Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(2): 217 – 234 (2024)
www.ejabf.journals.ekb.eg

Exploitation of Raw, Fermented and Microwave- Heated Rice Bran as Carbohydrate Alternatives in Young Common Carp (*Cyprinus carpio* L.) Diets

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ARTICLE INFO
Article History:
Received: Jan. 9, 2024
Accepted: March 7, 2024
Online: March 21, 2024

Keywords:
Agricultural waste,
Carbohydrate alternatives,
Microwave,
Fish nutrition,
Common carp

ABSTRACT
The current study was carried out to investigate the impact of using rice bran (*Oryza sativa*), raw, treated microbiologically through fermentation with dry yeast *Saccharomyces cerevisiae*, and thermally using microwaves as a partial substitute for wheat and yellow corn in preparing diets for young common carp (*Cyprinus carpio*). Four experimental diets were formulated with similar protein and caloric contents. The first diet (C) had no substitution, while the second diet (T1) used untreated rice bran with a substitution rate of 10% for wheat and 5% for yellow corn. The third diet (T2) utilized fermented rice bran with the same substitution rates, and the fourth diet (T3) used thermally treated rice bran with the same substitution rates. Statistical analysis results revealed significant differences ($P\leq 0.05$) among the various rice bran treatments. The preference was obvious for fish fed on fermented rice bran, followed by the diet containing microwave treated rice bran, then fish fed on the diet containing untreated rice bran, and finally, the control diet. In terms of growth parameters, the feed conversion rate was recorded as 2.75 2.81 2.39 2.65 for each of the diet C, T1, T2, T3, respectively, and digestibility was recorded as 82.22 75.10 83.34 75.10% for each of the diet C, T1, T2, T3, respectively. The study concluded that both fermentation and microwave treatments have improved the nutritional value of rice bran in the diets for young common carp which could be exploited for applying more non-conventional feed ingredients for sustainability of aquaculture.

INTRODUCTION

Aquaculture is considered one of the most vital sectors for the production of protein-rich food, especially with the increase in population and shortages of other food resources **(Ochokwu *et al.*, 2014)**. Fish culture has witnessed a significant growth in recent years and has become economically important in meeting the nutritional needs of consumers. It provides approximately half of the globally consumed fish, representing around 46% of the world's total fish supply **(FAO, 2022)**. This makes it a fundamental component in fulfilling a portion of the protein requirements through animal protein **(Khanum *et al.*, 2022)**. The sustainability of aquaculture heavily relies on the development of the feed industry, which constitutes 50- 60% of the economic cost of production **(Imran *et al*., 2019)**. Numerous research efforts have been conducted in the field of fishery resources to enhance the aquaculture sector, contributing to the upward trend in individual consumption of animal protein. This is achieved through the development of economically viable and biologically balanced commercial feeds **(Al-Noor *et al*., 2023)**. The use of unconventional and cost-effective feeds **(Kola & Mustapha, 2023)** such as inexpensive alternative ingredients, has been explored to reduce manufacturing costs **(Najim & Al-Tameemi, 2023)**. Globally, a considerable amount of agricultural waste is generated from manufacturing processes of grains for the human consumption. The disposal of such wastes poses significant environmental and economic problems, requiring high economic costs for burial or incineration, leading to environmental damage and air pollution **(Albadran *et al*. 2018; Koul, 2022)**. However, optimal utilization of these by-products can be achieved through recycling methods, including physical, chemical, and biological treatments. This process transforms the waste into more beneficial compounds suitable for various industrial, food, and feed applications **(Leeuwendaal *et al*., 2022)**. Currently, attention has shifted to the use of grain by-products in the feed industry, with one of the significant alternatives being rice bran (*Oryza sativa*). Rice bran has been introduced as a feed ingredient alternative to wheat flour and yellow corn, and it is considered a secondary product of rice milling and refining processes, constituting approximately 10% of the crop weight **(Gul *et al*., 2015)**. Rice bran contains 34- 55% carbohydrates (including fiber), 11- 16% protein, 12- 20% fat, and 8- 12% ash **(Spaggiari *et al*., 2021)**. It also contains antinutritional factors, such as phytates, necessitating biological, physical, or chemical methods to convert these residues into various beneficial substances in fish diets **(Moon & Chang, 2021)**. One approach involves fermentation using dry yeast *Saccharomyces cerevisiae* under anaerobic conditions, resulting in the production of various organic acids **(Leeuwendaal *et al*., 2022)**. Additionally, physical treatment with microwave irradiation is employed to process grain by-products, improve feed digestion, and deactivate enzymes that cause deterioration **(Sanswan *et al*., 2014; Pokkanta *et al*., 2022)**. Therefore, fermented and microwave-heated rice bran have become important food components that meet and fulfill consumers' demand for health-enhancing food, as well as environmental and legal requirements related to the recycling and utilization of agricultural waste **(Moon & Chang, 2021)**. The current study aimed to investigate the possibility of using rice bran, an agricultural waste readily available in large quantities and cost-effective, as a carbohydrate alternative to yellow corn and wheat flour in compounded feeds for the nutrition of common carp young. The ultimate objective was to enhance the sustainability of fish production through the recycling of agricultural waste into viable feed ingredients.

