The effects of clinoptilolite on piglet and heavy pig production

Luca Sardi, Giovanna Martelli, Paolo Parisini, Enrico Cessi, Archimede Mordenti

Dipartimento di Morfofisiologia veterinaria e Produzioni animali, Università di Bologna, Italy.

Corresponding author: Dr. Luca Sardi. DIMORFIPA. Facoltà di Medicina Veterinaria, Università di Bologna. Via Tolara di Sopra 50, 40064 Ozzano Emilia (BO), Italy. - Tel. +39-051-792872 - Fax: +39-051-792869 - Email: lsardi@vet.unibo.it

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ABSTRACT

To evaluate the effects of clinoptilolite on piglet and heavy pig production two separated trials have been performed. In the first trial 40 pigs of the initial body weight of 55 kg were used. Animals were homogeneously allocated to two groups: a control group traditionally fed and a clinoptilolite group in which feed contained the additive at 2%. Pigs were slaughtered at about 160 kg body weight. Blood samples were taken to determine blood urea nitrogen (BUN). In the second trial a total of 116 piglets from 12 litters was used. Six litters were fed from the 7^{th} day of life a diet containing clinoptilolite at 2%. According to the dietary treatment of the suckling period, 84 weaned piglets were homogeneously allocated to two groups fed up to 33 kg body weight a diet containing or not clinoptilolite at 2%. In both trials daily weight gain, feed intake and pigs' health were regularly recorded. The dietary inclusion of clinoptilolite at 2% did not resulted in any modification either of growing performances or of uraemia. Piglets on clinoptilolite diet showed a significant ($P<0.05$) improvement of faecal dry matter content. At slaughtering the dietary inclusion of clinoptilolite resulted in a trend towards an improvement of lean cuts yield and in a significant increase ($P<0.05$) of the ratio between lean and fat cuts. From our data it is suggested that clinoptilolite does not impair pig growing performances, determines a higher dry matter content of piglet faeces and improves carcass quality of heavy pigs with particular regard to lean cuts yield and lean to fat cuts ratio.

Key words: Clinoptilolite, Piglet, Heavy pig, Growing performance, Slaughtering performance.

RIASSUNTO

ESPERIENZE SULL'IMPIEGO DI CLINOPTILOLITE IN SUINICOLTURA

Con l'intento di valutare gli effetti nell'alimentazione del suino e del suinetto di una zeolite naturale ad alto contenuto di clinoptilolite (85%), sono state condotte due distinte esperienze, l'una articolatasi nel periodo di accrescimento-ingrasso e l'altra durante la fase compresa fra la nascita e il post svezzamento. La ricerca riguardante i suini in accrescimento-ingrasso è stata effettuata utilizzando 40 animali nell'arco di peso compreso fra i 55 e i 160 kg. Gli animali sono stati omogeneamente assegnati a due tesi che si differenziavano per la presenza o meno nella dieta del 2% di clinoptilolite. Per la sperimentazione riguardante i suinetti sono stati utilizzati 116 animali provenienti da 12 nidiate. A partire dal settimo giorno di vita a 6 nidiate è stato somministrato l'alimento contenente clinoptilolite (2%). Allo svezzamento, sulla base del trattamento alimentare ricevuto sotto scrofa, sono stati scelti 84 suinetti omogeneamente assegnati a due tesi nelle diete delle quali figurava o meno il minerale oggetto dello studio. La prova è terminata al raggiungimento dei 33 kg *di peso vivo. L'inserimento nelle diete della zeolite in oggetto non ha determinato modificazioni significative (P>0,05) delle prestazioni di allevamento e dell'uremia. Nell'ambito dello studio riguardante i suinetti è stato possibile osservare un significativo (P<0,05) aumento del tenore in sostanza secca delle feci (33,27* vs *31,21). In sede di macellazione si è rilevato un tendenziale (P<0,1) miglioramento della percentuale dei tagli magri e un significativo (P<0,05) aumento del rapporto tagli magri/tagli adiposi (1,99* vs *1,83). Sulla base dei rilievi sperimentali è possibile affermare che l'inserimento nella dieta del 2% di clinoptilolite non modifica significativamente l'accrescimento dei suini, migliora la qualità della carcassa (innalzando il valore del rapporto tagli magri/tagli adiposi) e aumenta la consistenza delle feci.*

