Kafkas Univ Vet Fak Derg
25 (1): 119-123, 2019
DOI: 10.9775/kvfd.2018.20453

Kafkas Universitesi Veteriner Fakultesi Dergisi
ISSN: 1300-6045 e-ISSN: 1309-2251
Journal Home-Page: http://vetdergikafkas.org
Online Submission: http://submit.vetdergikafkas.org

Research Article

Improvement in Pellet Production Parameters and Pellet Quality Characteristics with Sepiolite Supplementation in Dairy Cattle Concentrate [1]

Sakine YALÇIN [1,a] Ender BURÇAK [2,b] İlyas ONBAŞILAR [3,c]
Muhammad Shazaib RAMAY [1,d] Emre Sunay GEBEŞ [1,e] Mahlagha PİRPANAHİ [1,f]

[1] This study was supported by the Scientific Research Project Unit of Ankara University (Project number: 15H0239003)

[1] Department of Animal Nutrition and Nutritional Diseases, Faculty of Veterinary Medicine, Ankara University, TR-06110 Ankara - TURKEY
[2] Ministry of Agriculture and Forestry, TR-06800 Ankara - TURKEY
[3] Transgenic Animal Technology Application and Research Center, Hacettepe University, TR-06100 Ankara - TURKEY
[a] ORCID: 0000-0001-8640-2729; [b] ORCID: 0000-0002-1651-188X; [c] ORCID: 0000-0002-1464-4654; [d] ORCID: 0000-0002-7061-0483
[e] ORCID: 0000-0002-4509-6750; [f] ORCID: 0000-0002-8137-9811

Article ID: KVFD-2018-20453 Received: 30.06.2018 Accepted: 24.10.2018 Published Online: 27.10.2018

How to Cite This Article

Yalçin S, Burçak E, Onbaşilar İ, Ramay MS, Gebeş ES, Pirpanahi M: Improvement in pellet production parameters and pellet quality characteristics with sepiolite supplementation in dairy cattle concentrate. *Kafkas Univ Vet Fak Derg,* 25 (1): 119-123, 2019. DOI: 10.9775/kvfd.2018.20453

Abstract

The aim of this study was conducted to determine the effects of sepiolite usage on pellet production parameters and pellet quality characteristics for dairy cattle concentrate feed under regular industrial conditions. In the experiment, 14 mt pellet feeds for control and two treatment groups with 7 batch each were produced in a commercial feed factory. Each batch was 2 mt. Control group feed produced contained 87.37% dry matter, 18.06% crude protein, 6.95% crude fibre and 5.34% ether extract. For the treatment groups, 1% and 1.5% sepiolite (Exal T) were used as top dressed in the mixer. Pelleting disc having 6.5 mm hole diameter was used in the factory. Energy consumption during pellet manufacturing was decreased with sepiolite supplementation ($P<0.001$) and pellet durability index (PDI) was enhanced with 1.5% sepiolite ($P<0.05$). These findings demonstrated that 1.5% sepiolite in dairy cattle concentrates as top dressed may be used as a binder to improve pellet quality and to reduce energy consumption during pellet production in the feed mill.

Keywords: *Energy consumption, Dairy cattle concentrate, Pellet durability, Sepiolite*

Süt Sığırı Konsantre Yemlerinde Sepiyolit Kullanımı İle Pelet Üretim Parametreleri ve Pelet Kalite Özelliklerinin İyileştirilmesi

Öz

Bu çalışmanın amacı, endüstriyel koşullar altında süt sığırı konsantre yemlerinde sepiyolit kullanımının pelet üretim parametreleri ve pelet kalite özelliklerine olan etkisini belirlemektir. Denemede, kontrol ve 2 deneme grubunun her biri için yedişer parti olmak üzere toplam 14 tonluk pelet yem ticari bir yem fabrikasında üretilmiştir. Her parti 2 tondur. Üretilen kontrol grubu yemi %87.37 kuru madde, %18.06 ham protein, %6.95 ham selüloz ve %5.34 eter ekstraktı içermektedir. Deneme grupları yemine, %1 ve %1.5 sepiyolit (Exal T) karıştırıcıda dökme olarak (top dressed) ilave edilmiştir. Fabrikada 6.5 mm delik çaplı peletleme diski kullanılmıştır. Pelet üretimi süresince sepiyolit ilavesiyle enerji tüketimi azalmış ($P<0.001$) ve pelet dayanıklılık indeksi (PDI) ise %1.5 sepiyolit ilavesiyle artmıştır ($P<0.05$). Sonuçlar, dökme olarak %1.5 sepiolit ilavesinin, süt sığırı konsantre yemlerinde pelet kalitesini iyileştirmek ve yem fabrikasında pelet üretimi sırasında enerji tüketimini azaltmak için bir bağlayıcı olarak kullanılabileceğini göstermiştir.

