International Journal of Advanced Biochemistry Research 2024; SP-8(2): 283-288

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(2): 283-288
www.biochemjournal.com
Received: 12-10-2023
Accepted: 18-11-2023

Kavya A
Ph.D. Student, Department of Animal Nutrition, C.V.Sc., Tirupati, Andhra Pradesh, India

Devasena B
Professor & Head, Department of Animal Nutrition, C.V.Sc., Tirupati, Andhra Pradesh, India

Suryanarayana MVAN
Professor & Head, Department of LFC, C.V.Sc., Tirupati, Andhra Pradesh, India

Kalyana Chakravarthi
Senior Scientist & Head, AICRP-PIGS, C.V.Sc., Tirupati, Andhra Pradesh, India

Bhaskara Reddy GV
Assistant Professor & Head, Dept. of LPT, C.V.Sc., Tirupati, Andhra Pradesh, India

Nagi Reddy G
Regional Technical Manager, Kemin Aqua Science, Chennai, Tamil Nadu, India

Corresponding Author:
Kavya A
Ph.D. Student, Department of Animal Nutrition, C.V.Sc., Tirupati, Andhra Pradesh, India

The influence of dietary single and blend of organic acids on slaughter parameters and meat quality in finishing pigs

Kavya A, Devasena B, Suryanarayana MVAN, Kalyana Chakravarthi, Bhaskara Reddy GV and Nagi Reddy G

DOI: https://doi.org/10.33545/26174693.2024.v8.i2Sd.561

Abstract
An experiment was conducted to study the effects of a single and blend of organic acids on slaughter parameters and meat quality in finishing pigs with emphasis on their modes of action to improve pig productivity. A total of thirty finishing crossbred (LWY × Desi) pigs (51.74 ± 1.06 kg) were selected and randomly (CRD) allocated to five treatments. The pigs were fed a basal diet (T_1 - control), basal diet containing 1.5% citric acid (T_2), 1.5% fumaric acid (T_3), 1.5% benzoic acid (T_4) and 1.5% blend of citric, fumaric and benzoic acids each @ 0.5% (T_5). The experiment lasted for 6 weeks. At the end of the trial period, four pigs from each treatment were slaughtered. Carcass characteristics, organ weights and wholesale cuts were unaltered ($p > 0.05$) due to dietary organic acid supplementation. Similarly, the physico chemical properties of fresh meat (WHC, ERV, drip loss, cooking yield, FFA and total cholesterol) revealed non-significant ($p > 0.05$) differences among different treatments except for meat pH ($p < 0.05$). The meat composition in terms of percent moisture, CP, EE and TA of the meat was unaffected ($p > 0.05$) due to the dietary organic acids. Furthermore, the organic acids did not affected sensory evaluation of fresh meat ($p > 0.05$). In conclusion, supplementation of organic acids in finishing pigs can be considered as safe and can effectively replace the antibiotics in swine diets without altering the meat composition and meat quality attributes.

Keywords: Carcass characteristics, finishing pigs, meat quality, physico-chemical properties, sensory evaluation

Introduction
Antibiotic growth promoters were used extensively in animal diets to improve growth performance and maintain animal health (Brown *et al.* 2017) [8]. Several countries, however, have established legislation to limit and restrict antibiotic usage (Simon *et al.*, 2005) [26] in response to greater knowledge of antibiotic overuse and its negative consequences (drug resistance, toxicity, public health concerns, and environmental contamination). As a result, there have been enormous obstacles in exploring alternatives to antibiotic growth promoters in order to improve animal growth performance and health without causing undesirable side effects. Probiotics, prebiotics, acidifiers, enzymes, plant extracts, and yeast are among the feed additives gaining attention in the feed industry as a result of ongoing efforts to improve animal growth performance and intestinal health (Liu *et al.*, 2018, Khadeer *et al.*, 2023 and Lavanya *et al.*, 2023) [19, 15, 17]. Organic acids, due to their pollution-free, drug-resistant, and residue-free nature, have been widely used in monogastric animals (Dittoe *et al.*, 2018) [11].
In recent years, multiple reports have described the beneficial effects of dietary organic acids such as formic, fumaric, citric, butyric, benzoic, lactic and propionic acids by enhancing growth performance (Ngoc *et al.*, 2020 and Xiang *et al.*, 2021) [23, 31], nutrient digestibility (Oh *et al.*, 2018 and Bujnak *et al.*, 2021) [25, 9], modulating the intestinal microflora (Long *et al.*, 2018 and Bharathidhasan *et al.*, 2022) [20, 3] and improving the small intestinal morphology (Chen *et al.*, 2017 and Long *et al.*, 2018) [10, 20].
Although organic acid supplementation was originally intended for weaner piglets, there is accumulating evidence that dietary acidification may also benefit finishing pigs (Upadhaya *et al.*, 2014b) [28].

