Received: 12 September 2023, Accepted: 13 October 2023

Original Research

Journal of Advanced Veterinary Research
(2023) Volume 13, Issue 9, 1753-1760

# Growth Performance and Health Responses of Growing New Zealand White Rabbits Fed Different Levels of Dietary Synbiotic Supply

Amr A. Gabr[1*], Eman H. Maklad[1], Mona A. Ragab[2], Bassant K. Hegazya[1]

[1]Department of Animal Production, Faculty of Agriculture, Mansoura University, Mansoura 35516, Egypt.

[2]Animal Production Research Institute, Agricultural Research Center, Giza 12618, Egypt.

***Correspondence**
Corresponding author: Amr A. Gabr
E-mail address: dr.amrgabr@mans.edu.eg

## Abstract

Countering the antibiotics excessive use by the exploitation of promising immunostimulants alternatives is a trending strategy in modern animal husbandry. This research assessed the impact of novel dietary symbiotic supply at different levels on growing rabbits' performance. Forty-five New Zealand White rabbits (aged seven weeks, weighing 1075±9.78 g) were randomly allotted to five groups. Rabbits were fed the basal diet as control and the other groups supplemented with synbiotic (*Saccharomyces cerevisiae* along with β-glucan and mannan-oligosaccharide) at an inclusion level of 0.5, 1.0, 1.5, and 2.0 g/kg diet for 6 weeks. Results indicated that synbiotic addition increased the feed intake ($p=0.01$), enhanced the growth performance and feed conversion ratio (linear, $p\leq0.001$; quadratic, $p\leq0.002$) with the 0.5 g/kg diet level being the most effective. The synbiotic supply increased the serum total protein and albumin (quadratic, $p\leq0.024$) as well as lipase and amylase (linear, $p<0.001$; quadratic, $p=0.001$), while decreased alanine-aminotransferase, urea, triglycerides, and glucose (quadratic, $p\leq0.023$) as well as cortisol (linear, $p<0.001$; quadratic, $p\leq0.001$). The concentrations of immunoglobulin-G, immunoglobulin-M, red blood cells, hemoglobin, hematocrit, and platelet count increased (linear, $p\leq0.001$) and white blood cells decreased (linear, $p<0.001$) by the synbiotic inclusion. The hot carcass weight and the percentages of dressing, and carcass cuts were increased (quadratic, $p\leq0.02$) in which the 0.5 g/kg diet level was better. Taken together, the current dietary synbiotic supplementation of 0.5 g/kg diet could pave the way for promoting the rabbits' growth and health status, thus, it is advisable to utilize these findings in the husbandry of rabbits under commercial production conditions.

KEYWORDS
Synbiotic, growth performance, serum metabolites, carcass traits, New Zealand White rabbits.

## INTRODUCTION

To preserve human health, it was necessary to counter the excessive use of antibiotics in animal husbandry. Farm animals face many challenges during the different production stages that may negatively affect the animal health and consequently the productivity. Therefore, to replace or minimize the use of antibiotics, the exploitation of promising immunostimulants alternatives is required to provide animal safety, promote the production, and produce safe products. Generally, the rearing of farm animals without using antibiotics is a trending strategy in modern animal husbandry (Kango *et al*., 2022). This kind of strategy is built upon supplying animals with non-antibiotic feed additives like probiotic, prebiotic, and synbiotic.

Probiotics have gained recognition as effective alternatives to antibiotics or antimicrobial agents in animal health and production (Bhogoju and Nahashon, 2022). Among various yeast species, *Saccharomyces cerevisiae* (*S. cerevisiae*) has been extensively used as a probiotic supplement in animal production due to its abundant content of proteins, polysaccharides, small peptides, amino acids, vitamins, trace elements, nucleotides, and other growth factors (Pang *et al*., 2022). Therefore, it has been reported to improve animal production performance, enhance immune function, regulate intestinal flora balance, promote intestinal development, and improve meat quality (Bin *et al*., 2019; Elghandour *et al*., 2020).

Prebiotics, on the other hand, consist of indigestible carbohydrates that can be fed to animals to modulate the balance and activities of microbial populations in the gut (Lao *et al*., 2020). Mannan-oligosaccharide (MOS) and β-glucan are prebiotics derived from the cell wall of the *S. cerevisiae* yeast. These emerging feed additives have demonstrated biological functions in promoting the development of the animal gastrointestinal tract, regulating intestinal flora, improving animal immunity, enhancing feeding, and boosting growth performance (Chen *et al*., 2021; Kango *et al*., 2022; Xie *et al*., 2018).

Synbiotics refer to a combination of carefully selected probiotics and prebiotics, aiming to promote the growth of probiotics by providing specific nutrients for fermentation in the gastrointestinal tract (Dankowiakowska *et al*., 2019). These combinations offer advantages to the host by improving the survival and presence of beneficial microbial supplements in the gastrointestinal tract (Elliethy *et al*., 2022). It is crucial to note that an appropriate blend of probiotics and prebiotics can yield superior benefits compared to using either prebiotics or probiotics alone (Lao *et al*., 2020).

Among farm animals, rabbits are known for their ability to produce meat at a relatively low cost of feed and husbandry.


ISSN: 2090-6277/2090-6269/ 

Rabbit meat is considered a functional food due to its high digestibility, essential amino acids, unsaturated fatty acids, phosphorus, and calcium content. Additionally, it contains lower levels of fat, cholesterol, and sodium compared to traditional red meat (Ma *et al*., 2022). These nutritional qualities make rabbit meat popular globally (Krunt *et al*., 2022). The gut microbiota of rabbits plays a vital role in maintaining their health and facilitating digestion. Therefore, managing this microbiota is crucial, as a balanced gut microbiota contributes to rabbit performance and well-being. However, rabbits have a high susceptibility to pathogenic microflora, posing a significant biological risk to their husbandry (Kurchaeva *et al*., 2020). Furthermore, rabbits lack the ability to produce cellulolytic enzymes independently and heavily rely on gut bacteria for the digestion and utilization of dietary fiber (Liu *et al*., 2022). Therfore, the combination of probiotics and prebiotics holds great potential in rabbit production. It can enhance feed efficiency, growth performance, and overall health by promoting competitive exclusion of harmful microorganisms and exhibiting antimicrobial properties.

Although there are many previous studies on the effects of *S. cerevisiae*, β-glucan, and MOS individually on rabbits and other farm animals, there are limited information regarding the possible combination effects of these supplements in rabbits. Therefore, this study was conducted to estimate the effects of dietary synbiotic supplementation containing the commercially available probiotic of *S. cerevisiae* and prebiotics of β-glucan and MOS on the growth performance, blood parameters, and carcass characteristics of the growing New Zealand White rabbits.

