

Potential of Hydroponic Barley in Rabbit Diets: Effect on Productive Performance, Nutrient Digestibility, Microbiological and Physiological Responses

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Abstract

Application of agriculture hydroponic technology with a view to reduce the gap between the animal nutritional requirements and availability of feed ingredients create an important role in animal and rabbit production. Hydroponic fodder production such as barley is an alternative technology to cultivate fodder which provide the growing nutrients requirement for livestock feed with suitable prices, high quantity, a short growth period, a small land for production, a clean environment, water efficiently and reduces cultivate fodder resources. This study was investigated with view to give an overview on the possible role of hydroponic barley (HB) as a feed replacement in rabbit ration. Various scientific published research articles were used HB as a feed replacement in rabbit ration. The most observed and analyzed productive and reproductive performance, nutrient digestibility and physiological responses. Positive effect of feeding HB was observed on serum metabolic profile and microbial count of caecum of rabbits. However, the economics and nutritive values of hydroponic production system should be carefully estimated. This review provides an overview of and illustrates the positive effects of HB as a feed replacement in rabbit diets and their potential effects on productive performance, economic return, nutrient digestibility, microbiology and gut health of growing rabbits.

Keywords:

Hydroponic barley, Microbiology, Nutrition, Physiology, Rabbits.

DOI: 10.21608/svu.2021.67695.1114 Received: March 13, 2021 Accepted: June 12, 2021

Published: August 10, 2021

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Citation: Mohamed et al., Potential of Hydroponic Barley in Rabbit Diets: Effect on Productive Performance, Nutrient Digestibility, Microbiological and Physiological Responses. SVU-IJVS 2021, 4 (3): 12-23.

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Competing interest: The authors have declared that no competing interest exists.



Introduction

Since feed costs accounts more than 70% of total production cost, it is very important to feed the animals according to their nutrient requirements for potential production, economic growth and sustainability (Gupta, 2014). Hydroponic is now emerging as an alternative technology to grow fodder for the animal farm due to the limitations in the conventional method of cultivated green fodder in most of the Middle East and African countries, (Sneath and McIntosh 2003; Naik et al., 2011; Naik et al., 2012; and 2013). Therefore, fodder is produced without using any soil but growing the plants in water or mineral nutrient solution is known as hydroponics fodder or fresh fodder or sprouted grains (Dung et al., 2010; Bakshi et al., 2017). Furthermore, the increase of human requirements on land for producing cereal grains have made traditional green fodder cultivation hard to be augmented, beside other constrains such as climate change, water deficiency or water salinity, growth period, fertilizer requisite and expenses, (MOA, 2014; Gebremedhin et al., 2015; Saidi and Abo Omar, 2015; Hassanién et al., 2020; Gabr et al., 2020; Abdelsatar et al., 2021; Ali et al., 2021; Abdel-Lattief et al., 2020; Hassan et al., 2021; Farrag and Bakr, 2021).

Hydroponics is an alternative technology to cultivate fodder (Naik et al., 2011; Naik et al., 2012; and Naik et al., 2013). This technique can provide growing nutrients requirement for animal feed with suitable prices, and assurance of a continuous green forage production of high quantity over the year. Hydroponic barley (HB) production is a high technique of growing barley in a clean environment without chemicals and artificial fertilizer (Jensen and Malter, 1995). The HB production is alternative technology to cultivate fodder which provides the growing nutrients requirement for animal feed with suitable prices, high quantity, short growth period, small land for

production, clean soil, safe water and reduces cultivate fodder resources (Mooney, 2005). Furthermore, the biological and economic performance of HB production and utilization depends on the agriculture conditions, dry matter (DM) content and water consumption (Fazaeli et al., 2012; Kide et al., 2015).

