Effect of Noni (*Morinda citrifolia* L) on Growth Performance, Lipid Oxidation and Meat Quality Traits of Rabbits

Ana I. Mireles-Arriaga[1], Pedro A. Hernández-García[2], Enrique Espinosa-Ayala[2], Leticia X. López-Martínez[3], Ofelia Márquez-Molina[2]*

[1] Universidad Autónoma del Estado de México, Facultad de Medicina Veterinaria y Zootecnia, El Cerrillo Piedras Blancas, Toluca, Estado de México C.P. 50090, México
[2] Universidad Autónoma del Estado de México, Centro Universitario UAEM Amecameca, Carretera Amecameca-Ayapango K.M. 2.5. Amecameca, Estado de México C.P. 56900, México
[3] Universidad Autónoma del Estado de México, Facultad de Química. El Cerrillo Piedras Blancas, Toluca, Estado de México C.P. 50090, México
ofeliammolina@yahoo.com

Abstract: In this study, forty weaned rabbits breed New Zealand × California, were randomly assigned into four groups to be fed on diets supplemented with 0, 2, 4 and 6% of noni. Five production variables and eleven variables carcass characteristics were determined. Regarding the quality of the meat were carried out an analysis of lipid oxidation and texture profile and shear force. After of 35 days of experimentation, no significant differences on the growth rate, or the characteristics of the carcass ($P \geq 0.05$) were observed. The water drip loss down values showed 35.39, 35.34, 34.10 and 30.72% ($P=0.03$) for 0, 2, 4 and 6% respectively. In the color space CIE Lab, noni-fed rabbits showed a lower value parameter b* (yellowness) with a mean value of 3.37 ($P=0.03$). Textural profile analysis showed no significant effect except for resilience ($P=0.007$). Lipid oxidation showed a significant decrease in the values of malonaldehyde, 18, 58 and 69% for 2, 4 and 6% respectively, after twelve days of refrigerated storage. The results obtained indicate that antioxidant potential as dietary noni could be helpful to improve meat quality characteristics such as color, water drip loss and lipid stability.
[Ana I. Mireles-Arriaga, Pedro A. Hernández-García, Enrique Espinosa-Ayala, Leticia X. López-Martínez, Ofelia Márquez-Molina. **Effect of Noni (*Morinda citrifolia* L) on Growth Performance, Lipid Oxidation and Meat Quality Traits of Rabbits.** *Life Sci J* 2015;12(2s):61-67]. (ISSN:1097-8135). http://www.lifesciencesite.com. 9

Keywords: Antioxidants; *Morinda citrifolia*; rabbit meat

1. Introduction

The oxidation process is the main factor causing not biological detrimental at the meat quality. The breakdown of muscle components such as lipids and proteins produces the development of undesirable flavors, loss of color, texture and nutrients that reduce shelf life (Falowo *et al*., 2014). To reduce or prevent damage by oxidation, different strategies as the use of chemical preservatives and high pressures (Giménez *et al*., 2015), postmortem antioxidants addition (Realini *et al*., 2015) and the feed systems adoption, have been used (Rossi *et al*., 2014).

The inclusion of phytochemicals in animal diet is a strategy that has been used to improve animal productivity by promoting the production yield and quality of foods derived from these (Cedillo *et al.*, 2014; Salem *et al.,* 2014a,b; Valdes *et al*., 2015). The search for safe and effective phytochemicals capable of contributing to improving the quality characteristics of meat has focused on products like spices and fruits which contains secondary metabolites with high antioxidant activity.

Morinda citrifolia L. also known as "Indian mulberry" or "noni", is native of Southeast Asia and has been used as food and medicine in tropical regions worldwide (Kovendan *et al*., 2014). This fruit showed immune stimulating properties, particularly antibacterial and antioxidant activities (Kumar *et al*., 2014), because contains about 200 phytochemicals including phenolic compounds, all of them able to act on the absorption and neutralization of free radicals contributing to oxidative processes decrease (Wang *et al*., 2013).

