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Replacing crude fiber content of berseem hay by wheat straw with or without probiotics or enzymes in the diets of growing rabbits

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ABSTRACT

The goal of the current study was to assess the impact of partial or complete substitution of crude fiber content of berseem hay by wheat straw with or without probiotics or enzymes on growth performance, caecal contents parameters, nutrients digestibility and economic efficiency of growing rabbits. Eighty-four weaned New Zealand White rabbits of both sexes (at 30 days of age) were randomly assigned to seven groups, each consisting of twelve rabbits. The same feed ingredients as the control diet (D1) were used to create two experimental pelleted diets, but one source of roughage (wheat straw) was added in diets 2 (D2) and 3 (D3) which replaced 50 & 100% of the crude fiber content of berseem hay with or without probiotics or enzymes. The first group (control group) was given a basal control pelleted diet (D1) that included berseem hay as the primary source of crude fiber without additives. The second, third and fourth groups fed on the second pelleted experimental diet (D2) in which fiber content of wheat straw replaced 50% of berseem hay without (group 2) or with probiotics (group 3) or enzymes (group 4). The fifth, sixth and seventh groups fed on the third pelleted experimental diet (D3) in which fiber content of wheat straw replaced 100% of berseem hay without (group 5) or with probiotics (group 6) or enzymes (group 7). Experimental period extended for 42 days from weaning (at 30 days) to slaughter age (at 72 days). The results showed that replacing of 50 or 100% of berseem hay fiber by wheat straw with probiotics or enzymes in the diets of growing rabbits increased the final weight of the body, gaining in weight, the cumulative feed consumption and economical feed efficiency as well as improved the feed conversion ratio, performance index, the coefficients of digestion for all nutrient and also feeding criteria including DCP & TDN in comparison with control. During the entire trial, there was no mortality among rabbits fed diets made with wheat straw supplemented with probitoics or enzymes, while those fed the same diets without additives had a lower mortality rate than the control group, which had the highest mortality rate. Compared to other treatment groups and the control, rabbits fed diets containing wheat straw supplemented with enzymes, had the highest values of total bacterial count and total volatile fatty acids of the cecal content. In conclusion, it is cost-effective to replace 50 or 100% of the fiber in berseem hay with wheat straw fiber, either without or with probiotics or enzyme supplements, and the feed additives will enhance the growth performance metrics for growing New Zealand White rabbits.

Introduction

The primary issues of animal protein sources deficiency for humans in developing nations, which are caused by limited land resources and intense competition between humans and livestock for high-quality grains and protein supplements, are currently the scarcity of animal feeds in Egypt and their high cost. As a result, significant research efforts must be directed toward addressing the feed shortage by enhancing conventional sources and looking into more unconventional feeds (Al-Sharqawi *et al.*, 2019; Yassin *et al.*, 2020). The rabbit sector might be crucial in closing the gap between the supply and demand of animal protein. In addition, consumers regard rabbit meat as a high-quality meat product due to its nutritional and dietetic qualities. Lean and high in unsaturated fats (60 percent of total fatty acids), rabbit meat has a high protein content (20–21 percent) with good biological properties, very low levels of sodium and cholesterol, and high levels of potassium and magnesium (Agradi *et al.*, 2023).

The rabbit (*Oryctolagus cuniculus*) is a pseudo-ruminant that is regarded as superior to other livestock due to its rapid growth and high rate of reproduction. It is more productive than other meat animals and has high feed conversion efficiency (Sharma *et al.*, 2016). The ability of rabbits to utilize cheap and non-conventional feedstuffs is an important advantage over other monogastric animals. Rabbits can sufficiently degrade substantial amounts of fiber, making dietary fiber the main constituent of rabbit feed. The adoption of less expensive and locally accessible alternative (unconventional) feedstuffs has been the main focus of efforts to lower the high cost of feeds (Jalal *et al.*, 2023).

It is commonly known that between 60 and 70 percent of the total cost of production is spent on feeding. Finding the least expensive diets that completely satisfy animal needs is difficult for feed formulation (Omidiora *et al.*, 2013). Using unconventional, less expensive feed components or enhancing the use of conventional feeds with feed additives could help reduce feed costs.

The main mechanisms by which fiber helps rabbits avoid digestive disorders are the regulation of intestinal microbiota through its impact on the digestive tract and its capacity to serve as a substrate for bacterial development. To enhance competitive exclusion, the type of dietary fiber may be crucial in fostering the development of advantageous microbiota. Furthermore, the intestinal barrier and mucosal structure may be impacted by the type of fiber (Ye *et al.*, 2021). In rabbit diets, clover hay is a typical source of fiber that can be added in high percentages without having any negative effects. Rabbit diets should have at least 25–46% NDF, 15–23% ADF, and 3.5–6.5% ADL (De Blas and Mateos, 2010).

Straws, and other fibrous agricultural byproducts are examples of low-quality roughages that contribute significantly to environmental contamination in addition to being a waste of natural resources. Because of this, many nations have already passed legislation outlawing the burning of these agricultural wastes. However, there is a lack of feed for animals in many emerging nations, and the price of this feed keeps rising. The processing of fruits, vegetables, and cereals also results in the production of thousands of tons of agricultural trash and leftovers annually. Even though many farmers already fully utilize rice and wheat straws for bedding poultry farms or for feeding cattle, there is a lack of extensive research on these materials (El-Shahat *et al.*, 2010).