## MATERIALS AND METHODS

*Animal diet and management*

The experiment took place at a governmental station located in El-Serw, Agriculture Research Center, Ministry of Agriculture, Egypt. The study adhered to the stated ethics and animal rights guidelines (DRC) in accordance with the European Union Directive Regulations (2010/63/EU) for the protection of animals used in scientific and experimental purposes. Approval for the research was obtained from the Scientific Research Ethics Committee at the Faculty of Agricultural, Mansoura University, Egypt.

Forty-five New Zealand White male rabbits (aged seven weeks, weighing 1075±9.78 g) were used in the study and randomly allotted to five similar groups (9 rabbits/group). Rabbits were housed in galvanized wire batteries with standard dimensions (50x45x40 cm) throughout the experimental period of 6 weeks. All cages were supplied with galvanized steel automatic drinkers (nipples) and feeding hoppers. Before the beginning of the experiment, the rabbits were adapted to the basal diet for 2 weeks. The basal diet was formulated following the NRC (1977) (Table 1). The rabbits were fed basal diet as control group and the four treated groups received the basal diet supplemented with synbiotic at an inclusion level of 0.5, 1.0, 1.5, and 2.0 g/kg of the diet. Synbiotic levels were selected based on company recommendations (IRIS by EVICO, Egyptian veterinary industry company, Egypt) and it contained a unique and balanced mix of 70% *Saccharomyces cerevisiae* (dry yeast of $10^8$ CFU/g) along with 15% β-glucan and 15% mannan-oligosaccharide. The synbiotic powder was individually mixed at different levels in 1 kg of the basal diet. The mixed diets were then added to the required amount of feed for the experimental period and pelleted to a size of 3.5 mm. Rabbit cages were regularly cleaned and disinfected, and urine and feces were removed daily.

Table 1. Ingredients and nutritional composition of basal diet.

| Ingredient | Percentage (%) |
|---|---|
| Alfalfa hay | 31.4 |
| Wheat bran | 27 |
| Barley grain | 24.2 |
| Soybean meal (44% crude protien) | 12.25 |
| Molasses | 2 |
| Dicalcium phosphate | 1.6 |
| Limestone | 0.95 |
| Sodium chloride | 0.3 |
| Mineral-vitamin premix* | 0.3 |
| Determined nutrient composition | |
| Dry matter | 86.76 |
| On dry matter basis; | |
| Organic matter | 92.23 |
| Crude protein | 18.48 |
| Crude fat | 15.26 |
| Ether extract | 2.53 |
| Nitrogen-free extract | 55.96 |
| Ash | 7.77 |
| Digestible energy, kcal/kg | 2416 |
| Metabolizable energy, kcal/kg | 2219 |
| Calcium | 1.2 |
| Phosphorus | 0.76 |
| Lysine | 0.84 |

*Contains (unit/ kg diet): Vitamin A, 150,000 UI; Vitamin K3, 21 mg; Vitamin E, 100 mg; Vitamin B1, 10 mg; Vitamin B2, 40 mg; Vitamin B6, 15 mg; Vitamin B12, 0.1 mg; Niacin, 200 mg; Pantothenic acid, 100 mg; Choline chloride, 500 mg; Folic acid, 10 mg; Biotin, 0.5 mg; Mn, 600 mg; Zn, 450 mg; Fe, 0.3 mg; Cu, 50 mg; Se, 1 mg and Co, 2 mg.

*Feed intakes and growth performance*

Feed intakes and growth performance were monitored throughout the experiment. The pelleted ration was weighed and offered to the rabbits twice daily at 8:00 and 14:00 h. Clean water was continuously available through the nipples. Feed refusals were collected and weighed daily to measure feed consumption. The rabbits' body weights were recorded at the beginning of the experiment and once a week thereafter before the morning feeding. Feed allowance was adjusted based on changes in body weight to calculate feed efficiency. Average daily gain, total body weight gain, average daily feed intake, and feed conversion ratio (g feed/g weight) were calculated.

*Blood sampling and serum biochemical analysis*

At the end of the experiment (13 weeks of age), blood samples were collected from the rabbits' marginal ear vein after a 12-hour fasting period. Two blood samples were taken: the first sample (10 mL) contained an anticoagulant and was used for hematological analysis, including white blood cell count, red blood cell count, hemoglobin, hematocrit, platelet count, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), lymphocytes, and neutrophils concentration (hematology analyzer D-cell 60, Diagon Ltd., Hungary). The second blood sample (10 mL) was clotted at room temperature for 20 minutes, centrifuged at 3000 rpm for 15 minutes to separate the serum, and stored at -20°C for subsequent analysis. Serum biochemical analysis was performed to measure total protein, albumin, alanine aminotransferase (ALT), aspartate aminotransferase (AST), urea, creatinine, triglycerides, cholesterol, high-density lipoprotein (HDL),

low-density lipoprotein (LDL), glucose, lipase, and amylase using commercial test kits (Spectrum Diagnostics, Egypt) and a spectrophotometer (CHEM 7, ERBA, Mannheim, Germany). Globulin was calculated by subtracting values of serum albumin from total proteins. By using commercial quantitative ELISA kits (CUSABIO Biotech, Wuhan, China), serum cortisol, immunoglobulin-G (IgG) and immunoglobulin-M (IgM) concentrations were analysed.

*Carcass characteristics*

At the end of the experimental period, the rabbits were fasted for 12 hours, individually weighed, and then slaughtered. The carcass was eviscerated after removing the skin and giblets, and the weights of these components were measured. All carcass values were expressed as percentages relative to the pre-slaughter body weight. The dressing percentage was calculated as follows: "Dressing % = (hot carcass weight/pre-slaughter weight)x 100". The carcass was divided into three cuts: (1) forequarter, including thoracic insertion muscles; (2) loin, including the abdominal wall and ribs after the 7th thoracic rib; and (3) hindquarter, including the sacral bone and lumbar vertebrae after the 6th lumbar vertebra.

*Statistical analysis*

The data were analyzed with one-way analysis of variance (ANOVA) with the treatment as a constant factor using the following model: $Yij = \mu + Si + Eij$ where $\mu$ is the overall mean, Si is the experimental dietary supplementation effect, and Eij is the random error. Linear and quadratic responses to the level of synbiotic supplementation were tested for each variable. All analyses were conducted by using SAS version 9.3 (SAS Institute Inc. Cary, NC, USA). Each rabbit was regarded as the experimental unit. For each value, the least square means and their standard error are displayed. An integrated Tukey's test was used to evaluate differences between groups and statistical differences were considered significant when the p-value was less than 5%.