Different combinations of organic acids (Ahmed *et al*., 2014) [1] are increasingly being employed in diets for growing-finishing pigs due to their positive and synergistic benefits. However, most research have focused on animal performance and intestinal health, with little information available on the impact of organic acids on carcass characteristics, meat quality, and composition. Therefore, current study sought to explore the effects of a single and a combination of organic acids on carcass characteristics and meat quality in finishing pigs.

Materials and Methods

The Institutional Animal Ethics Committee (IAEC) of the College of Veterinary Science, Tirupati, under the Committee for Control and Supervision of Experiments on Animals (CPCSEA), India, approved the experimental protocol used in this study, vide Reg No 281/go/ReBi/S/2000/CPCSEA/ CVSc/TPTY/026 /Animal Nutrition /2022, dated 22.06.2022.

Procurement of organic acids

Organic acids (feed grade) used in the current experiment *viz.*, citric acid, fumaric acid and benzoic acid were purchased from local suppliers.

Experimental design, animals, housing, and diets

Thirty finishing pigs (LWY × Desi) with an average body weight of 51.74 ± 1.06 kg were used in this 6 weeks trial and were distributed randomly (CRD) into five homogenous treatment groups with six piglets in each treatment. Five iso-nitrogenous and iso-caloric experimental diets were formulated as per NRC (2012). The experimental diets were basal diet (T_1 - control), basal diet containing 1.5% citric acid (T_2), 1.5% fumaric acid (T_3), 1.5% benzoic acid (T_4) and 1.5% blend of citric, fumaric and benzoic acids each @ 0.5% (T_5). The ingredient composition of finisher diets were presented in Table 1. All pigs were provided with ad-libitum access to feed and water throughout the experiment.

Sampling and measurements

Individual body weight of each animal was recorded at the beginning and end of the experiment. At the end of the experiment, four pigs from each group were slaughtered at the slaughter house of All India Co-ordinated Research Project (AICRP) on pigs, Tirupati. A day (24 hours) prior to the slaughter, pigs were allowed to take *ad libitum* water without offering feed. The weight of pigs before slaughter was recorded as pre-slaughter weight. Sticking was conducted immediately after stunning, while the carcass was lifted onto the bleeding rail and let to bleed for five to six minutes. Carcass was dressed and eviscerated as per the procedure outlined by (Ziegler, 1968) [33]. After complete bleeding, the carcass was transferred to a scalding tank and plunged in hot water kept at 60 to 65 °C. The carcass was kept in the scalding tank, which was long enough to readily scrape off the hair and scurf. The carcass was immediately moved to the dehairing table after being scalded. Evisceration involved removing the intestines, stomach, liver, heart, lungs, bladder, and spleen. The dressing % was calculated with the following formula. Dressing percent (%) = (Dressed weight / Pre slaughter weight) X 100. The carcass length was measured in centimetres between the rear edge of the first rib and the anterior edge of the aitch bone.

The back fat thickness was assessed on the half carcass. The average thickness of back fat was measured at the first rib, last rib, and last lumbar vertebrae. The cross-sectional area of the longissimus dorsi muscle, located between the 10th and 11th ribs, was used to quantify the loin eye region. The outline was traced onto an acetate paper. The area of the loin eye was measured using a planimeter and expressed in cm^2.