MATERIALS AND METHODS

Rice bran samples

Rice bran of the Iraqi jasmine variety (*Oryza sativa* L.) was obtained from the rice milling facility in the Al-Mishkhab district, Najaf governorate, Iraq. The samples weighed 25 kilograms and were collected in September 2022, placed in polyethylene bags and transported to the laboratory in the Department of Fisheries and Marine Resources, College of Agriculture, University of Basrah for conducting examinations and analyses.

Rice bran processing: Fermentation

In the experiment, dry commercial bakery yeast (*Saccharomyces cerevisiae*) was used. Three grams of preactivated yeast were mixed with 40 grams of rice bran and placed into a glass container and left at a laboratory temperature of 25- 30°C for 48 hours. Subsequently, the fermentation process was halted by using an electric oven set at 60°C for 6 hours. Upon the completion of the fixation period, the sample was dried at 105°C, ground, and stored in plastic bottles for the further analyses as outlined by **Chinma *et al*. (2014)**.

Microwave heating

A quantity of 40 grams of rice bran was thoroughly mixed with 150ml of water in a glass container and placed in a KENWOOD microwave oven, model 110M, with a frequency of 50MHz. The mixture was exposed to 800 watts of power for 10 minutes at a temperature of 91- 94°C, then it was transferred to an electric oven for drying at 60°C for 48 hours to eliminate residual moisture. After drying, samples were grinded and stored in plastic containers for further analyses as outlined by **Sansuwan *et al*. (2014)**.

Determination of proximate composition

Moisture content was determined using an electric drying oven at a temperature of 105°C until a constant weight was achieved. The ash content was calculated after burning the samples in a Muffle furnace at a temperature of 525°C for 16 hours or until the ash turned white. Total nitrogen was measured using the Semi-Microkjeldahl method and multiplied by 6.25 to obtain the protein content. Fat content was determined using a Soxhlet extraction unit with organic solvents chloroform and methanol at a ratio of 1:2 **(Egan *et al*., 1988)**. Carbohydrate content was determined using the difference method after subtracting the amounts of moisture, protein, fat, and ash found by analysis **(AOAC, 2000)**. Total energy content in the feed was calculated based on the nutrient caloric values provided by **New (1987)**.

Amino acid profiles

The amino acid profiles of raw, fermented, and microwave-treated rice bran were estimated according to the method of **Vidotti *et al*. (2003)** using an ion exchange column and post-column derivatization with a Visible-6 Av UV-SPD detector from Shimadzu. This was achieved using a high-performance liquid chromatography (HPLC) system affiliated with the Ministry of Science and Technology in Baghdad, Iraq.

