2021). For this reason, fermentation is required to break down the fibre matrix while prolonging shelf life. Liquid fermentation and the use of exogenous enzymes can disrupt the fibre matrix structure, thereby improving the available nutrient utilization and, concomitantly, the performance of growing pigs.

Controlled fermentation is an attractive option for preserving high moisture by-products. Liquid feeding involves the use of a diet prepared from a mixture of liquid food industry by-products and conventional dry materials, or from dry raw materials mixed with water in varying proportions (Missotten *et al*., 2015). Canibe & Jensen (2003) defined fermented liquid feed (FLD) as a mixture of feed and water stored in a tank at a certain temperature and for a certain time before it is fed to the animals. A fermented liquid diet lowers stomach pH through increased lactic acid concentration and helps to decrease populations of pathogens such as *E. coli* and *Salmonella* spp*.* (Urriola *et al*., 2010); an FLD improves the nutritional value of the feed (Carlson & Poulsen, 2003; Lyberg *et al*., 2006).

Pigs do not produce enzymes that can degrade non-starch polysaccharides (NSP) (Kerr & Shurson, 2013). The lack of enzymatic capacity may be compensated for by supplementing diets with exogenous enzymes. It has been reported that exogenous enzymes improve nutrient digestion in pigs (Kerr & Shurson, 2013) and reduce DM losses in high moisture by-products (Nkosi & Meeske, 2010). The effect of feeding fermented sweet orange peel on carcass quality of broilers was investigated (Oluremi *et al.,* 2010). These authors reported a substantial effect on dressing percentage and concluded that a 30% replacement of maize with naturally-fermented sweet orange peel meal was practicable in a broiler production enterprise. Pigs fed low inclusion levels of fermented liquid potato hash diets treated with or without enzymes had improved feed intake, growth rate, and feed conversion ratio (Thomas *et al*., 2018). Therefore, fermenting high moisture by-products, such as potato hash, may replace conventional energy-rich feedstuffs, such as yellow maize, in pig diets (Lallo *et al*., 2003).

Therefore, it is necessary to investigate the use of liquid fermentation to improve the utilization of nutrients from potato hash and the subsequent effect on carcass characteristics. Dose–response trials were conducted to accurately determine the optimum inclusion levels of liquid-fermented potato hash in pig diets without adversely affecting carcass performance. Thus, the objective of the study was to determine the carcass characteristics of pigs fed a liquid-fermented potato hash diet. It was hypothesized that inclusion levels of liquid-fermented potato hash feed would have no effect on the carcass characteristics of growing pigs.

Materials and Methods

The experiment was carried out under the approbation and guidelines of the Agricultural Research Council Animal Ethics Committee (Reference Number: APIEC16/005). The study was conducted at the Agricultural Research Council (ARC), Animal Production Irene, South Africa. The institute lies at about 25° 34′ 0″ S and 28° 22′ 0″ E and is 1526 m above sea level, with an average annual temperature of 18.7 °C.

Potato hash was collected from Simba, a local food-producing company in South Africa and was made of potato peels (largest portion), rejected raw potatoes, and small quantities of yellow maize. Forty-two crossbred. male Large White × Landrace pigs aged 55 d with average weight of 25.5 ± 3 kg (mean ± standard deviation, SD) were randomly selected from the ARC pig herd in Irene. Pigs were housed individually in 1.54 m × 0.8 m pens in an environmentally-controlled house with the temperature of 22–25 °C. The housing facility was cleaned thoroughly and disinfected a week before the trial was undertaken. The temperature and relative humidity in the experimental house were maintained at 24.5 ± 1.9 °C and 62.7 ± 15.07 % (mean ± SD), respectively.