In case of rabbit meat, the use of vegetables with a high phenolic compounds content, has shown beneficial effects on carcass characteristics, such as decreased 6% in perirenal fat with the addition of 3 and 6% of tomato residues (Peiretti *et al*., 2013), also, their use have improved meat quality parameters, like water retention capacity increasing and color, with the addition of 3% whole thyme (Dal Bosco *et al*., 2014a). Liu *et al*. (2009) reported a decreased on lipid oxidation with 0.5% use of chestnut extract. Peiretti and Meineri (2011) found a diminish on atherogenic and thrombogenic index with the addition of 5% spirulina and Dal Bosco *et al*. (2014b) found an increase in polyunsaturated fatty acids (PUFAs) in meat by adding fresh alfalfa on rabbit diet.

Since evidence of use of distinct phenolic compounds on rabbit and the high antioxidant

capacity of noni fruit the purpose of this research was to determine the effect of the addition of 0, 2, 4, 6% dehydrated noni in the diet of rabbits and their effect on growth performance, carcass characteristics, lipid oxidation and meat quality.

2. Material and Methods

2.1. Plant Material and Determination of Total Phenolic Compounds

Whole noni fruit was used in green-yellow maturity state, and was dried at 56 ± 2 °C for 24 h in forced air oven. Then, the dried noni was pulverized and homogenized for incorporation in rabbit's diet.

To determine the content of total phenolic compounds of noni, the method proposed by Yang et al. (2010) was employed, using the Folin-Ciocalteau reagent the result were expressed milligrams of gallic acid equivalent (GAE)/g of dry matter.

Table 1. Proximal analysis of component diets

	Noni addition (%)			
	0	2	4	6
Ingredients (g/kg feed)				
Corn	380	360	340	320
Alfalfa	420	420	420	420
Soy Oil	20	20	20	20
Wheat bran	60	60	60	60
Soy past	120	120	120	120
Noni	0	20	40	60
Chemical composition (%)				
Dry matter	89.69	89.93	90.17	90.41
Crude protein	16.86	16.78	16.70	16.62
Ether extract	4.77	5.15	5.54	5.93
Crude fiber	12.76	12.72	12.68	12.63
ADF	25.51	26.14	26.78	27.41
NDF	17.21	17.80	18.38	18.96
Organic matter	4.89	5.46	6.02	6.59
GE (Mcal/kg)	2.89	2.86	2.83	2.80

All diets included: 02% bentonite; ADF: acid detergent fiber; NDF: neutral detergent fiber; GE: gross energy.

2.2. Animals and Diet

The experiment was conducted at Posta Zootécnica of Centro Universitario UAEM Amecameca. All procedures were conducted considering the animal protective law of the State of Mexico. Forty weaned rabbits breed New Zealand × California were randomly assigned into four groups (each rabbit was considered an experimental unit). The animals were fed a balanced diet using the NRC (1977) recommendations for rabbit feed, added with noni at 0, 2, 4 and 6% for each group. All diets were analyzed for dry matter, N, crude fiber, ash and ether extract using the methods of AOAC (2000). The neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by method proposed by Van Soest *et al*. (1991) as a showed in Table 1. The experiment lasted for 35 days, during this time the feed and water were offered *ad libitum*.

2.3. Growth Performance

At the beginning of the experiment, the animals were weighed and considered as initial weight (IW); the weight gain was taking every week during 35 days, the last data being considered as final weight. The weight gain (WG) was obtained by the difference between final and initial weight. Voluntary intake (VI) was obtained by the recorded food diary offered and rejected, feed conversion (FC) was calculated by the ratio of IV and WG.

2.4. Slaughter and Carcass Characteristics

At the end of the experimental period, sacrifice and carcass characteristics measurements were performed, according to suggest by Blasco and Ouhayoun (1993). Skin, gastrointestinal tract (GTI), hands and back legs were weighed. The carcass included head, thorax organs, liver and kidneys were chilled for 24 h at 4°C. After that, liver (L), kidneys (K), respiratory organs and heart (TO), scapular fat (SF) and perirenal fat (PF) were weighing. Besides the dorsal length (DL), lumbar circumference (LC) and meat to bone ratio (M/B) were obtained by following Blasco and Ouhayoun (1993) method.

2.5. Analysis of Meat Quality

The *longissimus dorsi* muscle was sectioned of backbone and divided into three parts, one of which was immediately used for quality testing of meat; another for analysis of lipid oxidation and the last was stored at -20 ° C for textural analysis and shear force. After 24 hours storage, pH (pH_{24}) was measured with a portable potentiometer (Orion) and color ($color_{24}$) with a colorimeter (Minolta C-K-400) at the seventh lumbar vertebra. Color results were expressed in terms of CIE LAB, also calculated Chroma and Hue angle $H = 180 + \left(\arctan \frac{b}{a}\right)$.

