American-Eurasian J. Agric. & Environ. Sci., 11 (5): 685-696, 2011
ISSN 1818-6769

Broccoli By-Products as a Partial Replacement of Lucerne Hay in Rabbit Diets Containing Different Levels of Protein

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Abstract: A total number of 54 male growing New Zealand rabbits were used to study the effect of broccoli by-products as a partial replacement of Lucerne hay in rabbit diets containing different levels of protein. Rabbits were classified into six equal groups (G_1-G_6). The 1st and 4th groups received basal ration with 100 % and 90 % protein requirements and served as first and second control, respectively. The 2nd and the 3rd groups received basal ration with 100% protein requirements replacement with broccoli by-product at the level of 3% and 6 % of Lucerne hay, respectively. The 5th and 6th groups received basal ration with 90% protein requirements with broccoli by-product at the level of 3% and 6 % of Lucerne hay, respectively. The 90% protein requirements significantly (P<0.05) increased the digestibility coefficients of (OM, EE and NFE) and TDN value, while insignificantly (P<0.05) increased the digestibility coefficients of (DM, CP and CF) compared with 100% protein. On the other hand decreasing level of protein requirement from 100 to 90% significantly (P<0.05) decreased DCP value. The 90% protein requirements with replacement level at 3% broccoli by-products (G_5) showed the best digestion coefficients of (OM, CP and CF) and nutritive values as (TDN and DCP). The 90% protein requirements with replacement level at 6% broccoli by-product (G_6) recorded the best digestion coefficients of EE as well as the best values of final weight, total body weight gain, average daily gain and feed conversion. The 100% protein requirement with Lucerne hay (G_1) showed lowest values of DM, OM and CF digestibility coefficients. The 100% protein requirements with replacement level at 3% broccoli by-product (G_2) showed the highest value of DM digestibility coefficient. Replacement at 3% or 6% of Lucerne hay with broccoli by-product significantly (P<0.05) improved the final body weight, total body weight gain and average daily gain compared to control diet, while showed insignificant (P>0.05) effects on feed intake of (DM, CP, DCP, TDN and DE) and feed conversion (g intake /g gain) of DM, CP, DCP, TDN and (Kcal intake /g gain) of DE. The protein levels had no significant effects (P>0.05) on either of the edible offal's weight of (liver, heart, kidneys, testes, spleen and lungs) and chemical analysis of the 9, 10 and 11th ribs as well as showed significant effects (P>0.05) on inedible offal's weight, digestive tract, carcass weight and carcass cuts. The broccoli by-product levels significantly decreased the dressing percentages. The 90% protein requirements significantly (P<0.05) decreased the inedible offal's, empty body weight, carcass weight, dressing percentages and carcass cuts. The highest value of net revenue, economical efficiency and relative economic efficiency as well as the lowest value of feed cost/ kg live body weight were recorded at the 90% protein requirements with broccoli by-product replacement at 6% level treatment flowed by the broccoli by-product replacement at 3% level treatment. From the data obtained under these conditions of this work, it can be mentioned that broccoli by-products can be used successfully in rabbit diets as a good alternative for Lucerne hay with no adverse effect on growth performance, digestion coefficients and carcass characteristics.

Key words: Broccoli by-product · Rabbits · Growth performance · Digestibility · Carcass characteristics · Economic evaluation

INTRODUCTION

Because of the increasing cost of protein feed ingredients, this effort were carried out to use untraditional feed ingredients to participate in facing protein shortage problem and at the same time to decrease feeding costs. Low dietary protein requirements may cause imbalance in the body metabolism and growth

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performance and they are often at the expense of the proportion of fiber in the diet. Broccoli used as untraditional feed ingredients is the dried whole plant of *Brassica oleracea* L. belonging to the family Brassicaceae [1]. The hypothesis that broccoli as food source for medicinal substances that contains sulfur and selenium as well as the high fiber quality can compensate the shortage of protein in rabbits diet. Broccoli is a rich source of chemo protective molecules including glucosinolates, which considered a class of organic compounds that contain sulfur and nitrogen [2] which often approaches 1% or more of their dry weight [3]. *Brassica oleracea* L. exhibited sulfur volatile compounds [4] which are a main component of the biochemical structure of the amino acids, cysteine, methionine, taurine and glutathione [5].

Selenium stimulates amino acid incorporation into protein in hepatocytes, mitochondria and post-mitochondria with increments of glutathione peroxidase activities [6]. Selenium from *Brassica oleracea L* offers the same advantage of selenium from sodium selenite of quail's tissue [7]. Selenium fortified broccoli has been proposed as a functional food for cancer prevention, based on its high glucosinolates content [8]. Sulfur and selenium provide an efficient means to synthesize, remodel and immobilize proteins and they have enabled us to interrogate biological systems [5]. Oxo-sulfur and selenium compounds have similar abilities to act as both antioxidants and pro-oxidants with different mechanisms [9]. Sulfur and selenium are enabling to interrogate protein structure and function with unprecedented precision [5]. Broccoli fiber quality can compensate the lack of protein in rabbit's diet. Microbiota in the gastrointestinal tract plays a crucial role in mediating the effects of foods on colonic health and host metabolism [10]. The forage *Brassica* is a useful model system of wood formation because the thickened cell walls of the vascular tissue vary widely in lignin content [11]. Broccoli protected the large bowel ecosystem by fermentable oligosaccharide which may be beneficial to some microbiota in cecum, altered cecal short-chain fatty acids and increased the colon crypt depth and the number of goblet cells per crypt as shown in rat by Paturi *et al.* [10].