Six pigs were assigned in a completely randomized design to each of six experimental diets and a control. The seven diets were formulated to be isoenergetic and isonitrogenous. The dietary treatments included a dry standard feed; liquid-fermented standard feed; liquid-fermented potato hash, 200 g/kg (as fed), with or without enzymes; and liquid-fermented potato hash, 400 g/kg (as fed), with or without enzymes. Diets were formulated to provide 14 MJ/kg digestible energy (DE), 180 g crude protein (CP)/kg, and 11.6 g lysine /kg which meet and exceed the requirements of growing pigs (NRC, 2012). The experiment lasted for 56 days. An environmental, facility, and dietary acclimatization period of seven days was allowed for pigs before data collection commenced. Diets were prepared in quantities sufficient to feed pigs for a week to prevent spoilage. Feed was supplied *ad libitum* and water was

always available through nipple drinkers. Ingredients and calculated nutrient analysis (g/kg as fed basis) of experimental diets are shown in Table 1.

Table 1 Ingredients and calculated nutrient analysis (g/kg as fed basis) of experimental diets fed to growing pigs

Ingredients, kg	**CON[1]**	**LLFPH[1]**	**HLFPH[1]**
Hominy chop	608.7	504.4	400
Molasses	20	15	10
Potato hash	0	200	400
Soybean oilcake	181.4	166.7	152.1
Corn meal	150	75	0
Monocalcium phosphate	5	8.1	11.2
Limestone	18.8	16.3	13.7
Lysine HCl	8	6.5	5
Salt	4	4	4
Vitamin–mineral premix[2]	4	4	4
Calculated composition			
Nutrients, g/kg			
Dry matter	89.2	60.5	59.9
Ash	2.5	3.1	3.7
Crude protein	16.8	16.3	15.9
Crude fibre	5.7	5.8	6.0
Calcium	0.91	0.91	0.91
Phosphorus	0.54	0.54	0.54
Lysine	1.46	1.30	1.15
Methionine	0.06	0.05	0.04
Digestible energy, MJ/kg	13.6	13.4	13.3

[1]The ingredient composition for positive and negative controls was the same
CON = negative control diet, LLFPH = low liquid-fermented potato hash diet; HLFPH = high liquid-fermented potato hash diet.
[2]Provided the following per kg of diet: 6,500 IU vitamin A, 1,200 IU vitamin D3, 40 IU vitamin E, 2 mg vitamin K3, 1–5 mg vitamin B1, 4.5 mg vitamin B2, 0.03 mg vitamin B12, 2.5 mg vitamin B6, 25 mg niacin, 12 mg calcium pantothenate, 190.5 mg choline, 0.6 mg folic acid, 0.05 mg biotin, 40 mg manganese, 100 mg zinc, 125 mg copper, 1 mg iodine, 100 mg ferrous, and 0.3 mg selenium

The back-slopping fermentation approach was followed, as described by Plumed-Ferrer and Von Wright (2009) to ferment diets. Liquid-fermented diets were prepared by mixing formulated diets with water at a ratio of 1:2 for 12 h. The liquid-fermented mixture were stored in a closed 100 L drum under agitation at 25 °C. After 12 h, 50 % of the content was taken out and replaced in the drum with an equal amount of fresh feed and water. Diet samples were taken from the drum weekly after fermentation and kept in a cool dry place until they were homogenized and subsampled for chemical and physicochemical analyses. The experimental dietary samples and potato hash were analysed in triplicate. The dry matter (DM; ID: 2001.12), ash (ID: 942.05), crude protein (CP; ID: 990.03), and ether extract (EE; ID: 963.15) were analysed following the methods from the Association of Official Analytical Chemists (AOAC, 2005). Neutral detergent fibre (NDF; ID: 7-07-06) and acid detergent fibre (ADF; ID: 08-26-05) were determined according to ANKOM Technology Method (Van Soest *et al*., 1991). The NDF content was assayed using heat stable α-amylase (Sigma A3306, Sigma Chemical Co., St. Louis, MO, USA). The gross energy (GE) was determined using bomb calorimetry (MS-1000 modular calorimeter, Energy Instrumentation, Centurion, South Africa). The bulk density of the diets and potato hash silage was measured using the water displacement method, as described by Kyriazakis and Emmans (1995). The water holding capacity (WHC) was measured using the centrifugation method as described by Whittemore *et al*. (2003). Swelling capacity was measured according to Canibe & Bach-

Knudsen (2002). The chemical composition and physicochemical properties (g/kg DM feed) of experimental diets are shown in Table 2.

