Received: 01 October 2023, Accepted: 20 October 2023

Original Research

Journal of Advanced Veterinary Research
(2023) Volume 13, Issue 10, 2051-2057

Effect of some Growth Promoters on Performance and Proximate Chemical Analysis of New Zealand Rabbit

Mona M.I. Elattar[1*], Ali M. Ahmed[1], Ibrahim M. Fares[2], Nada I.H. Ahmed[1]

[1]Department of Food Hygiene, Faculty of Vet. Med., Suez Canal University, Ismailia, Egypt.

[2]Department of Animal Behavior and Management, Faculty of Vet. Med., Suez Canal University, Ismailia, Egypt.

***Correspondence**
Corresponding author: Mona M.I. Elattar
E-mail address: dr.mona033@gmail.com

Abstract

Rabbit meat provides a good source of high-quality animal protein with low fat content, it is considered a functional food. This study aimed to determine the growth performance, carcass traits, and chemical quality of New Zealand White rabbit meat breeding treated with different growth promoters. Therefore, 40 apparently healthy New Zealand White male rabbits, 5 weeks of age, were allotted to 4 equal experimental groups. The first group was kept as a control group, the second group included rabbits fed ad libitum supplemented with a beta-glucan 2.0 g/kg diet, The third group comprised rabbits that were injected twice intramuscular of boldenone undecylenate (5 mg/kg body weight) with 3-weeks intervals, the fourth group included rabbits that injected intramuscular of 40 μg/kg body weight estradiol day by day for 30 days. The obtained results revealed that the treated groups with growth promoters had a significant increase ($P<0.05$) in growth performance (total body weight gain and daily weight gain) and dressing percentage. Administration of boldenone undecylenate resulted in a significant increase ($P< 0.05$) in protein content in their meat compared to the control group. Rabbits injected with estradiol show a nonsignificant effect ($P> 0.05$) on dressing % or protein content of meat. Rabbits feed on a beta-glucan-supplemented diet show the highest carcass dressing percentage. Further studies were challenging food investigators for the rabbit meat treated with hormonal growth promoters to study their residues and their impact on consumer health.

KEYWORDS
Growth promoters, Rabbit meat, Boldenone, Estradiol, Beta-glucan

INTRODUCTION

Rabbit meat is less preferred by consumers than other meat types despite its high nutritional and dietetic value and health benefits. The nutritional profile of rabbit meat, by comparison with beef, pork, and poultry, is attributed to significantly larger quantities of n-3 fatty acids and lower amounts of intramuscular fat, cholesterol, and sodium (Kumar *et al*., 2023). Rabbit meat has a tender flavour and is considered a good substitution for chicken meat (Zoltan *et al*., 2017).

However, rabbit meat consumption is not prevalent worldwide (Mancini *et al*., 2018). The Mediterranean basin nations have frequently consumed rabbit meat-based dishes since the earliest civilizations because rabbits are easy to grow on farms and in backyards and are eco-friendly, although there are substantial differences between nations in rabbit production (Blasco *et al*., 2018; Szendro *et al*., 2020). China is the world's largest rabbit meat-producing country, with production of 462,681 tons in 2021, followed by North Korea with 131,126 tons and Egypt with 72,000 tons (FAO, 2022).

Rabbit has a higher potential for commercial-level meat production since it has a shorter life cycle and gestation period, produces a large number of offspring, and is more tolerant to environmental changes. It grows at a faster rate and reaches a body weight of about 2–2.5 kg in 3–4 months, depending on nutrition and other management practices (Kumar *et al*., 2023).

Rabbit meat has a high protein content, which provides 80% of the total energy in the human diet (Ruleva *et al*., 2015). Morshdy *et al*. (2022) reported that the essential amino acids composition of meat samples of the New Zealand White rabbit breed were lysine, histidine, phenylalanine, valine, methionine, threonine, isoleucine, and leucine.

Numerous studies have advocated consuming proteins from animal sources is crucial for their high nutritional quality, which provides adequate nutrition for humans, particularly infants, to support their physical and cognitive development (Allen and Dror, 2011). Moreover, recent studies revealed that rabbit meat proteins exhibited angiotensin-converting enzyme inhibitory characteristics and antioxidant properties (Chen *et al*., 2021; Kumar *et al*., 2023). Therefore, rabbit meat is considered a functional food and highly recommended for hypertension, hyperlipidemia, cardiovascular, and cerebrovascular patients (Chen *et al*., 2021), pregnant women, young, and elderly people (Skladanowska-Baryza and Stanisz, 2019).

Rabbit meat has relatively high energy values (899 kJ/100 g in the forelegs and 603 kJ/100 g in the loin), which is mostly the same as many types of red meat frequently consumed (Buitrago-Vera *et al*., 2016). It is also a very good source of several minerals (Długaszek and Kopczynski, 2013). Rabbit meat is also a great source of B vitamins, as the consumption of 100 g of their

ISSN: 2090-6277/2090-6269/

meat provides about 8% of the daily requirement of vitamin B2, 12% of vitamin B5, 21% of vitamin B6, and 77% of vitamin B3 (Hernàndez and Dalle Zotte , 2010).

The world population is predicted to grow, reaching approximately 10 billion in 2050, which would lead to a substantial increase in global demand, particularly for protein, in the next few decades (FAO, 2009; Mottet and Tempio, 2017).

Animal husbandry is currently required to increase meat production to meet the demand of a growing global population (Ritchie *et al*., 2017). To overcome these challenges, farmers adopt different management practices to achieve an increase in meat production. Furthermore, the meat industry's interest has focused on improving carcass yield (Dalle Zotte, 2002).

The rabbit meat industry is still in a transitional stage although it has more potential to satisfy market demand in terms of nutritional profile (Kumar *et al*., 2023).

Growth promoters are all non-nutrient substances added to feed or injected into livestock to improve feed utilization, increase animals' growth rates, and improve their overall efficiency and carcass quality (Herago and Agonafir, 2017).