This work aimed to evaluate the efficacy of the partial replacement of Lucerne hay with broccoli by-products in rabbit diets contained different levels of protein on rabbit growth performance.

MATERIALS AND METHODS

Fifty four male New Zealand White rabbits aged 5 weeks with an average body weight of 553 ± 7.01 g were divided into six equal groups. The basal experimental diet was formulated and pelleted to cover the nutrient requirements of rabbits as a basal diet according to NRC [12] as shown in Table 1 and diets were offered pelleted at 4 mm diameter. Lucerne hay in control diet was replaced with broccoli by-products at the levels of 0%, 3% or 6%, feeding period was extended for 56 days and the experimental groups were classified as following:

Group 1: Basal diet with 100% protein requirements and served as control (G1),
Group 2: Basal diet with 100% protein requirements with replacement broccoli at 3% (G2)
Group 3: Basal diet with 100% protein requirements with replacement broccoli at 6 % (G3)
Group 4: Basal diet with 90% protein requirements and served as control (G4)
Group 5: basal diet with 90% protein requirements with replacement broccoli at 3% (G5)
Group 6: Basal diet with 90% protein requirements with replacement broccoli at 6 % (G6)

Rabbits individually housed in galvanized wire cages (30 x 35 x 40 cm). Stainless steel nipples for drinking and feeders allowing recording individual feed intake for each rabbit were supplied for each cage. Feed and water were offered *ad-libitum.* Rabbits of all groups were kept under the same managerial conditions and were individually weighed and feed consumption was individually recorded weekly during the experimental period. At the end of the experimental period all rabbits in feeding trials were used in digestibility trials over period of 7 days to determine the nutrient digestibility coefficients and nutritive values of the tested diets. Feces were daily collected quantitatively. Feed intake of experimental rations and weight of feces were daily recorded. Representative samples were dried at 60°C for 48 hrs, ground and stored for later chemical analysis. At the end of the experimental period, six representative rabbits from each treatment were randomly chosen and fasted for 12 hours before slaughtering according to Blasco *et al.* [13] to determine the carcass measurements. Edible offal's (Giblets) included heart, liver, testes; spleen, kidneys and lungs were removed and individually weighed. A full and empty weight of

Table 1: Composition of the experimental diets (kg/ton)

	Experimental diets					
	100% Protein requirements			90% Protein requirements		
Item	G_1	G_2	G_3	G_4	G_5	G_6
Yellow corn	100	100	100	150	150	150
Barley grain	250	250	250	250	250	250
Wheat bran	200	200	200	200	200	200
Soybean meal 44% CP	160	160	160	100	100	100
Lucerne hay	210	180	150	220	190	160
Broccoli by-products	--	30	60	--	30	60
Alfalfa straw	45	45	45	45	45	45
Sodium chloride	5	5	5	5	5	5
Anti fungal agent	4	4	4	4	4	4
Bone meal	17	17	17	17	17	17
Lime stone	3	3	3	3	3	3
Vit. & Min. mixture*	3	3	3	3	3	3
DL-Methionine	3	3	3	3	3	3
Price, L.E**/Ton	2208	2174	2139	2157	2122	2088

* Vit. & Min. mixture: Each kilogram of Vit. & Min. mixture contains: 2000.000 IU Vit. A, 150.000 IU Vita. D, 8.33 g Vit. E, 0.33 gVit. K, 0.33 gVit. B_1, 1.0 gVit.B_2, 0.33g Vit.B_6, 8.33 g Vit.B_5 1.7 mg Vit. B_{12} 3.33 g Pantothenic acid, 33 mg Biotin, 0.83g Folic acid, 200 g Choline chloride, 11.7 g Zn, 12.5 g Fe, 16.6 mg Se, 16.6 mg Co, 66.7 g Mg and 5 g Mn.** L.E: Livre Egyptian (Egyptian Pound) =0.18 American dollars approximately

digestive tract was recorded. Weights of Internal and external offal's were recorded. The 9, 10 and 11th ribs were frozen in polyethylene bags for later chemical analysis. The best 9, 10 and 11th ribs of samples were dried at 60°C for 24 hrs. The air-dried samples were analyzed for DM, EE and ash according to the A.O.A.C. [14] methods, while CP percentage was determined by difference as recommended by O'Mary *et al.* [15].

