Research Article
doi.org/10.56093/ijan.v43i2.180922

Postprandial glycaemic dynamics response of cockerels to extruded sweetpotato-bran diets

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Received: 30th June 2026
Accepted: 8th August 2026
Published: 20th August 2026 (Online)

Citation: Adeleye OO and Osofisan DB. Postprandial glycaemic dynamics response of cockerels to extruded sweet potato-bran diets. Indian Journal of Animal Nutrition. 2026 August 10; 43(2). doi.org/10.56093/ijan.v43i2.180922

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This study investigated extruded sweetpotato–bran energy concentrates in cockerels, emphasizing the effect of extrusion temperature and bran type on postprandial glycaemic dynamics. Sweetpotato roots were enriched with corn bran (SP-CB), rice bran (SP-RB), and wheat bran (SP-WB) and extruded at 80 °C, 100 °C, and 120 °C to create energy concentrates. Diets containing raw or extruded concentrates were fed alongside a reference diet to 8 cockerels each for 20 minutes, and blood glucose was obtained preprandial, plus 30, 60, 90, 120, 180, and 300 minutes postprandial per cockerel. Non-compartmental and one-compartment oral absorption models were applied to glucose concentration–time data obtained. The glucose absorption rate constant, Ka, absorption and elimination rate constant half-lives, t1/2Ka and t1/2K10, hydrolysis index, HI, and glycaemic index, GI, were recorded. Increasing extrusion temperature accelerated glucose absorption ($p < 0.05$) but, at the highest temperature (120 °C), tended to reduce total glucose exposure, AUC_0–t, in rice and corn-bran diets, suggesting retrogradation and restricted enzyme accessibility. Conversely, wheat-bran blends extruded at 120 °C exhibited elevated AUC_0–t, alluding to temperature-dependent modulation of fibre–starch interactions. Overall, rice bran enrichment produced the most consistent lowering of glycaemic indices. These results underscore the potential of extrusion and bran enrichment to control starch digestibility and glycaemic release in sweetpotato-based poultry diets and support the use of postprandial glycaemic response dynamics as a functional tool in poultry nutrition research.

Keywords: High-temperature short-time extrusion cooking, Glycaemic index, Resistant starch, Kinetic modeling, Bran enrichment

Introduction

Energy concentrates are feedstuffs of high calorific density and relatively low in other nutrients. While this term may refer to single-grain ingredients such as maize, barley, and wheat, it also describes energy blends and premixes offered as value-added products tailored to balance forage or protein feeds (Onche et al., 2025). Combined with commercial high-protein concentrates, it creates a complete feed (Adeleye and Ojeniyi, 2023). Calorie-dense feedstuffs such as cassava (*Manihot esculenta* L. Crantz) and sweet potato (*Ipomoea batatas*) tubers could also be harnessed to create energy concentrate blends. Despite the year-round availability of sweet potato and its comparable metabolizable energy to maize (Pandi et al., 2016; Woolfe, 1992), its use in poultry diets is constrained by high moisture content, which advances spoilage. Sweetpotato roots also contain trypsin inhibitors (Pandi et al., 2016), reducing sugars (Woolfe, 1992), soluble fibre, and ipomoein, its major soluble protein, all of which impair its digestibility and may elicit a laxative effect in chickens (Dominguez, 1991; Varon et al., 1989). These constraints to sweetpotato use in poultry feeding may be alleviated by extrusion processing.