The most applied growth promoters are feed additives, estrogenic and androgenic anabolic implants, bovine somatotropin, β-agonists, and probiotics (Getabalew *et al*., 2020). The most used growth promoters as feed additives are antibiotics and exogenous enzymes (Herago and Agonafir, 2017). Growth promoters are mainly used to increase meat production, improve fat and protein distribution in carcasses, and increase feed conversion rate. Most growth promoters used in the animal industry are orally active and can be given either in food or drinking water, while other active hormones are not, so they can be given in the form of small implants in the subcutaneous tissue of the ear (Toldra and Reig, 2016).

Growth promoters have many adverse effects on consumers, as hormonal growth promoters used in animal production may have a carcinogenic effect on consumers. Unable to follow the guidelines of probiotic manufacturing may lead to the development of pathogenic organisms. Residues of antibiotic growth promoters in meat can affect human health either directly or indirectly through the development of antibiotic resistance that may spread to a human pathogen (Herago and Agonafir, 2017). The benefits and risks of growth promoters remain a complex and controversial issue.

In recent years, there have been a lot of concerns raised about the presence of steroid hormones in food of animal origin due to their use as growth promoters in animal production for their anabolic effect (Donna *et al*., 2015). Excessive exposure to anabolic hormones can affect vital organs and systems, such as the cardiovascular system, bones, and the central nervous system. In addition, the tissues may respond to abnormal hormone levels through abnormal cell proliferation, leading to hyperplasia, neoplasia, breast, ovary, and prostate cancer (Fan *et al*., 2014).

Oda and El-Ashmawy (2012) reported that boldenone is heavily abused in Egypt, not only for animal production but also by athletes and bodybuilders.

β-glucan is one of the antibiotic growth promoter alternatives that enhances the performance and survival rate (Moon *et al*., 2016). Beta-glucan is a member of the prebiotic family that promotes the growth and activity of the desired natural intestinal microbiota while suppressing the growth of pathogens. It is crucial for gastrointestinal tract health, reducing inflammation and colon cancer risk (Ciecierska *et al*., 2019).

β-glucan is a natural group of non-starch soluble polysaccharides widely present in the cell wall of yeast, mushrooms, bacteria, and algae, as well as higher crops, such as barley, and oats. Because of its health benefits, β-Glucan is a functional food ingredient (Du *et al*., 2019). β-Glucans belong to bioactive dietary fibers group or polysaccharides derived from natural sources that have several medical significances as β-Glucans are well known to have anti-inflammatory, anti-obesity, anti-allergic, anti-osteoporotic, antitumor and immunomodulating activities (Bashir and Choi, 2017). Rabbit immunity was noted to be improved by supplementing β-1,3–1,6-glucan in rabbits (Crespo *et al*., 2017) Prebiotics in rabbits promote rapid growth, sustainability, and health, as well as improve overall production and the financial feasibility of rabbit farms (Dalle Zotte *et al*., 2016; Simonová *et al*., 2020). Therefore, this study was conducted to evaluate the effect of boldenone, estradiol and beta-glucan growth promoters on New Zealand White rabbit growth performance and the chemical quality of their meat.

MATERIALS AND METHODS

Ethical statement

The experimental work was carried out at the experimental farm. Faculty of Veterinary med., Suez Canal University, Egypt, during winter 2023. The experiment adhered to the guidelines of the ethical committee of the National Research Center, Egypt.

Experimental animals, housing, and management

A total of 40 rabbits, "apparently healthy, weaning growing, New Zealand White male rabbits, five weeks of age", were randomly chosen for a trial of breeding under 3 different treatment growth promoters. All animals were weighed and randomly distributed among 4 experimental groups. Each experimental group contained 10 rabbits, and the experiment was extended for six weeks. Rabbits were housed individually in cages with an automated drinking system and a manual feeder. Rabbits in all groups were housed and maintained under the same conditions. Animals were fed with an adequate standard post-weaning diet and fed ad libitum. The experimental diet was commercial pelleted standard rabbit ration (CP. 18.2 %, CF. 14%, E.E. 2.6%, and D.E. 2600 kcal/kg).

Experimental design

Rabbits were equally divided into four groups, the first group (G1) was kept as control. The second group (G2) included rabbits fed ad libitum supplemented with a beta-glucan 2.0 g/kg diet (Angel Yeast Egypt Co., Ltd). The third group (G3) comprised rabbits that were injected twice intramuscular of boldenone undecylenate (Five-Bold, Fivevet), 5 mg/kg body weight with 3-week intervals, the fourth group (G4) included rabbits that were injected intramuscular of 40 μg/kg body weight estradiol (Misr Co. for pharma ind.) day by day for 30 days.

Animal performance

The weight of each rabbit was recorded at the beginning of the study at the age of 5 weeks and then periodically at the age of 7, 9, and 11 weeks. The total body weight gain (BWG) of rabbits was calculated for the whole period.

Carcass traits

Five Rabbits at age 9^{th} and 11^{th} weeks from each group were randomly weighed and slaughtered according to Islamic rites.

After bleeding, skinning, and evisceration, each rabbit carcasses were weighed. The following carcass traits were recorded: dressing percentage, and organs weighed separately (liver, kidney, heart, lung).

Chemical analyses

Sample preparation

Frozen rabbit meat samples were kept at -18°C and used to determine the chemical proximate analysis (moisture, ash, protein, and fat content). Each carcass sample was deboned then ground and homogenized using (Lab. Blender).

Proximate chemical composition of meat

The analysis of moisture (using Titanox thermoventilated dry 20l model oven, Italy), protein (macro-Kjedahl protein method), fat (using Soxhlet Extraction), and ash content (using the Thermdyne F48010-33 model muffle furnace, United States) were performed using the standard methods of the Association of Official Analytical Chemists (AOAC, 1990).