## RESULTS

*Effect on growth performance*

The synbiotic supplementation in the rabbits' diet influenced ($p<0.001$) the growth performance and feed conversion ratio and increased ($p=0.01$) the daily feed intake (Table 2). The final body weight, total weight gain, and average daily gain linearly increased ($p=0.001$) and changed quadratically ($p=0.002$) as responses to synbiotic level in the diet. Increasing synbiotic level linearly increased ($p<0.001$) the daily feed intake, without differences among the synbiotic supplemented groups. The feed conversion ratio linearly decreased ($p<0.001$) then quadratically increased ($p<0.001$) with the increasing level of synbiotic in the diet. Rabbits fed the lowest synbiotic level (0.5 g/kg diet) showed the highest growth performance and the lowest feed conversion ratio. However, the synbiotic level of 0.5 g/kg diet enhanced ($p<0.001$) the average daily gain, final body weight, total weight gain, and feed conversion ratio by about 9.4%, 5.2%, 9.6%, and 7.6%, respectively, in comparison with those in the control group. No differences were detected for studied growth performance traits and feed conversion ratio between 1.0 g/kg diet synbiotic supplemented group and control group. The synbiotic supplementation at the levels of 1.5 and 2.0 g/kg diet impaired ($p<0.001$) the rabbits' final body weight, total weight gain, and feed conversion ratio compared to other groups.

*Effect on blood and serum parameters*

The serum biochemical variables of growing rabbits were affected ($p\leq0.01$) by synbiotic supplementation in the diet, except for globulin, alanine aminotransferase, and creatinine (Table 3). The serum concentrations of total protein, albumin, alanine aminotransferase, urea, triglycerides, HDL, LDL, and glucose quadratically responded ($p\leq0.02$) to the increasing level of synbiotic in the diet. The aspartate aminotransferase concentration linearly decreased ($p<0.001$) by increasing the synbiotic level in the diet. With quadratic responses ($p\leq0.001$) to the synbiotic level in the diet, the lipase and amylase concentrations were linearly increased ($p<0.001$) and cortisol linearly decreased ($p<0.001$). The synbiotic level of 0.5 g/kg diet showed the most effective biochemical variables response ($p<0.001$) compared with control group, followed by level of 1.0 g/kg diet group. No differences were observed between the higher doses of supplementation (1.5 and 2.0 g/kg diet) but both groups obtained lower ($p<0.001$) concentrations of aspartate aminotransferase and cortisol, and higher ($p<0.001$) amylase and lipase values compared with control group.

The blood hematological parameters of growing rabbits were affected ($p\leq0.002$) by synbiotic supplementation in the diet, except for platelet count, MCV, MCH, lymphocytes and neutrophils (Table 4). The concentrations of IgG, IgM, red blood cells, hemoglobin, hematocrit and platelet count were linearly increased ($p\leq0.001$) while the white blood cells linearly decreased ($p<0.001$) by increasing the synbiotic level in the diet. However, the synbiotic supplementation level of 0.5 g/kg diet showed no differences for all studied hematological parameters compared with control group. The 1.0 g/kg diet of synbiotic supplement tended to do so as well but showed ($p<0.001$) higher IgG and lower white blood cells in comparison to control group. The highest synbiotic

Table 2. Effect of different synbiotic levels on growth performance, feed intake and feed conversion ratio of growing New Zealand White rabbits during the experimental period.

| | Synbiotic supplementation (g/kg diet) | | | | | SEM | *p* values | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 1.5 | 2 | | Synbiotic | L | Q |
| Initial body weight (g) | 1072 | 1077 | 1073 | 1080 | 1073 | 9.78 | 0.97 | 0.81 | 0.70 |
| Final body weight (g) | 2203 $^{b}$ | 2323 $^{a}$ | 2197 $^{b}$ | 2153 $^{c}$ | 2050 $^{d}$ | 7.99 | <0.001 | 0.00 | 0.00 |
| Total weight gain (g) | 1133 $^{b}$ | 1247 $^{a}$ | 1123 $^{b}$ | 1073 $^{c}$ | 977 $^{d}$ | 4.59 | <0.001 | 0.00 | 0.00 |
| Average daily gain (g/day) | 26.9 $^{b}$ | 29.7 $^{a}$ | 26.7 $^{b}$ | 25.6 $^{b}$ | 23.3 $^{c}$ | 0.11 | <0.001 | 0.00 | 0.00 |
| Daily feed intake (g/day) | 76.9 $^{b}$ | 77.8 $^{a}$ | 78.0 $^{a}$ | 78.2 $^{a}$ | 78.7 $^{a}$ | 0.27 | 0.01 | <0.001 | 0.44 |
| Feed conversion (g feed/g gain) | 2.89 $^{c}$ | 2.67 $^{d}$ | 2.89 $^{c}$ | 3.02 $^{b}$ | 3.29 $^{a}$ | 0.02 | <0.001 | <0.001 | <0.001 |

$^{a, b, c, d}$ Within a row, values with different superscript letters mean there were significant differences ($p<0.05$).

supplementary dose (2.0 g/kg diet) observed the best values of IgG, IgM, and hematological parameters without differences with the 1.5 g/kg diet group.

*Effect on carcass characteristics*

The effect of synbiotic supplementation ($p<0.001$) on the pre-slaughter and hot carcass weights as well as the percentages of dressing, forequarter, loin and hindquarter was obtained (Table 5). The hot carcass weight and the percentages of dressing, forequarter, loin and hindquarter quadratically responded ($p=0.007$, 0.016, 0.003, 0.002, and 0.018, respectively) to the increasing level of synbiotic supplementation. The rabbits fed 0.5 g synbiotic/kg diet showed the highest ($p<0.001$) hot carcass weight and percentages of dressing, forequarter, loin and hindquarter, followed by the 1.0 g/kg diet group. The percentages of all studied carcass traits of rabbits that received synbiotic of 1.5 and 2.0 g/kg diet observed no differences compared to the control group. The synbiotic dietary supplementation at different levels did not affect the weight percentages of fure and internal organs compared to the control group.

## DISCUSSION

The current study was designed to estimate the impact of dietary synbiotic supply at different levels on growing rabbits. The growth performance traits and the feed conversion ratio of the current experiment rabbits were linearly ($p\leq0.001$) and quadratically ($p\leq0.002$) responded to the increasing level of synbiotic addition in the diet. The daily feed intake increased by synbiotic supplementation, without differences among the supplemented groups. However, the improvement in growth performance followed the same obtained trend with nutrient digestibility and

Table 3. Effect of different synbiotic levels on serum biochemical parameters of growing New Zealand White rabbits.