Anahtar sözcükler: *Enerji tüketimi, Pelet dayanıklılığı, Sepiyolit, Süt sığırı konsantre yemi*

INTRODUCTION

One of the most common feed processing techniques is pelleting of feeds. The main target of pelleting is to agglomerate smaller feed particles by the use of heat, mechanical pressure and moisture [1]. The history of the pellet is based on the nineteenth century [2]. However, it was reported that pelletization dates back to the time of

İletişim (Correspondence)
+90 312 3076076
ender.burcak@tarim.gov.tr

Napoleon where army horses were fed a type of feed that was agglomerated by an expeller [3]. Today, pellet feeding is widely used due to the fact that it improves animal performance and feed conversion ratio compared with feeding with meal form [4]. Some researchers [5,6] reported that broilers fed pellet feed performed greater feed intake, better feed conversion ratio and thus greater weight gain than that of mash feed. In pig, pelleted feed compared with mash, resulted in a decreased feed intake of 2%, increased weight gain of about 7% and improved feed utilisation of around 8% [3]. In ruminant, feed processing affects the rate of transit through the gastrointestinal tract and rate of passage of feed components [7]. When animal feed is pelleted, contribution to performance is important due to reducing selective feeding, decreasing feed wastage, reducing time and energy consumption, destructing of pathogenic organisms and improving palatability [4].

During this pellet formation, some factors affecting pellet quality are ingredients and nutrient composition of concentrate diet and its properties, process technology as well as certain pellet binders. In particular, components such as starch, protein, fat, fiber and sugar are important factors determining the hardness and durability of the feed. Starch has a function as an adhesive or binding agent in feed production [8]. After gelatinization, when starch includes in diets, it has affirmative effect on the pellet hardness and durability [9]. Sugars that in the form of molasses may positively effect of that as a binder [8]. Protein can act as a binding agent and during denaturation processing may positively affect the hardness and durability of the feed pellets. However, it is reported that the addition of fats in the diets has a negative effect on pellet hardness and durability. The addition of fats to the diets that serves as a lubricant between the mash and die occurs a low pressure during pressing [3]. Moreover, pellet binders such as bentonite, carboxymethylcellulose and lignosulphonates can be used to improve pellet hardness and durability by reducing the gaps to make the pellets more compact and durable [8]. The pellet binder property to improve durability especially in high fat diets, sepiolite is a good technological additive due to its properties such as reducing energy cost in pellet, increasing pellet durability, reducing the amount of dusting during the production and transport of feeds [10]. Sepiolite is a hydrated magnesium silicate ($Si_{12}.Mg_8.O_{36}.(H_2O)_{4\cdot 8}H_2O$) which belong to phyllosilicates. Sepiolite (E562) is currently authorised as binders, anti-caking agents and coagulants for all animal species according to Regulation (EC) No 1831/2003 of the European Union [11]. It is also stated that the use of sepiolite at different levels as a feed additive also makes positive contribution to the performance and quality parameters of animals [12-14]. Burçak and Yalçın [15] showed that 2% sepiolite supplementation added to the rations of lamb increased the IgG level in the blood serum and thus enhanced immunity. Yalçın et al.[16] reported that sepiolite addition at 1% to dairy cattle feed and fattening cattle feed as top-dressed decreased energy consumption during pelleting and enhanced pellet durability index (PDI). Sepiolite usage at 1% in layer diets significantly reduced energy consumption at the level of 16.14% and increased PDI [17]. However, there are limited studies with supplementation of different levels of sepiolite and other clay minerals in diets about pellet quality during the pelleting processes. Therefore, the purpose of this experiment was to evaluate the effects of different levels of sepiolite usage to concentrate feeds of dairy cattle on some pellet production parameters and pellet quality characteristics.

