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REGULAR ARTICLES

Growth performance and meat quality of rabbits under different feeding regimes

Kamran Khan[1] · Sarzamin Khan[2] · Rajwali Khan[2] · Asad Sultan[2] · Nazir Ahmad Khan[2] · Naseer Ahmad[2]

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Abstract This study evaluated the growth, carcass characteristics and meat quality of indigenous rabbits in northern Pakistan. Weaned rabbits (age 35 days, weight 323 g) of four distinct phenotypes (white, black and white, brown and black) were fed four experimental diets: alfalfa hay (AH), *berseem* fodder (BF), BF supplemented with low-level concentrate (50 %; LLC) and high-level concentrate (75 %; HLC). Each experimental diet was fed to 48 rabbits, 12 of each phenotype, in a randomized complete block design. The duration of the experiment was 55 days, including 1 week of adaptation. Rabbits fed the BF and AH diets had poor body weight gain ($P < 0.05$) compared to rabbits fed the LLC and HLC diets. Feed conversion efficiency was best in the LLC (4.47) and HLC (4.58) groups. Average carcass yield (743 g) and carcass dressing percentage (56.2) were higher ($P < 0.05$) in LLC. Growth rate was not improved significantly by feeding HLC. Fat deposition in animals was higher ($P < 0.05$) in the groups supplemented with concentrate. Cost per kilogram of rabbit meat was lowest ($P < 0.05$) for BF, followed by AH, LLC and HLC. Brown phenotypes had the best ($P < 0.05$) feed conversion efficiency, body weight gain, carcass yield and carcass dressing. It was concluded that local rabbits do not necessarily need high levels of concentrates but can be well fattened with low-level concentrates along with forages.

Keywords Indigenous rabbits · Growth rate · Carcass traits · Meat quality · Feeding regime · Nutrition

Introduction

The global demand for meat is expected to be 73 % higher in 2050, and a large part of this increase will occur in the developing countries (FAO 2011; OECD-FAO 2014) because of the rising incomes and rapid population growth (Makkar et al. 2014). There has been a major change to the diet with increased consumption of animal products. This trend is likely to continue in the coming decades. Animal production systems in many developing countries, such as Pakistan, face a profound challenge to meet the growing demand for quality meat products. As a consequence, the pressure on feed resources has been increased, particularly in the face of growing food-feed competition. This requires investigation of both alternate feed resources and affordable, more efficient animal production systems in order to sustainably meet an increasing demand for quality meat.

The domestic rabbit (*Oryctolagus cuniculus*) has many advantages for low-cost meat production, such as, fast growth rate, ability to utilize less competitive fibrous feeds, early sexual maturity, short gestation length, short generation interval and high-quality meat (Dalle Zotte 2002; Effiong and Wogar 2007). Rabbit meat has good flavour, is easily digested, has high nutritional and dietetic properties, such as high (20–21 %) protein and linolenic acid contents, and lower contents of sodium and cholesterol (Dalle Zotte 2002; DalleZotte and Szendro 2011; Hermida et al. 2006). The latter properties make rabbit meat favourable for cardiovascular patients and can benefit long-term human health (Hu and Willett 2002).

The potential of forages as feed for rabbit is of particular significance because of their low-cost availability and also the

✉ Rajwali Khan
rajwalikhan@aup.edu.pk

[1] Department of Animal Sciences, Shaheed Benazir Bhutto University Sheringal, Sheringal, Khyber Pakhtunkhwa, Pakistan

[2] Faculty of Animal Husbandry and Veterinary Sciences, The University of Agriculture Peshawar, Peshawar 25130, Khyber Pakhtunkhwa, Pakistan

ability of rabbits to effectively utilize and digest leaf protein (Musa 2003). In addition, the development of high-quality forage-based diets with simple supplements is a priority research area in developing countries (Linga et al. 2003). Rabbits are the most efficient converters of feed into flesh (Taiwo et al. 2004).

Several types of rabbits are reared under small-scale, backyard production system in northern Pakistan (Khan et al. 2014). More recently, rabbit production in the region has gained considerable interest due to a marked increase in the prices of conventional sources of meat, such as beef, mutton and poultry. Furthermore, the agro-climatic condition and feed resources of the region are conducive for rabbit production. To the authors' knowledge, very little research has been conducted to evaluate the growth performance and meat quality of indigenous rabbits under intensive production systems. Therefore, this research study was designed to investigate indigenous rabbits' growth performance, carcass characteristics and meat quality under an intensive production system with modern husbandry and feeding regimes.