Sample of *Longissimus dorsi* muscle was collected at the time of slaughter, from each pig and was stored at -20 °C for further analysis. Stored meat samples after thawing were analysed for proximate composition (AOAC, 2019) [2]. Immediately after the thawing, the lightness (L*), redness (a*), and yellowness (b*) values were measured at three locations on the surface of each sample using a Hunter Lab colour reader - Model: CR 20. At the same time, duplicate pH values of each sample were directly measured using a digital pH meter (Systronics µ pH system 361, Model: 7856, Type 361) which was calibrated against buffer of pH 4 and 7 (Bhaskar Reddy *et al.*, 2013) [4].

The water-holding capacity (WHC) was determined using the method given by Wardlaw *et al.* (1973) [29]. The extract release volume was determined using the Jay and Kontou (1964) [13] approach. Honikel's (1998) [12] plastic bag method was used to measure drip loss. The cooking yield was determined according to Bhaskar Reddy *et al.* (2022) [5]. The 2 -TBARS value was obtained using the Witte *et al.* (1970) [30] method. The free fatty acids (%) were measured using the Koniecko (1979) [16] technique. The cooked pork samples were served to trained panelists and rated for colour, flavor, tenderness, juiciness, and overall palatability using an 8-point descriptive scale (8 = extremely desired, 1 = extremely undesirable), as described by Keeton (1983) [14], with minor adjustments. Sensory evaluation took place between 3.30 and 4.00 PM, and panelists were given filtered water to rinse their mouths in between evaluation of various samples.

Statistical analysis

The data collected throughout the research were analysed using software (IBM SPSS Statistics, Version 26.0, IBM Corp, USA) with one-way ANOVA (Snedecor and Cochran, 1995) [27], and the means were compared using Duncan's multiple range test. The standard error of the mean was used to express the data's variability. P-values < 0.05 were considered statistically significant.

Results

Slaughter parameters and Meat quality attributes

The effects of organic acid supplementation on carcass characteristics, organ weights, and wholesale cuts were shown in Tables 2, 3 and 4, respectively. In the current investigation, no significant variations in carcass characteristics or wholesale cuts were found across any treatments ($p>$ 0.05; Table 2). Data from Table 3 data showed no significant ($p>$ 0.05) difference in different organ weights (Kg), with the exception of the weights of the stomach and intestines with content or digesta. Dietary interventions had no significant effect on meat quality parameters ($p>$ 0.05; Tables 5, 6, 7 and 8), except for meat pH ($p<$ 0.05; Table 5). Similarly, dietary organic acid supplementation did not influence the chemical composition of meat ($p>$ 0.05; Table 6).

Discussion

Evaluation of carcass characteristics is crucial as it provides valuable information for producers, processors and consumers. Carcass evaluation contribute to sustainable pork production by optimizing the use of resources. This includes efficient feed conversion, reduced wastage and improved environmental sustainability. It also provides valuable data for research and development in swine industry leading to innovations in nutrition and processing techniques.

In the current study, organic acid supplementation had no influence on carcass characteristics. Similar to the present study, other reports indicated that the dressing percentage (Meara *et al.*, 2020) [25] and Loin eye area (Oh *et al.*, 2018 and Nguyen *et al.*, 2018) [25, 24] were not influenced by dietary organic acids. Organ weights were consistent among treatments (p> 0.05), except for the stomach and intestines with digesta (p< 0.05). The weight differential observed between the stomach and intestines with digesta can be explained to the presence of undigested feed from the previous day meal in the stomach and intestine. The stomach and intestine contents vary from animal to animal based on feed intake and the rate at which digesta passes through the GI tract. However, the weights of the stomach and intestines after emptying the contents from the lumen were found to be non-significant (p> 0.05), indicating that the addition of organic acids had no effect on the weights of either the stomach or the intestine.