To obtain the value of water drip loss (WDL), a technique reported by Hernández *et al*. (2006) was used. As for the Shear Force (SF) *longissimus dorsi* samples were boiled and sliced according to reports from Rotolo *et al*. (2013), expressing the results as maximum cutting force in Newton (N). For texture profile analysis cubes 1 cm^3 of *longissimus dorsi* were compressed with a steel plate of 40 mm to 100 mm min-1 with 50% compressions with 30s between each (Rotolo *et al*., 2013), both analyzes were conducted employed a TA TX2 texturometer. Extraction technique and measurement given by Qwele *et al*. (2013) were used for the determination of total phenolic compounds and antioxidant activity as free radical scavenging capacity with DPPH (2,2-diphenyl-1-picrylhydrazyl).

2.6. Statistical Analyzes

The results were analyzed using PROC GLM of SAS (2005) in order to determine the linear and quadratic effect, with a significance level of P ≤0.05 (Steel *et al*., 1997).

3. Results and discussion

The Chemical composition of noni was 88% dry matter, crude protein 4.99%, 34.55% of ADF, 41.22 NDF and 1.99 Mcal / kg of digestible energy. The total concentration of total phenolic compounds in the noni powder was 25.32 mg GAE /g DM.

3.1. Growth performance and carcass characterization

The antioxidant compounds used as additives in the diet of rabbits, contribute to improving growth performance of rabbits as they can stimulate the production of digestive enzymes such as trypsin and amylase, promoting the efficient use of nutrients (Dalle Zotte *et al*., 2013). These compounds protect the intestinal mucous preventing pathogenic damage by immune modulatory properties (Ebeid *et al*., 2013), though noni has shown beneficial effects in modulating the immune system (Palu *et al*., 2008). In this study no linear or quadratic effect (P≥0.05) were observed on growth performance, final weight, food intake, weight gain, and feed conversion ratio (Table 2).

Table 2. Effect of noni (*Morinda citrifolia* L.) on rabbit growth performance and carcass characteristics

	Noni addition (%)				SEM	Contrast	
	0	2	4	6		Lin	Qua
Production variables							
Initial weight (g)	1018	1033	1036	1036	0.02	0.67	0.80
Final weight (g)	2184	2073	2225	2195	0.14	0.68	0.68
Voluntary intake (g)	106	103	110	107	0.15	0.73	0.75
Weight gain (g)	1166	1039	1189	1159	0.09	0.76	0.61
Feed conversion ratio	3.4	3.5	3.4	3.4	0.25	0.93	0.58
Characteristic of the carcass							
Dressing (%)	58.19	58.19	58.42	55.33	1.18	0.66	0.42
Carcass weight (g)	1158	1103	1178	1138	0.60	0.93	0.97
GIO (g/100 g)	20.50	22.00	20.42	22.93	0.07	0.63	0.41
L (g)	76.35	86.94	78.42	61.60	8.40	0.18	0.12
K (g)	12.43	12.80	14.13	13.41	0.62	0.13	0.39
TO (g)	31.81	27.57	29.96	28.35	1.86	0.32	0.46
M/B	4.47	4.99	4.98	4.66	0.05	0.93	0.16

GIO: gastrointestinal organs; L: liver; K: kidney; TO: thoracic organs; DL: dorsal length; DISL: distal length; M/B: meat to bone relation; Lin: Linear; Qua: Quadratic; (P ≤ 0.05).

The results showed in Table 2 are consistent with those reported by Liu *et al*. (2009), authors did not report changes in final weight, feed intake and weight gain in rabbits due to the addition of 0.5-1% of chestnut tannins extracts. The low palatability of noni, is one of the main problems for its acceptance, since the octanoic and hexanoic acids present provide an unpleasant aroma (Pino *et al*., 2010), low palatability of a diet consumption adversely influence growth performance as reported by Dal Bosco *et al*. (2012) with the decrease in the voluntary intake of 143.9 g to 126.4 g, weight gain from 2640 to 2450 g in rabbits supplemented with 5% olive residues, the diminish was attributed to the low acceptance of the diet for the animals. The lack of effect obtained in this study is an indication that the low palatability of noni fruit has no effect on the acceptance of diet and can therefore be used unaffected consumption up 6%.