It is known that the contents of energy and protein in the diets of growing rabbits affect their growth rate. Energy and protein are the greatest significant factors essential to get maximum weight gain (Lebas, 1989). The rabbits' diets should contain about 10.5 MJ digestible energy (DE) /kg DM and diets offered *ad libitum* with at least 9.5 MJ/kg DM DE improved growth performance (Santom et al., 1989). Feeding rabbits on diets containing low levels of fiber reduce growth performance of rabbits (De Blas et al., 1986). The HB contains about 15-18% crude protein and 8-10 MJ/kg DM DE which considered good nutritional value for rabbit nutrition. The use of HB in feeding growing male or female rabbits showed significant nutritional benefits (Abouelezz and Hussien, 2017) mainly due to it nutritional values. Partial substitution of corn grains with 20% barely grains in rabbit diets increase body weight, feed intake and feed conversion ratio (El-Adawy et al., 2012). Replacing of HB at 20 or 40 % of commercial feed in growing rabbit diets has favorable effects, however, higher level at 60% of HB in rabbit diets is not recommended because it negatively affects nutrients digestibility and feeding values of tested diets (Mehrez et al., 2018).

There are gradual decreases in DM and Nitrogen free extract (NFE) content, and increases in Ash, ether extract (EE), crude protein (CP) and crude fiber (CF) content by increasing age of HB sprouting (Mehrez et al., 2018). On the other hand, some researchers have indicated that replacing pelleted commercial feed by HB has negative effects on growth performance (Morales et al., 2009; Shanti et al., 2017;

Gabr et al. 2020). Feed intake and growth rate decreased linearly by HB increase (Morales et al., 2009; Shanti et al., 2017). Also, both CP and DE intake decreased linearly (Shanti et al., 2017). Growing rabbits fed concentrate feed mixture showed the highest significant values of average total and daily gain, relative growth rate, performance compared with those fed HB diets (Gabr et al. 2020).

Concerning, carcass yield was not affected by replacing pelleted commercial feed by HB (Morales et al., 2009; Shanti et al., 2017; Gabr et al. 2020). Positive significant effect of feeding HB at levels of 20 and 40% is shown on concentrations of blood total protein, albumin and glucose (Mehrez et al., 2018). Rabbits fed HB diets significantly increased the total viable count of bacteria in caecum (Mehrez et al., 2018). Hydroponic barley could be used up to 30% in diets of growing rabbits.

Previous studies showed varying results in this aspect, which could be due to growth period, environmental conditions, and cultivated grains. The knowledge gaps from the past studies are considered, and the use of HB in rabbit ration is suggested. The findings have motivated further study on HB to find out the most methods and their optimal doses in rabbit rations. Finally, this review provides an overview of and illustrates the positive effects of HB as a feed replacement in rabbit diets and their potential effects on productive performance, economic return, nutrient digestibility, microbiology and gut health.

Chemical composition and nutritional value of HB

Evaluation of nutritive value of HB (Fig. 1) is important aspect for the sustainability of products and productivity in rabbit production. Mehrez et al. (2018) reported that the barley seed form contains 93.1% DM, 97.6 % OM, 12.7% CP, 6.3% CF, 1.8% EE, 33.1% Neutral detergent fiber (NDF), 15.2% acid detergent fiber (ADF)

and 2.4% ash. On the other hand, Gebremedhin et al. (2015) found that the barley seed form contains 93.81% DM, 11.11% CP, 8.9% CF, 1.68% EE, 20.1% NDF, 1.81% total ash, and 8.0% ADF. Furthermore, Kide and Abrha (2016) reported that 6 days-HB contains 11.11% CP, 3.35% EE, 8.9% CF, 57.5% NDF and 38.36% ADF.