The physico chemical properties of the meat in pigs play a crucial role in determining the quality, safety, shelf life and acceptability of pork products. The meat's physico-chemical qualities remained unchanged throughout this investigation, with the exception of its pH (p< 0.05). Similar to the present study, Several studies (Oh *et al.*, 2018; Nguyen *et al.*, 2018 and Lei *et al.*, 2018) [25, 24, 18] found no significant (p< 0.05) effect of dietary organic acids on cooking loss or water holding capacity. The pH of meat is an important determinant of its overall quality. The optimal pH for fresh meat is 5.4 to 5.8. The current study found that meat pH varied (p< 0.05) across treatments, but remained within the optimal range, maintaining meat quality.

The chemical composition of pork is crucial as it influences both the nutritional value of the meat and overall quality of the pork products. The chemical composition of meat is determined by a variety of parameters, including animal origin, sex, age, nutritional status, and carcass portion (Yesuf *et al.*, 2017) [32]. In the current investigation, organic acids had no effect on the meat's chemical composition (%).

Dietary organic acid(s) had no effect on the sensory evaluation of meat. Similar to the current investigation, several authors found no significant variation in meat sensory evaluation due to organic acids (Oh *et al.*, 2018; Nguyen *et al.*, 2018; and Lei *et al.*, 2018) [25, 24, 18]. In contrast to the present study, Upadhaya *et al.* (2014b) [28] showed that incorporating a blend of organic acids (citric, fumaric, malic, capric, and caprylic acids @ 0.1 - 0.2%) improved the appearance score in meat. The general acceptability of meat products is mostly determined by flavor, juiciness, and textural characteristics (Bhaskar Reddy *et al.*, 2023a) [6]. During sensory evaluation of meat, several factors influence product acceptability, which might be related to the individual, the meal, or the context in which the meat/food is consumed (Bhaskar *et al.*, 2023b) [7].

The instrumental colour of meat demonstrated that L* (lightness), a* (redness), and b* (yellowness) for raw and cooked meat were unchanged. Similar to the current study, other researchers (Nguyen *et al.*, 2018 and Lei *et al.*, 2018) [24, 18] found that organic acid supplementation had no effect on meat colour. In contrast to the current study, Oh *et al.* (2018) [25] observed that the inclusion of a combination of organic acids reduced the redness of the meat and concluded that low redness has the drawback of consumers preferring darker meat. In the current investigation, we found no difference in meat colour. However, additional research is needed in this area to determine the association between organic acids and meat colour.

Table 1: Ingredient and nutrient composition (%) of experimental diets during finisher phase

Ingredient	T_1	T_2	T_3	T_4	T_5
Maize	73.1	71.3	71.3	71.3	71.3
Soybean meal	19.5	19.8	19.8	19.8	19.8
DORB	5.0	5.0	5.0	5.0	5.0
Salt	0.5	0.5	0.5	0.5	0.5
Mineral mixture#	1.5	1.5	1.5	1.5	1.5
Lysine	0.4	0.4	0.4	0.4	0.4
Citric acid	-	1.5	-	-	0.5
Fumaric acid	-	-	1.5	-	0.5
Benzoic acid	-	-	-	1.5	0.5
Total	100.0	100.0	100.0	100.0	100.0
Proximate composition (%)*					
Dry matter	92.62	90.31	91.09	90.74	89.91
Organic matter	87.28	84.40	86.21	87.72	88.4
Crude protein	13.75	13.79	13.80	13.69	13.72
Ether extract	1.74	1.47	1.57	1.63	1.82
Crude fiber	6.82	6.71	6.24	6.82	6.42
Total ash	8.72	8.6	8.79	8.28	8.6
Acid insoluble ash	2.32	2.65	3.01	2.26	2.21
Nitrogen free extract	68.97	69.43	69.6	69.58	69.44
ME (Kcal/Kg)**	3241.2	3225.6	3231.7	3283.3	3246.9
*On dry matter basis ** Calculated value					

Each Kg contained Calcium - 25.5%; Phosphorous - 12.75%; Sulphur - 0.72%; Zinc - 9600 mg; Manganese - 1500 mg; Sodium - 5.9 mg; Magnesium - 6000 mg; Potassium - 100 mg; Iron - 1500 mg; Iodine - 325 mg; Copper - 1200 mg and Cobalt - 150 mg.