Chemical analysis of experimental rations and feces were analyzed according to A.O.A.C [14]. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL)} were also determined according to Goering and Van Soest [16]. Hemicellulose was calculated as the difference between NDF and ADF, while cellulose was calculated as the difference between ADF and ADL. Gross energy (kilo calories per kilogram DM) was calculated according to Blaxter [17], where, each g of crude protein (CP) = 5.65 kcal, each g of ether extract (EE) = 9.40 kcal and each g crude fiber (CF) and nitrogen-free extract (NFE) = 4.15 kcal. Digestible energy (DE) was calculated according to Fekete and Gippert [18] using the following equation:

$$DE\ (kcal/\ kg\ DM) = 4253 - 32.6\ (CF\ \%) - 144.4\ (total\ ash).$$

Non fibrous carbohydrates (NFC) were calculated according to Calsamiglia *et al.* [19] using the following equation:

$$NFC = 100 - \{CP + EE + Ash + NDF\}.$$

Economical efficiency of experimental diets was calculated according to the local market price of ingredients and rabbit live body weight as following:

Net revenue = total revenue - total feed cost.
Economical efficiency(%)=net revenue/total feed cost%

Statistical Analyses: Collected data were subjected to statistical analysis as two factors-factorial analysis of variance using the general linear model procedure of SPSS [20]. Duncan's Multiple Range Test [21] was used to separate means when the dietary treatment effect was significant.

RESULTS AND DISCUSSION

Chemical Analysis and Cell Wall Constituents of the Tested Materials and the Experimental Diets: The strongly similarities in chemical analyses between broccoli by-product and Lucerne hay are shown in Table 2. The variations of crude protein contents of the six tested rations (G_1-G_6) were 16.11, 16.18, 16.07, 14.51, 14.58 and 14.53 %, respectively, were related to the quality and replacement levels of the different ingredients used. The chemical analysis of (OM, CF, EE and NFE); gross energy; digestible energy; non fibrous carbohydrates and

Table 2: Chemical analysis and cell wall constituents of the tested materials and the experimental diets

	Tested materials		Experimental diets					
			100% Protein requirements			90% Protein requirements		
Item	Lucerne hay	broccoli by-product	G_1	G_2	G_3	G_4	G_5	G_6
Dry matter (DM)	90.17	91.72	91.04	88.87	85.79	89.25	90.92	91.18
Chemical analysis on dry matter basis								
Organic matter (OM)	87.71	86.44	90.19	90.12	90.22	90.08	90.18	90.09
Crude protein (CP)	15.19	14.26	16.11	16.18	16.07	14.51	14.58	14.53
Crude fiber (CF)	25.04	23.87	10.16	9.92	10.2	9.78	9.9	9.75
Ether extract (EE)	1.52	2.35	3.29	3.35	3.28	3.3	3.39	3.26
Nitrogen-free extract (NFE)	45.96	45.96	60.63	60.67	60.67	62.49	62.31	62.55
Ash	12.29	13.56	9.81	9.88	9.78	9.92	9.82	9.91
Gross energy (kcal/ kg DM)[1]	3948	3925	4157	4159	4157	4129	4139	4128
Digestible energy (kcal/kg DM)[2]	1662	1517	2505	2502	2503	2508	2512	2504
Non fibrous carbohydrates (NFC)[3]	45.87	32.69	30.98	31.14	31.78	32.49	32.79	33.24
Cell wall constituents								
Neutral detergent fiber (NDF)	25.13	37.14	39.81	39.45	39.09	39.78	39.42	39.06
Acid detergent fiber (ADF)	19.87	21.05	16	15.96	15.92	15.75	15.71	15.68
Acid detergent lignin (ADL)	6.13	8.85	5.76	5.72	5.67	5.53	5.48	5.43
Hemicellulose	5.26	16.09	23.81	23.49	23.17	24.03	23.71	23.38
Cellulose	13.74	12.2	10.24	10.24	10.25	10.22	10.23	10.25

[1]Gross energy (kilo calories per kilogram DM) was calculated according to Blaxter [17] where, each g of crude protein (CP) = 5.65 kcal, each g of ether extract (EE) = 9.40 kcal and each g crude fiber (CF) and nitrogen-free extract (NFE) = 4.15 kcal. [2]Digestible energy (DE) was calculated according to Fekete and Gippert [18] using the following equation:

DE (kcal/ kg DM) = 4253 - 32.6 (CF %) - 144.4 (total ash).[3] Non fibrous carbohydrates (NFC), calculated according to Calsamiglia et al. [19] using the following equation: NFC = 100 - {CP + EE + Ash + NDF}.Hemicellulose = NDF - ADF.

Cellulose = ADF - ADL.

Table 3: Main effects of protein and brokely by-product levels on nutrient digestibility coefficients and nutritive values of the experimental diets

	Experimental diets						
	Protein levels			Broccoli by-product levels			
Item	100%	90%	SEM	0%	3%	6%	SEM
Digestibility coefficients							
Dry matter (DM)	81.34	83.78	1.00	79.01^{b}	85.38^{a}	83.33^{a}	1.00
Organic matter (OM)	75.98^{b}	79.00^{a}	0.68	75.77	78.63	78.07	0.68
Crude protein (CP)	76.45	78.88	0.87	75.15^{b}	79.06^{a}	78.79^{a}	0.87
Crude fiber (CF)	53.13	57.34	1.57	49.91^{b}	58.54^{a}	57.25^{a}	1.57
Ether extract (EE)	84.58^{b}	86.79^{a}	0.53	85.43	85.35	86.28	0.53
Nitrogen-free extract (NFE)	79.20^{b}	82.01^{a}	0.55	79.57	81.42	80.83	0.55
Nutritive values (%)							
Total digestible nutrient (TDN)	72.02^{b}	74.79^{a}	0.63	71.82^{b}	74.48^{a}	73.92^{ab}	0.63
Digestible crude protein (DCP)	12.32^{a}	11.47^{b}	0.16	11.52^{b}	12.13^{a}	12.04^{a}	0.16

a and b: Means in the same row within each treatment having different superscripts differ significantly ($P<0.05$).