Table 2 Chemical composition and physicochemical properties (g/kg DM feed) of experimental diets fed to growing pigs (n = 3)

Parameters	LFC	LFC+E	LLFPH	LLFPH+E	HLFPH	HLFPH+E
Dry matter g/kg DM	306	310	285	295	256	260
Ash g/kg DM	57.6	58.5	51.1	53.6	40.6	41.1
Gross energy (MJ/kg)	18.1	18.1	17.9	17.9	17.8	17.9
Ether extract g/kg DM	49.5	49.5	44.5	48.5	37.5	38.9
Crude protein g/kg DM	192.0	191	186	194	168	181
Water holding capacity (g W/ g DM)	2.20	2.20	1.50	1.70	1.20	1.30
Swelling capacity (ml/ g)	2.20	2.10	2.70	2.70	3.10	3.10
Bulk density (g DM/ ml)	1.50	1.50	1.60	1.50	1.60	1.60
Neutral detergent fibre (g/ kg DM)	132	130	245	202	466	418
Acid detergent fibre (g/ kg DM)	38.9	36.2	80.1	71.3	107	98.9

Abbreviations: LFC: Liquid-fermented control diet, LFC+E: Liquid-fermented control diet with enzyme, LLFPH: low liquid-fermented potato hash diet without enzyme, LLFPH +E: low liquid-fermented potato hash diet with enzyme, HLFPH: high liquid-fermented potato hash diet without enzyme, HLFPH+E: high liquid-fermented potato hash diet with enzyme

Total anaerobic bacteria such as *Lactobacillus* sp., *E. coli*, *Salmonella* sp., and *Clostridium perfringens* were determined in triplicate according to the methods of Jensen & Mikkelsen (1998). For microbiological enumeration, liquid feed samples (10 g) were transferred into flasks containing 90 mL of peptone water containing 10.0 g Bacto peptone (Merck 1.07213, Darmstadt, Germany)/L and 1.0 g Tween 80/L. The suspension was then transferred to a plastic bag and homogenised in a stomacher blender (Interscience, St. Nom, France) for 2 min. Then, 10-fold dilutions were prepared in peptone water using the technique of Miller & Wolin (1974) and samples (0.1 mL) were plated on selective media.

The concentration of lactic acid was assayed using the method of Jensen & Mikkelsen (1998) on de Man, Rogosa, and Sharp agar (Merck 1.10660.0500) following anaerobic incubation at 20 °C for 3 d. Enterobacteriaceae were enumerated on McConkey agar (Merck 1.05465.0500) following aerobic incubation at 37 °C for 1 d. Yeasts and moulds were enumerated on malt chloramphenicol/chlortetracycline MCA agar (10 g glucose [Merck 1.08337.1000]/L; 3 g malt extract [Merck 1.05397]/L; 3 g yeast extract [Merck 1.03753]/L; 5 g Bacto peptone [Merck 1.07224]/L; 50 mg chlortetracycline + 50 mg chloramphenicol [SR0177E, Oxoid Ltd, Basingstoke, Hampshire, UK]/L; 15 g agar [Merck 1.01614])/L) following aerobic incubation at 20 °C for 3 d. The pH was determined with a pH meter (Thermo Orion Model 525, Thermo Fisher Scientific, Waltham, MA, USA). The pH was taken at 0, 8, and 24 h in three different weeks in triplicate. The water-soluble carbohydrate (WSC) fraction was determined using the phenol–sulphuric acid method. Lactic acid (LA) content was determined using the colorimetric method of Pryce (1969). Samples were taken in three different batches after 8 h of incubation. Table 3 shows the microbial characteristics of the liquid-fermented potato hash diets.