3.2. Carcass Characteristics.

The carcass characteristics (Table 2) showed no linear or quadratic effects (P≥0.05), these results are similar to those reported by Peiretti and Meineri (2010) who found no changes in the carcass characteristics with the addition of 8 and 16% of flaxseed in the diet of rabbits. Regard to internal organs, no effects were found (P≥0.05), which is consistent with that reported by Peiretti *et al*. (2013), in rabbits supplemented with 3 and 6% of tomato pomace. The weight change of the internal organs could be indicative of metabolic disorders diet related, like as reported by Al-Mamary *et al*. (2001) who observe an increase in relative liver weight in rabbits due to a possible toxic effect of supplementation with sorghum tannin at 2.2%. Under this premise, the lack of effect on organ weights in this study is favorable as it is considered that noni not showed toxicity in rabbits.

3.3. Meat Quality

The pH_{24} in *longissimus dorsi* showed no changes in any treatment (P≥0.05) (Table 3), and are within the range considered ideal for rabbit meat (Blasco and Ouhayoun, 1993). The values obtained

are consistent with those reported by Peiretti *et al.* (2013) who found no changes in pH_{24} rabbit meat supplemented with 3 and 6% tomato pomace. Usually the changes on pH_{24} of rabbit meat are associated with events that generate stress in animals. Maria *et al.* (2006) and Liu *et al.* (2012) found differences in the pH in meat from rabbits subjected to prolonged travel before slaughter and high ambient temperatures respectively. The lack of effect on this parameter in the present study may be due the driving under proper welfare conditions.

Table 3. Effect of noni (*Morinda citrifolia* L.) on rabbit meat quality (*Longissimus dorsi*)

	Noni addition (%)				SEM	Contrast	
	0	2	4	6		Lin	Qua
pH24	5.62	5.57	5.59	5.66	0.30	0.09	0.81
L*	52.81	50.28	53.44	57.07	0.80	0.24	0.31
a*	5.94	3.98	5.11	4.62	0.62	0.43	0.36
b*	5.21	3.38	3.56	3.17	4.59	0.03	0.25
C	20.61	21.48	22.87	21.48	0.92	0.09	0.58
HUE	25.92	32.7	33.18	33.85	3.51	0.09	0.20
WDL (%)	35.39	35.34	34.10	30.72	1.55	0.03	0.22

L: Lightness; a*: redness; b*: yellownes; C: Chroma; HUE: Hue angle; WDL: water drip loss; Lin: linear; Qua: Quadratic; ($P \leq 0.05$).

Regarding color (Table 3), C and H showed no differences ($P \leq 0.05$); however, the parameter b* (yellowness) showed a descendent linear effect (P=0.03), which is favorable since the increase in this parameter is related to the decomposition of the meat. According to the study reported by Insausti *et al.* (2008), yellowness, is related to sensory loss of color, lipid oxidation and increased volatile compounds involved in the degradation of raw meat (2-propanone, 2.3 , 3-trimethylpentane, 2,2,5-trimethyl, 3-methyl-2-heptene, 2-octene and 3-octene).

The L* (Lightness) parameter showed an apparent increase (P=0.24) with the addition of 6% noni. Similar results were reported in rabbit meat by Dal Bosco *et al.* (2014a) with the addition of 3% of thyme. The authors suggest that the increase in L* is that the fact dietary antioxidants protect the cell membrane preventing the passage of water increasing intracellular spaces and light refraction, and keeping a bright color.

As the value of Water drip loss (WDL), a downward effect (P=0.03) was observed with increasing addition of noni. Generally, this reduction is related to the pH value (at lower pH greater loss of water); however, has also been demonstrated that WDL is also related to postmortem proteolysis starting by μ calpain; enzyme activity, which may itself be inactivated by oxidation processes, indeed prior reports that indicate antioxidants may interfere with proteolysis in meat (Jung *et al.*, 2010.). In this study, the improvement in decreasing the value of WDL may be due to the antioxidant effect of noni on oxidative status of rabbit meat resulting in an improvement WDL.

On the other hand, data from texture profile analysis (TPA) (Table 4) showed no linear and quadratic effect ($P \geq 0.05$) to shear force (SF) for none treatment. This result is similar to that described by Rotolo *et al.* (2013) who reported no changes in SF using oregano and sage in rabbit diets.