The structural reorganization and physicochemical changes that occur in the process of extrusion cooking induce starch gelatinization, protein denaturation, fibre modification, and inactivation of anti-nutritional factors (Ali et al., 2024; Adeleye et al., 2020a, 2020b; Roye et al., 2020). The resultant effect of extrusion conditions on physicochemical and nutritional properties of foods is somewhat complex as intrinsic properties of the ingredient or blends, such as amylose-amylopectin ratio, fibre, protein, and lipid content, interact with processing variables- barrel temperature, moisture, screw speed, and pressure- to collectively affect outcomes (Ali et al., 2024). The characteristic composition of individual ingredients in blended products also influences how extrusion cooking conditions affect their nutritional and physicochemical indices. Blending cereals with legumes or other fibres often increases SDS and lowers *in vitro* estimated Glycemic Index (GI) after extrusion (Wani et al., 2021), while purely starchy ingredients show marked GI increases under similar conditions (Adeleye et al., 2020b). The GI-lowering ability of extruded cereal-legume or cereal-fibre blends could be due to physical entrapment of starch granules by dietary fibre (Zhang et al., 2022), formation of amylose-lipid and starch-protein complexes (Altan et al., 2009), and/or increasing soluble fibre fractions (Khalid et al., 2022) that slow gastric emptying and starch hydrolysis (Fujiwara, et al., 2017). These processes limit the accessibility of digestive enzymes to starch, reducing the rate at which glucose is released into the bloodstream.

Riding on these desirable benefits of extrusion, the potential of the extrusion process to modify "glycaemic response dynamics" is crucial in nutritional studies (Zhao et al., 2024). While three independent pathways; *prandial* intestinal absorption, glycogenolysis, and gluconeogenesis- contribute to blood glucose concentrations, *postprandial glycaemic* concentrations primarily reflect glucose absorption from recent meals (Khan, 2001; Zebda et al., 2018). Kinetic indices derived from modeling glucose concentration-time data also reveal how rapidly glucose becomes available, how much glucose is supplied, how sustained the supply is, and how glucose/glucose precursors may interact with other nutrients (Huang et al., 2025). These kinetic features are highly relevant for animal performance, metabolic health, and developing formulation strategies. In the present study, we investigate the extent to which extrusion cooking × cereal bran combinations will alter glycaemic response dynamics in cockerels fed sweet potato-bran concentrates.

doi.org/10.56093/ijan.v43i2.180922

Materials and methods

Development of sweet-potato-bran energy concentrates and diets

White-fleshed sweet potato (*Ipomoea batatas*) roots were obtained from the open market, and cereal brans- corn, rice, and wheat- from reputable feed stockists. Sweet potato roots were washed to remove sand and debris, chipped, and dried in a forced-air oven at 60°C until constant weight was attained. The sweet potato chips and brans were then milled to obtain a fine texture. Sweetpotato-bran energy concentrates were created by blending sweet potato with corn bran or rice bran at a ratio of 3:2, and with wheat bran at a ratio of 7:3 (Table 1). Extrudates were prepared as described by Adeleye and Ojeniyi (2023), with slight modifications. The sweet potato-bran blends were adjusted to 30% moisture content and fed into a single-screw industrial extruder. Extruder characteristics were screw length-to-diameter (L/D) ratio, 6:1, barrel length, 317.5mm, screw speed: 305rpm, die diameter: 8mm, feed rate: 33.6 kg/h, and extrusion temperatures were 80, 100 and 120 °C. The extrudates were again dried in a forced-air oven at 50 °C until constant weight was attained.

Table 1. Calculated and analyzed composition of the un-extruded sweet potato-bran energy concentrates: sweet potato-corn bran, (SP-CB) sweet potato-rice bran (SP-RB) and sweet potato-wheat bran (SP-WB).

	SP-CB	SP-RB	SP-WB
	3:2	3:2	7:3
Calculated nutrients			
Crude protein, %	6.17	8.44	7.30
Sugars, %	4.78	5.00	6.05
Starch + sugars, %	54.47	53.98	55.13
Crude fibre, %	5.56	5.70	4.89
Calcium, %	0.11	0.16	0.16
Phosphorus, %	0.27	0.78	0.43
Non-phytate phosphorus, %	0.08	0.31	0.19
Lysine, %	-	-	-
Digestible lysine, %	0.11	0.20	0.16
Methionine, %	-	-	-
Digestible methionine, %	0.08	0.11	0.07
Digestible methionine + cysteine, %	0.13	0.18	0.13
Digestible threonine, %	0.12	0.16	0.13
Analyzed composition			
Gross energy, kcal/g DM			
Dry matter, %	91.05	88.00	90.00
Crude protein, %	6.00	6.00	5.65
Ether extract, %	4.90	4.50	4.70
Crude fibre, %	3.80	11.50	11.45
Carbohydrates (calculated as nitrogen free extract, %)	66.85	59.08	64.80
Ash, %	9.50	7.50	3.40