The final average body weight of pigs was 67.7 ± 8.7 kg at the end of the growth performance period. Pigs were weighed prior to slaughtering, fasted for 12 h, then transported in the early hours (07:30) of the morning to the ARC–Irene abattoir, where they were provided with fresh drinking water, kept calm, and then slaughtered. At the abattoir, standard pre-slaughtering procedures were followed. Each pig was electrically stunned with an electrical stunner set at 220 V and 1.8 A with a current flow for 6 s. Electrical stunner electrodes were positioned at the base of each ear. Exsanguination followed within 10 s of stunning. Dehairing and evisceration were done according to the abattoir's standard operating procedures. Warm carcass weight (WCW) was measured after dressing using an overhead scale.

Table 3 Microbial characteristics in liquid-fermented potato hash with or without enzyme diet

	Treatments								*Significance level*		
Parameters	LFC	LFC+E	LLFPH+E	LLFPH	HLFPH+E	HLFPH	SD	SEM	Diet	Enzyme	Diet * Enzyme
LAB	6.3^{b}	8.9^{a}	9.0^{a}	6.1^{b}	8.9^{a}	6.0^{b}	0.43		**	*	**
Enterobacteriaceae	5.0^{b}	4.2^{a}	4.3^{a}	5.5^{b}	4.6^{a}	5.5^{b}	0.56		*	*	NS
Yeast and Moulds	5.6^{a}	4.5^{b}	4.4^{b}	5.6^{a}	4.6^{b}	5.6^{a}	0.29		**	**	NS
E.coli	ND	ND	ND	ND	ND	ND	ND		NS	NS	NS
Lactic acid g/kg	66.2^{d}	72.0^{bc}	85.4^{a}	77.2^{b}	84.2^{a}	74.3^{b}		3.52	**	**	NS
WSC g/kg	61.9^{c}	68.5^{b}	74.4^{a}	65.0^{b}	75.1^{a}	63.4^{b}		5.04	**	**	NS
pH											
0 h	5.03	5.04	5.02	5.02	5.05	5.06	0.53		NS	NS	NS
8 h	3.60^{b}	3.57^{a}	3.55^{a}	3.63^{b}	3.57^{a}	3.64^{b}	0.42		***	***	**
24 h	3.58^{b}	3.57^{a}	3.54^{a}	3.61^{b}	3.55^{a}	3.62^{b}	0.56		***	***	*

^{a,b,c} Means with different superscripts within the same row are different, **P* <0.05; ***P* <0.01; ****P* <0.001, NS - not significant

ND - not detected, WSC - water soluble carbohydrates, h - hours, SD - standard deviation, SEM - standard error of mean, LFC - liquid-fermented control diet, LFCE - liquid-fermented control with enzyme, LLFPHE - low liquid-fermented potato hash with enzyme, LLFPH - low liquid-fermented potato hash without enzyme, HLFPH+E - high liquid-fermented potato hash with enzyme, HLFPH - high liquid-fermented potato hash without enzyme.

Detection level was 6 log cfu/g for Enterobacteriaceae, <3 log cfu/g for lactic acid bacteria (LAB) and yeasts for all diets, *E.coli - Escherichia coli*

Table 4 Carcass traits of Large White × Landrace pigs fed diets containing different inclusion levels of liquid-fermented potato hash with or without enzyme