MATERIAL and METHODS

Commercial concentrate feed for dairy cattle was used in this experiment. Manufacturing pellet feeds were produced in a commercial feed factory. Commercial dairy cattle concentrate feed contained mainly wheat bran (200 kg/t), sunflower seed meal (180 kg/t), rice bran (170 kg/t), canola seed meal (120 kg/t), broken rice (110 kg/t), corn gluten feed (70 kg/t), corn embryo meal (50 kg/t), condensed molasses solubles (40 kg/t) and corn (20 kg/t). Concentrate feeds for one control and two treatment groups were manufactured in this study. Sepiolite (Exal T, Tolsa Turkey Company-Polatlı, Türkiye) was added to the treatment concentrate feeds at 1% and 1.5% as top dressed to the mixer. Pellet concentrate feeds were produced with 7 batch (each batch was 2 t) and pellet diameter was 6.5 mm. Water was not used in the pellet manufacturing processes. Mixer capacity of the feed mill was 2 t and hole length of pellet disc was 90 mm.

In this commercial factory the data of steam temperature (°C), electric current (ampere) and pellet production time (min/10 t) were measured. Energy consumption of pelleting machine (electric power in kilowatts, kW) was calculated as multiplying electric current (in ampere) with voltage supply (volts) and then dividing by 1000. Voltage supply of feed pellet machine was 380 volts.

Seven samples from the mixer, after the conditioner and pelleted feed after cooling were collected from each group dairy cattle feed. Moisture content was analysed in all of the samples collected. Crude protein, crude fibre, ether extract, ash and starch analysis of control pelleted feeds were determined [18]. Metabolizable energy level was calculated according to the formula proposed by TSI [19]. Mineralogical composition was analysed by D8 Advance Diffractometer AXS (Bruker, Germany) and chemical composition was determined by Atomic Absorption Spectrometer (Varian Atomic Absorption Spectrometer AA240, Varian Inc., The Netherlands). PDI values of pelleted concentrate feeds were measured with a Pfost Box Equipment using the sieve having the hole diameter of 4.75 mm [20]. Quadruplicate measurements were done with each sample.

Data were analysed using the ANOVA procedure of the SPSS 23.0 (SPSS Inc., Chicago, IL, USA). The experimental unit was 7. The normality of data distribution was checked using the Kolmogorov-Smirnov test. The effects of graded levels of dietary sepiolite supplementation on different variables were analyzed using polynomial contrasts. Significant differences among groups were tested by Tukey test. Level of significance was taken as P<0.05 [21].

RESULTS

Sepiolite used in this trial was comprised of 73% of clay minerals (of which 65% was sepiolite), 21% dolomite and 6% calcite. Heavy metal analysis of sepiolite showed that it contained 1.6 mg/kg As, <1 mg/kg Cd, 1.72 mg/kg Pb and 0.02 mg/kg Hg. Chemical composition of sepiolite was given in *Table 1* and the nutrient composition of basal dairy cattle concentrate feed was shown in *Table 2*. Crude protein was 18.06% and metabolizable energy was 2.681 kcal/kg in concentrate feed. Production parameters during pelleting of dairy cattle concentrate feed were given in *Table 3*. Addition of 1% and 1.5% sepiolite to the mixer as top dressed significantly (P<0.001) decreased energy consumption during pelleting. There was also linear reduction in energy consumption with increasing sepiolite dose (P<0.001). Moisture content and PDI value of feeds during pellet manufacturing were shown in *Table 4*. PDI values of concentrate pellets were increased with 1.5% sepiolite supplementation (P=0.020). There was also linear increasing in PDI value with increasing sepiolite dose (P=0.006).