A class of feed compounds known as feed additives can influence an animal's development, metabolism, or pH in a way that is not related to nutrition. They are neither necessary nor a guarantee of good profitability or productivity, though. These additives are regarded as secure, dependable, and effective substitutes for antibiotics in rabbit diets. These non-antibiotic substances with bacteriostatic or bactericidal action, like probiotics and enzymes, have a variety of impacts on animals, ranging from immune system stimulation to gut microbiota and metabolism modifications to health promotion and animal production benefits (Djuragic *et al*., 2023).

Live microbes known as probiotics are supplemented into rabbit diet. Scientists have emphasized the benefits of probiotics since they can keep the microbial community in the intestinal system in balance. Probiotics in the diet may enhance overall health, gut structural integrity, physiological function, and intestinal immunity. Through the activation of antioxidative enzymes and the reduction of lipid peroxidation, probiotics also help to improve the antioxidative status (Abdelsalam *et al*., 2025). Furthermore, innate and acquired immunity, as well as pro- and anti-inflammatory cytokines, can be regulated by dietary probiotic microbes. It's interesting to note that probiotics lessen the detrimental effects of stressors on rabbits (Ebeid *et al*., 2025).

Biologically active proteins called enzymes can break certain chemical bonds to release nutrients for more digestion and absorption, as well as accelerate particular chemical reactions with the least amount of energy waste. Animals cannot fully digest and utilize feedstuffs made of plant material, cereal, and vegetable proteins, especially atypical ones used in animal feeding. Exogenous enzymes at feeding time have also been shown to enhance antioxidant status, improve nutrient digestion, lower blood lipids, and improve protein efficiency ratios while lowering daily caloric conversion ratios in growing rabbits (Abu Hafsa *et al*., 2022). For this reason, enzyme supplements are necessary, as they are known to aid in feed digestion and utilization (Abdelazeem *et al*., 2023). To increase the availability of nutrients in rabbit diets, several research have been conducted on the incorporation of exogenous enzymes and probiotic microorganisms (El-Adawy *et al*., 2013). This study examined the effects of partial or complete replacing the crude fiber content of berseem hay with wheat straw, either with or without feed additives (probiotics or enzymes), on the growth performance, mortality rate, cecal content parameters (such as TVFAs, TBC, pH, and ammonia concentrations, digestibility of various nutrients, feeding values (such as DCP & TDN) of the experimental diets, and economic efficiency of growing rabbits.

Materials and methods

Ethical approval

The Ethics Committee of the Faculty of Veterinary Medicine at Assiut University in Egypt granted ethical permission, and the prescribed ethical requirements were followed (Approval no. 06/2025/0343).

Experimental duration and location

The trial lasted 42 days, starting at 30 days of weaning and ending at 72 days of slaughter age. The last 3 days of experimental period were assigned for fecal collection and digestibility estimation. At the private rabbit farm in Abnub, El-Fateh, Assiut Governorate, Egypt, this experiment was conducted.

Experimental animal, design and management

Eighty-four (30 days old) New Zealand White rabbits of both sexes were employed in this experiment. The rabbits' starting weights were almost identical (561.7±14.3 g) at the beginning of the experiment and divided randomly into 7 groups, 12 rabbits in each. All the growing rabbits were kept apart in separate cages made of galvanized wire (50 x 50 x 40 cm), and they were set up in double-tier batteries that were divided into two rows so that urine and feces could be kept apart. Every cage has nipples (automated drinkers) and feeders (made of galvanized steel sheets). Throughout the duration of the experiment, the system supplies the animals with new, clean water. Every treated group of rabbits was housed in the same environment and with the same management style. The farm was adequately prepared, cleaned with 4% formalin, and organic waste was disposed of hygienically. Before the trial began, rabbits were put through a pharmacological and preventive program against bacterial and viral infections in order to control diseases and increase survivability.

Preparation of tested feed ingredients

Wheat straw

Wheat straw was purchased from local market and then chopped off again in a local hummer mill machine to obtain small fine parts (0.5-1 cm length) which can be used in the diet manufacturing and chemical composition.

Berseem hay

The second cut of Egyptian clover was used to make Berseem hay. It was then sun-dried, cleansed of any foreign objects, and chopped into small pieces that could be utilized in pelleted diets and chemical composition using a heavy-duty high rotation hummer mill equipment.

Probiotics

At 500g per ton of the diet, a commercial probiotic preparation called "Sanolife Pro-F" was added. A total of 1.0×10^{10} CFU/g is found in each gram of Sanolife PRO-F, which is made up of a mixture of Bacillus strains, including *Bacillus subtilis* 3.25×10^{9} CFU/g, Bacillus licheniformis 3.50×10^{9} CFU/g, and Bacillus pumilus 3.25×10^{9} CFU/g.

Enzymes

The addition of 500g of a commercial enzyme preparation called "Nutrikem dry" per ton of feed was made. The components of Nutrikem are β-glucanase (1175 IU⁄g), cellulase (2000 IU⁄g), α-amylase (200 IU⁄g), protease (225 IU⁄g), xylanase (10000 IU⁄g), and emulsifier (lecithin).