Parameters	Liquid-fermented potato hash with or without enzyme diets							SEM	*Significance level*		
	CON	LFC	LFC+E	LLFPH+E	LLFPH	HLFPH+E	HLFPH		Diet	Enzyme	Diet*Enzyme
WCW, kg	48.65	46.60	45.60	50.95	48.18	44.73	43.15	7.19	NS	NS	NS
CCW, kg	42.50	45.41	44.60	49.53	46.87	43.60	41.90	8.14	NS	NS	NS
DL, %	2.41^{c}	2.39^{c}	2.43^{c}	2.71^{ab}	2.75^{ab}	2.91^{a}	3.04^{a}	0.42	***	NS	NS
DP, %	69.95	69.89	69.98	71.01	71.04	70.98	70.97	9.16	NS	NS	NS
Lean, %	60.98^{c}	61.01^{c}	61.91^{c}	64.98^{ab}	65.15^{ab}	67.84^{a}	68.01^{a}	1.75	***	NS	NS
EMA, cm^{2}	9.99^{bc}	10.65^{ba}	10.55^{ba}	11.76^{a}	10.77^{ba}	9.32^{c}	9.30^{c}	5.64	***	**	NS
BF, mm	8.52^{a}	8.44^{a}	7.32^{b}	7.04^{b}	7.09^{b}	6.91^{b}	6.941^{b}	3.18	**	NS	**
P2, mm	7.91^{a}	7.46^{a}	5.56^{bc}	5.04^{b}	5.09^{b}	4.71^{b}	4.92^{b}	3.37	***	NS	NS
Shoulder fat, mm	18.83^{a}	18.83^{a}	15.98^{b}	15.16^{b}	15.78^{b}	15.00^{b}	15.16^{b}	6.15	***	NS	NS
CL, cm	82.33	81.35	78.00	79.67	84.33	80.50	82.36	4.68	NS	NS	NS

[a,b,c] Means with different superscripts in a row differ significantly; **P* <0.05; ***P* <0.01; ****P* <0.0001, NS - not significant; [1]CON, control diet; LFC, liquid-fermented control diet; LFCE, liquid-fermented controlwith enzyme; LLFPH, low liquid-fermented potato hash with enzyme; LLFPH, low liquid-fermented potato hash without enzyme; HLFPH, high liquid-fermented potato hash with enzyme; HLFPH, high liquid-fermented potato hash without enzyme; WCW, warm carcass weight; CCW, cold carcass weight; DP%, dressing percentage; CL, carcass length; P2, back-fat thickness; EMA, eye muscle area; Lean%, lean percentage; DL%, drip loss; BF, Back fat thickness at last rib

Table 5 Primal pork cut measurements of Large White × Landrace pigs fed diets containing liquid-fermented potato hash at low (LLFPH) and high (HLFPH) inclusion levels with or without enzymes

Component	Treatments							SEM	*Significance level*		
	CON	LFC	LFC+E	LLFPH+E	LLFPH	HLFPH+E	HLFPH		Diet	Enzyme	Diet*Enzyme
SWP%	14.16	14.19	13.98	14.00	14.21	14.25	14.19	1.27	NS	NS	NS
RWP%	11.04^{c}	11.51^{c}	12.59^{ab}	13.43^{a}	13.41^{a}	12.65^{ab}	12.00^{b}	0.69	***	NS	NS
HQL, cm	10.41	10.55	10.52	10.62	10.49	10.38	9.75	2.13	NS	NS	NS
HC, cm	59.83^{ab}	59.96^{b}	59.64^{ab}	61.00^{a}	60.98^{a}	57.20^{c}	57.16c	4.07	***	NS	NS
HL, cm	31.06	32.00	32.00	32.13	31.98	32.23	32.00	2.05	NS	NS	NS

[a,b, c] Means with different superscripts in a row differ significantly; **P* <0.05; ***P* <0.01; ****P* <0.0001, NS, not significant;
[1]HQL, hind quarter length; HC, ham circumference; HL, ham length; RWP, rib weight proportion; SWP, shoulder weight proportion;
[2]CON, control diet; LFC, liquid-fermented control diet; LFCE, liquid-fermented control with enzyme; LLFPH, low liquid-fermented potato hash with enzyme; LLFPH, low liquid-fermented potato hash without enzyme; HLFPH, high liquid-fermented potato hash with enzyme; HLFPH, high liquid-fermented potato hash without enzyme