Sprouting of cereal grains produced an increased nutrient quantity and quality such as protein, digestible energy, fats, sugars, minerals and vitamin contents (Cuddeford, 1989; Gebremedhin, 2015). Based on previous studies, the chemical structure of HB as DM, OM, CP, CF, EE, GE, NDF, ADF, ADL, contents were suitable to replacement the concentrate feed in rabbit. For example, HB contained suitable amount of DM, OM, CP, NDF, ADF and DE, which improve growth performance of rabbits (Shanti et al. 2017). Likewise, Abouelezz et al. (2019) indicated that HB contains 23.3% CP, 4.17% EE, 26.7% NFE, and 3.97% ash as DM basis. Moreover, the chemical compositions could be affected by the cultivation conditions in hydroponic systems. The increase in EE content could be due to the production of chlorophyll associated with plant growths that are recovered in ether extract measurement (Mayer and Poljakoff-Mayber, 1975). The higher content of CF in HB may be due to the synthesis of structural of NDF, ADF, ADL (Cuddeford, 1989).

The lower value of DM in HB may be related to that the increase of water initiates increases metabolic activity of resting seeds leading to loss of dry weight through the germination of HB (Morsy et al., 2013; Abd-El-Khalek, 2020). Such changes in nutrients profile and recovery are misleading, since they only described the alterations in the proportion of nutrients during growth and sprouting of seeds (Morgan et al. 1992). A change in the weight of either the nutrient led to proportional changes in other compositions.

Digestible crude protein has values from 11.26 to 11.36% while digestible energy has values from 2822 to 2945 kcal/kg diet (Mohsen et al., 2015). Mehrez et al. (2018) found that 7-day HB contains 15.0 % DM, 96.3 % OM, 16.0 % CP, 14.5% CF, 3.1% EE, 38.5% NDF, 3.7% ash, and 22.7 % ADF. Also, Nagadi (2019) reported that 8 days HB contains 17.5 % DM, 91 % OM, 15.2 % CP, 15.9 % CF, 4.0 % EE, 3.9 % ash, 39.4% NDF, 61 % NFE, 3171.2 (Kcal/kg DM) DE and 4424.3 (Kcal/kg DM) gross energy (GE). Furthermore, Kide and Abrha (2016) reported that the 8th-day grown HB contains 13.89% CP, 3.60% EE, 14.2% CF, 35.3% NDF and 16.20% ADF content. Moreover, Ata (2016) showed that the chemical composition of HB contains 15.3% DM, 22.5% CP, 11.4% CF, 3.2% EE, 32.5 % NDF and 13.1 % ADF. The fresh-8-day HB contains 13.64 % DM, 13.89% CP, 14.2% CF, 3.6% EE, 35.3% NDF, 4.1% total ash and 16.2% ADF. Also, fresh 7-day hydroponic barley fodder contains 14.2% DM, 14.44% CP, 5.67% EE and 13.5% CF, 64.66% NFE, 3.4% total ash, 0.68% Calcium content and 0.46% Phosphorus content (Gebremedhin, 2015). The fresh-8-days HB contained 16.38 % DM, 23.03 % CP, 4.17 % EE, 26.7 % NDF

and 3.97 % ash (Abouelezz et al., 2019). Also, the fresh-8-day HB contained 17.30% DM, 15.75% CP, 15.90% CF, 4.05% EE, 60.96% Nitrogen free extract (NFE) and 3.34% ash (Abouelezz and Hussein, 2017).

Furthermore, the chemical composition of HB contents 18.65% DM, 96.40% OM, 17.01% CP, 12.73% CF, 3.31% EE, 3.60% ash (Mohsen et al., 2015). Also, Gabr et al., (2020) reported that the chemical composition of HB resulted in 15.0% DM, 96.3% OM, 16.0% CP, 14.5% CF, 3.04% EE, 54.0% NFE and 3.70% ash. Shanti et al. (2017) found that the fresh-8-day HB contains 18.0% DM, 2.0 % CP, 15.0% CF, 2.50% EE, 62.0% NFE and 5.0% ash. Morales et al., (2009) showed that the chemical composition of HB contains 16.10% DM, 13.50% CP, 16.30% CF, 2.55% EE, 62.9% NFE and 4.80% ash. Abd Rahim and Omar (2015) showed that the chemical composition of HB contains 18.3% DM, 19.8% CP, 10.4% CF, 35.40 % NDF, 11.90 % ADF, 3.20% calcium, 4.10 % phosphorus and 3.60% ash. The nutritive value variations of HB in the precious studies may be due to HB growth period, cultivated conditions and methods as well as the chemical methods.