Statistical analysis

Data were analyzed using GraphPad Prism 8. Parameters were given as maximum, minimum, mean, and standard error. We studied differences in parameters between rabbits using one-way- ANOVA test followed by Tukey's test.

RESULTS

Growth Performance

The mean values of NZW male rabbits' growth rate during breeding for 45 days under β-glucan, boldenone, and estradiol growth promoters are shown in Figure 1. The effect of these growth promoters on the overall performance of male rabbits compared with the control group is shown in Table 1. The results revealed that boldenone injection in male rabbits resulted in a significant increase in total body weight gain (BWG), followed by a group of rabbits that received β-glucan, then estradiol, and finally the control group (1257.8 g, 1247 g, 1145 g, and 970 g), respectively. Average daily gain (ADG) significantly increased (P=0.0035) among groups; the best results were for the group that included rabbits, which received 2 intramuscular boldenone injections (G3), then the β-glucan group (G2), followed by estradiol (G4), and then the control group (G1).

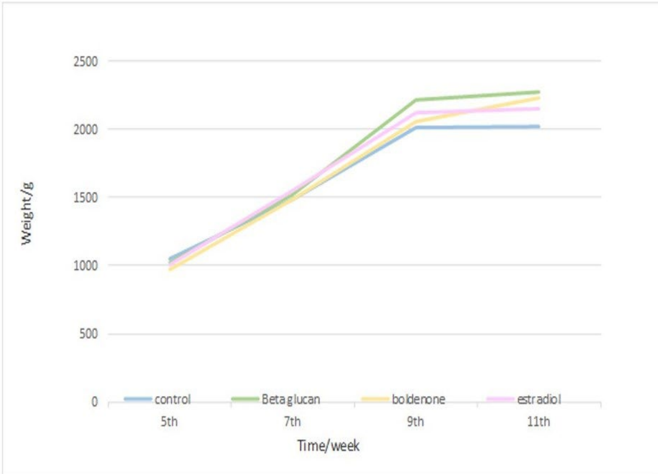

Figure 1. Growth promoters' effect on rabbits' growth rate.

Carcass Characteristics

A statistical analysis of data on carcass traits at the 9th week of age of NZW rabbits was presented in Table 2. The pre-slaughter weight, carcass weight, dressing percentage, and offal. Pre-slaughter weights (P=0.1044) were not significantly different among experimental groups, although carcass weights (P=0.0056) were significantly different (1253g, 1132g, 1114g, and 1090g) for β-glucan, boldenone, estradiol, and control groups, respectively. Furthermore, the dressing percentages of these carcasses were significantly different (P=0.0005), as the results were (56.69%, 55.07%, 54.16%, and 52.58%) for the β-glucan, boldenone, control, and estradiol groups, respectively. Lung (P

Table 1. Effect of growth promoters on growth performance parameters of New Zealand rabbits.

Parameters	Control	Beta-glucan	Boldenone	Estradiol	P value
Initial BW at 5 weeks (g)	1050^{a}±31.62	1023.8^{a}±49.92	970.2^{a}±36.52	1006^{a}±43.43	0.58
Final BW at 11 weeks (g)	2020^{a}±35.36	2270^{a}±49.497	2228^{a}±81.82	2151^{a}±117.2	0.15
ADG	21.56^{a}±0.35	27.69^{b}±0.48	27.95^{bc}±1.17	25.44^{bac}±1.84	0.00
Total BWG	970^{a}±15.81	1246.2^{b}±21.50	1257.8 ^{bc}±52.75	1145 ^{bac} ±82.58	0.00
Change percentage in BW	92.40%	121.80%	129.64%	113.82%	

Data are presented as Mean± Standard error (S.E.). Mean in the same row with different letters is considered extremely significant (P<0.05).
BWG: Body weight gain; ADG: Average daily weight gain.

Table 2. Effect of growth promoters on carcasses, dressing percentage, and giblets of rabbits slaughtered at 9 weeks of age.

Items	Control	Beta-glucan	Boldenone	Estradiol	P value
Pre-slaughter weight (g)	2012^{a}±32.31	2210^{a}±43.01	2055^{a}±50.30	2122 ^{a} ±83.03	0.10
Carcass WT(g)	1090 ^{a}±22.30	1253^{b}±28.53	1132^{ac}±28.79	1114 $^{a c}$±36.07	0.01
Lung (g)	14.31^{a}±0.76	19.05 ^{a} ±2.22	16 ^{a} ±0.32	15.42 ^{a} ±1.95	0.20
Liver (g)	73.3^{a}±3.56	92.7^{b}±6.65	72.3^{ac}±0.26	69.267^{ac}±2.05	0.00
Kidney (g)	17.48 ^{a}±0.87	16.37 ^{a} ±0.52	15.28 ^{a} ±0.18	16.76 ^{a} ±0.43	0.08
Heart (g)	6.43^{a}±0.42	7.63^{ab}±0.26	6.28^{ac}±0.37	8.35^{bd}±0.17	0.00
Dressing %	54.16 ^{a}±0.38	56.69^{b}±0.50	55.07^{ab}±0.29	52.58^{a}±0.81	0.0005***

Data are presented as Mean± Standard error (S.E.). Mean in the same row with different letters is considered extremely significant (P<0.05).

= 0.1978) and kidney (P=0.0792) were not significantly different among the experimental treatments, while heart (P=0.0007) and liver (P=0.0024) were significantly different.

Table 3. Presents the values for the mean and standard error of the pre-slaughter weight, carcass traits, dressing percentage, and offal of rabbits slaughtered at 11 weeks of age. Pre-slaughter weights (P=0.1546) were not significantly different, while carcass weights (P=0.0298) were significantly different among the experimental groups (1321g, 1245g, 1192 g, and 1109g) for β-glucan, boldenone, estradiol, and control groups, respectively. The dressing percentages of these carcasses were significantly different (P=0.0002), as the results were (58.39%, 55.80%, 55.49%, and 54.50%) for β-glucan, boldenone, estradiol, and control groups, respectively. Lung (P=0.1499), kidney (P=0.3499), and liver (P=0.2201) were not significantly different among the experimental treatments, while heart (P<0.0001) was significantly different.