Tabla 4. Effect of noni (*Morinda citrifolia* L.) on textural profile analysis (TPA) (*Longissimus dorsi*) rabbit meat

	Noni addition (%)				SEM	Contrast	
	0	2	4	6		Lin	Qua
SF (N)	10.29	11.09	12.46	10.96	0.60	0.21	0.06
HR (kg)	15.02	12.75	14.73	14.60	2.95	0.07	0.30
CH	0.41	0.42	0.41	0.39	0.02	0.68	0.61
SPR	0.63	0.64	0.66	0.68	0.03	0.37	0.90
GM (kg)	5.71	5.56	5.79	5.97	1.14	0.84	0.85
CW (kg)	3.81	3.50	3.85	4.06	0.77	0.75	0.73
RS	0.23	0.21	0.18	0.17	0.01	0.007	0.60
AD	0.41	0.18	0.28	0.43	0.07	0.61	0.02
FS	8.36	8.44	8.42	8.37	0.25	0.99	0.80

SF: shear force; HR: hardenss; CH: cohesiviness; SPR: spingness; GM: gumminess; CW: chewiness; RS: Resilience; AD: adhesiveness; FS: fibrosiveness; Lin: linear; Qua: quadratic; ($P \leq 0.05$).

With regard to the parameters of textural profile analysis the values of cohesiveness, springiness, chewiness, gumminess and hardness showed no effects ($P \geq 0.05$); however, the value of resilience (ability of meat to resume its original form) presents a downward linear effect ($P=0.007$) with increasing addition of noni. Resilience is associated with the elasticity of connective tissues present in the muscle (Dinh, 2008); probably high resilience values can be associated with a hard meat chewing. Another hypothesis suggests that this parameter and elasticity are linked to the amount of fat in the muscle; low values could be related to juiciness and flavor intensity (Caine *et al*., 2003).

Respect to total phenolic compounds a value of 51.08, 53.01, 53.13 and 55.95 mg GAE/g of sample for 0, 2, 4, 6% addition of noni respectively, without linear or quadratic effect ($P \geq 0.05$) was obtained. Similar to that obtained by Muíño *et al*. (2014), who found no effect in the presence of total phenolic compounds in meat goats using 900 mg of extract of red wine / kg feed. In contrast, Luciano *et al*. (2011) reported an increased total phenolic compound in meat goats fed a diet supplemented with 8.96% of quebracho extract. The lack of effect found in this study may be due to poor fixation of phenolic compounds of noni to animal tissue, although there is reference that phenolic compounds are absorbed in the small intestine or are hydrolyzed by colonic microflora (Muíño *et al*., 2014); still not enough reference research of their ability to accumulate in a specific tissue.

In order to determine the antioxidant capacity was tested the inhibition of DPPH (42.23, 43.77, 43.59, 42.04% for 0, 2, 4, 6%, respectively) showed no effect ($P \geq 0.05$) for none treatment, that results are contrary to those reported by Anjum *et al*. (2013) who evaluated the effect of diet incorporation of 5, 10, and 15% flaxseed (rich in lignans) on the antioxidant activity in chicken meat. In this case, the differences observed may be due to high levels of supplementation dietary flaxseed and differences in phenolic compounds, as in the case of lignans which are phytoestrogens with similar animal hormones structure, which hypothetically may contribute to a better fixation in animal tissue.

3.4. Lipid Oxidation

The effect of the addition of noni in lipid oxidation in rabbit meat (Figure 1), exhibits no differences of malonaldehyde values in the first day of storage. In the subsequent days shows a statistically significant difference ($P \leq 0.05$) as the level of addition of reducing dietary noni by 18, 58 and 69% malonaldehyde values for 2, 4 and 6% respectively in relation to the control at the end of the experiment.