Dressing percentage (DP) was determined from the warm carcass weight as a percentage of live weight. Carcasses were then placed in a cold room, kept at an approximate temperature of 0 ºC for 24 h after which cold carcass weights (CCW) were measured. The head from each carcass was removed at the atlanto–occipital joint; the tail was removed at the junction of the third and fourth sacral vertebrae; and the flare fat, kidneys, kidney fat, glands, and remaining parts of the diaphragm were also removed. Carcasses were then split into two parts along the median plane from the remaining sacral vertebra to the first cervical vertebra with a carcass-splitting band saw. Carcass length (CL) was measured from the first rib to the pubic bone using a measuring tape. Backfat measurements were taken at first rib (DFT1), last rib (DFT2), and last lumbar vertebra (DFT3). All other carcass measurements were taken from the left side. A cut was made between the l0th and 11th ribs and carried on through the spinal column. The fat measurement at 65 mm from the mid-dorsal line at the last rib (P2) was taken on each carcass with Vernier callipers over the eye muscle, 60 mm from the carcass midline.

Eye muscle length (EML) and three measurements of the eye muscle width (EMW) were taken from the cut interface. Lean meat percentage (Lean %) was calculated using the formula of Bruwer (1992):

$$\text{Lean \%} = 72.5114 - 0.4618V + 0.0547S \quad (1)$$

where V is the fat thickness (mm), and S is the muscle depth (mm).

The eye muscle area (EMA) was estimated using the formula of Zhang *et al*. (2007):

$$\text{EMA} = \text{EML} \times \text{EML} \times 0.7 \quad (2)$$

where EMW is the average of the three width measurements of the eye muscle.

From the same cut where the P2 measurements were taken, a sample joint measuring 2.5 cm thick and 16 cm long, measured along the surface of the back of the eye muscle, was cut out and weighed. This sample joint was placed in a nylon bag and inserted in a small plastic bag to prevent the sample joint from touching the bottom of the plastic bag. They were then stored in a refrigerator between 0 and 5 ºC for 24 h. Afterward, the drip loss was calculated as:

$$\text{Drip loss } (\%) = \frac{Initial\ mass_i - Final\ mass_i}{Initial\ mass_i} \times 100 \quad (3)$$

The measurements for hindquarter length (HQL), hindquarter length circumference (HQC), and rip weight proportion (RWP), shoulder weight proportion (SWP), and hindquarter weight proportion (HQWP) were carried out according to the method of Kanengoni *et al*. (2014).

Data for microbial characteristics of the feed, and carcass traits of growing pigs fed on fermented liquid potato hash diets treated with or without enzyme were analysed using the General Linear Model of procedures of SAS (2008).

The model used was:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha_i \times \beta_j) + \varepsilon_{ijk1} \quad (4)$$

where:
Y_{ijkl} is the microbial characteristics of feed and carcass traits
μ is the overall mean response common to all observations
α_i is the effect of liquid fermentation
β_j is the effect of inclusion of liquid-fermented potato hash with or without enzymes
$(\alpha_i \times \beta_j)$
ε_{ijk1} is the residual error.

Results

Microbial characteristics of liquid-fermented potato hash diets with or without enzymes are shown in Table 3. Lactic acid bacteria (LAB), Enterobacteriaceae, yeast and moulds, and *E. coli* in liquid-fermented diets with or without potato hash inclusion were influenced by the addition of enzymes (P <0.05). The low and high liquid-fermented potato hash diets with enzymes had higher LAB, Enterobacteriaceae, yeast and moulds, and *E. coli* levels than the low and high liquid-fermented potato

hash diets without enzymes (P <0.05). An effect of diet and enzyme was observed on lactic acid and water-soluble carbohydrates (P <0.05). There was no interaction between diets and enzymes on lactic acid and water-soluble carbohydrate concentration between the treatments. The pH of the three batches at 0 h did not differ between the inclusion levels of fermented liquid potato hash with or without enzyme (P >0.05). The low and high liquid-fermented potato hash diets without enzymes had a higher pH than the low and high liquid-fermented potato hash diets with enzymes at 8 and 24 h (P <0.05).