Table 2: Effect of organic acid supplementation on carcass characteristics in crossbred finishing pigs

Particulars	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
Pre-slaughter weight (Kg)	77.75±0.81	80.75±0.62	81.00±1.29	82.25±1.37	81.25±0.62	
Carcass length (cm)	88.50±2.06	88.00±0.91	88.50±1.70	90.00±1.08	89.25±1.49	0.409
Back - fat thickness (cm)	1.71±0.05	1.66±0.05	1.67±0.03	1.73±0.02	1.63±0.02	0.147
Loin-eye area (cm^2)	32.17±2.01	34.14±2.06	31.78±2.20	34.37±2.37	31.92±1.89	0.378
Dressing percentage (%)	67.48±1.07	69.50±1.22	69.71±0.46	69.37±0.61	70.88±1.54	0.488
Total meat weight (Kg)	41.37±1.16	45.98±0.89	46.62±1.14	47.87±0.59	46.00±1.58	0.107
Total bone weight (Kg)	10.59±0.65	10.14±0.38	9.84±0.37	9.19±0.97	10.87±0.27	0.336
Meat: Bone	3.90±0.40	4.53±0.15	4.73±0.27	5.20±0.45	4.23±0.50	0.611

Table 3: Effect of organic acid supplementation on organ weights of crossbred finishing pigs

Particulars	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
Head weight (Kg)	6.17±0.20	5.89±0.12	6.49±0.35	6.07±0.14	5.92±0.30	0.135
Tongue weight (Kg)	0.38±0.01	0.33±0.02	0.37±0.02	0.36±0.007	0.39±0.02	0.061
Shank weight (Kg)	1.85±0.02	1.84±0.06	1.87±0.03	1.97±0.07	1.92±0.04	0.142
Lungs and Trachea weight (Kg)	0.79±0.02	0.84±0.02	0.78±0.03	0.80±0.01	0.86±0.02	0.077
Heart weight (Kg)	0.32±0.01	0.34±0.02	0.30±0.01	0.30±0.01	0.33±0.01	0.116
Kidney weight (Kg)	0.23±0.01	0.20±0.004	0.25±0.02	0.21±0.01	0.19±0.01	0.081
Liver weight (Kg)	1.27±0.02	1.28±0.02	1.26±0.02	1.29±0.02	1.19±0.01	0.247
Spleen weight (Kg)	0.11±0.03	0.15±0.01	0.13±0.03	0.15±0.01	0.14±0.004	0.329
Testicles weight (Kg)	0.57±0.03	0.57±0.02	0.61±0.02	0.59±0.03	0.53±0.02	0.106
Tail weight (Kg)	0.19±0.01	0.14±0.009	0.16±0.01	0.17±0.02	0.19±0.02	0.085
Stomach - weight with contents (Kg)*	1.59±0.39^{ab}	1.20±0.14^{b}	1.46±0.09^{ab}	2.39±0.50^{a}	1.88±0.31^{ab}	0.035
Stomach - empty weight (Kg)	0.48±0.03	0.42±0.01	0.52±0.01	0.47±0.03	0.51±0.01	0.124
Intestine - weight with contents (Kg)*	7.94±1.02^{ab}	6.67±0.63^{b}	8.78±0.42^{a}	8.16±0.38^{ab}	9.60±0.33^{a}	0.047
Intestine - empty weight (Kg)	4.00±0.09	3.74±0.18	3.76±0.13	3.86±0.14	4.12±0.10	0.281

*abc values in a row not sharing common superscripts differ significantly ($p < 0.05$).

Table 4: Effect of organic acid supplementation on whole sale cuts in crossbred finisher pig carcass

Particulars	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
Jowl (Kg)	1.90±0.15	1.94±0.16	2.35±0.34	2.40±0.16	2.06±0.19	0.198
Boston butt (Kg)	6.11±0.37	6.17±0.40	6.46±0.51	6.15±0.52	6.78±0.47	0.813
Picnic shoulder (Kg)	8.32±0.46	7.74±0.48	8.43±0.24	9.39±0.53	10.83±0.51	0.242
Ham (Kg)	13.29±0.78	12.78±0.57	14.49±0.23	13.44±0.48	12.77±0.25	0.313
Loin (Kg)	14.91±1.09	14.32±0.35	16.37±0.62	16.03±0.90	14.24±0.77	0.246
Bacon (Kg)	7.16±0.55	6.55±0.35	7.61±0.23	7.12±0.12	7.62±0.17	0.193