| | Synbiotic supplementation (g/kg diet) | | | | | SEM | *p* values | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 1.5 | 2 | | Synbiotic | L | Q |
| Serum protein (g/dL) | | | | | | | | | |
| Total protein | 5.80 $^{bc}$ | 7.10 $^{a}$ | 6.33 $^{b}$ | 5.90 $^{bc}$ | 5.67 $^{c}$ | 0.19 | <0.01 | 0.19 | 0.02 |
| Albumin | 3.23 $^{c}$ | 4.37 $^{a}$ | 3.70 $^{b}$ | 3.33 $^{c}$ | 3.23 $^{c}$ | 0.07 | <0.001 | 0.23 | 0.02 |
| Globulin | 2.57 | 2.73 | 2.63 | 2.57 | 2.43 | 0.14 | 0.67 | 0.32 | 0.27 |
| Albumin/Globulin | 1.26 $^{b}$ | 1.62 $^{a}$ | 1.41 $^{ab}$ | 1.30 $^{b}$ | 1.33 $^{b}$ | 0.07 | 0.03 | 0.56 | 0.14 |
| Liver enzymes (IU/L) | | | | | | | | | |
| ALT | 47.7 | 39.8 | 39.9 | 44.4 | 46.3 | 2.45 | 0.14 | 0.77 | 0.02 |
| AST | 57.9 $^{a}$ | 44.4 $^{b}$ | 47.7 $^{b}$ | 37.6 $^{c}$ | 38.3 $^{c}$ | 1.99 | <0.001 | <0.001 | 0.16 |
| Kidney function (mg/dL) | | | | | | | | | |
| Creatinine | 1.07 | 0.83 | 0.83 | 1.07 | 1.07 | 0.11 | 0.31 | 0.54 | 0.11 |
| Urea | 45.0 $^{a}$ | 30.0 $^{c}$ | 31.0 $^{c}$ | 38.7 $^{b}$ | 40.7 $^{ab}$ | 1.78 | 0.00 | 1 | 0.00 |
| Serum lipids (mg/dL) | | | | | | | | | |
| Triglycerides | 127 $^{a}$ | 87.3 $^{b}$ | 83.3 $^{b}$ | 117 $^{a}$ | 122 $^{a}$ | 3.21 | <0.001 | 0.62 | <0.001 |
| Cholesterol | 139 $^{a}$ | 111 $^{c}$ | 126 $^{b}$ | 134 $^{ab}$ | 132 $^{ab}$ | 3.87 | 0.00 | 0.68 | 0.08 |
| HDL | 30.7 $^{b}$ | 36.7 $^{a}$ | 39.0 $^{a}$ | 28.0 $^{b}$ | 30.0 $^{b}$ | 1.15 | <0.001 | 0.26 | 0.02 |
| LDL | 31.8 $^{a}$ | 21.8 $^{b}$ | 20.8 $^{b}$ | 29.2 $^{a}$ | 30.4 $^{a}$ | 0.8 | <0.001 | 0.62 | <0.001 |
| Glucose (mg/dL) | 99.7 $^{a}$ | 90.7 $^{b}$ | 93.0 $^{b}$ | 97.7 $^{a}$ | 98.7 $^{a}$ | 1.11 | 0.00 | 0.51 | 0.00 |
| Lipase (U/L) | 46.7 $^{c}$ | 83.0 $^{b}$ | 84.7 $^{b}$ | 95.0 $^{a}$ | 99.0 $^{a}$ | 2.42 | <0.001 | <0.001 | 0.00 |
| Amylase (U/L) | 76.0 $^{c}$ | 78.0 $^{c}$ | 85.0 $^{b}$ | 86.7 $^{b}$ | 122 $^{a}$ | 2.17 | <0.001 | <0.001 | 0.00 |
| Cortisol (pmol/ml) | 1.25 $^{a}$ | 0.88 $^{b}$ | 0.75 $^{c}$ | 0.59 $^{d}$ | 0.51 $^{d}$ | 0.03 | <0.001 | <0.001 | <0.001 |

$^{a, b, c, d}$ Within a row, values with different superscript letters mean there were significant differences ($p<0.05$).

Table 4. Effect of different synbiotic levels on the blood hematological and immunity parameters of growing New Zealand White rabbits.

| | Synbiotic supplementation (g/kg) diet | | | | | SEM | *p* values | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 1.5 | 2 | | Synbiotic | L | Q |
| Immunoglobulin G (mg/dl) | 37.6 $^{c}$ | 40.9 $^{c}$ | 48.0 $^{b}$ | 61.8 $^{a}$ | 63.2 $^{a}$ | 2.1 | <0.001 | <0.001 | 0.76 |
| Immunoglobulin M (mg/dl) | 32.1 $^{b}$ | 37.0 $^{b}$ | 35.1 $^{b}$ | 50.0 $^{a}$ | 51.7 $^{a}$ | 2.9 | 0.00 | <0.001 | 0.70 |
| White blood cell ($\times10^3$/µl) | 12.6 $^{a}$ | 11.6 $^{a}$ | 9.37 $^{b}$ | 8.83 $^{bc}$ | 7.43 $^{c}$ | 0.47 | <0.001 | <0.001 | 0.58 |
| Red blood cell ($\times10^6$/µl) | 5.25 $^{c}$ | 5.49 $^{c}$ | 5.56 $^{cb}$ | 5.85 $^{ab}$ | 6.15 $^{a}$ | 0.14 | 0.00 | <0.001 | 0.14 |
| Hemoglobin (g/dL) | 10.8 $^{b}$ | 11.3 $^{b}$ | 10.7 $^{b}$ | 11.9 $^{a}$ | 12.5 $^{a}$ | 0.2 | <0.001 | 0.00 | 0.08 |
| Hematocrit (%) | 33.0 $^{c}$ | 35.0 $^{bc}$ | 33.9 $^{bc}$ | 36.6 $^{ab}$ | 38.3 $^{a}$ | 0.61 | 0.00 | <0.001 | 0.26 |
| Platelet count ($\times10^3$/µl) | 321 $^{b}$ | 369 $^{ab}$ | 355 $^{ab}$ | 413 $^{a}$ | 418 $^{a}$ | 25.8 | 0.11 | 0.01 | 0.77 |
| Mean corpuscular volume (µm$^3$) | 63 | 62.9 | 62.8 | 61.8 | 62.2 | 0.86 | 0.83 | 0.30 | 0.62 |
| Mean corpuscular hemoglobin (pg/cell) | 20.5 | 20.2 | 20.4 | 20.7 | 20.9 | 0.38 | 0.77 | 0.27 | 0.65 |
| Lymphocytes (%) | 40.2 | 41.6 | 43 | 38.7 | 40.3 | 1.49 | 0.37 | 0.61 | 0.39 |
| Neutrophils (%) | 49 | 49.3 | 48.3 | 52 | 50.3 | 1.34 | 0.40 | 0.23 | 0.9 |

$^{a, b, c, d}$ Within a row, values with different superscript letters mean there were significant differences ($p<0.05$).