Parole chiave: *Clinoptilolite, Suinetto, Suino pesante, Prestazioni produttive.*

Introduction

"Zeolites" is a collective term comprising some inorganic crystalline compounds, either natural or synthetic, characterised by ion-exchange capacity at low temperature (< 100°C) and reversibility of dehydration-hydration process below of 250-300°C (Mumpton e Fishman, 1977). From a chemical standpoint, zeolites are hydrate allumino-silicates of alkali metals (K and Na) and alkaline earth-metals (Ca and Mg) consisting of tetrahedrons of SiO_4 and AlO_4. Due to their structural properties zeolites are used in chemical and oil industries as well as in agriculture (sugar industries) and in animal production. The addition of zeolites either to litter or animal waste results in a reduction of gaseous emissions from manure (Malagutti *et al.*, 1995; Piersanti, 1995). Zeolites can also improve technological properties of feedstuffs: in fact they can make pellets more durable and determine a reduction of dust production (Melcion, 1995). Zeolite can bind undesirable contaminants of feedstuffs such as mycotoxins and metals, particularly caesium (Ramos e Hernandez, 1997). Due to their ammonia-binding capacity, zeolites act also as detoxicant agents along the gastrointestinal tract; this fact can improve swine growth and health. According to Poulsen and Oksbjerg (1995) and to Kyriakis *et al.* (2000) results attained by using zeolites are comparable with those obtained by adding some growth promoters to feed. Intestinal ammonia binding, which corresponds to a reduction of ammonia emissions, results in obvious environmental benefits (Kyriakis *et al.*, 2000; Theophilou, 2000). Zeolites can also act in controlling stocked cereals parasites by damaging arthropods tegument and causing parasites death due to dehydration (Contessi, 1995)

The properties of the different zeolites are not constant depending on the type of mineral (or minerals) and on the presence of other compounds (i.e. feldspar, apatite, calcite).

The wide variety of effects ascribable to the use of zeolites in animal feeding (particularly in monogastrics), has stimulated the present researches that were aimed to the investigation of the effect of clinoptilolite, a natural zeolite that has been recently approved by the EU (Reg.

Table 1. Physical-chemical properties of the zeolite used in the experiments.

Chemical analysis		Mineralogical analysis		Physical properties	
SiO_2	68.26%	clinoptilolite	≥85%	apparent density	1 g/cm^3
Al_2O_3	12.30%	feldspar	5%	hardness	3.5-4 (Mohs)
Fe_2O_3	0.08%	montmorillonite	4%	melting point	982°C
CaO	4.34%			conductivity	7μS/cm
MgO	1.05%			alkaly stability	7-11 pH
K_2O	0.94%			acid stability	2-7 pH
Na_2O	0.26%			pore volume	0.34 cm^3/cm^3
				granulometry	0-1 mm
				ion exchange capacity	150 meq (NH_3)/100g

Table 2. Composition of the diets supplied in the first trial (growing-fattening period)[1]

		1st period 55-110 kg BW	2nd period 110-160 kg BW
Maize meal	%	55	57
Barley meal	"	14.6	16
Soyabean meal	"	19	14
Soft wheat bran	"	7.5	10
Dicalcium phosphate	"	1.54	0.70
Limestone	"	1.20	1.35
L-lysine HCl	"	0.16	0.05
Trace mineral-vitamin premix	"	0.50	0.50
Sodium chloride	"	0.50	0.40

[1] *In clinoptilolite group 2.04 kg of clinoptilolite were added to 100 kg of feed.*

1245/99 and 1887/2000), on piglet and Italian heavy pig production.