Materials and methods

This research study was pre-approved in the Departmental Board of Studies meeting on the recommendation of its ethical committee for procedures involving live rabbits handling, welfare and standard laboratory protocols. The study was conducted in 2014 at the Rabbit Research Centre, University of Agriculture Peshawar, Pakistan (34°00′ N, 71°30′ E, 350 m altitude). Summer mean minimum and maximum temperatures were 24.5 and 37.4 °C, while in winter, mean minimum and maximum temperatures were 9.9 and 24.4 °C, with annual rainfall of 380 mm.

Rabbit selection and experimental design

Four types of commonly reared indigenous rabbit phenotypes were used: white, black and white, brown and black. A total of 192 weaned (35 days old; average body weight 323 g) rabbits, 48 of each of the four rabbit types, were selected from a herd maintained at University Research Centre. The rabbits were assigned to four experimental diets, according to a randomized complete block design. Each block consisted of 48 rabbits, 12 from each phenotype, and the blocks were further balanced for age and body weight. The four diets were (1) alfalfa (*Medicago sativa* L.) hay (AH; 100 %), (2) fresh *berseem* fodder (*Trifolium alexandrinum* L.) (BF; 100 %), (3) BF supplemented with low-level concentrates (LLC; 50 % BF and 50 % concentrate) and (4) BF supplemented with high-level concentrate (HLC; 25 % BF, 75 % concentrate). The concentrate was formulated according to NRC (1977) and was converted to pellet form at the feed processing unit of Agriculture University Peshawar. The ingredients and chemical composition of the experimental diets are presented in Table 1. The trial continued for 55 days including a week of adaptation period. The rabbits were housed in cages in the same shed and were provided with feed and water ad libitum. Four rabbits were housed in a single cage (122 cm × 122 cm, and 38.5 cm high). Each cage contained a separate feeder, drinker and a mesh floor for removal of faeces and urine.

Growth performance and carcass characteristics

Body weight was recorded weekly to calculate the average daily gain. Individual feed intake was recorded daily to calculate average daily feed intake and feed conversion ratio. At the end of the trial, six rabbits from each phenotype within each treatment group were sacrificed to record carcass characteristics. The carcass was prepared according to the World Rabbit Science Association procedures as described by Blasco and Ouhayoun (1996). Dressing percentage was calculated as

$$\text{Dressing percentage} = \frac{\text{Carcass weight}}{\text{live body weight}} \times 100$$

The hot carcass was allowed to cool for 30 min and then was chilled at 4 °C for 24 h. The liver, lungs, thymus, trachea, oesophagus, heart, kidney and intestine were removed to obtain the "reference" carcass comprising meat, fat and bone. The weight of hot and chilled carcass, and liver, kidney, lungs,

Table 1 Ingredients and chemical composition of the experimental diets

Ingredients (%)	Diets			
	AH	BF	LLC	HLC
Berseem	–	100.0	50.0	25.0
Alfalfa hay	100.0	–	–	–
Maize	–	–	24.0	35.5
Wheat bran	–	–	15.5	23.5
Soya bean meal	–	3.0	4.0	6.0
Cotton seed cake	–	–	5.0	7.5
Palm oil cake	–	–	1.5	2.5
Canola oil	0.05	–	–	–
Salt	–	–	0.10	0.18
Vitamin/mineral premix	–	–	0.10	0.18
Chemical composition				
Crude protein (%)	16.5	16.0	16.5	16.0
Crude fibre (%)	32.5	20.0	18.0	17.0
Ether extract (%)	1.3	1.2	2.9	3.8
Digestible energy (MJ/Kg)	9.63	9.64	9.68	9.70

AH alfalfa hay, *BF* fresh berseem fodder, *LLC* low-level concentrate, *HLC* high-level concentrate spleen and heart were recorded using a digital balance. The reference carcass was halved into sides and the *longissimus lumborum* muscle was excised. The muscle taken from the left side of the longissimus lumborum was used to measure pH, cooking loss and water-holding capacity. The muscle taken from the right side was vacuum-packed and frozen at −20 °C for chemical composition analysis.