SEM, standard error of the mean.

Table 4: Effect of interactions between protein and broccoli by-product levels on nutrient digestibility coefficients and nutritive values of the experimental diets

	Experimental diets						
	100% Protein requirements			90% Protein requirements			
Item	G_1	G_2	G_3	G_4	G_5	G_6	SEM
Digestibility coefficients							
Dry matter (DM)	76.06^{b}	86.22^{a}	81.75^{a}	81.96^{a}	84.48^{a}	84.91^{a}	1.00
Organic matter (OM)	75.37^{c}	76.66^{abc}	75.93^{c}	76.18^{bc}	80.61^{a}	80.22^{ab}	0.68
Crude protein (CP)	76.45^{bc}	75.76^{bc}	77.14^{bc}	73.85^{c}	82.35^{a}	80.43^{ab}	0.87
Crude fiber (CF)	48.95^{c}	55.82^{abc}	54.61^{abc}	50.86^{bc}	61.26^{a}	59.89^{ab}	1.57
Ether extract (EE)	85.74^{ab}	83.17^{b}	84.83^{ab}	85.11^{ab}	87.52^{a}	87.73^{a}	0.53
Nitrogen-free extract (NFE)	78.94^{b}	79.94^{ab}	78.71^{b}	80.21^{ab}	82.89^{a}	82.94^{a}	0.55
Nutritive values							
Total digestible nutrient (TDN)	71.50^{c}	72.57^{bc}	71.99^{c}	71.14^{bc}	76.39^{a}	75.85^{ab}	0.63
Digestible crude protein (DCP)	12.32^{a}	12.26^{a}	12.40^{a}	10.71^{b}	12.01^{a}	11.69^{a}	0.16

a, b and c: Means in the same row having different superscripts differ significantly ($P<0.05$). SEM, standard error of the mean.

cell wall constituents (NDF, ADF, ADL, hemicellulose and cellulose) were also slightly affected with the mentioned similarities power. This great similarity confirms that the existence of any significant results must be attributed to the medicinal substances or the bioactive compounds of broccoli. Gerendás *et al.* [22] pointed that glucosinolates represent bioactive compounds of Brassica vegetables whose health-promoting effects. The antigenotoxic in broccoli are being explored further for their mechanism of action [23]. Broccoli had more marked effects; which reinforces the importance of the matrix effects on the bioactivity of functional ingredients [24].

Nutrient Digestibility and Nutritive Values of the Experimental Diets: Rabbits received 90% of protein requirements containing diets significant improved ($P<0.05$) digestibility coefficients of (OM, EE and NFE) and TDN value (Table 3). While insignificant improved in digestibility coefficients of (DM, CP and CF) was realized. However, digestible crude protein was significant decreased ($P<0.05$) in comparison with 100% protein requirements. These results may be attributed to, when CP content is low the CF should be high and therefore the digestive efficiency in the small intestine appeared higher and must lead to improve the properties of digestion. Similar results obtained in rabbit by Milis and Liamadis [25]. Replacement alfalfa hay with broccoli by-product at 3% or 6% in rabbit diets significantly ($P<0.05$) increased digestibility coefficients of (DM, CP and CF) and nutritive values (TDN and DCP) compared to control diet; However, it had no significant effect on digestibility coefficients of OM, EE and NFE (Table 3). These significant results may be due to the content of glucosinolates that are a class of organic compounds includes sulfur and nitrogen in broccoli which submit the digestion gastrointestinal conditions as pH, temperature, enzyme and chemical conditions as observed by Vallejo *et al.* [26].

Data in Table 4 showed that there were significant ($P<0.05$) interaction between the protein and broccoli by-product levels on nutrient digestibility coefficients of (DM, OM, CP, CF, EE and NFE) and nutritive values (TDN and DCP). These results may be explained that the total cecal short chain fatty acids pools were higher while pH was lower from dietary oligosaccharide-containing broccoli by-product as well as from dietary low protein-high fiber compared with control diets. Similar results obtained by Campbell *et al.* [27].The 90% protein requirements with replacement at 3% broccoli by-product level (G_5) showed the best digestion coefficients of (OM, CP and CF) and nutritive values of (TDN and DCP) (Table 4). These best digestion coefficients may be due the large bowel ecosystem in rabbits fed broccoli by-product and conversely to be protected by fermentable oligosaccharides as reported by Paturi *et al.* [10]. The 90% protein requirements with replacement level at 6 % broccoli by-product (G_6) recorded the best digestion coefficients of EE. This best digestion coefficients of EE may be due to the ability of broccoli in improving fat metabolism as reported by Suido *et al.* [28] who showed that broccoli had ability in preventing fats accumulation.