Formulation of experimental diets

Four experimental diets were formulated by replacing raw rice bran (T1), fermented rice bran (T2), and microwave-treated rice bran (T3) with wheat flour and yellow corn at substitution rates of 10% for wheat flour and 5% for yellow corn of total ingredients. The fourth treatment was prepared as a control (C) without any replacement. After determining the initial nutritional content of experimental feed ingredients, as outlined in Table (1), ingredients were finely ground and sieved through a 2mm sieve and thoroughly mixed in the calculated proportions to achieve homogeneity. Subsequently, approximately 100ml of boiling water was added to every 250 grams of the mixture, and after thorough mixing, the mixture's temperature was raised to 80°C then allowed to cool, and vitamins and minerals were added. Feed dough was shaped into pellets using a meat grinder (Braun, Germany) with openings of 4mm in diameter. The compressed feed was left to air-dry at an ambient temperature in the laboratory for 48 hours, then stored in plastic containers with a capacity of 1kg in the refrigerator until use.

Table 1. Formulation ingredients (%) of experimental diets

Ingredient	C	T1	T2	T3
Fish meal	20	20	20	20
Soybean meal	20	20	20	20
Barley flour	20	10	10	10
Yellow corn meal	20	15	15	15
Rice bran	0	15	15	15
Wheat bran	15	17	17	17
Vegetable oil	3	1	1	1
premix	2	2	2	2
Chemical composition (%)				
Moisture	8.48	7.88	8.02	7.71
Crude protein	30.27	30.76	31.15	31.10
Crude lipid	6.90	6.93	6.93	6.54
Carbohydrate	48.18	46.84	46.28	46.89
Ash	6.17	7.79	7.62	7.76
Gross energy (Kcal/100 g)	445.7	440.4	441.3	439.5

Table 2. Proximate composition (%) and energy content (Kcal/ 100gm) of experimental diets

Nutrient (%)	C	T1	T2	T3
Moisture	8.12 ± 0.01 b	7.14 ± 0.10 c	8.06± 0.03 a	6.04 ± 0.03d
Crude protein	30.50± 0.70 b	30.25±0.33 b	31.53± 0.20 a	31.52±0.02 a
Crude lipid	8.48 ±2.79 a	10.99±1.39 a	9.77± 0.63 a	9.40±2.91 a
Carbohydrate	46.61±3.04 a	44.20±1.58 ab	42.10 ± 0.51b	44.90±3.47ab
Ash	6.56±0.45 b	7.40±0.40 ab	8.32±0.30 a	8.12±0.82 a
Gross energy (kcal/100 g)	437.26±16.45a	447.65±7.74 a	434.95±4.81 a	443.04±12.52 a
P:Eratio (mg protein/kcal)	69.15±2.60 bc	67.58±0.65 c	72.49± 0.37 a	71.18±2.09ab

*Values in each row with the different superscript letters indicate a significant difference ($P \leq 0.05$).

Experimental fish and culture system

Recirculating aquaculture system was used in this experiment. The system consisted of two separate units, each was comprised of 6 plastic tanks with a capacity of 30 liters arranged in two rows, and each was equipped with a main external filter unit divided into three sections serving as mechanical, biological and chemical filters. Young common carps (*C. Carpio* L.) with an average weight of 92.12± 18.0gm, obtained from the Aquaculture Unit, College of Agriculture, University of Basrah, were used in the experiment. At the beginning of the trial, ten fish were randomly assigned to each tank. The fish were acclimated to the experimental conditions for ten days and were fed the experimental diet during this period.