Table 5. Effect of different synbiotic levels on the carcass traits of growing New Zealand White rabbits.

| | Synbiotic supplementation (g/kg) diet | | | | | SEM | *p* values | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 1.5 | 2 | | Synbiotic | L | Q |
| Pre-slaughter weight (kg) | 2198 [b] | 2318 [a] | 2192 [b] | 2148 [c] | 2046 [d] | 3.57 | <0.001 | 0.00 | 0.00 |
| Hot carcass weight (kg) | 1208 [c] | 1392 [a] | 1242 [b] | 1182 [c] | 1107 [d] | 9.28 | <0.001 | 0.02 | 0.01 |
| Dressing (%) | 55.0 [c] | 60.0 [a] | 56.7 [b] | 55.0 [c] | 54.1 [c] | 0.38 | <0.001 | 0.09 | 0.02 |
| Forequarter (%) | 33.6 [c] | 34.3 [a] | 34.0 [b] | 33.7 [c] | 33.5 [c] | 0.16 | <0.001 | 0.28 | 0.00 |
| Loin (%) | 27.0 [c] | 27.8 [a] | 27.5 [b] | 27.2 [c] | 27.0 [c] | 0.17 | <0.001 | 0.35 | 0.00 |
| Hindquarter (%) | 38.6 [c] | 39.8 [a] | 39.3 [b] | 38.8 [c] | 38.8 [c] | 0.15 | <0.001 | 0.47 | 0.02 |
| Head (%) | 5.91 | 5.97 | 5.93 | 5.51 | 5.54 | 0.17 | 0.19 | 0.33 | 0.49 |
| Liver (%) | 3.18 | 3.16 | 3.19 | 2.95 | 3.01 | 0.12 | 0.49 | 0.13 | 0.81 |
| Kidney (%) | 0.8 | 0.78 | 0.78 | 0.76 | 0.78 | 0.02 | 0.68 | 0.23 | 0.50 |
| Heart (%) | 0.29 | 0.28 | 0.29 | 0.31 | 0.33 | 0.02 | 0.54 | 0.10 | 0.50 |

[a, b, c, d] Within a row, values with different superscript letters mean there were significant differences ($p<0.05$).

feeding values, the rabbits fed the lowest synbiotic level (0.5 g/kg diet) showed the highest growth performance and the lowest feed conversion ratio. Regardless of the increased daily feed intake, the growth performance and feed conversion ratio were not differed between the 1.0 g/kg diet synbiotic supplemented group and control group, further they were negatively affected by higher levels of supplementation.

Rabbits as monogastric animals cannot hydrolyze synbitics by the endogenous digestive enzymes in the small intestine, but they are hydrolyzed within the caecum by the beneficial bacterial populations or probiotics, and in turn confer synbiotic beneficial effects to the rabbit. In accordance, current positive findings may be related to the digestive environment generated in the rabbits' large intestine and could be stated that the 0.5 g/kg diet of the current experiment synbiotic is effective for enhancing intestinal function by maintaining an optimum gastrointestinal environment, thus improving nutrient digestibility and utilization.

Noteworthily, multiple research studies examining the microbiota of rabbits' gastrointestinal tracts have observed changes in the populations of microorganisms when probiotics are introduced, as noted in the review by Mancini and Paci (2021). Moreover, the yeast *S. cerevisiae* has the ability to lower the pH of the intestines by secreting organic acids like acetic and lactic acid (Elghandour *et al*., 2020), creating a more favorable environment for the existing gut microbiota. Additionally, probiotics can stimulate the synthesis of vitamins in the host by providing an additional source of nutrients (Markowiak and Slizewska, 2018). It is worth mentioning that probiotics may also produce enzymes that break down or release nutrients in the gastrointestinal tract (Bhogoju and Nahashon, 2022), and metabolized probiotic cells could contribute to the absorbed nutrition (Mancini and Paci, 2021). Furthermore, Jana *et al*. (2021) reviewed the use of various prebiotic oligosaccharides, including MOS, to modulate the gut microflora with the goal of enriching probiotic populations. Therefore, synbiotics can influence the community of gastrointestinal microbiota in favor of beneficial microorganisms in the intestines and cecum, while also providing specific active molecules that enhance feed digestion and nutrient absorption (Hashem *et al*., 2021).

However, previous findings regarding probiotic and prebiotic effects on rabbits' nutrient digestibility are inconsistent. For instance, El-Badawi *et al*. (2017) found that the nutrient digestibility of dry matter, crude protein, organic matter, and nitrogen-free extract were enhanced in rabbits fed 0.1% of *S. cerevisiae* and 0.1% of Bacillus subtilis, while their mix (0.05% of each probiotic) was similar to the control group. Conversely, all nutrient digestibility of growing rabbits, except for crud fiber, were not affected by dietary supplementation with 0.5, 1.0, and 2.0% *S. cerevisiae* compared with control group (Tag El Din, 2019). Moreover, the MOS addition with 0.5, 1.0 and 1.5 g/kg diet showed no differences in rabbits' nutrient digestibility (Tag El Din, 2020).

The result of prior studies on *S. cerevisiae*, MOS, and β-glucan dietary inclusion as individual or synbiotic did not always show improvement in all the rabbits' performance indices. In this regard, as reviewed by Elghandour *et al*. (2020), Jana *et al*. (2021), Mancini and Paci (2021), and Kango *et al*. (2022), the dietary supply with prebiotics and/or probiotics reported to enhance the growth performance, feed conversion and digestion coefficients, while lack of effects were also observed.

However, in agreement with current findings, positive results were obtained on growth performance of rabbits fed diets supplemented with current synbiotic components. For example, the dietary supplementation of *S. cerevisiae* (at rate 0.12 g/kg ration) accelerated rabbits' growth performance, increased feed intake and reduced feed conversion (Abd El-Aziz *et al*., 2021). Similarly, the growth performance and feed conversion of rabbits supplemented with 0.1% *S. cerevisiae* were improved than control group (El-Badawi *et al*., 2017). Although Kalma *et al*. (2018) revealed no effects on the rabbits' feed intake and feed conversion, the growth performance was enhanced by probiotics mix supplementation (0.5 g/kg feed of *S. cerevisiae* and L. sporogenes). Similar conclusion noticed for the basal diet augmented with β-glucan at rate of 0.5, 1.0, 1.5, and 2.0 g/kg diet, the rabbits' growth performance was linearly improved without any effects on feed intake and feed conversion compared to control group, however, the β-glucan at 1 g/kg diet showed the best growth performance (Gabr, 2021). Moreover, Ma *et al*. (2022) revealed increases in growth performance and daily feed intake when rabbits fed oat β-glucan (200 mg/kg body weight). The β-glucan at doses 0.25 and 0.5 ml/L of drinking water as oral administration, accelerated rabbits' growth performance, reduced feed intake, and feed conversion ratio, specifically the dose of 0.5 ml/L water (Abo Ghanima *et al*., 2020). Regarding dietary MOS supplementation, the rabbits' growth performance, feed intake, and feed conversion were enhanced by MOS addition with 0.5, 0.75, and 1.0 g/kg diet, the best results were obtained for the level of 1.0 g/kg diet (Mansour, 2020). On the other hand, New Zealand White rabbits fed 0.3% MOS supplemented diet observed higher final body weight and feed consumption, while showed no differences in the feed conversion (Abd El-Aziz *et al*., 2022).