Table 5: Effect of organic acid supplementation on physico-chemical properties of loin muscle of crossbred finisher pigs

Parameters	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
pH*	5.85±0.01^{a}	5.45±0.01^{c}	5.51±0.01^{b}	5.41±0.01^{d}	5.51±0.01^{b}	0.041
WHC (%)	65.50±0.95	64.50± 0.95	66.5±2.21	66.5±0.95	66.00±1.41	0.124
Drip loss (%)	6.64±0.04	6.47±0.01	6.42±0.02	6.26±0.02	6.31±0.01	0.101
ERV (per 100 gms)	26.10±3.82	27.30±2.26	26.70±1.91	26.60±0.27^{b}	27.60±1.63	0.129
Cooking yield (%)	64.33±0.54	63.17±0.85	64.38±0.64	65.10±0.35	65.48±0.47	0.814
2-TBARS (malonaldehyde-mg/kg)	0.35±0.01	0.30±0.01	0.31±0.01	0.31±0.01	0.30±0.01	0.028
Free fatty acids (% Oleic acid)	0.142±0.02	0.140±0.03	0.142±0.02	0.147±0.01	0.144±0.01	0.755
Total cholesterol (mg/100g)	60.33±0.54	62.17±0.85	61.38±0.64	59.70±0.35	62.48±0.47	0.814

abc values in a row not sharing common superscripts differ significantly ($p < 0.05$).

Table 6: Effect of organic acid supplementation on chemical composition of loin muscle of crossbred finisher pigs

Parameters*	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
Moisture (%)	67.50±0.13	69.72±1.29	69.00±0.67	68.50±1.01	68.00±1.07	0.378
Crude protein (%)	76.76±0.75	77.39±0.32	78.22±0.19	77.33±0.11	79.03±0.21	0.524
Ether extract (%)	3.77±0.03	3.94±0.12	3.79±0.07	3.82±0.19	3.89±0.20	0.863
Total ash (%)	1.21±0.02	1.18±0.02	1.01±0.09	1.16±0.02	1.11±0.01	0.429

*On dry matter basis

Table 7: Effect of organic acid supplementation on sensory evaluation of loin muscle of crossbred finisher pigs

Parameters	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
Appearance score (colour)	7.33±0.11	7.00±0.12	7.16±0.10	7.50±0.10	7.00±0.12	0.211
Flavour score	7.22±0.12	7.19±0.10	7.31±0.10	7.16±0.10	7.67±0.02	0.094
Tenderness score	7.66±0.11	7.33±0.13	7.16±0.10	7.66±0.10	7.03±0.12	0.767
Juiciness score	7.66±0.14	7.00±0.17	7.66±0.10	7.58±0.1	7.11±0.09	0.409
Overall palatability score	7.16±0.08	7.66±0.09	7.00±0.07	7.33±0.05	7.00±0.04	0.278

Table 8: Effect of organic acid supplementation on instrumental colour of loin muscle of crossbred finisher pigs

Parameters	Treatment groups					
	T_1	T_2	T_3	T_4	T_5	P - Value
Raw meat						
*L** (Lightness)	47.23±0.95	48.46±0.34	46.95±0.85	46.78±1.33	47.31±0.79	0.967
*a** (Redness)	6.63±0.73	6.15±1.00	6.13±0.35	6.83±0.52	6.01±0.34	0.107
*b** (Yellowness)	11.65±0.67	11.28±0.58	12.06±0.51	10.16±0.94	12.40±0.52	0.679
Cooked meat						
*L** (Lightness)	61.75±2.43	63.58±1.73	67.76±2.02	66.95±2.36	63.20±2.94	0.426
*a** (Redness)	4.58±0.28	4.26±0.58	4.33±0.44	4.91±0.15	4.23±0.21	0.807
*b** (Yellowness)	16.16±0.79	15.63±0.47	16.78±0.98	16.56±0.55	16.73±0.99	0.387

Conclusion

The ultimate goal of swine industry is to provide highly safe and quality meat for human consumption. Data from the current research indicated that supplementation of organic acids was neither beneficial nor detrimental on slaughter parameters and meat quality in finisher pigs. From the present research, it can be inferred that the organic acids can effectively replace antibiotics in swine without altering the meat composition and meat quality attributes.