Feeding and growth experiment

The feeding experiment extended for a period of 70 days from December 1, 2022, to March 1, 2023. Fish were fed at a rate of 5% body weight, divided into two daily meals at 8- 9 am and 1- 2 pm. Fish were biweekly weighed to adjust feed ration, and 30% of water was exchanged simultaneously. The total weight gain (TWG), daily weight gain (DGW), total growth rate (TGR), and specific growth rate (SGR) were calculated according to **Jobling (1993)** and **Sevier *et al*. (2000)**. Additionally, food conversion rate (FCR), relative growth rate (RGR), protein intake (PI), and protein efficiency ratio (PER) were calculated based on **Tacon (1990)** using the following formulas:

A – Total weight gain (TWG):

Total weight gain (g/fish) = Final weight (g) – Initial weight (g)

B – Daily weight gain (DGW):

Weight gain (g/day) = Weight gain (g) / additional period of this gain (day)

C – Relative growth rate (RGR):

Relative growth rate (%) = Weight gain (g) / Initial weight (g) × 100

D – Specific growth rate (SGR):

Specific growth rate (%/day) = (Ln of Final weight (g) - Ln of initial weight (g)) / Days × 100

E – Feed conversion ratio (FCR):

Feed conversion ratio = Feed intake (g) / Weight gain (g)

F – Protein intake (PI):

Protein intake (g/fish) = Feed intake (g) × Protein percentage in the feed

G – Protein efficiency ratio (PER):

Protein efficiency ratio (%) = Net weight gain of fish / Protein intake (g) × 100

Digestibility experiment

The total apparent digestibility coefficient and the apparent digestibility coefficient of nutrients in the feed were measured by an indirect method **(Talbot, 1985)**. Chromium oxide (Cr2O3) was added as a marker at a rate of 1% of the weight of feed. The fish were fed the feed containing chromium oxide daily at 9:00 AM until satiation. After one hour of feeding, the unconsumed feed was removed. Feces were collected using the siphoning method at intervals not exceeding 15- 20 minutes **(Schmit *et al*., 1983)**, then filtered and washed with distilled water. The collected feces were left to air-dry completely, preserved into tightly sealed plastic containers and stored in the refrigerator. The percentage of chromium oxide marker in the dried feces was determined according to **Olvera-Novoa *et al*. (1994)** using digestion flasks for a Kjeldahl apparatus. The absorbance of digested and diluted samples was read spectrophotometrically at a wavelength of 350nm. The absorbance was converted to the concentration of chromium oxide using the following equation:

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Where, X= Chromium oxide quantity (gm.) in sample

Y= Absorbance

The equation values indicate the constants of the curve measuring the values of chromium oxide known as the standard values.

After completing the estimation of the chromium oxide percentage in the feces, according to the total apparent digestibility coefficient (TADC) and the nutrient apparent digestibility coefficient (NADC), using the following equations:

Chromium oxide (%) = (Weight of chromium oxide sample weight) × 100

TADC (%) = 100 – (100 × % chromium oxide in feed / % chromium oxide in feces)

NADC (%) = 100 – {100 × [(% chromium oxide in feed / % chromium oxide in feces) × (% nutrient in feces ÷ % nutrient in feed)]}

Statistical analysis

The growth experiment was designed according to the complete randomized design (CRD) with four treatments, each with three replications. The same statistical analysis approach was applied for other studied feeding and growth parameters. The significant differences between treatment means was determined using the least significant difference (LSD) test. All statistical analyses were conducted using the Statistical Package for Social Sciences (IBM SPSS) version 26.0.

RESULTS

Proximate composition of rice bran

Table (3) illustrates the chemical composition of raw, fermented, and microwave-treated rice bran. The results showed variations in chemical composition among the studied treatments. Regarding protein content, fermented rice bran had the highest percentage of protein at 15.31%, with a significant difference ($P \leq 0.05$) compared to the protein content in raw rice bran and microwave-treated rice bran, which were 11.59 and 12.86%, respectively. As for fat content, the highest value was observed in the fermented rice bran at 15.46%, while the lowest fat percentage was recorded in the microwave-treated rice bran at 12.86%. The fat content in the raw rice bran was 14.08%. The statistical analysis results indicated no significant differences ($P > 0.05$) among all treatments. The moisture content for raw and microwave-treated rice bran was relatively close at 5.73 and 5.97%, respectively, showing a significant difference compared to the moisture content in fermented rice bran, which was 7.66%. The carbohydrate content was 57.26, 51.29, and 57.11% for raw, fermented, and microwave-treated rice bran, respectively. The statistical analysis revealed a significant difference ($P \leq 0.05$) between fermented rice bran with both microwave-treated and raw rice bran. The ash content was 11.43, 10.27, and 11.28% for raw, fermented, and microwave-treated rice bran, respectively, with no significant differences ($P > 0.05$) among all treatments.