Material and methods

First trial: growing-finishing pigs

Forty Duroc x (Landrace x Large White) barrows, ranging in body weight (BW) from 55 to160 kg, were used.

Pigs were homogeneously allocated to two experimental groups each containing 4 replications of 5 animals. Each group was made up of 20 pigs fed as follows:

- group A (control) in which pigs received a maize/soybean diet without clinoptilolite addition;
- group B in which pigs received the same feed as group A but added with clinoptilolite at 2.04 % (consequently clinoptilolite replaced all the other ingredients at 2%).

The main physical-chemical properties of the zeolite used in the present trials are displayed in table 1.

To meet the pigs' requirements, two different feed formulations were used (from 55 to 100 kg BW and from 110 to 160 kg BW). Percent composition and chemical analyses of these diets are shown in table 2 and 3, respectively. Chemical analyses were performed according to ASPA methods (Martillotti *et al.*, 1987).

Feed was offered as liquid; meal to water ratio was 1/3. Pigs were fed at the rate of 9% of their metabolic live weight ($LW^{0.75}$) up to a maximum of 3.4 kg per head per day.

To calculate average daily weight gain, animals were individually weighed at the beginning of the trial, after 89 days and at the end of the experiment.

Pigs were slaughtered at about 160 kg BW. At slaughtering the following data were collected: carcass weight, dressing out percentage, lean meat yield (by Fat-o-Meater), pH of the thigh at 45' and 24 hours *post-mortem*, colour of the thigh according to L*a*b* method (McLaren, 1980) by Minolta CR-200 colorimeter (pH and colour of the thigh were determined following ASPA directions [1996] on muscle *Semimembranosus*), percentages on the right side of the main commercial cuts (ham, shoulder and loin) and lean to fat cuts ratio (right side dissection was performed according to ASPA methods [1991]).

On the beginning of the trial, on day 89th of trial and on the end of the experiment, after a 18 hours fast, blood samples from the jugular vein were taken from 10 pigs per group to determine blood urea nitrogen (BUN) by using a Boeringher Mannheim kit.

Second trial: piglets from birth to post-weaning

116 piglets deriving from 12 litters were used. Sows were homogeneously chosen with respect to farrowing order (second parity-dams) and genetics (Duroc x Large White). Piglets were weighed at birth. Litters were equalised to assign to each sow the same number of piglets of the same sex.

Litters were allotted to two experimental groups:

- group A (control) in which the 6 litters received a feed without clinoptilolite addition;

Table 3. Chemical composition of the diets used in the first trial (growing-fattening period).

		1st phase 55-110 kg BW		2nd phase 110-160 kg BW	
		control	clinoptilolite	control	clinoptilolite
Moisture	%	11.79	11.61	11.93	11.72
Crude protein (N x 6.25)	"	15.1	14.61	13.4	13.07
Ether extract	"	2.68	2.60	2.76	2.70
Crude fibre	"	4.20	4.11	4.17	4.08
Ash	"	6.06	7.84	5.20	7.00
Calcium	"	0.90	0.88	0.77	0.75
Total phosphorus	"	0.70	0.64	0.58	0.56
Digestible energy[1]	kcal/kg	3190	3126	3190	3126
Net energy[1]	"	2323	2277	2357	2310
Lysine	%	0.86	0.85	0.67	0.65

[1] *Calculated values (Noblet et al., 1989).*

Table 4. Composition of the diets used in the second trial (piglets)[1]