SP-CB: sweet potato-corn bran, SP-RB: sweet potato-rice bran, SP-WB: sweet potato-wheat bran

Experimental Animals Management

In three different assays, cockerels (n=40) with a weight/bird of 2.15 ± 0.28 kg were obtained from a research flock and used to investigate *postprandial* glycaemic response to extrusion temperatures per sweetpotato + cereal bran combination. Cockerels were pre-tagged for individual identification and housed in metabolic cages, 120cm × 69cm × 85cm, 2 birds per cage and 4 cages per treatment. Cages were equipped with feeding troughs and nipple drinkers and placed in an open-sided house with natural ventilation and lighting (14L: 10D).

Diets and glycaemic response dynamics study

In three independent assays, combinations of sweet potato+ bran energy concentrates; sweet potato-corn bran (SP-CB), sweetpotato-rice bran (SP-RB), or sweet potato-wheat bran (SP-WB) (Table 2), were assessed. Feed was withdrawn 12 hours proceeding, with *ad libitum* water to ensure thorough emptying of the gastrointestinal tract. At commencement of the study, *preprandial* glucose values were obtained by glucometry (ACCUCHEK active, Roche Diagnostics GmbH, Mammheim, Germany) in a "prick glucose test" which involved applying a lancet to the wing vein and obtaining 20-50µL of blood via a capillary tube. Birds in four cages (n=8) were offered the diets for 20 minutes, and blood glucose values were again obtained at 30, 60, 90, 120, 180, and 300 minutes *postprandial*.

Calculations and Statistical Analysis

Concentration-time curves were analyzed by non-compartmental analysis and fitted with a one-compartment oral absorption model (Bateman function) using PK Solver 2.0 (Zhang et al., 2010).

The hydrolysis index, HI, of each sweet potato-bran energy concentrate was obtained per bird, calculated as the ratio of the area under the glucose concentration-time curve of the bird on the

Table 2. Gross composition of experimental diets used in this study

	Reference diet	SP-CB diet				SP-RB diet				SP-WB diet			
		Raw	80°C	100°C	120°C	Raw	80°C	100°C	120°C	Raw	80°C	100°C	120°C
Ingredients													
Glucose monohydrate	48.50	-	-	-	-	-	-	-	-	-	-	-	-
Fibre concentrate, 66% CF	3.50	-	-	-	-	-	-	-	-	-	-	-	-
Fish meal, 72% CP	8.00	-	-	-	-	-	-	-	-	-	-	-	-
Soy oil	-	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Protein concentrate, 30% CP	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Sweet potato + cereal bran concentrate	-	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00	57.00
	100	100	100	100	100	100	100	100	100	100	100	100	100

SP-CB: sweet potato-corn bran, SP-RB: sweet potato-rice bran, SP-WB: sweet potato-wheat bran

test diet to the area under the glucose concentration-time curve of the bird on the reference diet. The glycaemic index (GI) was calculated by the equation of Goñi et al. (1997).

"Glycaemic index (GI) = 39.71+(0.549 * HI)"

One-way analysis of variance, ANOVA, comparisons was conducted to assess the effect of extrusion cooking temperature within each sweet potato-bran energy concentrate using SPSS.