Experimental diets and feeding

Using the AOAC (2023) method, representative samples of feed ingredients (yellow corn, soybean meal, sunflower meal, wheat bran, berseem hay, molasses, corn stover, and wheat straw) were examined before the diet was created for proximate chemical composition (DM, CP, EE, CF, Ash, and NFE). Digestible energy content of wheat bran and berseem hay cited from NRC (1977), while DE of yellow corn, soybean meal, sunflower meal and molasses adapted from the feed composition tables of Cheeke (1987). In addition, DE of wheat straw was estimated by bomb calorimeters and then calculated using De Blas *et al*. (1992) equation [DE=GE x (0.867-0.0012 ADF)]. According to Van Soest *et al*. (1991), the components of cell walls such as neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were identified. Basal control pelleted diet was formulated from ground yellow corn, soybean meal, wheat bran, berseem hay, molasses, common salt, ground limestone, methionine and premix. With or without probiotics or enzymes, two experimental pelleted diets were created using the same feed ingredients as the control diet. One source of roughage, wheat straw, was used to replace 50% and 100% of the crude fiber content of berseem hay. In accordance with NRC (1977), the control and two experimental pelleted diets were created to satisfy the nutritional needs of growing rabbits. All the diets had comparable amounts of crude fiber (12% CF), were iso-caloric (2500 kcal/kg), and were iso-nitrogenous (16% CP). Table 1 displays the physical and computed chemical composition (%) of the control and experimental diets.

Table 1. Physical and computed chemical composition (%) of the control and experimental diets.

Ingredients	Diets		
	D1 (control)	D2	D3
Physical composition (%)			
Yellow corn	26.3	27.24	35.46
Soybean meal	10.55	9.86	14.15
Sunflower meal	1.1	9.28	13.2
Wheat bran	16	18	4
Berseem hay	40	16	-
Wheat straw	-	13.12	26.24
Molasses	5	5	5
Common salt	0.5	0.5	0.5
Ground limestone	-	0.45	0.9
Methionine	0.25	0.25	0.25
Premix*	0.3	0.3	0.3
Total	100	100	100
Calculated chemical composition (%)			
Dry matter	88.21	87.47	86.76
Organic matter	80.52	81.45	81.56
Crude protein	16.02	16.02	16.02
Crude fiber	12.51	12.56	12.9
Ether extract	2.92	3.02	2.82
Nitrogen free extract	49.07	49.85	49.82
Ash	7.69	6.02	5.2
DE(kacl/kg)	2528	2533	2585
Calcium	0.49	0.44	0.46
Total Phosphorus	0.24	0.25	0.23
Methionine	0.46	0.47	0.46
NDF	27.89	31.48	31.33
ADF	17.13	18.05	19.22
ADL	3.94	4.43	4.76
Hemicellelose**	10.76	13.43	12.11
Cellulose***	13.19	13.62	14.46

*Multivita company, Each 3 kg premix contains: 1 kg vitamins (Vit.A 8000000 IU; Vit. D3 4000000; IU; Vit. E 30000mg; calcium carbonate material carrier up to 1kg) and 2kg minerals (Zinc 50000 mg; Manganese 50000 mg; Iron 50000mg; Copper 10000; Iodine 500 mg; Selenium 200mg; Cobalt 100mg; calcium carbonate material carrier up to 2kg).
**Hemicellulose = Neutral detergent fiber (NDF) – Acid detergent fiber (ADF).
***Cellulose = Acid detergent fiber (ADF) – acid detergent lignin (ADL).

Weaned rabbits were distributed into 7 groups, a control and 6 experimental groups according to the source of dietary fiber and the feed additives used. The first group was given a basal control pelleted diet (D1) that included berseem hay as the primary source of crude fiber without additives. This group served as a control group against which the other treated groups were compared. The second, third, and fourth groups of animals were fed on the second pelleted experimental diet (D2) in which fiber content of wheat straw replaced fiber percentage of berseem hay at the level of 50% without or with probiotics or enzymes addition, respectively. Rabbits in the fifth, sixth and seventh groups were fed on the third pelleted experimental diet (D3) in which wheat straw replaced 100% of fiber content of berseem hay without or with probiotics or enzymes addition, respectively. All growing rabbits received fresh, clean water ad libitum (via stainless steel nipple) through the duration of the experiment, and diets were provided in pellets ad libitum every day at 9:00 am and 5:00 pm.

Performance parameters

Weekly records were kept of performance metrics like mortality, feed consumption, and live body weight. As suggested by Soliman and Hassan (2017), weight gains, feed conversion ratio (FCR%), and performance index (PI%) were computed.

Cecal parameters

Following sacrifice, three caecal content samples from each treated rabbit were taken in order to quickly estimate the pH value using a digital pH meter. The cecal contents were then separated into three sections: two of these sections were used to measure the amounts of ammonia (NH_3-N) and total volatile fatty acids (TVFAs), while the third section was utilized to measure the caecal microbial activity.