The carcass weights and dressing percentage results for rabbits slaughtered at 9th and 11th weeks of age were illustrated in Figure 2 and Figure 3, respectively.

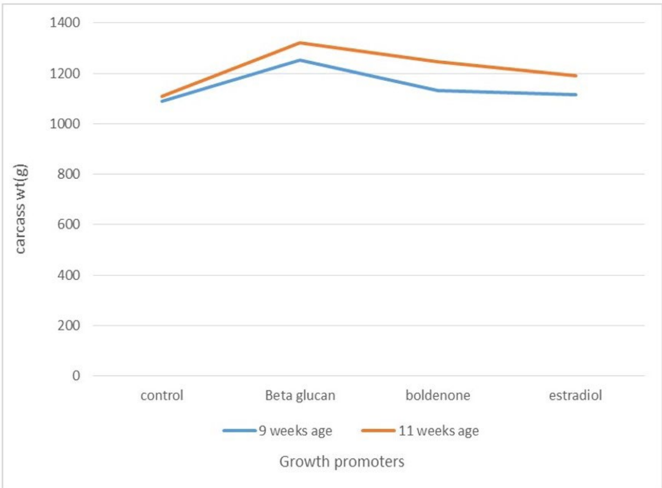

Figure 2. Carcasses weights of rabbits slaughtered at 9th and 11th weeks age.

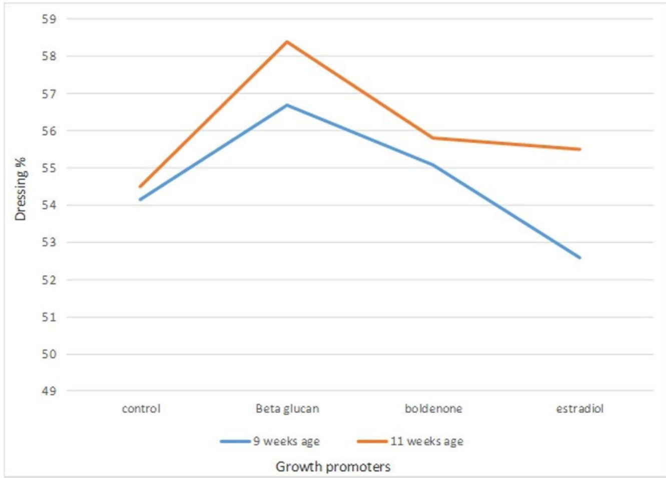

Figure 3. Dressing percentage of rabbits slaughtered at 9th and 11th weeks of age.

Proximate Composition of New Zealand Rabbit Meat

Table 4. Presents the proximate composition of NZW rabbit meat (g/100 g) slaughtered at the 9th week of age, while Table 5. Displays the proximate composition of rabbit meat (g/100 g) slaughtered at the 11th week of age.

DISCUSSION

The primary objective of this study was to evaluate the effects of boldenone undecylenate, estradiol, and beta-glucan growth promoters on the growth performance, carcass traits, and meat chemical quality of NZW rabbits.

Based on the results of this study, the growth performance improved in the treated groups relative to the control group. The total body weight gain (BWG) of the estradiol-injected group shows a slight increase compared to the control group, with the same results obtained (Uwaeziozi, 2017). This finding complies with the results of Hunter (2009); where estrogen was used as a hormonal growth promoter for beef production.

Also, the growth rate improved and BWG increased for rabbits injected with boldenone, which corresponds to the previous findings by Thabet *et al.* (2010); Tousson *et al.* (2012) and Mohammed

Table 3. Effect of growth promoters on carcasses, dressing percentage, and giblets of rabbits slaughtered at 11 weeks of age.

Items	Control	Beta-glucan	Boldenone	Estradiol	P value
Pre-slaughter weight (g)	2020^{a}±35.36	2270^{a} ±49.50	2228^{a} ±81.82	2151^{a} ±117.2	0.15
Carcass WT(g)	1109±29.74	1321±30.51	1245±49.24	1192±59.09	0.03
Lung (g)	13.58^{a} ±0.95	15.58^{a} ±0.57	13.64^{a} ±1.46	11.84^{a} ±1.11	0.15
Liver (g)	57.94^{a} ±2.30	56.08^{a} ±0.14	65.88^{a} ±5.24	58.8^{a} ±3.48	0.22
Kidney (g)	15.22^{a} ±0.45	16.4^{a} ±0.60	15.54^{a} ±0.99	16.7^{a} ±0.35	0.35
Heart (g)	6.54^{a}±0.20	8.74^{ab}±0.07	6.9^{b}±0.18	6.78^{b}±0.12	P<0.0001
Dressing %	54.50^{a}±0.81	58.39^{b}±0.26	55.80^{ac}±0.27	55.49^{ac}±0.35	0.00

Data are presented as Mean± Standard error (S.E.). Mean in the same row with different letters is considered extremely significant (P<0.05).

Table 4. Chemical proximate composition of rabbit meat slaughter at 9th week of age.