The 100% protein requirement with Lucerne hay (G_1) showed the lowest values of DM, OM and CF digestibility coefficients. In contrast, the 100% protein requirements with replacement level at 3% broccoli by-product (G_2) showed the highest value of DM digestibility coefficient. This may be due to that broccoli fiber quality of oligosaccharides content by increasing bifidobacteria that may be beneficial in improving rat gastrointestinal health [27]. In other words, may be due to the potential water-holding capacity was lower for broccoli by-product than Lucerne hay as observed in human by McBurney *et al.* [29] or may be due to *Brassica oleracea L.* exhibited aldehydes, sulfur volatile compounds, ketone, terpenes and norisoprenoid compounds [4] that will be useful for identifying enzymes as a substrate [30].

Growth Performance of the Experimental Groups: The 90% protein requirements significantly ($P<0.05$) increased the final weight, total body weight gain and average daily gain while showed insignificant effects ($P>0.05$) on all the other performance parameters includes feed intake and feed conversion as shown in Table 5. These results may be due to rabbits offered low protein had a lower ideal pH that may be beneficial in improving gastrointestinal health as noticed in pigs by Varley *et al.* [31]. Replacement at 3 or 6% level of Lucerne hay with broccoli by-product significantly ($P<0.05$) improved the final body weight, total body weight gain and average daily gain compared to control diet, while showed insignificant ($P>0.05$) effects on feed intake of (DM, CP, DCP, TDN and DE) and feed conversion (g intake /g gain) of DM, CP, DCP, TDN and (Kcal intake/g gain) of DE (Table 5). These results also agreed with Kataya and Hamza [32] who noticed that *Brassica oleracea* extract restored renal function and body weight loss. These significant results may be due the activity of broccoli as antioxidant prevents protein insolubilization as reported by Vibin *et al.* [33]. In other words, the chemical property of cruciferous plants is their

Table 5: Main effects of protein and broccoli by-product levels on growth performance of the experimental groups

	Experimental diets						
	Protein levels			Broccoli by-product levels			
Item	100%	90%	SEM	0%	3%	6%	SEM
Initial weight, g	553	553	7.01	556	554	551	7.01
Final weight, g	2414[b]	2440[a]	8.66	2378[b]	2440[a]	2464[a]	8.66
Total body weight gain, g	1861[b]	1887[a]	8.53	1822[b]	1886[a]	1913[a]	8.53
Duration period (days	56	56	---	56	56	56	---
Average daily gain ADG, g	33.23[b]	33.70[a]	0.15	32.54[b]	33.68[a]	34.16[a]	0.15
Feed intake as:							
Dry matter (DM), g/h/d	108	108	3.09	110	109	107	3.09
Crude protein (CP), g/h/d	17.41	15.76	0.49	16.79	16.68	16.28	0.49
Digestible crude protein (DCP), g/h/d	13.31	12.43	0.38	12.63	13.17	12.82	0.38
Total digestible nutrient (TDN), g/h/d	77.78	81.04	2.29	78.64	80.82	78.77	2.29
Digestible energy (DE), Kcal/h/d	270	272	7.72	274	272	267	7.72
Feed conversion(g intake/ g gain) of							
Dry matter	3.25	3.22	0.093	3.37	3.22	3.11	0.093
Crude protein	0.52	0.47	0.015	0.51	0.5	0.48	0.015
Digestible crude protein	0.4	0.37	0.011	0.39	0.39	0.38	0.011
Total digestible nutrient	2.34	2.41	0.068	2.42	2.4	2.31	0.068
Digestible energy, (Kcal intake/g gain)	8.14	8.07	0.233	8.44	8.08	7.8	0.233

a and b: Means in the same row within each treatment having different superscripts differ significantly ($P<0.05$). SEM, standard error of the mean.

Table 6: Effect of interactions between protein and broccoli by-product levels growth on performance of the experimental groups

	Experimental diets						
	100% Protein requirements			90% Protein requirements			
Item	G_1	G_2	G_3	G_4	G_5	G_6	SEM
Initial weight, g	554	555	551	557	553	550	7.01
Final weight, g	2391[cd]	2415[c]	2437[bc]	2364[d]	2464[ab]	2491[a]	8.66
Total body weight gain, g	1837[de]	1860[cd]	1886[bc]	1807[e]	1911[ab]	1941[a]	8.53
Duration period (days	56	56	56	56	56	56	---
Average daily gain ADG, g	32.80[de]	33.21[cd]	33.68[bc]	32.27[e]	34.13[ab]	34.66[a]	0.15
Feed intake as:							
Dry matter (DM), g/h/d	112	108	104	107	109	109	3.09
Crude protein (CP), g/h/d	18.04	17.47	16.71	15.53	15.89	15.84	0.49
Digestible crude protein (DCP), g/h/d	13.8	13.24	12.9	11.46	13.09	12.7	40.38
Total digestible nutrient (TDN), g/h/d	80.08	78.38	74.87	77.19	83.27	82.68	2.29
Digestible energy (DE), Kcal/h/d	281	270	260	268	274	273	7.72
Feed conversion(g intake /g gain) of							
Dry matter	3.41	3.25	3.09	3.32	3.19	3.14	0.093
Crude protein	0.55	0.53	0.5	0.48	0.47	0.46	0.015
Digestible crude protein	0.42	0.4	0.38	0.36	0.38	0.37	0.011
Total digestible nutrient	2.44	2.36	2.22	2.39	2.44	2.39	0.068
Digestible energy, (Kcal intake /g gain)	8.57	8.13	7.72	8.3	8.03	7.88	0.233