Briefly, the cecal contents of the slaughtered rabbits were extracted and evacuated in tubes. Samples were then put in 50 ml tubes filled with sterile saline (0.9 g sodium chloride in 100 ml distilled water) and stored at 40 C until they were needed for an analysis of the total bacterial count. The conventional pour plate method (Quinn *et al*., 1992) was used to count the number of live organisms in cecal contents per gram. Samples in a saline suspension were shaken vigorously many times. 1 ml of each tenfold serial dilution was aseptically placed into two sterile Petri dishes after being aseptically made from a suspension of cecal contents using sterile saline as a diluent. 10 milliliters of sterile standard plate count agar, which had been melted and allowed to cool at 45 degrees Celsius, were aseptically added to the Petri dishes and completely combined with the saline suspension. After solidification, the plates were incubated for 48 hours at 37°C. Colonies on plates with an average of 30 to 300 were chosen and counted. Parker and McMillan (1976) employed gas chromatography to determine the amounts of total volatile fatty acids in the second cecal sample. At 20°C, 5 ml of distilled water was used to extract 1 g of the caecal sample. After five minutes of centrifugation at 3000 rpm, the mixture was filtered using a Schleicher and Schull membrane filter (BA-83, 0.2 µm). A 1 µl aliquot of the extract was injected using an on-column technique with an auto-sampler into a wide-bore capillary column that was installed in a gas chromatograph. The column was operating in a temperature-programmed mode and had a PTV injection port and a flame ionization detector. It was used in split mode with a split vent flow of 100 ml/min. The temperatures for the injector and detector ports were 230°C and 240°C, respectively. Helium served as carrier gas, and the oven was set to run for 30 minutes by raising the temperature from 60 to 200 degrees Celsius at a rate of 5 degrees Celsius per minute and holding it there for two minutes. A measurement was made of the peak area. Every peak was located and measured using pure standards (Sigma Chemical). According to Broderick and Kang (1980), the ammonia concentration (NH_3-N) of the supernatant was measured spectrophotometrically at 660 nm after the third portion of the cecal fluid was centrifuged for 10 minutes at 10,000 rpm.

Digestion coefficients

Three rabbits from each group were retained at the conclusion of the experiment to conduct the digestibility test. Each rabbit was kept in a digestibility cage that separated urine from feces. Faeces collection method was designed to permit a quick escape of urine and avoid direct contamination of faeces. The experimental diets were provided daily at 9:00 am, and feed consumption was tracked for five successive days. Pellets found outside the feeder were gathered and kept at -18°C. To determine the DM intake, the dry matter (DM) content of the pellets was measured at the conclusion of the collection period (in a hot air oven set at 105°C for 24 hours). Total faecal excretion was collected daily at 9.0 am, avoiding the inclusion of rabbits lost hair. Total fecal output (hard faeces) was collected in the same individual bag and stored at -18°C or less. DM excreted was

assessed into successive steps: a first drying of the whole faeces at 80°C for 24 h followed by a final drying of around half of the faeces at 105°C for 24 h. The first drying extracted the major part of the water from the feces without deterioration of their chemical constituents. The last drying made it possible to get rid of the remaining water. The portion of the feces that had only been dried at 80°C was subjected to chemical analysis (Xiccato *et al.*, 1995). The apparent digestibility coefficient of each nutrient was determined for each rabbit using the traditional formula (Maynard, 1979):
Digestion Coefficient of any nutrient = Nutrient intake – Nutrient in feces /Nutrient intake ×100

The experimental diets' nutritional values

The experimental diets' nutritional values were computed using the Cheeke *et al.* (1982) formula and expressed as digestible crude protein (DCP) and total digestible nutrients (TDNs):

TDN = DCP +DCF +DNFE + (DEE X 2.25)

DCP= CP intake – CP excreted

where, DCP = Digestible crude protein, DCF= Digestible crude fiber, DNFE = Digestible nitrogen free Extract and DEE = Digestible Ether Extract.

CP intake (g) = % CP in feed x whole feed intake (g)/ 100

CP excreted (g) = % CP in feces x whole feces excreted (g)/ 100

Monetary value

The price of 30-day-old rabbits as well as the expenses for management, housing, veterinary care, feeding, and heating were included in the total production cost. The amount of feed used throughout the experiment was noted in order to calculate the economic efficiency of meat production. The cost of the experimental diets was determined by considering the local market price at the time of the experiment. The selling price was determined by multiplying the total live body weight of the produced rabbits by the going rate per unit weight. The following formulas were then used to determine net revenue, economic feed efficiency, and relative economic feed efficiency:

Net revenue = Price of body weight – Total production costs

$$\text{Economic feed efficiency (EFE)} = \frac{\text{Net revenue}}{\text{Total production costs}} \times 100$$

$$\text{Relative economic feed efficiency (REFE)} = \frac{\text{EFE of group}}{\text{EFE of control}} \times 100$$

Statistical analysis

Means and standard errors were computed from statistical analyses of the experimental raw data. The Statistical Analysis System's one-way analysis of variance approach was used to determine whether the differences were significant (SPSS, 2008). Duncan's multiple range test (1955) was used to determine whether there were significant differences (P<0.05) between treatment means. Significant differences were defined as P<0.05.

Results

Performance parameters

Table 2 showed that probiotic or enzyme supplementation significantly increased (p<0.05) the final weight of the body (LBW), total weight gain (BWG) and cumulative feed consumption of rabbits fed experimental diets that substituted 50% or 100% wheat straw fiber for berseem hay fiber. While, the lowest LBW, BWG & cumulative feed consumption were recorded in rabbits fed diets containing wheat straw without additives in comparison with control. Numerically, the highest values were recorded in the fourth group (2130.7, 1575.3 & 4989 g, respectively), while the lowest values were in the fifth group (1969.4, 1412.2 & 4622 g, respectively).