Table 1. *Chemical composition of sepiolite*

Chemical Composition	Content, %
SiO_2	42
Al_2O_3	1.1
MgO	20
CaO	13.90
Fe_2O_3	0.50
Na_2O	0.32
K_2O	0.44
Mn_2O_3	0.01

Table 2. *Nutrient composition of basal dairy concentrate feed*

Nutrient Composition	Content
Dry matter, %	87.37
Crude protein, %	18.06
Crude fibre, %	6.95
Ether extract, %	5.34
Starch, %	16.40
Sugar, %	7.00
Ash, %	6.75
ADF, %	13.97
NDF, %	29.51
Metabolizable Energy, kcal/kg	2.681

DISCUSSION

Sepiolite clay used in this study had high content of sepiolite (65%). Heavy metal analysis of sepiolite also suggested no contamination of heavy metals according to the Turkish Communique of 2014/11 [22] that was harmonized by the Directive of 2002/32/EC [23]. Many factors in feed pelleting processes may affect pellet quality, such as feed moisture, feed nutritional composition, ingredient particle size, conditioning temperature and time, compression rate of pellet die, cooling process, etc.[24-29].

In the present study, the conditions of amount of production, mixer capacity, disc hole diameter and disc hole length were same in the manufacturing of pellet concentrate feeds for control group and treatment groups. Sepiolite is a feed additive used as a binder and anticaking agent up to 2% in all feeds for all animal species [11]. Sepiolite supplementation at the rate of 1-1.5% to the mixer as top dressed significantly (P<0.001) reduced energy consumption at the level of 13.81-18.45% with increasing steam temperature at the level of 24.39-37.73%. Similar results were obtained with the layer concentrate pellets using 1% sepiolite [17]. Yalçın et al.[17] reported that 1% sepiolite supplementation in layer diet reduced energy consumption at 16.14% and increased steam temperature at 36.74%. Yalçın et al.[16] also indicated that energy consumption during pelleting for dairy cattle feed and fattening cattle feed is 9.63% and 5.27% lower (P<0.01) in group feed supplemented sepiolite than control group. In

Table 3. *Production parameters during pelleting of dairy cattle concentrate feed*

Production Parameters	Sepiolite			SEM*	Significance	
	0%	1%	1.5%		Combined	Linear
Steam temperature, °C	31.86^c	39.63^b	43.88^a	1.330	<0.001	<0.001
Electric current, Ampere	126.52^a	109.06^b	103.18^c	2.656	<0.001	<0.001
Energy consumption**, kW	48.08^a	41.44^b	39.21^c	1.009	<0.001	<0.001
Production time, min for 14 t	79	78	78			

** Pooled standard error of mean; ** Energy consumption was calculated using 380 of voltage in pelleting machine*
^{a,b,c} means a row followed by different letters differ significantly (P<0.01)

***Table 4.** Moisture content and PDI value of feeds during pellet manufacturing*

Feed Characteristics	Sepiolite			SEM*	Significance	
	0%	1%	1.5%		Combined	Linear
Moisture in the mixer, %	13.12	13.08	13.07	0.010	0.132	0.094
Moisture after conditioner, %	14.18^b	14.21^b	14.54^a	0.048	<0.001	<0.001
Moisture after pellet cooling, %	13.00	13.06	13.16	0.031	0.106	0.038
PDI, %	95.80^b	96.12^{ab}	96.43^a	0.096	0.020	0.006

** Pooled standard error of mean; ^{a,b} Means a row followed by different letters differ significantly (P<0.01)*

the present study, similar production time was obtained for the control group and treatment groups. Similarly, sepiolite supplementation to the layer diets [17] and dairy cattle concentrate [16] did not affect pellet manufacturing time. However, in some studies sepiolite supplementation reduces the pellet production time by 8.47% in fattening cattle feed [16] and 10.60% in broiler starter diets [30]. These differences among the studies may be due to the ingredients and chemical composition of diets, disc hole diameter, disc hole length and steam temperature.

Moisture content of dairy concentrate feeds in mixer was 13.12, 13.08 and 13.07% for control and treatment groups, respectively. Sepiolite supplementation at the level of 1.5% increased moisture content of concentrate feed after conditioner (P<0.001). There was a linear relation (P<0.001) with moisture content and dose of sepiolite. This increase may be due to the increase in steam temperature. Higher moisture content achieved after conditioning had lubricating effect and decreased the specific energy consumption [23]. No significant effect was seen in moisture content of concentrate pellet feeds among groups. However, there was a linear relation (P<0.05) with moisture content and dose of sepiolite.