a, b, c, d and e: Means in the same row having different superscripts differ significantly ($P<0.05$). SEM, standard error of the mean.

Table 7: Main effects of protein and broccoli by-product levels on dressing percentages, carcass cuts and chemical analysis of the 9, 10 and 11th ribs of the experimental groups

	Experimental diets						
	Protein levels			Broccoli by-product levels			
Item	100%	90%	SEM	0%	3%	6%	SEM
Slaughter weight (SW), g	2608^{a}	2522^{b}	12.72	2565	2552	2579	12.72
Inedible offal's*, g	526^{a}	507^{b}	4.37	514	522	514	4.37
Head, g	159^{a}	150^{b}	2.27	150	156	159	2.27
Digestive tract							
Full, g	530^{b}	560^{a}	5.46	545	542	548	5.46
Empty, g	249^{b}	262^{a}	2.52	256	255	257	2.52
Contents	281^{b}	297^{a}	2.95	290	288	291	2.95
Empty body weight, g (EBW)	2327^{a}	2225^{b}	13.92	2276	2265	2288	13.92
Edible offal's (Giblets)**							
Liver	87.67	83.67	3.55	74.50^{b}	88.00^{ab}	94.50^{a}	3.55
Heart	9.33	9.76	0.22	9.5	9	10	0.22
Kidneys	17.33	17.33	0.57	18.5	16.5	17	0.57
Testes	9.83	9.5	0.27	9.25	9.5	10.25	0.27
Spleen	1.58	1.83	0.01	1.88	1.75	1.5	0.01
Lungs	12.58	12.67	0.43	12.38	12.75	12.75	0.43
Total edible offal's	138.3	134.7	3.49	126.00^{b}	137.5^{ab}	146.0^{a}	3.49
Carcass weight (CW_1), g	1254^{a}	1171^{b}	11.83	1231^{a}	1195^{b}	1212^{ab}	11.83
Carcass weight including giblets (CW_2)	1393^{a}	1306^{b}	11.41	1357^{a}	1333^{b}	1358^{a}	11.41
Carcass weight including giblets and head (CW_3)	1552^{a}	1456^{b}	12.7	1507^{a}	1489^{b}	1517^{a}	12.7
Dressing percentages (DP)%							
DP ^{1} (CW_1/ SW)	48.09^{a}	46.43^{b}	0.29	47.98^{a}	46.82^{b}	46.98^{ab}	0.29
DP ^{2} (CW_1/ EBW)	53.90^{a}	52.63^{b}	0.28	54.08^{a}	52.77^{b}	52.96^{b}	0.28
DP ^{3} (CW_2/ EBW)	59.85^{a}	58.68^{b}	0.21	59.62	58.84	59.35	0.21
DP ^{4} (CW_3/ EBW)	66.69^{a}	65.44^{b}	0.21	66.19	65.73	66.28	0.21
Carcass cuts							
Fore part, g	433^{a}	413^{b}	4.87	423	423	423	4.87
Middle part, g	271^{a}	245^{b}	4.92	260	254	260	4.92
Hind part, g	550^{a}	513^{b}	7.44	548^{a}	518^{b}	529^{ab}	7.44
Chemical analysis of the 9,10 and 11th ribs							
Dry matter	27.79	29.77	0.68	27.14	28.87	30.34	0.68
Chemical composition on DM basis							
Crude protein (CP)	69.7	69.04	0.7	69.64	70.43	68.04	0.7
Ether extract (EE)	19.45	20.08	0.75	19.11	18.84	21.36	0.75
Ash	10.84	10.87	0.24	11.25	10.73	10.6	0.24

a and b: Means in the same row within each treatment having different superscripts differ significantly ($P<0.05$). SEM, standard error of the mean. * Inedible offal's: included fur, ears, legs and blood. ** Edible offal's (Giblets): included liver, heart, kidneys, testes spleen and lungs. Empty body weight (EBW) = slaughter weight - digestive tract contents.