During the entire trial period, the feed conversion ratio (FCR) and performance index (PI) of groups fed on diets in which 50% or 100% of the berseem hay fiber was substituted with wheat straw fiber, either with or without probiotics or enzymes, shown a significant improvement over the control. The fourth group gained the highest body weight (P<0.05), consumed the most feed (P<0.05), and consequently had the best (P<0.05) FCR and PI (3.17 & 67.21%, respectively), followed by the third group (3.20 & 65.81%, respectively) in comparison to the control group (3.34 & 60.09%, respectively).

There was no mortality rate in the groups that were fed wheat straw diets enhanced with probiotics or enzymes for the duration of the experiment. However, rabbits fed on the same diets without additives had a mortality rate of 8.33% in comparison with the control group which had the greatest mortality rate (16.66%) as shown in Table 2.

Cecal parameters

Table 3 showed that there were no appreciable variations in the cecal content's pH or ammonia levels across the treatments. Regarding the total bacterial count per gram and the total volatile fatty acid values of the cecal content, the data revealed that the various experimental groups and the control group differed significantly in both measurements. The rabbits in the fourth and seventh groups had the highest TBC and TVFAs values (36x10^4, 65.21 & 34 x10^4, 65.21 mmol/L, respectively), while the third and sixth groups had the lowest values (12x10^4, 41.25 & 10 x10^4,

Table 2. Performance metrics for growing rabbits during the trial.

Parameters	Groups**						
	1	2	3	4	5	6	7
Initial body weight (g/rabbit)	557.5±13.3	561.7±14.3	554.7±12.3	555.4±11.4	557.2±13.9	555.6±11.8	556.5±12.9
Final body weight (g/rabbit)	2007.0±35.6^{c}	1990.8±33.4^{c}	2105.8±45.3^{a}	2130.7±44.3^{a}	1969.4±32.4^{c}	2050.9±40.3^{b}	2070.4±39.3^{b}*
Total weight gain (g/rabbit) (30-72 day)	1449.5±33.0^{c}	1429.1±35.9^{c}	1551.1±39.2^{ab}	1575.3±38.0^{a}	1412.2±34.9^{d}	1495.3±35.2^{bc}	1513.9±35.7^{b}
Cumulative Feed consumption (g/rabbit)	4844.6±35.5^{b}	4650.0±30.7^{c}	4970.0±47.6^{a}	4989.0±45.3^{a}	4622.0±31.4^{c}	4915.0±45.5^{a}	4930.0±44.7^{a}
Feed conversion ratio (FCR)	3.34±0.10^{a}	3.25±0.08^{ab}	3.20±0.0b^{ab}	3.17±0.07^{b}	3.27±0.09^{ab}	3.29±0.07^{ab}	3.26±0.10^{ab}
Performance index (PI) %	60.09±1.29^{d}	61.26±1.42^{c}	65.81±2.41^{ab}	67.21±2.63^{a}	60.23±1.52^{cd}	62.34±1.57^{bc}	63.51±1.70^{b}
Mortality rate %	16.66%	8.33%	-	-	8.33%	-	-

* Significant differences exist between means within the same row with different superscripts (P<0.05).

**G1: control group fed on the basic diet (100% berseem hay fiber without additives); G2: fed on diet containing 50% berseem hay fiber+ wheat straw without additives; G3: fed on diet containing 50% berseem hay fiber+ wheat straw with probiotics; G4: fed on diet containing 50% berseem hay fiber+ wheat straw with enzymes; G5: fed on diet containing 0% berseem hay fiber+ wheat straw without additives; G6: fed on diet containing 0% berseem hay fiber+ wheat straw with probiotics; G7: fed on diet containing 0% berseem hay fiber+ wheat straw with enzyme.

41.30 mmol/L, respectively).

Digestion coefficients and feeding values of the experimental diets

The experimental diets' digestion coefficient data showed that there was no significant difference in the digestion coefficient of EE across all treatments, as shown in Table 4. Additionally, the table demonstrated that there were substantial differences in the feeding values (DCP & TDN) and digestion coefficients (DM, CP, CF & Ash) between the several experimental groups and the control. Growing rabbits fed diets substituting 50 or 100% berseem hay fiber with wheat straw fiber supplemented with probiotics or enzymes showed significant ($P<0.05$) improvements in their digestion coefficients of nutrients and feeding values (DCP & TDN). The feeding values and digestion coefficients of diets containing wheat straw without additions were nearly the same as those of the control.

Economical evaluation (monetary value)

According to the results of the economical evaluation, all experimental groups fed diets in which 50 or 100% of the berseem hay fiber was substituted with wheat straw fiber, either with or without probiotics or enzymes, had lower prices per kilogram of feed, total feed costs, and total production costs than the control group (Table 5). Inclusion of wheat straw without additives decreased total feed cost in the 2nd group by about 10.92% followed substitution of berseem hay by wheat straw in the fifth group (13.75%). Therefore, compared to the control group (38.63 & 100%), the rabbits in the seventh group (45.16 & 116.90%) had the best economical feed efficiency and relative economic feed efficiency (REFE) values, followed by the fourth group (45.01 & 116.52%). These findings demonstrated the benefits of using wheat straw fiber instead of 50 or 100 % berseem hay fiber, either with or without probiotics or enzyme supplementation in the growing rabbit diets. They could also be a beneficial tool for developing the least expensive ration formula in rabbit production.