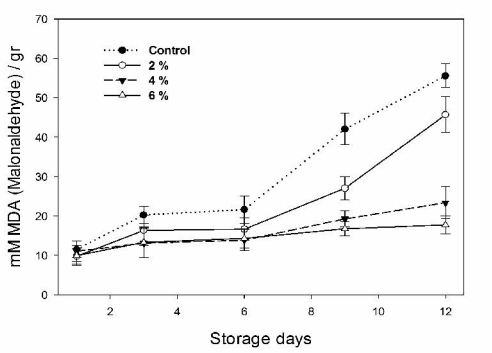

Figure 1. Effect of noni (*Morinda citrifolia* L.) on lipid oxidation of rabbit meat (*Longissimus dorsi*)

The decreased of lipid oxidation of this study showed no direct correlation ($R = 0.09$) with antioxidant capacity, this observation is similar to that obtained by Eid *et al*. (2010) who observed no correlation between antioxidant activity and a reduction in the amount of malonaldehyde in rabbits. The lack on correlation between the two values may be due to the antioxidant compounds that may act by different mechanisms such as reduction and chelation of radical reactive species (Singh and Singh, 2013) or can act indirectly by favoring the antioxidant animal endogenous enzyme activity (Liu *et al*., 2012).

Malonaldehyde reduction suggests that the use of the dosages noni promotes fat stability in storage by the presence of compounds in the fruit capable of retarding lipid oxidation and the formation of peroxide radical (Ramamoorthy and Awang, 2007). The noni fruit has been shown to be effective in reducing lipid oxidation in postmortem addition in beef. Tapp *et al*. (2012) report that noni puree 2, 4, 6% significantly improves lipid oxidation during storage, however mention the unpleasant taste of the fruit is still detectable at 2%, in this way, the use of noni dietary can be a viable form to reduce lipid oxidation without disagreeable flavors.

4. Conclusion

The results obtained in this study indicate that the addition of Noni dietary rabbits can be used to improve the water holding capacity, color and texture, and drastically delayed lipid oxidation of the meat during storage without showing negative effects on productive variables and the carcass characteristics.

Corresponding Author:
Dra. Ofelia Márquez Molina
Centro Universitario UAEM Amecameca
Universidad Autónoma del Estado de México
Amecameca, Estado de México C.P. 56900, México