Meat quality variables

The ultimate pH (pH_{24}) was measured 24 h postmortem. The pH was measured with a digital pH metre (JENWAY 3505, UK), through insertion of its electrodes to 3 mm depth on the left side of the longissimus lumborum muscle at the level of fourth lumbar vertebra. The pH measurements were taken in triplicate. The percentage of released water was measured on a meat sample from the longissimus lumborum (seventh lumbar vertebra) using the filter paper press method described by Grau and Fleischmann (1957). Cooking loss was determined according to the method described earlier by (Boccard et al. 1981). The meat chemical composition was determined according to the standard method of the Association of Official and Analytical Chemist (AOAC) 1990).

Statistical analysis

The effects of diet composition and rabbit types on growth potential parameters, meat quality parameters (pH, water holding capacity, cooking losses) and contents of nutrients were analysed using PROC MIXED procedure (Littell et al. 2006) of the Statistical Analysis System (SAS Institute, 2003). The following model was used for the analysis:

$$Y_{ijk} = \mu + RG_i + PS_j + \epsilon_{ijk}$$

Where, Y_{ijk} is the observation on dependent variable, μ the overall population mean, RG_i is the fixed effect of rabbit types (i = white, black and white, brown and black), PS_j is the fixed effect of diets (j = AH, BF, LLC and HLC) and ϵ_{ijk} is the residual. When significant ($P < 0.05$) differences were detected, post hoc analyses were carried out using theTukey-Kramer test to compute pairwise differences in the means. Results are presented as least square means and model estimated standard error of the mean (SEM).

Results

Data showing the effects of diet composition and rabbit types on daily feed intake, total feed intake, average daily weight gain, total body weight gain, final body weight, feed to gain ratio and cost per rabbit are summarized in Table 2. Total body weight gain was higher (915 g; $P < 0.05$) in rabbits fed on LLC. The feed conversion efficiency was improved (P 0.05) in rabbits fed on concentrate supplemented groups. In contrast, the average final body weight was higher ($P < 0.05$) for LLC-supplemented group. The average daily feed ($P < 0.05$) consumption was higher for BF and AH than LLC and HLC.

Data about the hot and chilled carcass yield, carcass dressing percentage, reference carcass weight, bone ratio, organ weight and cost per kg rabbit meat, as affected by diet composition and rabbit types, are presented in Table 3. The hot and chilled carcass yield, dressing percentage and reference weight were higher ($P < 0.05$) for LLC. Bone ratio did not differ significantly due to diet composition. Kidney weight was higher ($P < 0.05$) for AH and BF. However, the weight of the liver, lungs, heart and spleen did not differ ($P > 0.05$) among dietary treatments. The diet significantly ($P < 0.05$) affected cost per kilogram rabbit meat and was found lowest for BF, followed by AH and LLC, respectively, and highest for HLC.

Data presenting the meat quality parameters such as pH, percentage of release water, cooking losses and contents of moisture, crude protein, fat and ash, as affected by diet composition and rabbit types, are summarized in Table 4. The meat pH, percentage of water release and cooking losses were affected ($P > 0.05$) by diet composition. However, the content of fat was positively and significantly affected ($P < 0.05$) by concentrate-supplemented feeding, while, a non-significant ($P > 0.05$) effect was found for diet composition on the contents of moisture, protein and ash.

Comparison of the phenotypes revealed that brown rabbits had better ($P < 0.05$) feed conversion ratio, higher ($P < 0.05$) average daily weight gain leading to the highest ($P < 0.05$) final body weight (Table 2). Moreover, the brown rabbits had a higher ($P < 0.05$) carcass yield and reference carcass weight. Non-significant variation ($P > 0.05$) was observed in organ weight (Table 3) and meat quality parameters (Table 4) due to rabbit types.

Discussion

High growth rate in the human population in under-developed countries leads to increasing demand of protein especially meat. This draws the attention of researchers to exploit the maximum potential of existing animal production systems (Mermelstein 2002; Sloan 2002). The rabbit has many production advantages, such as high prolificacy, rapid growth and a shorter generation interval, conversion of low-cost fibre-rich forages and organic wastes in to energy and useful nutrients and with less competition for feed with human and monogastric animals (Effiong and Wogar 2007; Finzi 2008; Hassan et al. 2012). *Despite this, limited work has been done on local rabbits to exploit their potential for meat production.*

Table 2 Growth traits, feed to gain ratio and cost per rabbit under different feeding regimes