		Prestarter < 12 kg BW	Starter 12-25 kg BW	Starter 25-35 kg BW
Maize meal	%	25,9	30,0	33,0
Barley meal	"	21,0	22,5	22,5
Barley flakes	"	15,0	10,0	6,0
Wheat bran	"	5,0	8,0	8,0
Soyabean meal 44% CP	"	12,0	14,5	17,0
Herring meal	"	6,0	4,5	3,5
Milk powder	"	10,0	5,0	5,0
Soya oil	"	3,0	2,0	2,0
Limestone	"	-	1,65	1,35
Dicalcium phosphate	"	0,80	0,60	0,70
Sodium chloride	"	0,30	0,30	0,30
Trace mineral-vitamin premix	"	0,50	0,50	0,50
L-lysine HCl	"	0,25	0,25	0,15
DL-methionine	"	0,15	0,1	-
L-threonine	"	0,10	0,1	-

[1] *In clinoptilolite group 2.04 kg of clinoptilolite were added to 100 kg of feed.*

- group B (treated) in which the remaining 6 litters received the same feed as group A but added with clinoptilolite at 2.04% so that zeolite substituted the other ingredients for 2%.

Prestarter feed was offered as meal from the 7th day of life up to weaning. Weaning occurred on the 27th day of life.

After weaning, according to dietary treatment of the previous phase, 84 piglets were placed in 14 post-weaning cages (7 per thesis) each one containing 6 piglets.

During this period a pellet starter feed was offered.

Chemical composition and analyses of feeds are shown in tables 4 and 5, respectively.

Piglets were individually monitored for: weight at birth, weight at weaning, weight on the end of the trial, average daily gain during each phase, mortality (and causes) during the first 7 days of life, mortality at weaning and mortality in the post-weaning period; diarrhoea incidence during the different phases and diarrhoea score (severe, medium and mild intensity; to perform this classification the number of pigs in each cage and faces consistency were used); feed intake and feed conversion rate.

During the post weaning period 4 samples of faeces per thesis (in all 24 samples) were collected every two weeks to determine dry matter percent by freeze-drying.

All the data obtained in both trials were submitted to analysis of variance by using the model

$$y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

were: y_{ij} = dependent variable; α_i = effect of the diet (i = 2); ε_{ij} = error contribution.

To compare data from mortality and diarrhoea score, chi-square test was used.

Results and discussion

First trial

Due to foot diseases, that were not experiment-related, two pigs (one for each group) were removed from the trial. Consequently, data on breeding performances refer to 19 pigs per thesis (table 6). Growing parameters were similar between the two experimental groups. At the end of the growing-fattening period (data collection stopped when one half of the animals attained the required body weight for slaughtering) average body weight was, in fact, of 149.4 for control pigs and of 149.5 kg for clinoptilolite-fed animals. As a consequence of the similarity in growth rhythm, daily weight gains -

Table 5. Chemical composition of the diets supplied in the second trial (piglets).

		Prestarter		Starter 12-25 kg BW		Starter 25-35 kg BW	
		control	clinoptilolite	control	clinoptilolite	control	clinoptilolite
Moisture	%	10.39	10.28	10.84	10.67	10.70	10.59
Crude protein (N x 6.25)	"	18.62	18.25	18.15	17.76	17.56	17.20
Ether extract	"	6.98	6.83	5.27	5.16	5.46	5.36
Crude fibre	"	3.83	3.75	4.39	4.29	4.27	4.18
Ash	"	4.44	6.25	4.46	6.27	5.82	7.60
Calcium	"	1.17	1.15	1.15	1.13	0.86	0.84
Total Phosphorus	"	0.64	0.63	0.63	0.62	0.65	0.64
Digestible energy[1]	kcal/kg	3492	3422	3357	3290	3334	3267
Net energy[1]	"	2377	2330	2419	2371	2420	2372
Lysine	%	1.32	1.29	1.21	1.19	1.09	1.07

[1] *Calculated values (Noblet et al., 1989).*

Table 6. Growing parameters and BUN in the growing-finishing phase.