Table 8: Effect of interactions between protein and broccoli by-product levels on dressing percentages, carcass cuts and chemical analysis of the 9, 10 and 11th ribs of the experimental groups

	Experimental diets						
	100% Protein requirements			90% Protein requirements			
Item	G_1	G_2	G_3	G_4	G_5	G_6	SEM
Slaughter weight (SW), g	2617^{a}	2567^{b}	2640^{a}	2513^{c}	2537^{bc}	2517^{c}	12.72
Inedible offal's*, g	527^{ab}	533^{a}	518^{ab}	500^{b}	510^{ab}	510^{ab}	4.37
Head, g	157^{a}	155^{ab}	165^{a}	142^{b}	157^{a}	152^{ab}	2.27
Digestive tra^{c}t							
Full, g	527^{bc}	517^{c}	547^{ab}	563^{a}	567^{a}	549^{ab}	5.46
Empty, g	247^{bc}	243^{c}	257^{ab}	264^{a}	266^{a}	257^{ab}	2.52
Contents	280^{bc}	274^{c}	290^{abc}	299^{a}	301^{a}	292^{ab}	2.95
Empty body weight, g (EBW)	2337^{a}	2293^{b}	2350^{a}	2214^{c}	2236^{c}	2225^{c}	13.92

Table 8: continue

Item	Experimental diets: 100% Protein requirements G1	G2	G3	90% Protein requirements G4	G5	G6	SEM
Edible offal's (Giblets)**, g							
Liver	75[b]	100[a]	88[ab]	74[b]	76[b]	101[a]	3.55
Heart	9	9	10	10	9	10	0.22
Kidneys	18	16	18	19	17	16	0.57
Kidneys	10[ab]	9[ab]	10.50[a]	8.50[b]	10[ab]	10[ab]	0.27
Spleen	1.75	1.5	1.5	2	2	1.5	0.01
Lungs	12.25	12.5	13	12.5	13	12.5	0.43
Total edible offal's	126[c]	148[ab]	141[abc]	126[c]	127[bc]	150[a]	3.49
Carcass weight (CW_1), g	1280[a]	1214[b]	1269[a]	1182[c]	1176[c]	1155[c]	11.83
Carcass weight including giblets (CW_2)	1406[a]	1362[b]	1410[a]	1308[c]	1303[c]	1306[c]	11.41
Carcass weight including giblets and head (CW_3)	1563[a]	1517[b]	1575[a]	1450[c]	1460[c]	1458[c]	12.7
Dressing percentages (DP)%							
DP 1 (CW_1/ SW)	48.91[a]	47.29[bc]	48.07[ab]	47.04[bc]	46.35[c]	45.89[c]	0.29
DP 2 (CW_1/ EBW)	54.77[a]	52.94[bc]	54.00[ab]	53.39[abc]	52.59[bc]	51.91[c]	0.28
DP 3 (CW_2/ EBW)	60.16[a]	59.40[ab]	60.00[a]	59.08[ab]	58.27[b]	58.70[b]	0.21
DP 4 (CW_3/ EBW)	66.88[a]	66.16[ab]	67.02[a]	65.49[b]	65.30[b]	65.53[b]	0.21
Carcass cuts							
Fore part, g	425a[b]	442[a]	432[ab]	421[ab]	403[b]	414[ab]	4.87
Middle part, g	280[a]	256[abc]	277[ab]	240[c]	251[bc]	243[c]	4.92
Hind part, g	575[a]	516[b]	560[a]	521[b]	522[b]	498[b]	7.44
Chemical analysis of the 9,10 and 11[th] ribs							
Dry matter	25.85	27.27	30.25	28.43	30.46	30.43	0.68
Chemical composition on DM basis							
Crude protein (CP)	70.04	71.66	67.41	69.24	69.21	68.67	0.7
Ether extract (EE)	18.98	17.33	22.06	19.24	20.35	20.66	0.75
Ash	10.98	11.01	10.53	11.52	10.44	10.67	0.24

a, b and c: Means in the same row having different superscripts differ significantly (P<0.05). SEM, standard error of the mean. Inedible offal's: included fur, ears, legs and blood. ** Edible offal's (Giblets): included liver, heart, kidneys, testes spleen and lungs. Empty body weight (EBW) = slaughter weight - digestive tract conten*ts*.

Table 9: Economic evaluation of the experimental groups

Item	Experimental diets: 100% Protein requirements G1	G2	G3	90% Protein requirements G4	G5	G6
Marketing weight, Kg	2.391	2.415	2.437	2.364	2.464	2.491
Feed consumed / rabbit, as it is, kg	6.888	6.776	6.776	6.72	6.72	6.72
Costing of one kg feed, (LE)1	2.208	2.174	2.139	2.157	2.122	2.088
Total feed cost, (LE)	15.21	14.73	14.49	14.5	14.26	14.03
Management/ Rabbit, (LE)2	4	4	4	4	4	4
Total cost, (LE)3	34.21	33.73	33.49	33.5	33.26	33.03
Total revenue, (LE)4	52.6	53.13	53.61	52.01	54.21	54.8
Net revenue	18.39	19.4	20.12	18.51	20.95	21.77
Economical efficiency5	0.5376	0.5752	0.6008	0.5525	0.6299	0.6591
Relative economic efficiency6	100	107	112	103	117	123
Feed cost / kg LBW (LE)7	6.36	6.1	5.95	6.13	5.79	5.63

high content of glucosinolates products had ability to produce in non-enzymatic and enzymatic reactions [3]. Replacement at 6% level of Lucerne hay with broccoli by-product in rabbit diet significantly ($P<0.05$) increased the average daily gain by 4.98% (Table 5). Replacement at 3% of Lucerne hay with broccoli by-product insignificantly increased average daily gain by 3.50% compared to the control group. These significant results related to broccoli may be due many factors; it's caused higher stability in phenolics and vitamin C which promote the growth performance [26], able to prevent vitamin A deficiency as shown in Mongolian gerbils [34] provided high yields of DM with large variability average daily gain as shown in sheep [35] and has excellent antioxidative potential effect [36].