Acknowledgments

The authors highly acknowledge the staff of ICAR - All India Co-ordinated Research Project (AICRP) on pigs, SVVU, Tirupati for providing experimental animals and facilities for smooth conduction of trial.

References

1. Ahmed ST, Hwang JA, Hoon J, Mun HS, Yang CJ. Comparison of single and blend acidifiers as alternative to antibiotics on growth performance, fecal microflora, and humoral immunity in weaned piglets. Asian-Australas J Anim Sci. 2014;27(1):93.
2. AOAC. Official methods of analysis of AOAC International. 21st ed. Washington DC; c2019.
3. Bharathidhasan A, Narayanan R, Ronald BSM. Effect of citric acid supplementation on growth performance of large white Yorkshire pigs. Indian J Vet Anim Sci Res. 2022;50(3):29-36.
4. Bhaskar Reddy GV, Sen AR, Pramod N, Nair Sudhakar Reddy K, Kondal Reddy K, *et al*. Effects of grape seed extract on the oxidative and microbial stability of restructured mutton slices. Meat Sci. 2013;95:288-294.
5. Bhaskar Reddy GV, Sen AR, Ambedkar YR, Vivekananda Reddy BV. Effect of buckwheat flour on quality characteristics of chevon sausages. Indian J Small Ruminants. 2022;28(2):365-372.
6. Bhaskar Reddy GV, Reddy SVK, Amaravathi P, Mandal PK, Desai AS, Sen AR. Influence of whey protein concentrates as a novel binder on physiochemical, textural and ultrastructural properties of restructured buffalo meat slices. Int J Food Sci Technol. 2023a;58:6362-6371.
7. Bhaskar Reddy GV, Amaravathi P, Bhaskar Ganguly Sen AR, Vivekananda Reddy BV. The effect of herbal supplements on the carcass characteristics, fatty acid profile and meat quality attributes of Broilers. Vet Arh. 2023b;93(4):447-462.
8. Brown K, Uwiera RRE, Kalmokoff ML, Brooks SPJ, Inglis GD. Antimicrobial growth promoter use in livestock: a requirement to understand their modes of action to develop effective alternatives. Int J Antimicrob Agents. 2017;49:12-24.
9. Bujnak L, Nad P, Mihok T. Effects of Organic acid Blend on Growth Performance, Nutrient Digestibility and Concentration of Volatile Fatty Acids in the Feces of Young Pigs. Folia Veterinaria. 2021;65(2):42-47.
10. Chen JL, Zheng P, Zhang C, Yu B, He J, Yu J, *et al*. Benzoic acid beneficially affects growth performance of weaned pigs which was associated with changes in gut bacterial populations, morphology indices and growth factor gene expression. J Anim Physiol Anim Nutr. 2017;101(6):1137-1146.
11. Dittoe DK, Ricke SC, Kiess AS. Organic acids and potential for modifying the avian gastrointestinal tract and reducing pathogens and disease. Front Vet Sci. 2018;5:216.
12. Honikel KO. Reference methods for the assessment of physical characteristics of meat. Meat Sci. 1998;49(4):447-457.
13. Jay JM, Kontou KS. Evaluation of the extract-release volume phenomenon as a rapid test for detecting spoilage in beef. Appl Microbiol. 1964;12(4):378-383.
14. Keeton JT. Effects of fat and NaCl/phosphate levels on the chemical and sensory properties of pork patties. J Food Sci. 1983;48(3):878-881.
15. Khadeer BS, Prasad Reddy LSSV, Bhaskar Reddy GV, Kumar AVNS, Naik BR. Influence of mannan oligosaccharides and tulasi (*Ocimum sanctum*) on carcass and meat quality characteristics of rabbits. J Meat Sci. 2023;18(2):1-8.
16. Koniecko EK. Handbook for meat chemists. Wayne, New Jersey, USA: Avery Publishing Group Inc.; c1979. p. 68-69.
17. Lavanya M, Bhaskar Reddy GV, Kamalnath Reddy M, Sai Anjana N, Suresh Babu D, *et al*. Anti-Inflammatory