Parameters %	Growth promoters				
	Control	Beta glucan	Boldenone	Estradiol	P value
Protein	20.22^{a}±0.099	20.63^{ab}±0.13	21.66^{c}±0.27	20.55^{ab}± 0.07	P<0.0001
Fat	3.79^{a}±0.197	4.35^{b}±0.10	4.45^{bc}±0.13	3.61^{a}±0.08	P<0.0008
Moisture	72.35^{a}±0.54	73.49^{ab}±0.45	74.53^{bc}±0.10	74.26^{bcd}±0.45	0.01
Ash	0.898^{a}±0.02	0.89^{a}±0.04	1.38^{c}±0.03	1.64^{d}±0.03	P<0.0001

Data are presented as Mean± Standard error (S.E.). Mean in the same row with different letters is considered extremely significant (P<0.05).

et al. (2016). This effect may be ascribed to the stimulation of growth hormone, insulin-like growth factor secretion, and animal appetite (Ferreira *et al*., 1998), or a decrease in glucocorticoid receptor levels and sensitivity to endogenous glucocorticoids that promote protein synthesis and animal tissue building. Therefore, the strong growth-promoting potency of boldenone is based not only on its anabolic activity but also on its catabolic activity as an anti-glucocorticoid (Melloni *et al*., 1997; Thienpont *et al*., 1998).

In the current study, oral administration of β-glucan improved the growth performance and BWG, the same result recorded by Bhatt *et al*. (2017); El-Badawi *et al*. (2018); Abo Ghanima *et al*. (2020). β-glucan supplementation led to an increase in the villus height of the intestine and improved intestinal health (Zhang *et al*., 2005), which increased digestibility and better absorption of the diet, reflecting improved growth efficiency (Resta-Lenert and Barrett, 2003).

In addition, carcass weight reflected the condition of livestock, and carcass weight was also influenced by interactions between breed and feed, which showed efficient utilization of energy, protein, and possibly minerals (Soeparno, 1992).

β-glucan administration significantly increased ($P<0.05$) dressing yield compared with the control group, the same result was indicated by Abo Ghanima, *et al*. (2020). The result revealed that boldenone injection improved the dressing percentage, the same finding recorded by (Mohammed *et al*., 2016).

Fadare (2015) recorded a higher dressing yield of NZW rabbits 67.95% than the dressing percentage of control rabbits in the current study. Klont *et al*. (1998) indicated that breed, age of animals, diet, ante-mortem, and post-mortem have a great influence on the quality of rabbit meat and its carcass.

Protein content is one of the most important indicators of high-quality food. From Tables 4 and 5, there is no significant difference ($P>0.05$) between the meat of rabbits in the control rabbits, estradiol-injected rabbits, and rabbits fed a β-glucan-supplemented diet in terms of protein contents. However, the rabbit group injected with two doses of boldenone in a three-week interval was extremely significant (21.66%–22.89%), while lower content was recorded for other groups. This was due to the anabolic effects of anabolic-androgenic steroids, which promote protein synthesis, muscle growth, and erythropoiesis (Mottram and George, 2000). Boldenone increases the muscle size of injected animals by promoting positive nitrogen balance by stimulating protein production and reducing protein destruction (Guan *et al*., 2010; Tousson *et al*., 2012).

The mean protein contents of rabbit's meat were (20.11%, 20.72%, 22.89%, and 20.62%) for control, β-glucan, boldenone, and estradiol, respectively, of rabbits slaughtered at 11 weeks of age. The lower level of protein content in NZW rabbit meat was (18.63–18.86%), as recorded by Haque *et al*. (2016). Several studies also reported relatively the same value of protein content (18.60–22.40%) for rabbit meat (Pla *et al*., 2010; Dalle Zotte and Szendro 2011; Cavani and Petracci, 2012). The same results obtained by Fadlilah *et al*. (2020) protein content of rabbit meat was (19.99%). While Asamoah *et al*. (2019) reported a higher protein content of rabbit meat (27.09%), this could be due to the type of breed, age of animals, diet, and post-mortem handle, as stated by Klont *et al*., (1998).

According to Rasinska *et al*. (2018) and Fadlilah *et al*. (2020) protein content of the rabbit carcass forepart was (16.5%–21.8%) and the hind part was (18.2%–22.1%.) Rabbit meat contains high levels of essential and non-essential amino acids. Different studies of rabbit meat proximate chemical composition, including crude protein, crude fat, moisture, and ash contents of different rabbit breeds, ranged from 20.0%–26.18%, 0.44%–6.56%, 62.10%–75.60%, and 0.67%–1.57%, respectively (Kumar *et al*., 2023).

Rabbit meat has a low-fat content relative to its protein density, so it is considered lean and tougher than other meat types (Warner *et al*., 2017). The rabbit breed has a great effect on its lipid profile; for instance, the NZW rabbit had the highest proportion of its fat in the form of saturated fatty acid (SFA), followed by polyunsaturated fatty acid (PUFA), then monounsaturated fatty acid (MUFA) 34.70%–50.11%, 20.58%–40.70%, and 21.00%–36.52% of total fatty acids, respectively (Mattioli *et al*., 2017 and Perna *et al*., 2018). while synthetic rabbit lines had the highest proportion of (PUFA), followed by (SFA) and (MUFA) (Martínez-Álvaro *et al*., 2018).

In terms of fat contents, there was no significant difference between control and estradiol-injected rabbits, while there was a significant difference between the control, beta-glucan, and boldenone rabbit groups for rabbits slaughtered at 9 weeks of age.

In this study, the fat contents of rabbit meat samples were (4.84%, 4.37%, 3.89%, and 3.73%) for boldenone, beta-glucan, control, and estradiol, respectively, for rabbits slaughtered at 11 weeks of age, with the highest fat content recorded in the boldenone-injected rabbit group, followed by the beta-glucan group. There was no significant difference between control and estradiol-injected rabbits. Sex and genotype of rabbits did not have a significant effect on their meat fat content (Simonová *et al*., 2010; Belichovska *et al*., 2017), while increasing rabbits age may have a significant fat content increase (Haque *et al*., 2016). The lower fat content value was (3.29%), as reported by Asamoah *et al*. (2019). and (2.31%) was recorded by Fadlilah *et al*. (2020).