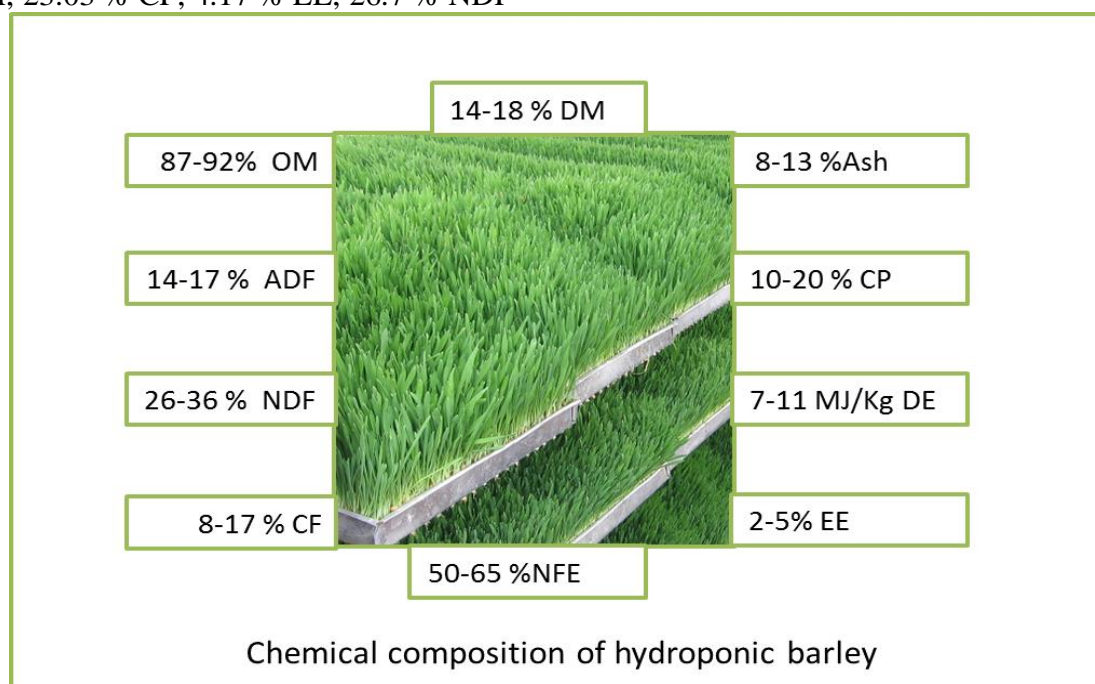


Fig. 1. Approximate chemical composition of hydroponic barley

Influence of hydroponic barley on growth performance and feed cost of growing rabbits

Recently, rabbit production has developed rapidly, most especially to cover the increasing demand in fresh meat for human consumption as well as extra income for farmers therefore much research was conducted to improve the productive performance and meet quality of rabbits (Abdel-Wareth et al., 2015; Abdel-Wareth et al., 2018; Abdel-Wareth et al., 2019; Abdel-Wareth and Metwally, 2020; Abdel-Wareth et al., 2020). Several feeding strategies have been developed during the last two decades for the utilization of safe and cheap feed for animals. Furthermore, various studies have been conducted to explore the use of HB on growth performance of rabbits. Abouelezz and Hussein (2017) carried out two experiments in order to conclude the nutrient composition and feeding value of the hydroponic barley fodder (HBF) and that HBF irrigated with bakers' yeast (HBFY) for the growing Californian and White New Zealand rabbits. They showed that the male rabbits provided with HBF recorded the highest body weight, body weight gain and feed intake ($P<0.05$), while HBFY male rabbit had the worst ($P<0.01$) feed conversion ratio and for females, they found that the animals fed HBF and HBFY had lower ($P<0.01$) concentrate feed intake compared to control females (111.9 and 127.0 vs. 157.6 g/d) and HBF improved feed conversion ratio in HBF females compared to control group. The rabbits fed HB plus anaerobic probiotics addition are higher in final body weight, total body weight gain and daily body weight gain and feed conversion ratio than the other tested groups of rabbits (Nagadi, 2019).