Carcass traits of Large White × Landrace pigs fed diets containing different inclusion levels of liquid-fermented potato hash with or without enzyme are shown in Table 4. There was a difference in DL, lean percentage, eye muscle area (EMA), back fat (BF), and back fat thickness (P2) among the diets provided to pigs (P <0.05). A control and fermented control diet had similar low drip loss and lean percentage (P <0.05). Fermented potato hash with or without enzyme led to a higher drip loss and lean percentage (P <0.05). Pigs fed the control and high liquid-fermented diets had a smaller EMA than the other diets (P <0.05). The control and liquid-fermented control diets had a higher back fat than other treatments (P <0.05). There were no differences in warm carcass, cold carcass weights, dressing percentage, carcass length, and shoulder fat between the treatments (P >0.05). There was no interaction between diet and enzyme on carcass traits (P >0.05). Primary pork cuts of Large White × Landrace pigs fed diets containing different inclusion levels of liquid-fermented potato hash with or without enzyme are shown in Table 5. There was an effect of diets on rib weight proportion (RWP) and ham circumference (HC) in pigs (P <0.05). Pigs fed fermented diets that contained potato hash and fermented control diets with enzyme had good RWP, but greater values were observed on low liquid-fermented potato hash diets (P <0.05). Other primary pork cuts were similar between the diets (P >0.05). There was no diet × enzyme interaction for primary pork cuts in pigs (P >0.05).

Discussion

Food fermentation is one of the oldest ways of food processing and preservation. As expected, fermented liquid potato hash diets treated with enzymes had low enteropathogens (Beal *et al.,* 2005). Lactic acid (LA) is the strongest of all liquid-fermented dietary acids and its presence will drop pH more effectively than volatile fatty acids (McDonald *et al.,* 2010). The same was true in the current study, which recorded a lower pH (<3.6) and higher LA levels on fermented liquid potato with enzymes. The pH and LA can be associated with an increase in fermentable carbohydrates by hydrolysis of the cell wall, which increases fermentation by LAB. Water-soluble carbohydrates are regarded as essential substrates for the growth of LAB for proper fermentation (McDonald *et al.,* 2010), and low levels may restrict LAB growth. A low pH indicates that the fermented-liquid potato hash diets were well-preserved. It is well-documented that one of the most important factors affecting LFD quality is the rate of decrease in pH of the material being preserved (Moran *et al.,* 2006).

The increase in pH during the first hours of incubation was probably due to the acid binding capacity of the dietary ingredients (Scholten *et al.,* 2001a). All diets showed a drop in pH after 8 to 24 h of fermentation. The decreasing counts of Enterobacteriaceae in the liquid-fermented potato diets followed a pattern previously observed by Canibe & Jansen *(*2003). In the present study, the counts of yeasts during fermentation of liquid feed were lower than previously observed (Geary *et al.,* 1999). Similar to Nadeau *et al.* (2000), the present study demonstrated an improved sugar content in cellulose of fermented potato hash diet treated with enzymes.

Feeding fermented liquid feed to pigs has been proposed as an approach to maintain high and regular feed and water intake. It has also been shown to decrease the incidence of diarrhoea (Højberg *et al*., 2003) and pig dysentery (Lindecrona *et al*., 2000), as well as the spread of zoonoses to the consumers (Brooks *et al*., 2003) compared with dry feed. Brooks *et al*. (2003) reported that fermented cereal grains could decrease the pH value and improve the palatability of fermented liquid feed.