Results

Figure 1 shows the *postprandial* glucose concentration-time curves of matured cockerels fed sweet potato-corn bran (SP-CB), sweet potato-wheat bran (SP-WB), and sweet potato-rice bran (SP-RB), energy concentrates. Extrusion cooking had no significant effect on glucose concentrations of the cockerels from 30-300 minutes

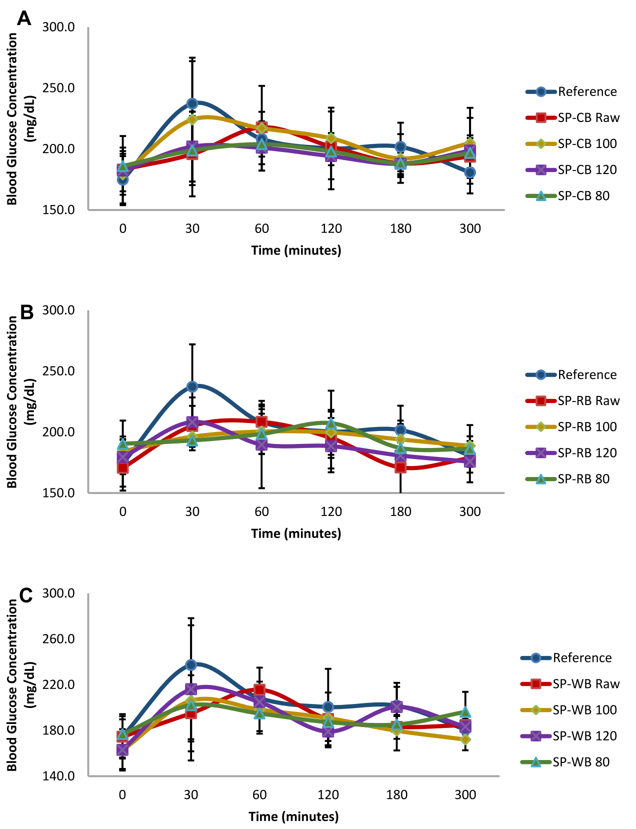

Figure 1(A-C). The effect of extrusion cooking temperature (80- 120 °C) on *postprandial* glucose concentration-time curves of matured cockerels fed the sweet potato-bran energy concentrates; SP-CB (sweet potato-corn bran), SP-RB (sweet potato-rice bran), SP-WB (sweet potato-wheat bran), Raw- unextruded sweet potato-bran treatments. n=8

postprandial except for SP-RB at 30 minutes (p=0.08) and SP-WB at 300 minutes (p=0.01) where glucose concentration was higher in cockerels on the reference diet.

Table 3 shows the effect of extrusion cooking temperatures on indices of glycaemic dynamics in matured cockerels fed sweet potato-corn bran (SP-CB), sweet potato-wheat bran (SP-WB) and sweet potato-rice bran (SP-RB), energy concentrates. Parameters of interest estimated from the compartmental analysis of the *postprandial* glucose concentration-time curve include the peak glucose concentration in the blood, C_{max}, time taken for blood concentration to reach the peak, T_{max}, and area under the glucose concentration-time curve, AUC_{0-t} which is considered the observed systemic glucose exposure over the study period, i.e. 300 mins *postprandial*. C_{max} peaked in cockerels offered the 100 °C extruded SP-CB diet, declined with increasing extrusion temperatures in cockerels on the extruded SP-RB diets ($p < 0.05$) while remaining unaffected by extrusion in cockerels fed the SP-WB diets. Conversely, T_{max} decreased with increasing extrusion temperatures ($p < 0.05$) in cockerels offered the 120°C extruded SP-CB (0.36h), SP-RB (0.40h), and SP-WB (0.35h) diets. The AUC_{0-t} estimate was not impacted by lower extrusion temperatures, i.e., 80 and 100 °C, in cockerels fed the SP-WB and SP-RB diets but significantly peaked in the cockerels fed the 120 °C SP-WB diet (9.69 mg/mL*h, $p < 0.05$). Conversely, AUC_{0-t} estimate was lowest in cockerels fed the 120 °C SP-RB diet (8.99 mg/mL*h, $p < 0.05$). Cockerels fed the raw, 80 °C, and 120 °C extrudate SP-CB diets showed similar AUC_{0-t} estimate with the highest AUC_{0-t} estimate recorded in cockerels on the 100 °C extrudate diet (10.29 mg/mL*h, $p < 0.05$).