On the contrary to present results, the rabbits' growth performance, daily feed intake and feed conversion were not affected by *S. cerevisiae* with the supplementation of 0.12 g/kg diet (Emmanuel *et al*., 2019). Similar no improvements in final body weight, average daily gain, and feed intake were observed for rabbits supplemented with 0.5, 1.0, and 2.0% *S. cerevisiae* in the diets (Tag El Din, 2019). The previous author, in agreement with current study findings, reported that the feed conversion ratio was reduced by the lowest level of *S. cerevisiae* supplementation (0.5%) than the 1% *S. cerevisiae* level which showed no difference with control group (Tag El Din, 2019). Moreover, the MOS addition with 0.5, 1.0 and 1.5 g/kg diet showed no differences in rabbits' growth performance, daily feed intake, and feed conversion

with control group (Tag El Din, 2020).

Previous studies conducted using synbiotics containing one or more of current components stated the improvement of rabbits' growth performance but with varied effects on feed intake or feed conversion ratio. For example, El-Deeb *et al*. (2023) found that rabbits fed 0.5, 0.75 and 1.0 g/Kg diet of synbiotic (contains β-glucan and mannan-oligosaccharide with Bacillus subtilis), the dose of 1.0 g/kg diet increased the growth performance and feed intake without effect on the feed conversion ratio. Similar results obtained by supplying rabbits with a dose 0.5 g/kg diets of synbiotic contains mannan-oligosaccharide and probiotic mix of *S. cerevisiae*, lactobacillus acidophilus, streptococcus facecium, and lactic corrosive microorganisms (Abo El-Maaty *et al*., 2018). However, enhancing of growth performance and feed conversion with no effect on feed intake was reported by supplying rabbits with encapsulated synbiotic ($11x10^{11}$ CFU of *S. cerevisiae* and 0.15 g Moringa oleifera leaf extract/kg diet) (Hashem *et al*., 2021).

There were many linear effects ($p<0.001$) of current synbiotic supplementation levels on serum biochemical parameters and some quadratic effects ($p\leq0.02$) as well, while the affected blood hematological parameters showed linear ($p\leq0.001$) responses only. However, the synbiotic supply at dose of 0.5 g/kg diet showed positive effects on the most of serum biochemical variables without any differences for all studied hematological parameters in comparison with control group, followed by 1.0 g/kg diet supplemented group. Interestingly, regardless of the reduction effect obtained by the higher doses of synbiotic addition (1.5 and 2.0 g/kg diet) on the rabbits' growth performance and feed conversion, both groups showed normal physiological values of the blood and serum parameters. Furthermore, both groups in comparison with the other groups obtained positive responses ($p<0.001$) of aspartate aminotransferase, cortisol, amylase, and lipase concentrations, as well as they revealed pronounced responses ($p<0.001$) of IgG, IgM, and all hematological parameters. However, the lack effect obtained by the high levels of the synbiotic addition (1.5 and 2.0 g/kg diet) on the rabbits' nutrient digestibility and its positive effect on the blood hematological and immune parameters may indicate that these levels did not negatively affect the intestine absorption efficiency, but they could affect the gastrointestinal environment or the gut microbiota.

Generally, as observed in previous studies the effectiveness of dietary probiotics, prebiotics, and synbiotics inclusions on rabbits' biochemical and hematological parameters are variable. Some researchers showed no effects of probiotics on rabbits' blood biochemical and hematological parameters, while a significant increase or decrease of some blood parameters was also obtained as reviewed by Mancini and Paci (2021). However, Bhogoju and Nahashon (2022) verified that probiotics have numerous anticipated modes of action, some of these mechanisms are related to the enteric pathogenic microbe inhibition. Moreover, Paës *et al*. (2020) clarified that prebiotics contribute to digestive health preservation by serving as fermentable substrates for gut bacteria, preventing pathogen implantation, functioning as anti-adhesives, and stimulating immune maturation.

The present results are partially in agreement with previous studies obtained by individual supplying of rabbits' diet with *S. cerevisiae*, β-glucan, and MOS. Supplementing rabbits' diet with *S. cerevisiae* (at rate 0.12 g/kg diet) decreased the blood cholesterol and total glycerides while increased blood total protein, albumin and albumin/globulin ratio (Abd El-Aziz *et al*., 2021). On contrary, no differences were observed in total protein, albumin, globulin, albumin/globulin ratio, glucose and triglycerides levels among the groups by supplementing rabbits' diet with probiotic mix (0.5 and 1.0 g/kg diet of *S. cerevisiae* and L. sporogenes), while cholesterol level was reduced (Kalma *et al*., 2018). On the other hand, the MOS addition at all levels of 0.5, 0.75, and 1.0 g/kg diet reduced rabbits' serum concentrations of glucose, triglycerides, LDL, AST, ALT, and creatinine compared to control group (Mansour, 2020). Moreover, decreases in white blood cells, AST, ALT, urea, and cholesterol concentrations and increases in glucose were recorded when rabbits treated with MOS (35 mg/kg body weight), without differences in the total protein, triglycerides, and other blood hematological parameters (Hassan *et al*., 2022). Regarding the β-glucan supplementation in rabbits' diet, the dose of 10 mg/kg body weight of β-glucan caused increases in total protein, globulin, white blood cells, lymphocytes and monocytes percentages, while no effects were obtained on albumin and albumin/globulin ratio (Alkenany and Khalil, 2022). Moreover, rabbits supplemented with β-glucan at 0.5, 1.0, 1.5, and 2.0 g/kg diet revealed at all levels decreases in glucose, triglycerides, and total cholesterol concentrations, while no differences in serum total protein, albumin, globulin, urea and creatinine were obtained (Gabr, 2021). Administrating rabbits with β-glucan at a dose 0.5 ml/L drinking water increased blood total protein and globulin concentrations, while creatinine and urea values were not changed in comparison to control (Abo Ghanima *et al*., 2020). However, rabbits fed diet with β-glucan (500 mg/day) showed no differences in total protein, albumin/globulin ratio, creatinine, urea, hemoglobin, and hematocrit values (Santurio *et al*., 2020).