Effect of Polyherbal Feed Supplements in Heat Stressed Pigs. Indian Vet J. 2023;100(4):32-35.
18. Lei XJ, Lee SI, Lee KY, Nguyen DH, Kim IH. Effects of a blend of organic acids and medium-chain fatty acids with and without Enterococcus faecium on growth performance, nutrient digestibility, blood parameters, and meat quality in finishing pigs. Can J Anim Sci. 2018;98(4):852-859.
19. Liu Y, Espinosa CD, Abelilla JJ, Casas GA, Lagos LV, Lee SA, *et al*. Non-antibiotic feed additives in diets for pigs: A review. Anim Nutr. 2018;4:113-125.
20. Long SF, Xu YT, Pan L, Wang QQ, Wang CL, Wu JY, *et al*. Mixed organic acids as antibiotic substitutes improve performance, serum immunity, intestinal morphology and microbiota for weaned piglets. Anim Feed Sci Technol. 2018;235:23-32.
21. Meara FM, Gardiner GE, Doherty JV, Lawlor PG. Effect of dietary inclusion of benzoic acid (VevoVitall®) on the microbial quality of liquid feed and the growth and carcass quality of grow-finisher pigs. Livest Sci. 2020;237:104043.
22. National Research Council (NRC). Nutrient Requirements of Swine. 11th revised ed. Washington, DC: National Academic Press; c2012.
23. Ngoc TTB, Oanh DT, Pineda L, Ayudhya S, De Groot N, Han Y. The effects of synergistic blend of organic acid or antibiotic growth promoter on performance and antimicrobial resistance of bacteria in grow-finish pigs. Transl Anim Sci. 2020;4(4):211.
24. Nguyen DH, Lee KY, Tran HN, Kim IH. Effect of a protected blend of organic acids and medium-chain fatty acids on growth performance, nutrient digestibility, blood profiles, meat quality, faecal microflora, and faecal gas emission in finishing pigs. Can J Anim Sci. 2018;99(3):448-455.
25. Oh HJ, Kim IH, Song MH, Kwak WG, Yun W, Lee JH, *et al*. Effects of microencapsulated complex of organic acids and essential oils on growth performance, nutrient retention, blood profiles, fecal microflora, and lean meat percentage in weaning to finishing pigs. Can J Anim Sci. 2018;99(1):41-49.
26. Simon O, Vahjen W, Scharek L. Micro-organisms as feed additives-probiotics. Adv Pork Prod. 2005;16(2):161.
27. Snedecor GW, Cochran WG. Statistical Methods. 8th ed. Ames, IA: Iowa State University Press; c1989.
28. Upadhaya SD, Lee KY, Kim IH. Protected organic acid blends as an alternative to antibiotics in finishing pigs. Asian-Australas J Anim Sci. 2014;27(11):1600.
29. Wardlaw FB, Maccaskill LH, Acton JC. Effect of postmortem muscle changes in poultry meat loaf properties. J Food Sci. 1973;38:421-424.
30. Witte VC, Krause GF, Bailey ME. A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. J Food Sci. 1970;35(5):582-585.
31. Xiang XD, Deng ZC, Wang YW, Sun H, Wang L, Han YM, Sun LH. Organic acids improve growth performance with potential regulation of redox homeostasis, immunity, and microflora in intestines of weaned piglets. Antioxidants. 2021;10(11):1665.
32. Yesuf KY, Mersso BT, Bekele TE. Effect of different levels of turmeric, fenugreek and black cumin on carcass characteristics of broiler chicken. Livest Sci. 2017;8:11-17.
33. Ziegler TP. The Meat We Eat. Danville, Illinois: The Interstate Printers and Publishers; c1968.