E-mail: ofeliammolina@yahoo.com

References

1. (a) Dal Bosco A, Gerencsér Z, Szendrő Z, Mugnai C, Cullere M, Kovàcs M, Dalle Zotte A. Effect of dietary supplementation of Spirulina (*Arthrospira platensis*) and Thyme (Thymus vulgaris) on rabbit meat appearance, oxidative stability and fatty acid profile during retail display. Meat Science 2014b;96(1):114–9.
2. (b) Dal Bosco A, Mugnai C, Roscini V, Mattioli S, Ruggeri S, Castellini C. Effect of dietary alfalfa on the fatty acid composition and indexes of lipid metabolism of rabbit meat. Meat Science 2014a;96(1):606–9.
3. Al-Mamary M, Molham AH, Abdulwali AA, Al-Obeidi A. In vivo effects of dietary sorghum tannins on rabbit digestive enzymes and mineral absorption. Nutrition Research 2001;21(10):1393-1401.
4. Anjum F, Haider M, Khan M, Sohaib M, Arshad M. Impact of extruded flaxseed meal supplemented diet on growth performance, oxidative stability and quality of broiler meat and meat products. Lipids in Health and Disease 2013;12(1):13. doi:10.1186/1476-511X-12-13.
5. AOAC (2000) Official methods of analysis, 17th ed., (Gaitherburg, Maryland, Association of Official Analytical Chemists), Inc.
6. Blasco A, Ouhayoun J. Harmonization of criteria and terminology in rabbit meat research. Revised proposal. World Rabbit Science 1993; 4(2):93–99.
7. Caine WR, Aalhus JL, Best DR, Dugan MER, Jeremiah LE. Relationship of texture profile analysis and Warner-Bratzler shear force with sensory characteristics of beef rib steaks. Meat Science 2003;64, 333–339.
8. Dal Bosco A, Mourvaki E, Cardinali R, Servili M, Sebastiani B, Ruggeri S, Castellini C. Effect of dietary supplementation with olive pomaces on the performance and meat quality of growing rabbits. Meat Science 2012;92(4):783–8.
9. Dalle Zotte A, Sartori A, Bohatir P, Rémignon H, Ricci R. Effect of dietary supplementation of Spirulina (*Arthrospira platensis*) and Thyme (*Thymus vulgaris*) on growth performance, apparent digestibility and health status of companion dwarf rabbits. Livestock Science 2013;152(2-3):182–191.
10. Dinh, NTT. Meat quality: understanding of meat tenderness and influence of fat content on meat flavor. Tạp chí Phát triển Khoa học và Công nghệ 2008;9(12).
11. Ebeid TA, Zeweil H, Basyony MM, Dosoky WM, Badry H. Fortification of rabbit diets with vitamin E or selenium affects growth performance, lipid peroxidation, oxidative status and immune response in growing rabbits. Livestock Science 2013;155(2-3):323–331.
12. Eid Y, Zewehil H, Ahmed M, Basyony M, Farok M. Effect of plant source of omega-3 fatty acids and green tea powder on the performance and meat quality of growing rabbits. Egyptian Journal of Rabit Science 2010;20(2):115–134.
13. Falowo AB, Fayemi PO, Muchenje V. Natural antioxidants against lipid–protein oxidative deterioration in meat and meat products: A review. Food Research International 2014;64:171–181.
14. Giménez B, Graiver N, Califano A, Zaritzky N. Physicochemical characteristics and quality parameters of a beef product subjected to chemical preservatives and high hydrostatic pressure. MESC, 2015;100:179–188.
15. Hernández P, Ariño A, Grimal B, Blasco A. Meat Comparison of carcass and meat characteristics of three rabbit lines selected for litter size or growth rate. Meat Science 2006;73:645–650.
16. Insausti K, Beriain MJ, Lizaso G, Carr TR, Purroy A. Multivariate study of different beef quality traits from local Spanish cattle breeds. Animal-Cambridge University Press 2008;2(3):447.
17. Jung S, Choe JH, Kim B, Yun H, Kruk ZA, Jo C. Effect of dietary mixture of gallic acid and linoleic acid on antioxidative potential and quality of breast meat from broilers. Meat Science 2010;86(2):520–6.
18. Cedillo J, Vázquez-Armijo JF, González-Reyna Salem AZM, Kholif AE, Hernández-Meléndez J, Martínez-González JC, Jiménez RM, Rivero N, López D. Effects of different doses of *Salix babylonica* extract on growth performance and diet in vitro gas production in Pelibuey growing lambs. Ital J Anim Sci. 2014; 13: 609-613.
19. Kovendan K, Shanthakumar SP, Praseeja C, Kumar PM, Murugan K, Vincent S. Mosquitocidal properties of *Morinda citrifolia* L. (Noni) (Family: Rubiaceae) leaf extract and *Metarhizium anisopliae* against malaria vector, *Anopheles stephensi* Liston. (*Diptera: Culicidae*). Asian Pacific Journal of Tropical Disease 2014;4(1):173–180.
20. Kumar SNK, Suresh M, Kumar SA, Kalaiselvi P. Bioactive compounds, radical scavenging, antioxidant properties and FTIR spectroscopy study of *Morinda citrifolia* fruit extracts. International Journal Curr. Microbiological Applied Science 2014;3(2):28–42.
21. Liu H, Zhou D, Tong J, Vaddella V. Influence of chestnut tannins on welfare, carcass characteristics, meat quality, and lipid oxidation in rabbits under high ambient temperature. Meat Science 2012;90(1):164–9.
22. Liu HW, Gai F, Gasco L, Brugiapaglia A, Lussiana C, Guo KJ, Zoccarato I. Effects of chestnut tannins on carcass characteristics, meat quality, lipid oxidation and fatty acid composition of rabbits. Meat Science 2009;83(4):678–83.
23. Luciano G, Vasta V, Monahan FJ, López-Andrés P, Biondi L, Lanza M, Priolo A. Antioxidant status, colour stability and myoglobin resistance to oxidation of *longissimus dorsi* muscle from lambs fed a tannin-containing diet. Food Chemistry 2011;124(3):1036-1042.
24. Maria GA, Buil T, Liste G, Villarro M, Sañudo C, Olleta JL. Effects of transport time and season on aspects of rabbit meat quality. Meat Science 2006;72(4):773–7.
25. Muíño I, Apeleo E, de la Fuente J, Pérez-Santaescolástica C, Rivas-Cañedo A, Pérez C, Lauzurica S. Effect of dietary supplementation with