Pellet physical characteristics, which are usually used for determination of pellet quality, are hardness and durability. In this study, adding 1.5% sepiolite improved pellet durability when compared to the control group (P<0.05). A linear effect of PDI with sepiolite dosage was seen (P<0.05) in *Table 4*. Sepiolite is a binder used in feed technology to improve physical pellet quality. In line with our results, Angulo et al.[10] reported that sepiolite improved the performance of pelleted diets. Similarly, since sepiolite acts as a filler and thereby decreases porosity in pelleted feed, it improved pellet durability [16,17]. However, Pappas et al.[31] indicated that palygorskite, a clay with similar physical properties to sepiolite [32] did not statistically affect pellet durability. When sepiolite increased the pelleting temperature, increasing durability and hardness of the pellets could cause more friction in the die. During this pellet formation, the feed can be exposed to high friction temperatures. Actually, when too much heat is applied, temperature of pellets is higher on account of frictional heat and of this effect will be impaired pellet quality [33]. Cutlip et al.[34] reported that high temperature conditioning increased PDI and decreased total fine particles. Similarly, Abdollahi et al.[35] indicated that if conditioning temperature increases from 60 to 90°C, pellet hardness and durability of broiler diets was improved. However, Vukmirovic et al.[36] stated that increasing the moisture content of diets to 15.97% and 21.88% resulted in decreasing pellet durability during pelleting process.

In present study, crude protein and starch content of diet was 18.06% and 16.40, respectively *(Table 2)*. Diet ingredients also strongly effect pellet durability. In our study, with together sepiolite usage, increasing protein and starch content of diet might have been caused an increase in pellet quality. Similarly, Briggs et al.[37] found an affirmative relationship between pellet durability and increased protein content of broiler diets. Wood [9] also reported that binding properties were based on the denaturation of the protein rather than gelatinisation of the starch during steam conditioning. However, Zimonja and Svihus [38] reported that pellet durability was lower (P<0.05) for gelatinised starch containing diets than non-starch diets.

In conclusion, 1 and 1.5% sepiolite supplementation decreased energy consumption during pellet manufacturing and 1.5% sepiolite supplementation increased pellet durability index. Therefore, from the results obtained in this study it is concluded that 1.5% sepiolite supplementation to dairy cattle concentrate feeds can be useful to improve pellet durability and to reduce energy consumption in the feed mill.

Acknowledgments

This authors would like to thank Tolsa, SA (Madrid, Spain). and Bursa Feed Mill for pellet production.

REFERENCES

1. Abdollahi MR, Ravindran V, Svihus B: Pelleting of broiler diets: An overview with emphasis on pellet quality and nutritional value. *Anim Feed Sci Technol*, 179 (1-4): 1-23, 2013. DOI: 10.1016/j.anifeedsci.2012.10.011

2. Schoeff RW: History of the formula feed industry. **In,** Mc Ellhiney RR (Ed): Feed Manufacturing Technology IV, 2-11, American Feed Industry Association. Arlington, Virginia, 1994.

3. Thomas M, Van Vliet T, Van der Poel AFB: Physical quality of pelleted animal feed 3. Contribution of feedstuff components. *Anim Feed Sci Technol,* 70 (1-2): 59-78, 1998. DOI: 10.1016/S0377-8401(97)00072-2

4. Behnke KC: Factors affecting pellet quality. **In**, Proceedings - Maryland Nutrition Conference for Feed Manufacturers. Feed Ind. Counc. and Univ., College Park., Maryland, 44-54, 1994.

5. Corzo A, Mejia L, Loar RE: Effect of pellet quality on various broiler production parameters. *J Appl Poult Res*, 20 (1): 68-74, 2011. DOI: 10.3382/japr.2010-00229

6. Dozier WA: Cost effective pellet quality for meat birds. *Feed Management,* 52 (2): 21-24, 2001.

7. Van der Poel AFB, Verstegen MWA, Tarnminga S: Chemical, physical and nutritional effects of feed processing technology. **In,** *16th Western Nutrition Conference,* 13-14 September 1995, 266, Saskatoon Sask., Canada. 1995.