Table 3. Proximate composition of raw, fermented, and microwave-heated rice bran

	Moisture	Crude protein	Crude lipid	Carbohydrate	Ash
Raw rice bran	5.73±0.43b	11.59±0.15c	14.08±0.02c	57.23±0.98a	11.34±0.58a
Fermented rice bran	7.66±1.36a	15.31±0.02a	15.46±0.95a	51.27±2.61b	10.27±3.33a
Microwave-heated rice bran	5.97±0.15b	12.86±0.05b	12.86±0.09b	57.14±1.15a	11.18±1.34a

*Different letters within one column indicate the presence of significant differences at the level ($P < 0.05$). Values represent the mean ± standard deviation.

Amino acid profiles of rice bran

The results in Table (4) show the analysis of amino acids using HPLC for raw, fermented and microwave-treated rice bran. The findings indicate significant differences in amino acid concentrations, especially the essential amino acids, due to the fermentation process and, to a lesser extent, due to microwave treatment. The total concentration of essential amino acids increased from 38.40µg/ 100g in raw bran to 54.22 and 41.38µg /100g in fermented and microwave-treated bran, respectively. This is evident in the total amino acid concentration (TAA), which rose from 38.40µg/ 100g in raw bran to 41.38µg/ 100g in microwave-treated bran. Regarding non-essential amino acids (TNEAA), the highest value was observed in the fermented rice bran at 35.75µg/ 100g, followed by heat-treated bran at 30.42µg/ 100g, and the lowest content in raw rice bran at 28.51µg/ 100g. The ratio of essential amino acids to total amino acids (∑EAA/∑NEAA) was the highest in the fermented bran at 60.30%, while it was lower in the raw rice bran and microwave-treated bran at 57.4 and 57.6%, respectively. The ratio of the essential amino acids to non-essential amino acids (∑EAA / ∑NEAA) was the highest in the fermented rice bran at 151.70%, and the lowest ratio was observed in the raw rice bran at 28.51%. The highest concentration of the essential amino acid leucine was found in the fermented rice bran at 6.27µg/ 100g, while the lowest concentration of the essential amino acid tryptophan was found in the raw rice bran at 1.01µg/ 100g.

Table 4. Amino acid profiles fo raw, fermented, and microwave-heated rice bran

Amino acid	Raw rice bran	Fermented rice bran	Microwave-heated rice bran
Arginine	1.63	2.72	1.61
Histidine	4.73	6.88	5.3
Isoleucine	3.71	5.01	3.98
Leucine	6.84	9.14	7.11
Lysine	5.12	6.27	5.23
Methionine	1.67	2.79	1.81
Phenylalanine	4.11	6.17	4.72
Threonine	3.6	5.88	4.11
Tryptophan	1.01	1.89	1.21
Valine	5.98	7.47	6.3
∑ EAA	**38.40**	**54.22**	**41.38**
∑non EAA	**28.51**	**35.75**	**30.42**

EAA: Essential amino acids, NEAA: Non-essential amino acids.