Discussion

The growth performance parameters including live weight of the body, weight gain, feed conversion ratio and performance index of rabbits were considerably ($p<0.05$) increased when 50 or 100% of the fiber from berseem hay was replaced with wheat straw fiber supplemented with probiotics or enzymes. These results are consistent with the findings of Abo EL-Maaty *et al.* (2014) who reported that the growth performance measures were improved when cucumber vine straw was added to the diet at levels of 7.5, 15, 22.5 & 30% in place of 25, 50, 75, and 100% clover hay with MOS or NZ. Additionally, Omer *et al.* (2019) demonstrated that, in comparison to untreated rice straw and control, the use of treated rice straw in place of 33 and 66% of clover hay resulted in a substantial increase ($P<0.05$) in final body weight (FBW) and total body weight gain

Table 3. Cecal parameters of growing rabbits in the experiment.

Parameters	Groups**						
	1	2	3	4	5	6	7
pH value	6.37±0.47	6.28±0.55	6.50±0.48	6.12±0.57	6.27±0.36	6.53±0.73	6.17±0.62
TBC/g (x10^4)	19.00±0.58^b	22.00±1.53^b	12.00±2.08^c	36.00±2.52^a	24.00±2.65^b	10.00±1.53^c	34.00±0.58^a
TVFAs (mmol/L)	53.30±2.93^b	53.28±2.34^b	41.25±1.31^c	65.30±2.88^a	53.24 ±2.18^b	41.30 ±1.32^c	65.21 ±3.48^a
NH3-N (mmol/L)	28.40±1.16	27.82±2.39	28.59±0.94	26.90±2.35	27.50±0.58	28.43±0.56	26.87±1.21

* Significant differences exist between means within the same row with different superscripts ($P<0.05$).

Table 4. Nutrient digestion coefficient (%) and feeding values (%) of the experimental diets given to the experimental groups.

Items		Groups						
		1	2	3	4	5	6	7
Digestion coefficient	DM	57.59±0.73^b	57.05±0.69^b	61.23±0.70^a	64.07±0.70^a	57.89±0.71^b	61.83±0.78^a	61.23±0.61^a
	CP	68.07±0.58^b	65.52±0.52^b	72.21±0.68^a	73.73±0.63^a	66.42±0.64^b	72.17±0.61^a	69.32±0.67^{ab}
	EE	83.97±1.14	83.2±1.09	85.88±1.18	88.66±1.33	84.03±1.2	86.48±1.3	85.77±2.24
	CF	24.72±0.46^b	24.47±0.33^b	29.75±0.53^{ab}	32.00±0.59^a	25.25±0.42^b	30.88±0.58^a	28.16±0.37^{ab}
	NFE	65.39±0.73^b	64.44±0.78^b	67.81±0.81^{ab}	71.54±0.92^a	65.07±0.66^b	67.84±0.77^{ab}	68.80±0.82^{ab}
	Ash	28.36±0.63^b	34.05±0.80^{ab}	36.81±0.87^{ab}	37.47±0.85^{ab}	38.35±0.77^{ab}	43.63±0.94^a	41.38±0.90^a
Feeding values	DCP	10.91±0.24^b	10.50±0.38^b	11.57±0.46^a	11.81±0.41^a	10.49±0.33^b	11.56±0.43^a	11.10±0.46^a
	TDN	51.76±0.59^c	50.72±0.52^c	54.28±0.71^{ab}	56.62±0.82^a	50.79±0.54^c	53.93±0.69^b	53.54±0.62^b

* Significant differences exist between means within the same row with different superscripts ($P<0.05$).

Table 5. Economical evaluation of experimental diets.

Items	Groups						
	1	2	3	4	5	6	7
Price/kg feed (L.E)	4.16	3.86	4.03	4.03	3.76	3.93	3.93
Total feed cost (L.E)	20.15	17.95	20.03	20.1	17.38	19.32	19.37
Total production cost (L.E)	65.15	62.95	65.03	65.1	62.38	64.32	64.37
Cost per kilogram of body weight (L.E)	45	45	45	45	45	45	45
Price/rabbit or Total revenue (L.E)	90.32	90.26	94.09	94.4	89.83	93.14	93.44
Net revenue (L.E)	25.17	27.31	29.06	29.3	27.45	28.82	29.07
Economic feed efficiency (%)	38.63	43.38	44.69	45.01	44	44.81	45.16
Relative economic feed efficiency	100	112.3	115.69	116.52	113.9	116	116.9

(TBWG).

Final LBW, total BWG, FCR, and PI were all enhanced when probiotic organisms were added to rabbits' diets (Abdel-Wareth *et al*., 2021). Furthermore, as demonstrated by Abu Hafsa *et al*. (2022), exogenous enzymes improved nutritional digestibility, growth performance, and the protein efficiency ratio. By lowering pH, removing pathogens, and lowering anti-nutrient levels in wheat straw, enzymes or probiotics may help improve the intestinal microbial environment and lead to a noticeable improvement in productive performance, which in turn improves rabbit health and feed utilization efficiency (Elbaz *et al*., 2023; Elghandour *et al*., 2024). Conversely, Tag-El-Din *et al*. (1999) found that supplementing growing rabbits with Cel-con (a yeast culture predominantly of *Saccharomyces cerevisiae*) at doses of 10, 20, or 30% reduced their live body weight and body weight gain when clover hay was substituted with dry corn stalk. But according to El-Shahat *et al*. (2010), there was no statistically significant difference in body weight development, body weight gain, FCR and PI when biologically treated corn stalks were substituted for berseem hay at levels of 10, 20, or 30%.