High fibre diets increase the weight of visceral organs in pigs (Montagne *et al*., 2003). Diets containing different inclusion levels of fermented liquid potato hash with or without enzyme did not have a lower DP, as expected. This concurs with studies done on potato hash silage (Ncobela *et al*., 2018) and potato chip scraps (Borton & Rahnema, 1998). Pigs fed low and high fermented-liquid potato hash with or without enzyme had greater drip loss values than pigs fed the control or fermented-liquid control diets with or without enzyme. Drip loss (DL) of pork fed high moisture diets is affected by numerous and complex factors, including rate of pH decline and ultimate pH, presence of the halothane gene, and transportation (Fischer, 2007). Although drip loss is of economic importance, the mechanism behind this phenomenon has not been adequately studied (Otto *et al*., 2007). Because the high fermented-liquid potato hash with or without enzyme had a greater ultimate pH, the DL results contradict the assertion by Huff-Longergan *et al*. (2002) that a higher ultimate pH is associated with better water holding capacity, translating into lower drip losses during storage.

Experimental diets did not influence the length of the carcass in the study. Carcass length affects the weight of the most valuable meat cuts (Poto *et al*., 2007) and determines the amount of rashers of back bacon obtained (Kanengoni *et al*., 2014). English *et al*. (1988) stated that carcass weight and the genotype of the pig largely influence CL. The control and fermented-liquid control diets with or without enzyme had more subcutaneous fat than the low and high liquid-fermented potato hash diets with or without enzyme; this was demonstrated by a lower lean percentage. Different inclusions of fermented liquid potato hash with or without enzymes reduced back-fat measurements. Back-fat thickness, P2, and shoulder fat measures were lower on the fermented-liquid potato hash diets with or without enzyme, compared to the control and fermented-liquid control diets. Inclusions of liquid-fermented potato hash diets with or without enzyme, however, did not negatively affect some commercially important pork cut measurements of the hindquarter, ham length, and shoulder. The hindquarter length, circumference, and weight and the shoulder weight measures were affected mainly by diet.

Nyachoti *et al*. (2004) reported that replacing non-fibrous ingredients with bulky feedstuffs limited intake. The feed with a high inclusion of liquid-fermented potato hash treated with or without enzyme had a higher NDF and was bulkier. The reduced carcass performance in the high liquid-fermented potato hash diets, with or without enzymes, suggests that high NDF content in the diet compromised carcass performance in pigs. Considering that CP was low in diets with high liquid-fermented potato hash, the effect of CP was likely to have been confounded with NDF and CF content of these feeds. Evidence exists that an average of 31% of protein in commonly used fibre sources is bound to the NDF and is not available for the pig (Bindelle *et al*., 2005). In the current study, the enzymes consisted of xylanase, amylase, and protease, which targeted substrates such as NSP, indigestible starch, and protein. In the experiment of Kim *et al*. (2003), the enzymes used were β-1,4-mannanase, β-1,4-mannosidase, and β-1,6-galactosidase, which only targeted NSPs. Enzyme supplementation improved the digestibility of gross energy, crude protein, and dry matter. This result is consistent with previous findings (Olukosi *et al*., 2007).

Conclusions

The use of the liquid fermentation method to preserve and improve utilization of industrial by-products is a promising approach. It can be concluded from this study that enzyme-treated diets had good microbial quality, which suggests that the liquid-fermented potato hash was properly preserved. The addition of enzyme to liquid-fermented potato hash increased lactic acid production and decreased pH. Liquid-fermented potato hash reduced backfat thickness. Pigs fed less fermented-liquid potato hash, with or without enzymes, had improved carcass traits. The influence of liquid-fermented potato hash on other carcass measurements was not definitive.

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Contributions made by authors

RST & MC conceived project. RST, CN, & PS conducted experiments. CN & VH analysed data and wrote the manuscript. MC edited and improved the manuscript. All authors read and approved the manuscript.

Data and material availability

The data are available from the corresponding author on request

Consent to participate

Authors agreed upon the roles and responsibilities taken towards one another throughout the study

Conflict of interest

The authors declare that they have no conflict of interest.

Consent for publication

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