The first-order rate constants, absorption rate constant (K_a) and the elimination rate constant (K_{10}) reflect how quickly glucose enters the systemic circulation of the cockerels after feeding extruded sweet potato–bran diets, and how it is eliminated from circulation through metabolic use, tissue uptake, or excretion. K_a estimates steadily increased with increasing extrusion temperature, peaking at 120°C for SP-CB. Similarly, K_a estimates for SP-RB and SP-WB peaked at 120°C ($p < 0.05$); however, K_a was unaffected by extrusion of SP-RB at 80 and 100°C and extrusion of SP-WB at 100°C. However, there were no significant effects of SP-RB extrusion at lower temperatures (i.e. 80 and 100°C) on K_a estimates, as they were similar to K_a estimates from cockerels fed the unextruded SP-RB diets. Cockerels fed the SP-WB diet with 120 °C extrudates also showed similar K_a estimates ($p > 0.05$) with the 80 °C extrudates group. The K_{10} remained unaffected by extrusion temperature in cockerels fed the SP-RB and SP-WB diets, while decreasing with increasing extrusion temperature ($p < 0.05$) in cockerels fed the SP-CB diets. Conversely, the absorption half-life ($_{t1/2}K_a$) and the elimination half-life ($_{t1/2}K_{10}$) represent the time required for half of the

doi.org/10.56093/ijan.v43i2.180922

orally administered dose of glucose or glucose precursors in the sweet potato-bran diets to be absorbed from the gastrointestinal tract into systemic circulation, and the time required for blood glucose concentration to decrease by half owing to metabolic utilization or excretion. Absorption half-life ($_{t1/2}K_a$) was unaffected by extrusion at lower temperatures, i.e., 80 and 100 °C in cockerels fed the SP-RB and SP-WB diets and was lowest in the 120 °C extrudate diet. However, $_{t1/2}K_a$ decreased progressively with increasing extrusion temperature (0.15 h > 0.09 h > 0.03 h, $p < 0.05$), indicating a faster glucose absorption rate at higher processing temperatures.

The peak elimination half-life ($_{t1/2}K_{10}$) was attained at 66.10h, 45.86h, and 31.31h in cockerels fed the SP-CB, SP-RB, and SP-WB diets containing 80 °C extrudates, while extrusion at 120 °C did not impact $_{t1/2}K_{10}$ differently from the control ($p > 0.05$).

The hydrolysis index, HI, and glycaemic index (GI) values were highest in cockerels fed the diets containing SP-CB and SP-WB extruded at 100°C ($p < 0.05$). At the same time, extrusion cooking significantly lowered HI and GI in cockerels fed the SP-RB diets.

Table 3. The effect of extrusion cooking temperature on indices of glycaemic response kinetics in matured cockerels fed the sweet potato-bran energy concentrates