8. Rakic L: Feed structure: Effects on physical quality of the feed, chemical status of the feed and nutritional consequence. *MSc Thesis* in Feed Manufacturing Technology. Norwegian University of Life Science Department of Animal and Aquaculture Sciences, 2012.

9. Wood JF: The functional properties of feed raw materials and their effect on production and quality of feed pellets. *Anim Feed Sci Technol*, 18 (1): 1-17, 1987. DOI: 10.1016/0377-8401(87)90025-3

10. Angulo E, Brufau J, Esteve-Garcia E: Effect of sepiolite on pellet durability in feeds differing in fat and fibre content. *Anim Feed Sci Technol*, 53 (3-4): 233-241, 1995. DOI: 10.1016/0377-8401(94)00749-Y

11. EFSA: Scientific opinion on the safety and efficacy of a preparation of bentonite and sepiolite (Toxfin Dry) as feed additive for all species. *EFSA J*, 11 (4): 3179, 2013.

12. Eser H, Yalçın S, Yalçın S, Şehu A: Effects of sepiolite usage in broiler diets on performance, carcass traits and some blood parameters. *Kafkas Univ Vet Fak Derg*, 18 (2): 313-318, 2012. DOI: 10.9775/kvfd.2011.5472

13. Yalçın S, Yalçın S, Gebeş ES, Şahin A, Duyum HM, Escribano F, Ceylan A: Sepiolite as a feed supplement for broilers. *Appl Clay Sci,* 148, 95-102, 2017. DOI: 10.1016/j.clay.2017.08.007

14. Yalçın S, Eser H, Onbaşılar İ, Yalçın S, Karakaş Oğuz F: Effects of dietary sepiolite on performance, egg quality and some blood parameters in laying hens. *Ankara Üniv Vet Fak Derg*, 63 (1): 25-29, 2016. DOI: 10.1501/Vetfak_0000002705

15. Burçak E, Yalçın S: Effects of dietary sepiolite usage on performance, carcass characteristics, blood parameters and rumen fluid metabolites in Merino cross breed lambs. *Appl Clay Sci*, 163, 291-298, 2018. DOI: 10.1016/j.clay.2018.07.001

16. Yalçın S, Onbaşılar İ, Gebeş ES, Ramay MS, Güntürkün OB: Effects of sepiolite usage in the manufacturing of pellet concentrate feeds for dairy cattle and fattening cattle on some production parameters and pellet quality characteristics. *Lalahan Hay Araşt Enst Derg*, 57 (1): 39-43, 2017.

17. Yalçın S, Çıvracı S, Burçak E, Onbaşılar İ: Effects of usage of sepiolite in layer diet on pellet quality and pellet production parameters. *Kocatepe Vet J*, 11 (2): 134-139, 2018. DOI: 10.30607/kvj.372107

18. AOAC: *Official Methods of Analysis, Association of Official Analytical Chemists*. AOAC International. 17th ed., Maryland. Chapter 4, 1-41, 2000.

19. TSI: Animal Feeds-Determination of Metabolizable Energy (Chemical Method) TS9610, Turkish Standards Institution, Turkey, 2-3, 1991.

20. Başer Ö, Yalçın S: Determination of some quality characteristics in pet foods. *Ankara Üniv Vet Fak Derg,* 64, 21-24, 2017. DOI: 10.1501/Vetfak_0000002768

21. Dawson B, Trapp RG: Basic and Clinical Biostatistics, 3rd ed., pp. 161-182, Lange Medical Books/McGraw-Hill Medical Publishing Division, New York, USA, 2001.

22. TC Resmi Gazete: Yemlerde İstenmeyen Maddeler Hakkında Tebliğ (Tebliğ No: 2014/11. 19 Nisan 2014. Sayı: 28877, 2014.

23. EC (European Commission): Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed. *Off J Eur Comm,* L.140, 10-21, 2002.