Data on rabbits' cumulative feed intake revealed that substituting 50 or 100% of the fiber from berseem hay with wheat straw fiber supplemented with probiotics or enzymes substantially increased total feed intake when compared to the control and other treated groups without feed additives. The results obtained are consistent with those of Abo El-Maaty*et al*. (2014) who found that feeding developing rabbits cucumber vine straw at levels of 7.5, 15, 22.5 & 30% in place of 25, 50, 75, and 100% clover hay with MOS or NZ boosted feed intake when compared to the control. The ability of exogenous enzymes and probiotic bacteria to hydrolyze the diet's fiber and non-starch polysaccharide into easily digestible components, thereby making the nutrients available to the rabbits, may have contributed to the study's increased feed intake (Oguntoye *et al*., 2017). Researchers found that probiotics' capacity to increase feed intake through enhanced palatability accounts for a portion of their growth-promoting qualities (Ezema and Eze, 2015). However, Abo El-Maaty *et al*. (2019) showed that rabbits fed diets with varying amounts of fennel and basil hay mixture, either without or with symbiotic in place of alfalfa hay, consumed noticeably less feed than the control groups.

The overall feed intake was considerably reduced when the fiber content of wheat straw at 50% or 100% without additions was substituted for the fiber in berseem hay. These results are consistent with those of Asar *et al*. (2010) who stated that rabbits' feed intake was lower when dried faba bean straw was used in place of berseem hay than when the control diet was used. Fiber makes feed bulkier in the gut, which lowers feed consumption in monogastric animals, which could explain the declining feed intake of rabbits fed experimental diets devoid of additives (Adeniji *et al*., 2014). In contrast, Omer and Badr (2013) observed that growing rabbits' feed intake was considerably ($P \leq 0.001$) enhanced when clover hay was partially or completely replaced with pea straw. However, Sherif *et al*. (2010) demonstrated that feeding growing rabbits a mixture of parsley and caraway straws at 25, 50, 75, or 100% in place of alfalfa hay had no discernible impact on their feed intake.

During the entire experiment, the mortality rate of growing rabbits was lower when berseem hay fiber was partially or completely replaced with crude fiber of wheat straw, either with or without probiotics or enzymes. This implies that growing rabbits can use varying amounts of wheat straw in their diet together with feed additives. Compared to the control group, which had the highest death rate (16.66%), rabbits fed the same meals without additives had an 8.33% mortality rate per rabbit. These outcomes are consistent with those of Lebas *et al*. (2012) who observed that the mortality rate of growing rabbits fed diets including alfalfa hay was significantly higher (26.4%) and significantly lower (9.3%) than those fed diets containing wheat straw. By altering volatile fatty acid concentrations and promoting caecal fermentation, exogenous fibrolytic enzymes can influence the colonization of beneficial bacteria in the caecum and help preserve the animal's overall health. Cellulase and non-starch-polysaccharide (NSP) enzymes may be the most promising for enhancing rabbit performance and sanitary conditions (Alderey *et al*., 2024). Additionally, probiotics have a particularly positive impact on the microbial balance in the caecum when added to rabbit diets. In intensive rabbit breeding, a constant microbial metabolism in the caecum is crucial for preventing digestive disruptions, ensuring optimal production parameters, and lowering the mortality rate (Yan and Polk, 2020). Numerous Bacillus species have been studied as probiotics in rabbits that are growing and reproducing. From a technical standpoint, supplementing Bacillus is simpler than using other probiotics because the spores are resistant to storage and feed processing. Bacillus species and pathogenic flora have been demonstrated to compete at the gastrointestinal level, which may contribute to the preservation of healthy flora and good health by lowering the mortality rate (Guo *et al*., 2017). It is well established that certain probiotics may suppress intestinal E. coli in a dose-dependent way. It's possible that they encourage modifications to the gut microbiota, which prevents certain viruses from adhering efficiently. Probiotic-treated experimental newborn rabbits experienced a 25% decrease in E. coli levels in their small intestine. Furthermore, the incidence of bacterial translocation in the liver, spleen, and lymph nodes was much lower in rabbits, suggesting a lower risk of systemic infection (Chandrasekaran *et al*., 2024). According to Abdelhady and El-Abasy (2015), adding probiotics to the diet stimulates the immune system by increasing the number of lymphocytes and the total leukocytic count, as well as phagocytic activity. Because leucocytes are crucial for either innate or nonspecific immunity, and because their number might be interpreted as a sign of comparatively reduced disease susceptibility and mortality, the phagocytic index indicated a stronger innate immune response and higher resistance. However, Martínez *et al*. (2010) found that growing rabbits fed a ration that replaced dried entire maize plants for alfalfa hay at full maturation stages had a higher mortality rate (29%) than the control group (25%).