The use of vegetated fenugreek seeds (SF) and/or barley grains (SB) on rice straw and their mixtures at different levels (0, 25, 50, 75 and 100%, respectively) in growing New Zealand White rabbit's diet resulted in rabbits fed 28% SF and 28% SB diet have

higher body weight gain than those fed control (clover hay) diet (Sekken et al., 2012). The effect of substitution of corn with different levels of barley grains (0, 5, 10, 15, 20 and 25%) of the total diet on growth performance of growing male New Zealand White rabbits resulted in rabbits fed the 20% barley grains diet have significantly ($P<0.05$) the highest live body weight value, while those fed the 25% barley grains diet have significantly ($P<0.05$) the highest feed intake value and the highest feed conversion ratio (FCR) is recorded for rabbits fed 20% BG diet and then those of 15% BG and 25% BG diets (El-Adawy et al., 2012). Gabr et al., (2020) studied the effect of partial replacing of concentrate feed mixture (CFM) diet by HB on productive performance of growing APRI male rabbits resulted in rabbits fed control diet is significantly ($P<0.05$) higher in body weight gain, relative growth rate, and performance index, than those fed HB diets. Replacing pelleted commercial feed by HB for 32 days of age growing local Baladi rabbits resulted in dry matter feed intake and growth rate reduced linearly by 1.16 ± 0.080 g/d ($P<0.001$) and 0.998 ± 0.062 g/d ($P<0.001$) per unit of HB increase (Shanti et al., 2017).

Substituting HB offer a commercial feed of growing New Zealand rabbits from 35 to 70 day of age resulted in dry matter feed intake and growth rate decreased in substituting treatments, however, feed conversion was not influenced by treatments (Morales et al., 2009). Recently, it has been a major aim for Nutritional scientists to study the rabbit performance and minimize the feeding costs. Moreover, the most important factors involved in achievement of maximum meat production efficiency values depend on the body weight gain, the growing period length and the cost of feed. Application of HB as a substitution concentrate feed in growing rabbit diets improved economic return and reduced the total feed cost (Nagadi, 2019). Furthermore, Abouelezz and Hussein (2017) reported that substitution HB of commercial diet of

fattening rabbits reduced feed cost per gain than the control. In economic point of view, HB has a short growth period between 7-10 days and requires a small piece of land area for production (Mooney, 2005). Also, HB improved body weight gain, feed conversion ratio and economic efficiency (Fayed, 2011).

Influence of hydroponic barley on nutrient digestibility of growing rabbits

Sprouting of cereal grains produced an increased nutrient quantity and quality such as protein, digestible energy, fats, sugars, minerals and vitamin contents (Cuddeford, 1989; Gebremedhin, 2015). Moreover, HB is rich in enzymes, therefore, feeding of the HB improves the digestibility and productive performance of animals due to removal the acidic conditions. As well as, sprouting grains are serving in the removal the anti-nutritional. The digestibility of OM, TDN, CP and NFE in HB was higher than values of control diet (Sekken et al., 2012). Also, Nagadi (2019) studied the effects of feeding partial substitution of fresh 8 days-age HB with different levels (0, 25, 50%) for concentrate fodder with or without probiotics on digestible coefficients of growing male New Zealand white rabbits and resulted in DM, CP, CF and NFE digestible coefficients for rabbits fed rabbits fed HB plus anaerobic probiotics addition are significantly higher ($p < 0.05$) than other rabbit's groups. Also, all rabbits' groups have DM higher than those fed control diet. The TDN and DCP nutritive values are higher for rabbits fed 25% HB diet and rabbits fed HB plus anaerobic probiotics addition diet than other groups.