Several studies have confirmed positive effects of synbiotics on some variable blood parameters. However, the different results they clarified may be probably regarded to different synbiotics types, doses, and thus mechanisms of action. El-Deeb *et al*. (2023) reported that supplementing rabbits with 0.5, 0.75 and 1.0 g/Kg diet of synbiotic (β-glucan and mannan-oligosaccharide with Bacillus subtilis), the dose 1.0 g/kg diet decreased the concentrations of lymphocytes, cholesterol, and AST, and increased hemoglobin and triglycerides when compared with control group. Synbiotic consisted of *S. cerevisiae* and 0.15 g Moringa oleifera leaf extract boosted the immunity of growing rabbits (Hashem *et al*., 2021). Rabbits supplemented with synbiotic consisted of 1.0 g mann-oligosacchride plus 0.4 g probiotics (Bacillus subtilis and Bacillus licheniformis) showed no changes in albumin, ALT, AST, creatinine and urea, but increased the total protein and globulins concentrations, while albumin/globulin ratio, glucose, triglycerides and cholesterol were decreased in all treated rabbit groups when compared with control group (Abdelhady and El-Abasy, 2015). Moreover, previous mentioned synbiotic revealed no changes in red blood cells count, hemoglobin concentration, MCV, and MCH (Abdelhady and El-Abasy, 2015). The increased concentrations of rabbits' total protein, globulin, and HDL and decreased triglycerides were obtained as a response to 0.5 g synbiotic/kg diet (mannan-oligosaccharide and probiotic mix of *S. cerevisiae*, lactobacillus acidophilus, streptococcus facecium, and lactic corrosive microbes), while no differences were observed for albumin, albumin/globulin ratio, total cholesterol, and LDL concentrations (Abo El-Maaty *et al*., 2018).

Generally, the current obtained positive effects of synbiotic supplementation on the rabbits' growth performance, biochemical parameters and immunity indicate the opportunity of using the experiment synbiotic as growth promoter and antibiotic alternative. These positive effects of synbiotics could be mostly related to the prevalence of beneficial intestinal and cecal microorganisms as concluded by Hashem *et al*. (2021).

The synbiotic supplementation of present study quadratically affected ($p\leq0.02$) the rabbits' pre-slaughter and hot carcass weights as well as the percentages of dressing, forequarter, loin and hindquarter without affecting the percentages of the internal organs. As expected, the rabbits fed 0.5 g/kg diet of synbiotic showed the highest ($p<0.001$) hot carcass weight and percentages of dressing, and carcass three cuts, followed by the 1.0 g/kg diet group. However, regardless the obtained reduction in pre-slaughter and hot carcass weights by the synbiotic addition at 1.5 and 2.0 g/kg diet, both groups observed no differences for all studied carcass traits as percentages compared to those of control group.

The present findings are partially comparable to the results reported by El-Sawy *et al*. (2021), who found that supplementing rabbits with *S. cerevisiae* (0.4 g/kg diet) increased the hot carcass weight and carcass percentage compared to the control group. However, other studies using *S. cerevisiae*, such as those conduct-

ed by El-Badawi *et al*. (2017) and Abd El-Aziz *et al*. (2021), did not observe any effects on rabbits' carcass traits with dietary supplementation of *S. cerevisiae* at levels of 0.1% and 0.12 g/kg diet, respectively. Similarly, oral administration of β-glucan at doses of 0.25 and 0.5 ml/L of drinking water did not result in significant differences in rabbits' carcass traits, except for dressing percentages when compared to the control group (Abo Ghanima *et al*., 2020). This aligns with previous conclusions from studies by Mansour (2020), who used dietary MOS supplementation at levels of 0.50, 0.75, and 1.0 g/kg diet, and Abd El-Aziz *et al*. (2022), who used 0.3% MOS on New Zealand White rabbits, and found no significant impact on carcass traits.

However, rabbits supplied with synbiotic (mannan-oligosaccharide and probiotic mix of *S. cerevisiae*, lactobacillus acidophilus, streptococcus facecium, and lactic corrosive microorganisms) in a dose of 0.5 g/kg diets had increased hot carcass yield and total edible parts and decreased the liver weight percentages (Abo El-Maaty *et al*., 2018). Contrary, El-Deeb *et al*. (2023) showed no differences in the carcass traits of rabbits supplemented with 0.5, 0.75 and 1.0 g/Kg diet of synbiotic (β-glucan and mannan-oligosaccharide with Bacillus subtilis).

## CONCLUSION

Based on the current study findings, it would be appropriate to add 0.5 g/kg diet of the experiment synbiotic combination of *S. cerevisiae* as probiotic and prebiotics of β-glucan and MOS to enhance the rabbits' growth performance, feed utilization, and health status during the fattening period as well as ameliorate the carcass traits. Current synbiotic showed synergistic effects that could pave the way for more sustainable rabbit production and could be a promising approach to minimize the use of antibiotics and therefore recommended for use in rabbits' husbandry under commercial production conditions. However, the understanding of the regulatory role of current synbiotic on the intestinal health and the mechanism of action warrants further study.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## REFERENCES


Abd El-Aziz, A.H., El-Kasrawy, N.I., Abd El-Hack, M.E., Kamel, S.Z., Mahrous, U.E., El-Deeb, E.M., Atta, M.S., Amer, M.S., Naiel, M.A.E., Khafaga, A.F., Metwally, A.E., Abo Ghanima, M.M., 2022. Growth, immunity, relative gene expression, carcass traits and economic efficiency of two rabbit breeds fed prebiotic supplemented diets. Animal Biotechnology 33, 417-428.

Abd El-Aziz, H., Mahrose, K.M., EL-Kasrawy, N.I., Alsenosy, A.A., 2021. Yeast as growth promoter in two breeds of growing rabbits with special reference to its economic implications. An Acad Bras Cienc 93, e20190274.

Abdelhady, D.H., El-Abasy, M.A., 2015. Effect of prebiotic and probiotic on growth, immuno-hematological responses and biochemical parameters of infected rabbits with Pasteurella multocida. Benha Veterinary Medical J. 28, 40-51.

Abo El-Maaty, H.M.A., Dorra, T.M.I., Hanafy, A.F., 2018. Efficiency of utilizaing basil and fennel hay without or with synbiotic in diets on performance and some metabolic responses of growing rabbits. Egyptian J. Nutrition and Feeds 21, 133-146.

Abo Ghanima, M.M., Abd El-Aziz, A.H., Noreldin, A.E., Atta, M.S., Mousa, S.A., El-Far, A.H., 2020. β-glucan administration improves growth performance and gut health in New Zealand White and APRI rabbits with different breed responses. PLoS ONE 15, e0234076.

Alkenany, M.R., Khalil, L.W., 2022. The effect of Lentinan administration on some immunological and biochemical parameters in intact rabbits. International Journal of Health Sciences 6, 6362–6381.

Bhogoju, S., Nahashon, S., 2022. Recent advances in probiotic application in animal health and nutrition: A review. Agriculture 12, 304.

Bin, D., Shuang, X., Lu, L., Xi, C., 2019. Research progress on application of *Saccharomyces cerevisiae* in animal production. Feed Res 7, 114-116.

Chen, Q., Chen, P., Li, J.Y., Cui, S.H., Qiao, Q., 2021. Effects of yeast β-glucan and zinc compound formula on immune regulation in immunosuppressed young mice. Sci. Technol. Food Indust. 42, 313–319.

Dankowiakowska, A., Bogucka, J., Sobolewska, A., Tavaniello, S., Maiorano, G., Bednarczyk, M., 2019. Effects of in ovo injection of prebiotics and synbiotics on the productive performance and microstructural features of the superficial pectoral muscle in broiler chickens. Poultry Science 10, 5157-5165.