Unlike beef, rabbit fat is not deposited in the muscles but forms relatively thin layers subcutaneously, providing consumers with a "fat-free muscle" diet. This reduces the risk of cardiovascular disease by preventing the consumption of large amounts of fat (Tărnăuceanu *et al*., 2011). Unsaturated fatty acids (UFA) represent around 60% of the total fatty acids (FA), and polyunsaturated fatty acids (PUFA) constitute about 32.5% of the total FA in rabbit meat, which is much higher than in other red meats and poultry (Salma *et al*., 2007).

In this study, moisture content was (77.95%, 76.8%, 73.20%, and 71.28%) for beta-glucan, boldenone, estradiol, and the control group, respectively, for rabbits slaughtered at 11 weeks of age. The level of moisture content in NZW rabbit meat was 75.84% (Fadlilah *et al*., 2020) higher than the level recorded for the control group in this study. Gabriela *et al*. (2014) indicated that the moisture content level of rabbit meat ranged from (63.6%–75.93%) in both female and male rabbits, while higher results were recorded in this study for beta-glucan and boldenone rabbit groups.

The moisture content of meat was more influenced by the level of dehydration of animals before slaughter (Lawrie, 2003). The moisture level of rabbit meat decreased dramatically with increasing age; rabbit species or sex had no effect on moisture content (Belichovska *et al*., 2017).

Ash content was (0.95%, 1.10%, 1.40%, and 1.85%) for the control, beta-glucan, boldenone, and estradiol groups, respectively, for rabbits slaughtered at 11 weeks of age. Fadlilah *et al*. (2020); Fadare *et al*. (2017) recorded a higher ash content of fresh NZW rabbit meat than the ash content in the control rabbit group in this study. The average ash content in rabbit meat was 1.06%–1.19%. This difference can be influenced by the mineral content of the feed (Brahmantiyo *et al*., 2014).

Moreover, the ash and moisture contents of boldenone-injected rabbit meat markedly increased and were significantly different than the control group due to the role of boldenone in the retention of body water, nitrogen, sodium, potassium, and calcium ions (Mooradian *et al*., 1987).

CONCLUSION

Treating NZW rabbits with growth promoters, boldenone undecylenate, estradiol, and β-glucan, has a positive and significant effect on their growth performance (total and daily weight gain) and dressing percentage. NZW rabbits treated with Beta-glucan recorded higher dressing percentage while Boldenone recorded higher protein content in their musculature which improves their nutritive values.

ACKNOWLEDGMENTS

The authors extend their gratitude to all staff for assistance in carrying out this work and to anonymous referees for their helpful comments on the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

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.

Allen, L.H., Dror, D.K., 2011. Effects of animal source foods, with emphasis on milk, in the diet of children in low-income countries. Nestle Nutr Workshop Ser. Pediatr. Program. 67,113-30.

AOAC, 1990. Official Methods of Analysis. 15th Edition, Association of Official Analytical Chemist, Washington DC.

Asamoah, E.A., Barimah, J., Akwetey, W.Y., Boateng, R., Dapuliga, C.C., 2019. Sensory and physicochemical characteristics of rabbit meat sausages produced with refined palm stearin (RPS). Journal of Food Science and Technology 4, 796–803.

Bashir, K.M.I., Choi, J.S., 2017. Clinical and Physiological Perspectives of β-Glucans: The Past, Present, and Future. Int. J. Mol. Sci. 18, 1906.

Belichovska, D., Belichovska, K., Pejkovski, Z., Uzunoska, Z., 2017. Effect of genotype on physicochemical characteristics of rabbit meat. Meat Tech. 58, 10-15.

Bhatt, R.S., Agrawal, A.R., Sahoo, A., 2017. Effect of probiotic supplementation on growth performance, nutrient utilization and carcass characteristics of growing Chinchilla rabbits. J Appl Anim Res. Taylor & Francis. 45, 304–309.

Blasco, A., Nagy, I., Hernández, P., 2018. Genetics of growth, carcass and meat quality in rabbits. Meat Sci. 145, 178–185.

Brahmantiyo, B., Setiawan, M.A., Yamin, M., 2014. Physical and chemical properties of rex and local rabbit's (*Oryctolagus cuniculus*) Meat. J. Peternakan Indonesia. 16, 1-7.

Buitrago-Vera, J., Escribá-Pérez, C., Baviera-Puig, A., Montero-Vicente, L., 2016. Consumer segmentation based on food-related lifestyles and analysis of rabbit meat consumption. World Rabbit Sci. 24, 169–182.

Cavani, C., Petracci, M., 2012. Trends in rabbit meat processing. In proceedings of the 10th World Rabbit Congress, pp. 851-858.

Chen, J., Yu, X., Huang, W., Wang, C., He, Q., 2021. A novel angiotensin-converting enzyme inhibitory peptide from rabbit meat protein hydrolysate: Identification, molecular mechanism, and antihypertensive effect in vivo. Food Funct. 12, 12077–12086.

Ciecierska, A., Drywień, M.F., Hamulka, J., Sadkowski, T., 2019. Nutraceutical functions of beta-glucans in human nutrition. Rocz. Panstw. Zakl. Hig. 70, 315–324.

Crespo, H., Guille´n, H., de Pablo-Maiso, L., Go´mez-Arrebola, C., Rodrı´guez, G., Glaria, I., 2017. Lentinula edodes β-glucan enriched diet induces pro- and anti-inflammatory macrophages in rabbit. Food Nutr. Res. Swedish Nutrition Foundation. 61, 1412791.

Dalle Zotte A., 2002. Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. Livestock Production Science. 75, 11-32.

Dalle Zotte, A., Szendro, Z., 2011. The role of rabbit meat as functional food. Meat Sci. 88, 3, 319–331.

Dalle Zotte, A., Cullere, M., Rémignon, H., Alberghini, L., Paci, G., 2016. Meat physical quality and muscle fibre properties of rabbit meat as affected by the sire breed, season, parity order and gender in an organic production system. World Rabbit Sci. 24,145–154.

Długaszek, M., Kopczynski, K., 2013. Elemental composition of muscle tissue of wild animals from central region of poland. Int. J. Environ. Res. 7, 973–978.