Fish growth experiment

Table (5) illustrates growth parameters; initial weight (g), final weight (g), weight gain (g), daily growth rate (g/day), relative growth rate (%), specific growth rate (%/day), feed conversion ratio (FCR), protein efficiency ratio (PER%), for young common carp during a 71-day growth experiment. The statistical analysis of weight gain rates indicatessignificant differences ($P \leq 0.05$) in daily growth, specific growth rate, and relative growth rate between the treatments (replacement and control). The weight gain, daily growth, specific growth rate, and relative growth rate reached the highest values in the T2 treatment, amounting to 139.67g, 3.39g/ day, 5.27%/ day, and 242.28%, respectively. In contrast, the lowest values were observed in the control group C (0% substitution), with 85.29 grams, 2.60 grams/ day, 4.94%/ day, and 187.69%, respectively. The results showed that the substitution process in the T1, T2, and T3 dietary systems provided a better growth compared to the control diet. T2 outperformed all other treatments in growth criteria.

Table 5. Feeding and growth parameters of experimental fish

Parameter	C	T1	T2	T3
IW (g)	97.32±1.06a	98.26±1.74a	98.21±0.90a	97.67±1.10a
FW (g)	182.61±4.93c	197.01± 3.61cb	237.88±13.18a	206.98±12.17b
WG (g)	85.29±4.93c	98.75±3.61cb	139.67±13.81a	109.31±11.87b
RGR (%)	2.6±0.06c	2.81±0.05bc	3.39±0.18a	2.95±0.17b
DGW(g/day)	187.6±6.58c	200.54±5.42bc	242.28±15.23a	211.93±12.94b
SGR (%/day)	4.94±0.03c	5.04±0.02bc	5.27±0.06a	5.104±0.07b
FCR	2.75±0.08a	2.81±0.12a	2.39±0.18b	2.65±0.06a
PER	1.18±0.03b	1.17±0.05b	1.33±0.10a	1.19±0.03b

*****Different letters within one row indicate the presence of significant differences at the level ($P \geq 0.05$). Values represent the mean ± standard deviation.

The results presented in Table (6) indicate the values of the total apparent digestibility coefficient and apparent digestibility of nutrients in the experimental diets to demonstrate the effect of adding raw, fermented, and microwave-treated rice bran to the diets of young common carp. The current results show that the highest total digestion coefficient reached 83.34 in treatment T2, where 10% wheat flour and 5% yellow corn were replaced with fermented rice bran. The lowest was 75% in the diet T1 and T2 (replacing 10% wheat flour and 5% yellow corn with untreated rice bran and microwave-treated rice bran), respectively.

Table 6. Apparent digestibility coefficients of major nutrients in experimental diets

Nutrient	C	T1	T2	T3
Total apparent digestibility	82.22±1.92ab	75.10±8.33b	83.34±0.01a	75.10±0.01b
Protein digestibility	83.83±2.51ab	77.12±7.73b	88.99±0.17a	80.16±0.01b
Lipid digestibility	86.81±2.51a	85.10±8.58a	93.10±5.19a	83.71±7.28a
Carbohydrate digestibility	78.34±2.66a	64.41±12.83a	76.38±0.55ab	66.89±2.71ab
Ash digestibility	83.15±1.28a	86.70±4.67a	85.87±0.48a	85.06±1.36a

*Different letters within one row indicate the presence of significant differences at the level ($P \geq 0.05$). Values represent the mean ± standard deviation.