On the other hand, Mehrez et al. (2018) showed that DM, OM, EE and NFE digestibility in rabbits fed commercial concentrate feed mixture are significantly ($P < 0.05$) higher than those fed 20%, 40% and 60% HB diets. Conversely, values of CP and CF digestibility for the group fed 20% HB diet (78.62 % and 59.42 %, respectively) are significantly ($P < 0.05$) higher than those fed

40% HB diet and control diet. They also observed that the CP and CF values for the group fed 60% HB diet (59.42 % and 25.74 %, respectively) are the lowest between the four diets. For the nutritive value of tested diets, but TDN and DE values for the groups fed control diet and 20% hydroponic barley diet (64.91 and 63.30 %, respectively) are significantly ($P < 0.05$) higher than those fed 40% hydroponic barley diet (55.22 %) and 60% hydroponic barley diet (45.11 %). Also, Mohsen et al. (2015) showed that the digestibility coefficients of different nutrients and nutritive values are almost comparable for the commercial rabbit diet and the diets contained 30% HB.

Using HB could be increased the digestible of the nutrients which could be qualified to the tenderness of the fodder (Naik et al., 2013). These enhancements might be due to high content of leafy, roots sprouts which is easy to digest and hydrolysis by the enzymes of gut microflora, as well as enzymatic digestion such as proteases present in the lytic vacuoles of plant cells. In this connect, Chung et al. (1989) said that high soluble protein and amino acids refer to the response in the early plant growth and enzymatic changes of sprouted grains are responsible for improving the digestibility in the animals.

Microbiological, Physiological and histological response of rabbits to hydroponic barley

Related to microbiological response of rabbits to HB, also, rabbits fed HB diets (20, 40 and 60%) was significantly ($P < 0.05$) increased total viable count of bacteria in caecum and high percentage of diarrhoeal cases compared with those fed the control diet without HB (Mehrez et al., 2018). This may be related to the moisture content of HB diets and could be increased by pathogenic bacteria such as coliforms and especially *E. coli* which are important opportunist pathogens and can be a major cause of enteritis and losses in rabbit farm. The

pathogenic and toxigenic bacteria cause diarrhea in rabbits (Harcourt-Brown, 2002). However, more studies are needed to clarify the fractions of population of bacteria (beneficial or pathogenic bacteria) in cecum of rabbits fed HB diets to implement the intestinal health of rabbits (Bivolarski *et al.* 2011). Also, Belenguer *et al.* (2000) indicated that concentration of total bacteria is higher ($P < 0.05$) in barley grains diets than corn grains diets and high addition of barley grains augmented the total bacterial count in the cecum.

Replacing concentrate feed mixture with HB significantly increases the total viable bacterial count, since HB has shown much improving positive effects on growth performance and control of pathogenic bacteria (El-Gogary *et al.* (2018).

It is important to consider the specific effects of HB on physiological response of rabbits before used as feed. Furthermore, serum metabolic profiles are reflected on health status and are good indicators of rabbit physiological, pathological, and nutritional status. Nagadi (2019) studied the substitution of HB as a partial replacement for concentrate feed contains anaerobic probiotics and resulted in HB diet with or without addition of anaerobic probiotics have higher total protein, globulin, albumin total lipid and total cholesterol in serum blood than those fed control diet, but there are no significant differences between the groups on creatine, aspartate aminotransferase (AST) and alanine aminotransferase (ALT). Mehrez *et al.* (2018) reported positive significant ($P < 0.05$) influence of substituting a commercial feed with HB at levels of 20 and 40 % on total protein, albumin, AST and glucose, however, globulin, cholesterol, triglycerides, urea and creatine were not significantly differences among tested groups. They also, concluded that most plasma parameters values are within the normal ranges for rabbits given 5.4–7.3 g/dl total protein, 2.4–4.5 g/dl albumin, 2.9–4.9 g/dl globulin, 80–150 mg/dl glucose, 10–80

mg/dl cholesterol, 10–45 IU/l ALT and 10–120 IU/l AST. Shanti *et al.* (2017) studied the effect of substituting a commercial feed with HB on 32 days of age growing local Baladi rabbit blood biochemistry and showed that blood metabolites are within the MEDIRABBIT standards and are variably affected by the diets fed. Feeding HB had no effects on creatine, albumen, globulin and AST. Nevertheless, HB decreased levels of blood urea and total protein and has variable effects on other blood metabolites as cholesterol, triglycerides and ALT.