Donna, L.D., Benabdelkamel, H., Taverna, D., Indelicato, S., Aiello, D., Napoli, A., Sindona, G., Mazzotti, F., 2015. Determination of ketosteroid hormones in meat by liquid chromatography-tandem mass spectrometry and derivatization chemistry. Anal. Bioanal. Chem. 407, 5835–5842.

Du, B., Meenu, M., Liu, H., Xu, B. 2019. A Concise Review on the Molecular Structure and Function Relationship of β-Glucan. Int. J. Mol. Sci. 20, 4032.

El-Badawi, A.Y., 2018. Growth performance of male NZW rabbits fed diets supplemented with beneficial bacteria or live yeast. Agric. Eng. Int. CIGR J. 19, 220–226.

Fadare, A.O., 2015. Carcass traits of New Zealand White, californian, palomino brown and havana black rabbit in the humid tropics. IOSR Journal of Agriculture and Veterinary Science. 8, 19-23.

Fadare, A.O., Doka, Z.B., Odimayo, O.M., Fesobi, M.E., 2017. Effect of genotype on the proximate composition and sensory properties of rabbit meat. FUTA J. Res. Sci. 13, 2, 266-73.

Fadlilah, A., Rosyidi, D., Susilo, A., 2020. Chemical quality of fresh New Zealand White rabbit meat in Batu, Indonesia. IOP Conf. Ser. Mater. Sci. Eng. 811, 012024.

Fan, Y.B., Yin, Y.M., Jiang, W.B., Chen, Y.P., Yang, J.W., Wu, J., Xie, M.X., 2013. Simultaneous determination of ten steroid hormones in animal origin food by matrix solid-phase dispersion and liquid chromatography-electrospray tandem mass spectrometry. Food Chem. 142, 170–177.

FAO, 2009. Proceedings of the expert meeting on how to feed the world in 2050, 24-26. June 2009, FAO Headquarters Rome. http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf (Accessed 25 August 2020).

FAO, 2022. Food and Agricultural Organization Statistical Database: Production of meat. http://faostat.fao.org (accessed 26 October 2022).

Ferreira, I.M., Verreschi, I.T., Nery, L.E., Goldstein, R.S., Zamel, N., Brooks, D., 1998. The influence of 6 months of oral anabolic steroids on body mass and respiratory muscles in undernourished COPD patients. Chest. 114, 19-28.

Gabriela, T.F., Lazar, R., Biosteanu, P., 2014. Research regarding nutritional quality of rabbit meat (Belgian giant breed). University of Agriculture Science and Veterinary Medicine Iasi, Scientific Papers – Animal Science Series. 62, 45-8.

Getabalew, M., Alemneh, T., Zewdie, D., 2020. Types and uses of growth promoters in beef cattle. J. Vet. Med. Animal Sci. 3, 1, 1027

Guan, F., Ubon, C., Soma, R., You, Y., Liu, Y., Li. X., 2010. High-throughput UHPLC-MS/MS method for the detection, quantification and identification of fifty-five anabolic and androgenic steroids in equine plasma. J. Mass Spectrometry. 45, 1270-1279.

Haque, A., Rahman, M., Bora, J., 2016. Effect of breed, weaning age and feeding regime on chemical composition of rabbit meat. Int. J. Vet. Sci. Animal Husbandry. 1, 1, 12-3.

Herago, T., Agonafir, A., 2017. Growth promoters in cattle. Advances in Biological Research. 11, 1, 24-34.

Hernàndez, P., Dalle Zotte, A., 2010. Influence of diet on rabbit meat quality. In: Nutrition of the rabbit. Poletenica, D.U and Wiseman, M.G. (Eds), University of Nottingham, UK, 2nd, pp. 163– 178.

Hunter, R.A., 2009. Hormonal growth promotant (HGP) use in the Australian Beef Industry. Animal Production Science. 50,7, 637-659.

Klont, R.E., Brocks, L., Eikelenboom, G., 1998. Muscle fibre type and meat quality. Meat science. 49, 219-229.

Kumar, S.A., Kim, H.J., Jayasena, D.D., Jo, C., 2023. On-farm and processing factors affecting rabbit carcass and meat quality attributes. Food Sci. Anim. Resour. 43, 2, 197-219.

Lawrie, R.A., 2003. Meat Sci. 5th Ed. Perganon Press, Oxford.

Mancini, S., Secci, G., Preziuso, G., Parisi, G., Paci, G., 2018. Ginger (*Zingiber officinale Roscoe*) powder as dietary supplementation in rabbit: Life performances, carcass characteristics and meat quality. Ital. J. Anim. Sci. 17, 867–872.

Martínez-Álvaro, M., Blasco, A., Hernández, P., 2018. Effect of selection for intramuscular fat on the fatty acid composition of rabbit meat. Animal. 12, 2002–2008.

Mattioli, S., Cardinali, R., Balzano, M., Pacetti, D., Castellini, Bosco, C.D., Frega, N.G., 2017. Influence of dietary supplementation with prebiotic, oregano extract, and vitamin E on fatty acid profile and oxidative status of rabbit meat. J. Food Qual. 3015120.

Melloni, R.H., Conner, D.F., Hang, P.T., Harrison, R.J., Ferris, C.F. 1997. Anabolic androgenic steroid exposure during adolescence and aggressive behavior in golden hamsters. Physiol. Behav. 61, 359-364.

Mohammed, H.H., Badawi, M.E., El-Tarabany, M.S., Rania, M., 2016. Effects of boldenone undecylenate on growth performance, maintenance behaviour, reproductive hormones and carcass traits of growing rabbits. Polish Journal of Veterinary Sciences. 19,2, 245–251.