red wine extract or vitamin E, in combination with linseed and fish oil, on lamb meat quality. Meat Science 2014;98(2):116-123
26. NRC. National Research Council. Nutrient requirements of domestic rabbits. National Acad. Science; 1977, Washington DC, USA.
27. Palu, A. K., Kim, A. H., West, B. J., Deng, S., Jensen, J., & White, L. The effects of *Morinda citrifolia* L. (noni) on the immune system: Its molecular mechanisms of action. Journal of Ethnopharmacology 2008;115(3), 502-506.
28. Peiretti PG, Meineri G. Effects of diets with increasing levels of Spirulina platensis on the carcass characteristics, meat quality and fatty acid composition of growing rabbits. Livestock Science 2011;140(1-3):218–224.
29. Peiretti PG, Gai F, Rotolo L, Brugiapaglia A, Gasco L. Effects of tomato pomace supplementation on carcass characteristics and meat quality of fattening rabbits. Meat Science 2013;95(2):345–51.
30. Peiretti PG, Meineri G. Effects of diets with increasing levels of golden flaxseed on carcass characteristics, meat quality and lipid traits of growing rabbits. Italian Journal of Animal Science 2010;9(4):372-377.
31. Pino JA, Márquez E, Quijano CE, Castro D. Volatile compounds in noni (Morinda citrifolia L.) at two ripening stages. Ciencia E Tecnologia de Alimentos 2010;30(1):1–5.
32. Qwele K, Hugo A, Oyedemi SO, Moyo B, Masika PJ, Muchenje V. Chemical composition, fatty acid content and antioxidant potential of meat from goats supplemented with Moringa (Moringa oleifera) leaves, sunflower cake and grass hay. Meat Science 2013;93(3):455–62.
33. Ramamoorthy P, Awang B. Antioxidant activity, total phenolic and flavonoid content of. Journal of Engineering Science and Technology 2007;2(1):70–80.
34. Realini CE, Guàrdia MD, Díaz I, García-Regueiro JA, Arnau J. Effects of acerola fruit extract on sensory and shelf-life of salted beef patties from grinds differing in fatty acid composition. Meat Science 2015;99:18–24.
35. Rossi R, Ratti S, Pastorelli G, Crotti A, Corino C. The effect of dietary vitamin E and verbascoside on meat quality and oxidative stability of Longissimus dorsi muscle in medium-heavy pigs. Food Research International 2014;65:88-94.
36. Rotolo L, Gai F, Nicola S, Zoccarato I, Brugiapaglia A, Gasco L. Dietary Supplementation of Oregano and Sage Dried Leaves on Performances and Meat Quality of Rabbits. Journal of Integrative Agriculture 2013;12(11):1937–1945.
37. Salem AZM, Kholif AE, Olivares M, Elghandour MMY, Mellado M, Arece J. Influence of S. babylonica extract on feed intake, growth performance and diet in vitro gas production profile in young lambs. Trop Anim Health Prod 2014a (46): 213–219.
38. Salem AZM, Domínguez-Vara IA, Kholif AE, Elghandour MMY, Mellado M.. Effect of increasing levels of seven tree species extracts added to a high concentrate diet on in vitro rumen gas output. Anim Sci J 2014b (85): 853–860.
39. Singh DR, Singh S. Phytochemicals in Plant Parts of Noni (Morinda citrifolia L.) with Special Reference to Fatty Acid Profiles of Seeds. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences 2013;83(3):471–478.
40. Steel GDR, Torrie JH, Dickey DA. Principles and procedures of statistics. A biometrical approach. The McGraw-Hill Companies, Inc., 1997:637.
41. Tapp NW, Yancey JWS, Apple JK, Dikeman ME, Godbee RG. Noni puree (*Morinda citrifolia*) mixed in beef patties enhanced color stability. Meat Science 2012;91(2):131–6.
42. Valdes KI, Salem AZM, Lopez S, Alonso MU, Rivero N, Elghandour MMY, Domínguez IA, Ronquillo MG, Kholif AE. Influence of exogenous enzymes in presence of *Salix babylonica* extract on digestibility, microbial protein synthesis and performance of lambs fed maize silage. J Agr Sci, Camb 2015; doi. 10.1017/S0021859614000975.
43. Van Soest PV, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 1991;74(10):3583-3597.
44. Wang MY, Peng L, Jensen CJ, Deng S, West BJ. Noni juice reduces lipid peroxidation-derived DNA adducts in heavy smokers. Food Science & Nutrition 2013;1(2):141-149.
45. Yang J, Gadi R, Paulino R, Thomson T. Total phenolics, ascorbic acid, and antioxidant capacity of noni (*Morinda citrifolia* L.) juice and powder as affected by illumination during storage. Food Chemistry 2010; 122(3):627–632.