Parameters	Extrusion temperature				
	Raw	80°C	100°C	120°C	SEM
Sweet potato – corn bran, SP-CB					
T_{max}, h	0.99[ab]	1.12[a]	0.73[b]	0.36[c]	0.13
C_{max}, mg/ml	2.17[ab]	2.07[b]	2.29[a]	2.07[b]	0.04
AUC_{0-t}, mg/ml*h	9.73[b]	9.52[b]	10.29[a]	9.43[b]	0.15
K_a, 1/h	10.63[c]	16.01[b]	17.38[b]	29.09[a]	3.66
K_{10}, 1/h	0.07[a]	0.03[c]	0.04[b]	0.03[c]	0.00
$t_{1/2}k_a$, h	0.16[a]	0.15[a]	0.09[b]	0.03[c]	0.20
$t_{1/2}k_{10}$, h	16.14[c]	66.10[a]	39.46[b]	14.29[c]	10.24
HI	1.98[b]	1.25[b]	3.09[a]	1.13[b]	0.47
GI	40.80[b]	40.40[b]	41.41[a]	40.33[b]	0.26
Sweet potato – Rice bran, SP-RB					
T_{max}, h	0.65[b]	0.81[a]	0.72[b]	0.40[c]	0.09
C_{max}, mg/ml	2.10[a]	2.03[b]	2.06[ab]	2.03[b]	0.03
AUC_{0-t}, mg/ml*h	9.43[a]	9.50[a]	9.58[a]	8.99[b]	0.12
K_a, 1/h	15.46[b]	13.56[b]	13.48[b]	32.58[a]	3.63
K_{10}, 1/h	0.05	0.03	0.03	0.03	0.01
$t_{1/2}k_a$, h	0.09[a]	0.11[a]	0.09[a]	0.04[b]	0.01
$t_{1/2}k_{10}$, h	24.94[b]	45.86[a]	45.91[a]	11.55[b]	7.58
HI	1.05[a]	1.04[a]	0.46[b]	0.67[b]	0.20
GI	40.29[a]	40.28[a]	39.96[c]	40.08[b]	0.11
Sweet potato – Wheat bran, SP-WB					
T_{max}, h	0.78[a]	0.53[b]	0.76[a]	0.35[c]	0.11
C_{max}, mg/ml	2.12	2.04	2.08	2.30	0.59
AUC_{0-t}, mg/ml*h	9.51[b]	9.37[c]	9.38[c]	9.69[a]	0.12
K_a, 1/h	15.60[c]	29.79[b]	18.74[c]	34.58[a]	3.98
K_{10}, 1/h	0.04	0.03	0.04	0.03	0.01
$t_{1/2}k_a$, h	0.10[a]	0.07[a]	0.10[a]	0.02[b]	0.02
$t_{1/2}k_{10}$, h	22.27[b]	31.31[a]	24.64[ab]	18.60[b]	3.82
HI	1.51[b]	1.27[b]	1.92[a]	1.37[b]	0.31
GI	40.54[b]	40.41[b]	40.77[a]	40.46[b]	0.17

Means with different superscripts along the row differ significantly ($p<0.05$)
T_{max} = time taken for blood glucose concentration to reach the peak, C_{max} = peak glucose concentration in the blood, AUC_{0-t} = area under the glucose concentration-time curve, K_a = absorption rate constant, K_{10} = elimination rate constant, $t_{1/2}k_a$ = absorption rate half-life, $t_{1/2}k_{10}$ = elimination rate half-life

Discussion

Monogastric animal production benefits from extrusion technology because it improves feed texture, digestibility, and palatability; however, incorporating extruded high-starch ingredients at high levels in diets tends to accelerate glucose release, disrupting glucose and amino acid release patterns (Zhao et al., 2024). Non-starch feed components, particularly fibre, stall glycaemic and insulin spikes that arise from high dietary concentrations of rapidly digesting starch, RDS, which are often observed in extruded diets (Tu et al., 2025). This study aimed to develop value-added sweet potato-based energy concentrates to balance commercial protein concentrates (often about 30-40% CP), creating balanced custom feed mixes for poultry. Extrusion in this study was necessitated by the need for textural modification to address the dusty and bulky nature of sweet potato tubers, while the choice of blending with brans was to mitigate the extent of starch damage and free glucose release during extrusion. In the past, extrusion of sole sweet potato tubers reportedly resulted in brittle, dense, and burnt extrudates due to their high sugar content (Khalil and Henry, 1997).

Sweet potato starch represents the main component of sweet potato tubers, up to 80% dry weight (Zhu et al., 2011); hence, the *postprandial* glycaemic response kinetics of these sweet potato-bran energy concentrates largely reflect the extent and rate of their starch digestibility *in vivo* (Butterworth et al., 2022) as affected by fibre dilutions and processing conditions. When investigating the influence of extrusion on the digestibility of starch in whole sweet potato flour, Waramboi et al. (2014) reported a significant increase in "very rapidly digesting starch" from 2.3-11.1 g/100g dry starch to 7.9-18.4g/100g dry starch. In contrast, bran enrichment dilutes the starch content of formulations, competes with fibre molecules for water, and favours the formation of amylose-lipid complexes, ultimately limiting the extent of gelatinization (Tyl et al., 2021), mitigating glucose release.