Traits	Diets				SEM	Rabbit types				SEM	Significance	
	AH	BF	LLC	HLC		Brown	Black and white	Black	White		Diets	Types
Initial body weight (g)	325	325	320	325	0.800	325	325	320	320	0.60	ns	ns
Final body weight (g)	1080[c]	1070[c]	1240[a]	1230[b]	1.55	1170[a]	1155[b]	1150[bc]	1140[c]	2.25	**	**
Average daily gain (g)	15.0[b]	15.0[b]	18.5[a]	18.5[a]	0.05	17.0[a]	17.0[b]	16.5[bc]	16.5[c]	0.10	**	**
Total weight gain (g)	750[c]	750[c]	915[a]	905[b]	1.35	845[a]	830[b]	825[bc]	820[c]	1.65	**	**
Total feed intake (g)	4155[b]	4275[a]	4005[c]	4055[c]	46.5	4075	4100	4150	4170	48.00	**	ns
Daily feed intake (g)	86.5[b]	89.0[a]	83.5[c]	85.0[c]	0.940	85.0	85.5	86.5	87.0	1.00	**	ns
Feed to gain ratio	5.68[b]	5.80[a]	4.47[c]	4.58[c]	0.063	4.98[c]	5.10[b]	5.19[ab]	5.25[a]	0.11	**	*
Cost/rabbit[e]	101[b]	81.5[a]	125 [c]	150[c]	1.20	115	115	115	115	1.13	**	ns

Values are expressed as mean

AH alfalfa hay, *BF* fresh berseem fodder, *LLC* BF supplemented with low-level concentrate, *HLC* BF supplemented with high-level concentrate, *SEM* standard error of the mean, *ns* non-significant

*$P < 0.05$; **$P < 0.001$

[a–d] Within a row, within diets or rabbit types, with different superscript letters differ at $P < 0.05$ level

[e] in PKR on basis of live weight

The results of this study are the first reported data on the growth performance, carcass yield and meat quality of indigenous rabbits, as affected by diet composition and rabbit types, under an intensive production system. The database can be used to devise management and feeding strategies for the local rabbits.

The results of the present study showed that supplementation of forage base diets with low level of concentrate (50 % forage and 50 % concentrate) increased body weight gain and improved feed conversion efficiency. This positive and significant effect may be due to better fermentation ability leading to the release of more nutrient and energy in the ileum and caecum from forages (Leng 2006) and also maintaining the health and micro-ecological ecosystem of the gut (Gidenne et al. 2002). On the other hand, lower feed conversion efficiency and growth rate in rabbits due to the consumption of sole forage diet in the absence of concentrate could be related

Table 3 Carcass characteristics, organ weight and cost per kilogram rabbit meat under different feeding regimes

Traits	Diets				SEM	Rabbit types				SEM	Significance	
	AH	BF	LLC	HLC		Brown	Black and white	Black	White		Diets	Types
Hot carcass weight (g)	610[c]	615[c]	745[a]	720[b]	3.40	690[a]	670[b]	670[b]	660.0[b]	4.50	**	**
Chill Carcass weight (g)	560[c]	560[c]	695[a]	670[b]	3.30	640[a]	620[b]	620[b]	610.0[b]	4.50	**	**
Dressing percentage	52.0[c]	53.0[c]	56.0[a]	55.0[b]	0.30	55.0	54.0	54.0	53.5	0.40	**	ns
Reference carcass weight (g)	480[c]	480[c]	615[a]	590[b]	3.60	560[a]	540[b]	540[b]	530.0[b]	4.80	**	**
Bone ratio	8.20	8.25	8.20	8.20	0.20	8.40	8.20	8.20	8.0	0.20	ns	ns
Liver (g)	55.0	56.0	56.0	57.0	1.80	55.0	59.0	54.0	56.0	2.30	ns	ns
Kidney (g)	9.80[a]	9.60[a]	9.30[ab]	8.70[b]	0.20	9.50	9.30	8.95	1.0	0.50	*	ns
Heart (g)	4.20	4.20	4.00	3.95	0.05	4.05	4.00	4.00	4.0	0.10	ns	ns
Lung (g)	9.20	8.70	9.10	8.90	0.20	9.00	8.90	9.10	9.0	0.90	ns	ns
Spleen (g)	0.70	0.70	0.70	0.70	0.05	0.70	0.70	0.70	0.70	1.00	ns	ns
Cost/kg meat[d]	170[c]	130[d]	170[b]	205[a]	1.60	165[c]	165[c]	170	170.0	2.95	***	ns

Values are expressed as mean

AH alfalfa hay, *BF* fresh berseem fodder, *LLC* BF supplemented with low-level concentrate, *HLC* BF supplemented with high-level concentrate, *SEM* standard error of the mean, *ns* non-significant