Unfortunately, there are no studies on impact of HB on development of gut and internal organs health of rabbits, therefore, more studies are needed to clarify the impact of HB on histological response of rabbits.

Effects of HB on carcass criteria of rabbits

The rabbits provided with fresh HB recorded the highest carcass weight, forelegs weight, and hind part than the values obtained in control and HB irrigated with bakers' yeast groups (Abouelezz and Hussein, 2017). Nagadi (2019) reported that empty carcass with head and dressing ratio was significantly improved by rabbits fed 50% HB with anaerobic probiotics addition diet. The rabbits fed HB diet with addition of anaerobic probiotics have higher liver %, kidney %, and edible giblets percentage than those fed control diet. Nevertheless, all rabbits' groups show insignificant differences in heart percentage. Gabr *et al.* (2020) studied the effect of partial replacing of concentrate feed mixture diet by HB on carcass traits of growing male rabbits and reported that the dressing percentage, liver, lung and the relative weight of intestine are not significantly differ among rabbits fed control diet and those fed HB diets. However, the weight of hot carcass is significantly ($P < 0.05$) influenced by inclusion of HB in the diet, where rabbits fed concentrate feed mixture are the heaviest (1132 g) then rabbits fed 40% HB, 20% HB,

and 60% HB diets (870 g, 835 g and 727 g, respectively). El-Adawy et al. (2012) studied the effect of substitution of corn with different levels of barley grains at 0, 5, 10, 15, 20 and 25% of the total diet on carcass characteristics of growing male New Zealand White rabbits and found that the per-slaughter weight, hot and cold carcass weight and dressing percentage are significantly ($P < 0.05$) different in the tested groups and that the group of rabbits fed 20% barley grains diet has the highest value. They also showed that the relative weight of liver, heart, spleen, gallbladder, lungs plus trachea and full is not differ among the tested rabbit groups. Though, kidneys relative weight is significantly differed ($P < 0.05$) among the tested rabbits' groups. Mohsen et al. (2015) reported that the slaughter and carcass weights and dressing percentage are not affected by HB addition in diets And indicated that the weights and percentages of organs are slightly influenced by HB enclosure in diets with the exception of liver percentage, spleen weight and the weight and percentage of shoulder fat shown significant differences ($P < 0.05$). Morales et al., (2009) showed that dressing percentage of rabbits is not affected by replacing a commercial feed with hydroponic green barley forage. Also, Shanti et al. (2017) reported that inclusion of HB has variable effects on visceral organs of rabbits and the higher levels of HB addition (40 and 60%) produced a significant increase ($P < 0.05$) in gall bladder and heart weights but other visceral organs are not affected by HB feeding. Mehrez et al. (2018) reported that the significantly ($P < 0.05$) highest cecum length was recorded with rabbits fed 40 and 60 % HB, while the significantly ($P < 0.05$) lowest value was observed with group fed 20% HB. Similarly, Sekken et al. (2012) found that the length of rabbit caecum was significantly higher in HB diets than control.

Conclusions and Future Perspective

The findings of various scientific studies on hydroponic barley reveal that

hydroponic barley represents an effective partial replacement for the commercial diets in rabbit nutrition. Their apparent actions include improved growth performance, nutrient digestibility, economic benefits of feed efficiency and serum metabolic profile as well as inhibition of pathogens.

Conflict of interest statement

The author declares that there are no conflicts of interest regarding publication of this article.

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