While there exists a paucity of studies that report the effect of extrusion temperatures x bran enrichment on plasma glycaemic response conducted in poultry, the combined effect of extrusion and bran enrichment on glycaemic responses is reportedly variable. An assessment of glycaemic responses of male Wistar rats to high-fibre cookies made from wheat flour and wheat + sweet potato flour, both enriched with corn and sorghum brans, showed the ability of brans to moderate blood glucose concentrations compared to a glucose reference group and a wheat flour cookie control group (Saha et al., 2025). A similar effect of wheat and oat bran enrichment of wheat-based rolls has been reported (Knudsen et al., 2000). According to Lewko et al. (2025), an increased absorption rate constant (ka) reflects faster glucose appearance in the plasma owing to enhanced starch gelatinization and increased enzymatic accessibility. Hence, our results allude to the ability of the selected brans to mitigate complete gelatinization in sweet potato-bran blends. Although the application of first-order kinetics to *in vivo* glycaemic response studies remains relatively underexplored—being more commonly employed in pharmaceutical research— the combined effects of starch gelatinization and molecular fragmentation induced by extrusion significantly enhance the initial rate of enzymatic hydrolysis and glucose release (Jiang et al., 2022). This acceleration corresponds to an increased absorption rate constant (K_a) and a shorter half-life of absorption, ($_{t1/2}K_a$). Experimental data also indicate that higher extrusion temperatures are associated with reduced area under the glucose concentration time curve (AUC) as seen in cockerels fed sweet potato–corn bran (SP-CB) and sweet potato–rice bran (SP-RB) diets extruded at 120 °C in the current study. This reduction in total glucose exposure may be attributed to partial dextrinization and retrogradation, both of which facilitate the gradual formation of resistant starch (Gulzar et al., 2021). High extrusion temperatures intensify the structural modifications that promote the formation of resistant starch, leading to a lower overall glycaemic response. Furthermore, physical encapsulation of starch granules by bran fibre, coupled with increased resistant starch, limits the availability of digestible starch, similar to resistant starch 1, RS1 (Han et al., 2023), collectively contributing to a diminished glycaemic response. High-temperature extrusion, 100-150°C, of rice bran-enriched corn-based snack and wheat bran-enriched cassava-defatted soy flour composite showed a significant reduction in starch digestion and estimated glycaemic index (Oladiran and Emmambux, 2017; Renoldi et al., 2021). This was attributed to an extrusion-induced conversion of insoluble arabinoxylans in wheat bran to soluble fibres, which increase viscosity and reduce postprandial glucose response (Renoldi et al., 2021). Also Yadav et al. (2009) described the low solubility of rice bran and its inability to achieve proper expansion and texture during extrusion as a plausible cause.

Conclusion

Postprandial glycaemic response kinetics in cockerels provide a dynamic and mechanistic measure of starch digestibility, reflecting how extrusion-induced modifications in the sweet potato–bran matrix alter glucose availability. The findings reveal that extrusion temperature and bran type modulate glucose absorption and clearance rates, with rice bran showing the greatest glycaemic moderation. Elevated extrusion temperatures accelerate starch gelatinization and glucose appearance but may simultaneously promote retrogradation and resistant starch formation, thereby reducing total glycaemic exposure. Integrating postprandial glycaemic kinetics into poultry nutrition and feed processing research offers a framework for a deeper understanding of how ingredient composition and processing conditions influence nutrient synchronization and metabolic energy utilization. Quantitative indices derived from kinetic modelling tools similar to PKSolver enable more precise synchronization of energy–amino acid metabolism to support feed efficiency in poultry.

Ethical requirements and declaration

The experimental protocols, adopted in this study, were reviewed and approved by the Department of Animal Science, University of Ibadan, Nigeria, according to the guidelines for ethical conduct and reporting of animal research (Jarvis et al., 2005; Kilkenny et al., 2010).

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request

Author's contribution

Adeleye, O.O-Conceptualization, Methodology, Data curation, Manuscript Writing, and Supervision; Osofisan, D.B- Investigation, Data curation, Formal analysis

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors

Conflict of interest statement

None of the authors have a conflict of interest to disclose

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