*$P < 0.05$; **$P < 0.001$; ***$P < 0.0001$

[a–c] Within a row, within diets or rabbit types, with different superscript letters differ at $P < 0.05$ level

[d] in PKR on basis of carcass weight

Table 4 Meat chemical composition and quality parameters of indigenous rabbits under different feeding regimes

Traits	Diets				SEM	Rabbit types				SEM	Significance	
	AH	BF	LLC	HLC		Brown	Black and white	Black	White		Diets	Types
pH	5.70	5.70	5.70	5.6	0.20	5.70	5.70	5.65	5.70	0.90	ns	ns
Release water (%)	16.0	16.0	16.0	15.0	0.50	15.0	16.0	16.5	15.0	1.30	ns	ns
Cooking loss (%)	35.0	35.5	36.0	35.0	0.90	35.0	35.5	37.0	34.0	1.30	ns	ns
Moisture (%)	71.0	72.0	71.0	72.0	0.85	71.5	72.0	71.0	72.0	1.60	ns	ns
Protein (%)	21.2	20.4	20.5	20.7	0.40	20.9	21.0	21.0	20.0	1.35	ns	ns
Fat (%)	7.37^{b}	7.31^{b}	8.29^{a}	8.08^{a}	0.150	7.64	7.80	7.95	7.60	0.20	**	ns
Ash (%)	1.31	1.30	1.29	1.27	0.02	1.28	1.30	1.25	1.25	1.00	ns	ns

Values are shown as mean

AH alfalfa hay, *BF* fresh berseem fodder, *LLC* BF supplemented with low-level concentrate, *HLC* BF supplemented with high-level concentrate, *SEM* standard error of the mean, ns not significant

**$P < 0.001$

[a–b] Means within a row, within diets or rabbit types, with different superscript differ significantly at $P < 0.05$ level

to the depressant effect on the hind gut fermentation due to the poor amino acid profile. The findings of the present study were consistent with the finding of (Omoikhoje et al. 2006), who reported a significantly higher growth rate and better feed conversion efficiency in rabbit's reared on mixed feeding regimes comprising of concentrate and forage as compared to sole concentrate or forage diet. Similarly, Taiwo et al. (2005) reported higher weight gains and improved feed utilization efficiency in rabbits fed with a mixture of *Tridax procumbens* and concentrate as compared to 100 % concentrate diet.

Dressed weight is an important index of carcass characteristics because the higher the dressed value, the greater the proportion of lean meat and economic value (Adeyemo et al. 2014). Carcass traits are influenced by the final body weight and maturity of rabbits at slaughter (Dalle Zotte 2002). The weight of the kidney, liver, lung and heart did not follow any regular pattern, hence, did not reveal any particular dietary influence on these organs. This may be due to the low concentrate feed which needs less physiological responses during metabolism as compared to rich concentrate feeding and, hence, dressing percentage was positively affected. Our findings are supported by (Adewumi et al. 2004), who reported that the relative weight of the liver, kidney, heart and spleen of the rabbits were not affected by the dietary source.

In the present study, with the exception of carcass fat, the contents of moisture, protein and ash did not alter due to diet composition. The probable reason of increase in the fat content could be due to the higher fat and lower fibre fraction in concentrate-supplemented groups than in BF and AH groups. The postmortem meat pH was not affected by diet composition. This finding is in agreement with the findings of (Tumova et al. 2006; Carrilho et al. 2009). Moreover, the percentage of release water and cooking losses did not alter due to the dietary treatment affect. Among rabbit phenotypes, the brown had a higher carcass yield (691 g) and dressing percentage (54.7). In contrast to our findings, Das and Bardoloi (2010) reported a higher carcass yield (851 g) and dressing percentage (55.4) in the *Soviet Chinchilla* breed. The discrepancy in the findings of the two studies might be due to the differences in breed types and environment as well as that of feeding and husbandry practices.

Conclusion

These results showed that most production performance, carcass and meat quality traits of indigenous rabbits were improved ($P < 0.05$) with low level (50 % of diet dry matter) concentrate supplementation to forage-based diets. However, a further increase in concentrate level (75 % of diet dry matter) did not cause any further improvement in the rabbits' performance and meat quality. Moreover, the diet composition had no adverse effect on the meat quality parameters. Although the cost incurred per kilogram meat was lower for *berseem* fodder, sustainable mass production under farm conditions could be made possible through low-level concentrate supplementation along with available forages. Brown rabbits performed comparatively better.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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