El-Badawi, A.Y., Helal, F.I.S., Yacout, M.H.M., Hassan, A.A., El-Naggar, S., Elsabaawy, E.H., 2017. Growth performance of male NZW rabbits fed diets supplemented with beneficial bacteria or live yeast. Agric. Eng. Int. CIGR J Special issue, 220–226.

El-Deeb, M.M., Fahim, H.N., Ragab, M.A., Shazly, S.A., 2023. Effect of using Biogen as feed additive on the productive performance of growing rabbits. Egyptian Journal of Rabbit Science 33, 121-139.

El-Sawy, B.M.A., Ahmed, A.M.H., Badawi, Y.K., El-Wardany, I.H., 2021. Impact of *Saccharomyces cerevisiae* boulardii supplementation as probiotic on productive performance and economic efficiency of growing rabbits. Arab Univ. J. Agric. Sci. 29, 795-800.

Elghandour, M., Tan, Z., Abu Hafsa, S., Adegbeye, M., Greiner, R., Ugbogu, E., Cedillo Monroy, J., Salem, A., 2020. *Saccharomyces cerevisiae* as a probiotic feed additive to non and pseudo-ruminant feeding: a review. Journal of Applied Microbiology 128, 658-674.

Elliethy, M.A., Abdel Fattah M.A., A.A., M., 2022. Influence of prebiotic, probiotic and synbiotic supplementation on digestibility, haemobiochemical profile and productive performance in Barki lambs. Egyptian J. Nutrition and Feeds 25, 199-210.

Emmanuel, D., Amaka, A., Okezie, E., Sunday, U., Ethelbert, O., 2019. Epididymal sperm characteristics, testicular morphometric traits and growth parameters of rabbit bucks fed dietary *Saccharomyces cerevisiae* and/or zinc oxide. Braz. J. Poult. Sci. 21, 1-10.

Gabr, A.A., 2021. Efficacy of glucans on growth variables, antioxidant potential, and immunity of growing rabbits. J. of Animal and Poultry Production 12, 175–180.

Hashem, N.M., El-Desoky, N., Hosny, N.S., Shehata, M.G., 2021. Gastrointestinal microflora homeostasis, immunity and growth performance of rabbits supplemented with innovative non-encapsulated or encapsulated synbiotic. Proceedings 73, 5.

Hassan, S.S., Habiba, H.I., Alsenosy, A.A., 2022. Immune indicators, growth, hematological parameters, liver enzymes and kidney function of growing rabbits as affected by bee pollen and/or mannan-oligosaccharides. J of Animal and Poultry Production 13, 131-136.

Jana, U.K., Suryawanshi, R.K., Prajapati, B.P., Kango, N., 2021. Prebiotic mannooligosaccharides: Synthesis, characterization and bioactive properties. Food Chemistry 342, 128328.

Kalma, R.P., Chauhan, H.D., Srivastava, A.K., Pawar, M.M., 2018. Growth and blood profile of broiler rabbits on probiotic supplementation. . Indian J. Small Ruminants 24, 66-69.

Kango, N., Jana, U.K., Choukade, R., Nath, S., 2022. Advances in prebiotic mannooligosaccharides. Current Opinion in Food Science 47, 100883.

Krunt, O., Zita, L., Kraus, A., Bures, D., Needham, T., Volek, Z., 2022. The effect of housing system on rabbit growth performance, carcass traits, and meat quality characteristics of different muscles. Meat Sci. 193, 108953.

Kurchaeva, E., Vostroilov, A., Vysotskaya, E., Maksimov, I., 2020. Feed synbiotic additive to improve the productivity and quality of rabbit meat. BIO Web of Conferences 17, 00253.

Lao, E.J., Dimoso, N., Raymond, J., Mbega, E.R., 2020. The prebiotic potential of brewers' spent grain on livestock's health: a review. Tropical Animal Health and Production 52, 461-472.

Liu, B., Cui, Y., Ali, Q., Zhu, X., Li, D., Ma, S., Wang, Z., Wang, C., Shi, Y., 2022. Gut microbiota modulate rabbit meat quality in response to dietary fiber. Front. Nutr. 9, 849429.

Ma, L., Luo, Z., Huang, Y., Li, Y., Guan, J., Zhou, T., Du, Z., Yong, K., Yao, X., Shen, L., Yu, S., Zhong, Z., Hu, Y., Peng, G., Shi, X., Cao, S., 2022. Modulating gut microbiota and metabolites with dietary fiber oat b-glucan interventions to improve growth performance and intestinal function in weaned rabbits. Front. Microbiol. 13, 1074036.

Mancini, S., Paci, G., 2021. Probiotics in rabbit farming: growth performance, health status, and meat quality. Animals 11, 3388.

Mansour, A.M., 2020. Effects of feed enhanced with Agri-MOS prebiotic on productive performance, carcass traits, blood plasma parameters, oxidative status and histo-morphologicaly of growing NZW rabbits. J. of Animal and Poultry Prod. 11, 597-603.

Markowiak, P., Slizewska, K., 2018. The role of probiotics, prebiotics and synbiotics in animal nutrition. Gut Pathogens 10, 1-20.

NRC (National Research Council), 1977. Nutrient requirements of rabbits: 2nd revised edition; The National Academies Press: Washington, DC, USA.

Paës, C., Gidenne, T., Bébin, K., Duperray, J., Gohier, C., Guené-Grand, E.,

Rebours, G., Bouchez, O., Barilly, C., Aymard, P., Combes, S., 2020. Early introduction of solid feeds: ingestion level matters more than prebiotic supplementation for shaping gut microbiota. Front. Vet. Sci. 7, 261.

Pang, Y., Zhang, H., Wen, H., Wan, H., Wu, H., Chen, Y., Li, S., Zhang, L., Sun, X., Li, B., 2022. Yeast probiotic and yeast products in enhancing livestock feeds utilization and performance: An overview. Journal of Fungi 8, 1191.

Santurio, J.M., Alves, S.H., Pereira, D.I.B., Vetvicka, V., de Oliveira, C.A., 2020. Effect of yeast purified β-glucan in experimental treatment of pythiosis in rabbits. Int. Clin. Pathol. J. 8, 14–20.

Tag El Din, N.T.H., 2019. Effect of dry live yeast inclusion in fattening rabbit diets on productive performance and digestibility of nutrients. Egyptian Journal of Rabbit Science 29, 219- 233.

Tag El Din, N.T.H., 2020. Growth performance and feed utilization during fattening period as affected by mannan-oligo-saccharides addition to Californian rabbits. J of Animal and Poultry Prod. 11, 73-77.

Xie, M., Wang, H., Yang, J., Wang, G., Li, J., Li, C., 2018. Effects of yeast mannan oligosaccharides on growth performance, serum immune, inflammatory and antioxidant indicators of Mongolian sheep. Chinese Journal of Animal Nutrition 30, 219-226.