There were interactions between protein and the replacement of broccoli by-product levels on final body weight, body weight gain and average daily gain weight while, there were no interaction on feed intakes of (DM, CP, DCP, TDN and DE) and feed conversion (g intake /g gain) of DM, CP, DCP, TDN and (Kcal intake /g gain) of DE (Table 6). The 90% protein requirement with replacement at 6% broccoli by-product recorded the best values of final weight, total body weight gain, average daily gain and feed conversion. These interactions may be due that broccoli is excellent food source for medicinal substances, including 18 sulforaphane and related compounds synthesized that exhibits antimicrobial properties as reported by Moon *et al.* [37] and Koralewska *et al.* [38]. On the other hand, as reported by Trepel [39] when the dietary protein is low the dietary fibers play an essential role in the physiology of the gastrointestinal tract and modify the absorption of nutrients in the small bowel as well as accelerate the gut transit time and determine stool composition and quantity, above they is the main nutritional source for the colonic microflora.

Carcass Characteristics of the Experimental Groups: The main effects of protein and broccoli by-product replacement levels on dressing percentages, carcass cuts and chemical analysis of the 9, 10 an 11^{th} ribs of the experimental groups are presented in Table (7). The protein levels had no significant effect ($P>0.05$) on either of the edible offal's weight of (liver, heart, kidneys, testes, spleen and lungs) and chemical analysis of the 9, 10 and 11^{th} ribs. The 90% protein requirements significantly ($P<0.05$) decreased the inedible offal's, empty body weight, carcass weight, dressing percentage and carcass cuts. These significant results insured the protein priority for the muscle composition and public health as reported by Chen *et al.* [40]. The broccoli by-product levels showed had no significant ($P>0.05$) effects on inedible offal's weight, digestive tract, carcass weight and chemical analysis of the 9, 10 and 11^{th} ribs (Table 7). These results may be due to the ability of broccoli in preventing fats accumulation especially in inedible offal's. Similar results in human patients showed by Suido *et al.* [28] who noticed that the daily consumption of broccoli may be useful in lowering the low-density lipoprotein cholesterol levels in hypercholesterolemic.

Data in Table 8 showed significantly ($P<0.05$) interaction between protein and broccoli by-product levels on dressing percentages and chemical analysis of the 9, 10 and 11^{th} ribs (DM & ash contents). There were no interaction between protein and broccoli by-product levels on inedible offal's, digestive tract, empty body weight (EBW), liver weight, testes weight, total edible offal's, carcass weight, dressing percentages and carcass cuts. The significant results of broccoli by-product on decreasing dressing percentages may be attributed to the ability of broccoli in preventing fat disposition. An *et al.* [41] cleared that *Brassica campestris* prevent high-fat diet-induced obesity via beta (3)-adrenergic regulation of white adipocyte lipolytic activity.

Economical Evaluation: The profitability of using broccoli by-product replacement of Lucerne hay in rabbit diets depends upon the price of tested diets and the growth rabbit performance is shown in Table 9. Costing of one kg feed (LE) decreased by 1.54%, 3.13%, 2.31%, 3.89% and 5.43% for G_2, G_3, G_4, G_5 and G_6, respectively, compared to the control diet (G_1) which affected by the low price of broccoli by-product compared to Lucerne hay. The 90% protein requirements with broccoli by-product replacement at 6% level (G_6) showed the highest value of net revenue (21.77 LE), economical efficiency (0.6591) and relative economic efficiency (123%) as well as showed the lowest value of feed cost/kg live body weight (5.63 LE) are presented in Table 9. These high economical values may be attributed to the ability of broccoli in improving the utilization of low protein diet by conferred some protection in terms of colon morphology [10] via its antimicrobial properties against several microorganisms of clinical importance [42].

The 90% protein requirements with broccoli by-product replacement at 3% level (G_5) recorded the second high value of net revenue (20.95 LE), economical efficiency (0.6299), relative economic efficiency (117%) and the feed cost/ kg live body weight (5.79 LE).

These high values may be attributed to the ability of broccoli in improving the growth performance via fermentation and proliferation of desirable bacterial species that beneficial in improving gastrointestinal health as reported in rat by Campbell *et al.* [27].

CONCLUSION

Replacement at 6% level of Lucerne hay with broccoli by-product showed the highest value of net revenue, economical efficiency and relative economic efficiency as well as showed the lowest value of feed cost/ kg live body weight flowed by the treatment of broccoli by-product replacement at 3% level. Our data suggest that the partial replacement of Lucerne hay with broccoli by-products in rabbit diets can be considered effectively for improving the utilization of low protein diet.

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