24. Arshadi M, Gref R, Geladi P, Dahlqvist SA, Lestander T: The influence of raw material characteristics on the industrial pelletizing process and pellet quality. *Fuel Process Technol*, 89 (12): 1442-1447, 2008. DOI: 10.1016/j.fuproc.2008.07.001

25. Colovic R, Vukmirovic D, Matulaitis R, Bliznikas S, Uchockis V, Juskiene V, Levic J: Effect of die channel press way length on physical quality of pelleted cattle feed. *Food Feed Res,* 37 (1): 1-6, 2010.

26. Fairfield DA: Pelleting for profit - Part 1. *National Grain and Feed Association*, 54 (6): 1-5, 2003.

27. Lemme A, Wijtten PJA, Van Wichen J, Petri A, Langhout DJ: Responses of male growing broilers to increasing levels of balanced protein offered as coarse mash or pellets of varying quality. *Poult Sci*, 85 (4): 721-730, 2006. DOI: 10.1093/ps/85.4.721

28. Liu SY, Selle PH, Cowieson AJ: Influence of white and red-sorghum varieties and hydrothermal component of steam-pelleting on digestibility coefficients of amino acids and kinetics of amino acids, nitrogen and starch digestion in diets for broiler chickens. *Anim Feed Sci Technol,* 186 (1-2): 53-63, 2013. DOI: 10.1016/j.anifeedsci.2013.08.006

29. Muramatsu K, Massuquetto A, Dahlke F, Maiorka A: Factors that affect pellet quality: A review. *J Agr Sci Tech A,* 9 (2): 717-722, 2015. DOI: 10.17265/2161-6256/2015.09.002

30. Durna Ö, Onbaşılar İ, Yalçın S, Escribano F: Effects of sepiolite usage in broiler feed on pellet quality and pellet production parameters. **In,** *1st International Animal Nutrition Congress,* September 28th-October 1st 2016. Spice Hotel and Spa. Antalya-Turkey (Poster), 2016.

31. Pappas AC, Zoidis E, Theophilou N, Zervas G, Fegeros K: Effects of palygorskite on broiler performance, feed technological characteristics and litter quality. *Appl Clay Sci*, 49 (3): 276-280, 2010. DOI: 10.1016/j.clay.2010.06.003

32. Galan E: Properties and applications of palygorskite-sepiolite clays. *Clay Miner*, 31, 443-454, 1996.

33. Thomas M, Van der Poel AFB: Physical quality of pelleted animal feed 1. Criteria for pellet quality. *Anim Feed Sci Technol,* 61 (1-4): 89-112, 1996. DOI: 10.1016/0377-8401(96)00949-2

34. Cutlip SE, Hott JM, Buchanan NP, Rack AL, Latshaw JD, Moritz JS: The effect of steam-conditioning practices on pellet quality and growing broiler nutritional value. *J Appl Poult Res* 17 (2): 249-261, 2008. DOI: 10.3382/japr.2007-00081

35. Abdollahi MR, Ravindran V, Wester TJ, Ravindran G, Thomas DV: Influence of conditioning temperature on performance, apparent metabolisable energy, ileal digestibility of starch and nitrogen and the quality of pellets, in broiler starters fed maize- and sorghum-based diets. *Anim Feed Sci Technol*, 162, 106-115, 1987. DOI: 10.1016/j.anifeedsci.2010.08.017

36. Vukmirovic D, Ivanov D, Colovic R, Kokic B, Levic J, Duragic O, Sredanovic S: Effect of steam conditioning on physical properties of pellets and energy consumption in pelleting process. *J Proc Energy Agr,* 14 (2): 106-108, 2010.

37. Briggs JL, Maier DE, Watkins BA, Behnke KC: Effects of ingredients and processing parameters on pellet quality. *Poult Sci*, 78, 1464-1471, 1999. DOI: 10.1093/ps/78.10.1464

38. Zimonja O, Svihus B: Effects of processing of wheat or oats starch on physical pellet quality and nutritional value for broilers. *Anim Feed Sci Technol*, 149, 287-297, 2009. DOI: 10.1016/j.anifeedsci.2008.06.010