In our results, data showed that groups fed diets containing wheat straw with enzymes had higher total bacterial count and total volatile fatty acid values than other treated groups and the control, while groups fed the same diets with probiotics had the lowest values in terms of the total bacterial count per g and total volatile fatty acid values of the cecal content. These results are in line with those of Oso *et al*. (2013) who found that the lowest ($P<0.05$) caecal concentration of total volatile fatty acids (VFA) was reported in rabbits fed diets containing probiotics (Pediococcus acidilactici, *Bacillus cereus*). It is possible that the increased influence of multiple enzymes on the proliferation of microflora in the gut and caecum, which in turn increases the generation of volatile fatty acids and the digestibility of organic matter, is the cause of the improvement in cecal activity in enzyme-supplemented groups (Abd El-Latif*et al*., 2008). Conversely, Zduńczyk *et al*. (2011) found that the caecal ammonia concentration was significantly greater in rabbits fed probiotic-containing diets than in control rabbits. Additionally, when growing rabbits were fed graded amounts of cucumber vine straw instead of clover hay with enzyme supplementation, Abo-Egla *et al*. (2013) found no appreciable changes in the concentrations of ammonia-N (NH_3-N) or cecal pH. Furthermore, growing rabbits fed a diet supplemented with prebiotics and 100% phaseolus vulgaris straw rather than clover hay showed a significant decrease in caecal ammonia content, although TVFA concentrations remained same (Elgohary and Abo El-Maaty, 2014).

Growing rabbits fed diets that contained 500 or 100% berseem hay fiber substituted with wheat straw fiber supplemented with probiotics or enzymes showed a significant ($P<0.05$) increase in the experimental diets' digestibility coefficients (DM, CP, CF, NFE, and ash) and feeding values (DCP & TDN). In contrast, groups that were fed identical diets devoid of additives recorded values that were almost identical to the control. Similar findings were reported by Abaza and Omara (2011) who found that when corn cobs were substituted for berseem hay at 10% and 20% with kemzyme supplementation, the digestibility values for DM, OM, CP, CF, EE, and NFE as well as the nutritional values of the diets (TDN and DCP) were significantly ($P<0.05$) higher than those of rabbits fed diets devoid of enzymes. Additionally, Abo El-Maaty*et al*. (2018) found that the digestibility coefficients of DM, OM, CP, CF, and EE and feeding values of the diets (TDN and DCP) were considerably increased when growing rabbits were fed diets containing dried Sugar Beet Tops (SBT) with prebiotic in place of dietary alfalfa hay. Since monogastric animal diets suffer from underutilization of nutrients due to the absence of enzymes necessary for hydrolyzing non-starch polysaccharides in the foregut, the addition of multiple enzyme products, which contain protease, α-amylase, xylanases, glucannase, and cellulase, may be the reason for the improvement in nutrient digestibility (Elghandour *et al*., 2020; Helal *et al*., 2021). Furthermore, probiotic bacteria have a positive impact on the growth and function of the gastrointestinal organs and aid animals in digesting diets that contain indigestible ingredients like roughages. They also raise the digestion coefficient and feeding values of the diets (Omer *et al*., 2019). On the other hand, Abd El-Hakim *et al*. (2006) found that rabbits fed diets that contained 35% rice straw that had been biologically treated with bacteria rather than clover hay showed the lowest levels of TDN & DCP and digestibility coefficient of nutrients. However, Abo-Egla *et al*. (2013) observed that feeding developing rabbits varying amounts of cucumber vine straw rather than 25, 50, 75, and 100 clover hay with MOS or NZ supplementation had no discernible effects on the feeding parameters and nutritional digestibility. According to Elgohary and Abo El-Maaty (2014); Omer *et al*. (2018), the apparent nutrient digestibility and nutritional values of the experimental diets (TDN and DCP) were unaffected by the 100% substitution of phaseolus vulgaris straw for clover hay.

According to the results of the economical evaluation, using wheat straw fiber instead of 50 or 100 % berseem hay fiber, either with or without probiotics or enzyme supplements, is advantageous for expanding rabbit diets. It might also be a useful tool for developing the least expensive ration formula in rabbit production. These results are consistent with the findings of Hemid *et al*. (2013); Omer and Badr (2013); Abo EL-Maaty *et al*. (2014) who found that replacing clover hay with canola straw, pea straw, or cucumber vines straw decreased overall feed costs, enhanced net revenue, and raised relative economical feed efficiency compared to control. Conversely, Sherif *et al*. (2010) observed that all rabbit groups fed diets with four levels of parsley and caraway straw mixtures instead of 25, 50, 75, or 100% alfalfa hay in the basal diet did not significantly differ in economic efficiency values. The productivity of a flock can be determined by an economic production evaluation. Feed is a significant input that contributes ~70%–80% of the total cost of rearing rabbits. In addition, employing feed additives such as enzymes and probiotics is an affordable technique to enhance the nutritional value of novel non-conventional feed ingredients and improve the growth performance and immune function of rabbits. Improving the efficiency of low-quality products and reducing nutrient loss through the utilization of Enzymes and probiotics might have a substantial impact on the productivity of poultry and animals, with potential economic benefits (Alderey *et al*., 2024).

Conclusion

It is cost-effective to replace 50 or 100% of the fiber in berseem hay with wheat straw fiber, either without or with probiotics or enzyme supplements, and the feed additives will enhance the growth performance metrics for growing New Zealand White rabbits.

Conflict of interest

The authors have no conflict of interest to declare.

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