DISCUSSION

Proximate composition of rice bran

The variation in the chemical composition among the treatments can be attributed to the different processing methods applied to rice bran **(Ranjan *et al*., 2023)**. As mentioned by **Gul *et al*. (2015)**, the protein content in raw rice bran depends on the precision of the milling process. Nevertheless, microwave heating can modify and break down the molecular structure of proteins, leading to an increase in their percentage **(Sansuwan *et al*., 2014)**. The increase in protein content in fermented rice bran could be also attributed to the role of bakery yeast in producing various nutrients including proteins **(Hettiarachchy, 2018)**. The differences in fat content among the treatments may not only be attributed to the fatty acid composition but also to rice variety, the degree of milling, as well as the extraction method and technique used **(Reis *et al*., 2022)**. The high fat content in raw rice bran is attributed to its inclusion of the embryo and the aleurone layer, which is rich in fat, with the embryo constituting 20% of the bran's fat content **(Wan, 2010)**. The decrease to 12.86% in microwave-treated rice bran could be due to the inhibition of lipase enzyme activity and the loss of fats during microwave thermal treatment, resulting from the oxidation process of unsaturated fats. Fatty acids may be significantly affected based on the time and temperature of the treatment **(Reis *et al*., 2022)**. As for fermented rice bran, the increase in fat content to 15.46% is attributed to the fermentation process, which leads to the breakdown of fats in the raw material, resulting in an increase in fatty acid content. These findings are consistent with the results presented by **Kalpanadevi *et al*. (2018)**. The carbohydrate levels were lower in fermented rice bran due to its consumption by yeast fermentative activity **(Chinma *et al*., 2014)**. In regards with raw and microwave treated rice bran, no factor was found to engage in carbohydrate level decrease except for heat, which led to an obviously minimal breakdown **(Sansuwan *et al*., 2014)** The increase in ash content in rice bran indicates a higher mineral content, and the slight variation in ash content among the current study treatments is attributed to changes in other components, leading to alterations in ash content, as observed by **Oliveira *et al*. (2010)** who stated that microbial fermentation of rice bran led to a 30% increase in ash content. One of the essential mineral characteristics of rice bran is its high content of calcium and phosphorus, making it a significant nutritional indicator compared to other grain bran **(Spaggiari *et al*., 2021)**. For instance, barley bran contains 2- 3% ash **(Qaddoori & Al-Ubaydi, 2018)**.

Amino acid profiles of rice bran

The findings indicate significant differences in amino acid concentrations, especially essential amino acids, due to the fermentation process and, to a lesser extent, owing to microwave treatment. This increase is primarily attributed to the yeast activity in breaking down rice bran proteins, resulting in higher concentrations of amino acids **(Raheemah & Alnoor, 2022)**. This enhanced bioavailability of amino acids is beneficial to the body when consumed in feed. Furthermore, the breakdown of proteins resulting from microwave treatment also led, although to a lesser extent, to an increase in the concentrations of some amino acids. The variation in the values of amino acids between the treatments is consistent with those obtained by **Sereewatthanawut *et al*. (2008)**, who demonstrated that thermal treatment of rice bran can lead to the production of more valuable proteins and amino acids. The quantity of produced protein increases with higher temperatures, treatment duration, and storage time. However, some amino acids could decrease with the increase in temperature, as observed in the current study and in those of **Hunsakul *et al*. (2021)**, **Rashid *et al.* (2022)** and **Somdee *et al*. (2023)**. Moreover, **Oliveira *et al*. (2010)** noted that fermentation showed an increase in digestible amino acid levels by 27.6% in the digestibility of produced proteins. Additionally, the results demonstrated by **Zarei *et al*. (2017)** confirmed that rice bran is a good source of amino acids and vitamins that meet nutritional requirements. They classified 209 components of rice bran as amino acids, cofactors, and vitamins, which could be significant indicators that encourages the exploitation of rice bran as an ingredient in fish nutrition.