Moon, S.H., Lee, I., Feng, X., Lee, H.Y., Kim, J., Ahn, D.U., 2016. Effect of dietary beta-glucan on the performance of broilers and the quality of broiler breast meat. Asian-Australasian J. Anim. Sci. Asian-Australasian Association of Animal Production Societies (AAAP). 29, 384.

Mooradian, A.D., Morley, J.E., Korenman, S.G., 1987. Biological actions of androgens. endocrine reviews. 8, 1–28.

Morshdy, A.E.M., Darwish, W.S., El Sayed, S., Ali, S.M., 2022. Amino acid profile of rabbit meat: dietary intake and the effect of freezing on the amino acid composition. Thai J. Vet. Med. 52, 251-258.

Mottet, A., Haan, C.d., Falcucci, A., Tempio, G., Opio, C., Gerber, P.J., 2017. Livestock: on our plates or eating at our table? a new analysis of the feed/food debate. Global Food Security. 14, 1–8.

Mottram, D.R., George, A.J., 2000. Anabolic steroids. Best Pract. Res. Clin. Endocrinol. Metab. 14, 55–69.

Oda, S.S., El-Ashmawy, I.M., 2012. Adverse effects of the anabolic steroid, boldenone undecylenate, on reproductive functions of male rabbits. Int. J. Exp. Path. 93, 172–178

Perna, A., Simonetti, A., Grassi, G., Gambacorta, E., 2018. Effect of a cauliflower (*Brassica oleraceae* var. botrytis) leaf powder-enriched diet on performance, carcass and meat characteristics of growing rabbit. Meat Sci. 149, 134–140.

Pla, M., Pascual, M., Ariño, B., 2010. Protein, fat and moisture content of retail cuts of rabbit meat evaluated with the NIRS methodology. World Rabbit Science. 12, 3, pp.149-158.

Rasinska, E., Czarniecka-Skubina, E., Rutkowska, J., 2018. Fatty acid and lipid contents differentiation in cuts of rabbit meat. CYTA-J. Food. 16, 807–813.

Resta-Lenert, S., Barrett, K.E., 2003. Live probiotics protect intestinal epithelial cells from the effects of infection with enteroinvasive *Escherichia coli* (EIEC). Gut. 52, 988–997.

Ritchie, H., Rosado, P., Roser, M., 2017. Meat and dairy production. https://ourworldindata.org/meat-production (Accessed 15 December 2022).

Ruleva, T.A., Sarbatova, Y.N., Yu, S.K., 2015. Nutritional value of rabbit meat. World Sci. 4, 68–70.

Salma, U., Miah, A. G., Maki, T., Nishimura, M., Tsujii, H., 2007. Effect of dietary Rhodobacter capsulatus on cholesterol concentration and fatty acid composition in broiler meat. Poultry Science. 86, 20−1926.

Simonová, M.P., Chrastinová, Ľ., Mojto, J., Lauková, A., Szaboova, R., Rafay, J., 2010. Quality of rabbit meat and phyto-additives. Czech J. Food Sci. 28, 161-7.

Simonová, M.P., Chrastinová, Ľ., Lauková, A., 2020. Effect of beneficial strain Enterococcus faecium EF9a isolated from Pannon White rabbit on growth performance and meat quality of rabbits. Ital. J. Anim. Sci. 19, 650–655.

Skladanowska-Baryza, J., Stanisz, M., 2019. Pre-Slaughter Handling Implications on Rabbit Carcass and Meat Quality-A Review. Ann. Anim. Sci. 19, 875–885.

Soeparno, 1992. Meat Scince and Technology. Gadjah Mada University Press, Yogyakarta.

Szendro, K., Szabó-Szentgróti, E., Szigeti, O., 2020. Consumers' attitude to consumption of rabbit meat in eight countries depending on the production method and its purchase form. Foods. 9, 5, 654.

Tărnăuceanu, G., Lazăr, R., Ionescu, O., Boișteanu, P.C., 2011. Research on the chemical characterization of meat harvested from rabbits and hares. Lucrări Științifice-Universitatea de Științe Agricole și Medicină Veterinară. Seria Zootehnie. 56, 273–280.

Thabet, N.S., Abdelrazek, E.M., Ghazy, E.W., Elballal, S.S., 2010. Effect of the anabolic steroid, boldenone undecylenate on reproductive performance of male rabbits. J. Reprod. Infertility. 1, 8-17.

Thienpont, L., Verhseghe, P., Brussel. K. V., De-Leenheer, A., 1998. Efforts by industry toward standardization of serum estradiol-17 f measurements. Clin. Chem. 44, 671-674.

Toldra, F., Reig, M., 2016. Residue analysis. In: Encyclopaedia of meat sciences Edt. Devine, C. and Dikemann, M. Edn. 2nd. Elsevier Science. 217–221.

Tousson, E., El-Moghazy, M., Massoud, A. Akel, A., 2012. Histopathological and immunohistochemical changes in the testes of rabbits after injection with the growth promoter boldenone. Reproductive Sciences. 19, 3, 253–259.

Uwaeziozi, U.C., 2017. Effect of estradiol on body weight and some testicular parameters of pre-pubertal rabbit bucks. International Journal of BioSciences and Technology. 10, 53–57.

Warner, R.D., McDonnell, C.K., Bekhit, A.E.D., Claus, J., Vaskoska, R., Sikes, A., Dunshea, F.R., Ha, M., 2017. Systematic review of emerging and innovative technologies for meat tenderization. Meat Sci. 132, 72–89.

Zhang, A.W., Lee, B.D., Lee, S.K., Lee, K.W., An, G.H., Song, K.B., 2005. Effects of yeast (*Saccharomyces cerevisiae*) cell components on growth performance, meat quality, and ileal mucosa development of broiler chicks. Poult Sci. 84, 1015–1021.

Zoltan, J., Karoly, B., Marta, P., Istvan, P.Z., Laszlo, M., 2017. Global rabbit meat production with a special focus on the role of China. Lucrări Ştiinţifice. 19, 31-36.