Fish growth experiment

The results showed that the substitution process in the T1, T2, and T3 dietary systems provided a better growth compared to the control diet. T2 outperformed all other dietary systems in growth criteria, indicating the success of the substitution process in all three dietary systems. Notably, T2, in particular, stood out due to its inclusion of fermented rice bran, serving as an excellent blend with prebiotic properties, a rich source of protein, essential amino acids, saturated fatty acids, vitamins, minerals, and salts **(Muaddama *et al*., 2020)**. A study by **Azrinnahar *et al*. (2022)** explored the impact of fermented nutrition through the fermentation of rice bran with dry yeast on the growth of broilers and bone mineralization. It revealed a positive effect on the performance of broiler chickens, phosphorus availability, and increased bone strength. Similarly, the treatment with microwave irradiation had an obvious effect on the biological properties of non-starchy carbohydrate compounds, such as pectin, cellulose, and phytate, which may negatively interfere with the digestion and assimilation of nutrients by losing their ability to form hydrogen bonds. Consequently, they cannot complex protein and carbohydrate compounds, making them free for breakdown into simpler absorbable compounds by the digestive system. This positive impact on growth parameters which was also shown by the current study aligns with the previous findings of **Chang and Moon (2021)**. The results also support those of **Sashi *et al*. (2014)**, who used thermally treated rice bran as the main ingredient in the feed for common carp, achieving improvements in fish production rates. Furthermore, the use of thermal treatment to enhance the nutritional value of agricultural processing by-productss is endorsed by **Shiau (2002)**. The current study's results are consistent with the findings of **Romano (2018)**, who used fermented rice bran in the diet of African catfish, as well as **Al-**

Humairi *et al*. (2020) and **Albassam (2021)** in the nutrition of common carp. Moreover, the results are aligned with the study of **Rusmadania *et al*. (2022)**, who used fermented rice bran in different doses to feed kol fish larvae.

Digestibility

The results indicated that treatment T2 outperformed other treatments in digestibility coefficients for nutrients (protein, fat, and ash), followed by treatments C, T3, and T1; these results are consistent with the findings of **Mmanda *et al*. (2020)**, where the total digestibility coefficient for tilapia reached 78.70%. The digestion coefficient for the control diet (C) was 82.22%. This superiority in treatment T2 can be attributed to the addition of fermented rice bran with bakery yeast, which helped increase the digestion of protein and fat due to sufficient energy in the diet, contributing to covering the digestion processes of protein and fat **(Putra *et al*., 2021)**. This confirms that the presence of probiotics in fish diets including yeast, leads to the activation of digestive enzymes in food materials, and consequently increasing nutrient digestion **(Rhema & Al-Noor, 2022)**. The results regarding protein and fat digestion are consistent with the findings of **Rahman *et al*. (2016)**, where protein digestion ranged between 87.20 and 93.20%, and fat digestion ranged between 83 and 90.5% in extruded pellet. Carbohydrate digestion had the highest percentage in the control diet (0% replacement), reaching 78.34%. This can be attributed to the composition of the rice bran-free diet, which contains structurally complex components that are challenging to digest **(Yuangsoi *et al*., 2016)**. In diets T1 and T3, the digestibility coefficients were close, measuring 64.41 and 66.89%, respectively. The decreased digestibility in these treatments can be ascribed to several factors, including the replaced raw material (rice bran) and its high carbohydrate content. Additionally, the presence of structural components such as hemicellulose and cellulose in rice bran could contribute to the reduced digestibility. These dietary fibers might affect the digestion by limiting the production of digestive enzymes from beneficial bacteria or fish intestines **(Debi *et al*., 2022)**. The structural carbohydrates may impair fish digestion by coating nutrient elements or increasing the viscosity of intestinal contents **(Sansuwan *et al*., 2014)**. For treatment T2, the digestibility reached 76.38%, which is higher than treatments T1 and T3, but lower than the control treatment. This result could be traced back to the microbial fermentation process using bakery yeast, which led to the consumption of a portion of carbohydrates in addition to the breakdown of hard-to-digest structural components **(Ryan *et al*., 2011)**. **Hemre *et al*. (2003)** emphasized that the digestibility of carbohydrates depends on various factors, including structure and their proportion in the feed.

CONCLUSION

In conclusion, this study emphasizes the importance of rice bran as an important and widely available agricultural processing by-product as an ingredient and carbohydrate alternative in fish diets. Rice bran's seasonal availability and low cost render it an excellent alternative to more expensive maize and wheat flour, both of which are also staple foods for humans. This could contribute significantly in improving fish culture economics, as well as supporting the sustainability of aquaculture sector in general.

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