Groups		control	clinoptilolite	SEM
Pigs	n.	19	19	
Initial weight	kg	55.2	55.1	1.01
Intermediate weight (89 d)	"	95.4	95.9	1.51
Final weight (170 d)[1]	"	149.4	149.5	2.67
ADG:				
- 1-89 d	g/d	451	458	12.5
- 89-170 d	"	667	661	21.7
- 1-170 d	"	554	555	14.6
Feed intake:				
- 1 - 89 d	kg/d	1.831	1.828	0.3270
- 89-170 d	"	3.087	3.076	1.0147
- 1-170 d	"	2.430	2.423	0.5721
FCR:				
- 1-89 d		4.07	4.03	0.124
- 89-170 d		4.65	4.78	0.231
- 1-170 d		4.40	4.40	0.126
BUN[2]:				
- initial sampling	mg/dl	25.48	24.17	0.669
- intermediate sampling (100 kg)	"	30.15	29.17	0.751
- final sampling (at slaughtering)	"	36.78	37.61	1.260

No significant differences were observed.

[1] *Data collection stopped when one half of the pigs attained the required slaughtering body weight.*

[2] *On 10 samples.*

either referring to the whole trial (554 *vs.* 555 g/d) or to the single phases (1-89 d and 89-170 d) - were the same for the two groups.

Feed intake and feed conversion did not differ significantly, too.

The dietary addition of clinoptilolite did not resulted in any modification of blood urea nitrogen.

The incorporation of clinoptilolite in the diet at the rate of 2% resulted in a slight reduction of crude protein and energy intake (0.33 *vs.* 0.34 kg/d and 7.57 *vs.* 7.75 Mcal ED/d). Considering that growing parameters were similar between the two groups, an improvement (even if it was not significant) of protein and energy efficiencies (0.62 *vs.* 0.60 kg/kg and 14.05 *vs.* 13.76 Mcal ED/kg, respectively) could be supposed; this improvement may also corresponds the observed difference in meat yield of carcasses (table 7). Facing to similar dressing out percentages, pigs receiving clinoptilolite showed, in fact, a tendential ($P<0.1$) improvement of lean cuts (ham, loin and shoulder) yield. This difference become significant ($P<0.05$) on lean to fat cuts ratio (1.83 *vs.* 1.99). This result agrees with our previous findings (Parisini *et al.*, 1993) on the use of another clay (sepiolite), in heavy pigs feeding.

Data concerning meat pH and colour (expressed by lightness, hue and chroma) did not differ between the groups and fall within the normal range

Besides the positive effects on lean to fat cuts ratio, it must be highlight that the incorporation in the feed of a compound that has no caloric power as clinoptilolite, did not reduce energy efficiency at all. This consideration allows the theoretical recover and attribution to clinoptilolite of the same amount of digestible and net energy as that lost by adding an energy-less material. This

Table 7. First trial (growing-fattening pigs): slaughtering performances.

Groups		control	clinoptilolite	SEM
Pigs	n.	19	19	
Body weight	kg	162.2	160.8	2.25
Carcass weight (CW)	"	135.2	133.8	2.01
Dressing out	%	83.3	83.2	0.25
Lean meat (by F-o-M)	"	49.4	50.0	0.53
SR [1]	mm	27.74	25.44	1.05
F [1]	"	56.63	58.94	0.81
Ham	% CW	24.8	25.2	0.31
Loin + neck	"	14.0	14.4	0.20
Shoulder	"	23.8	24.1	0.35
Lean cuts	"	62.7	63.8	0.79
Fatty cuts	"	34.6	33.6	0.81
Lean cuts/fatty cuts		1.83a	1.99b	0.075
pH 45′ *post mortem*		6.68	6.67	0.042
pH 24 h *post mortem*		5.69	5.77	0.037
Lightness		43.26	43.29	0.671
Hue		0.23	0.24	0.017
Chroma		8.51	8.83	0.351

a, b: P<0,05.

[1] *SR: fat thickness at loin; F: lean thickness at loin.*

result agrees with the findings of Monetti *et al.* (1996) and Malagutti *et al.* (1997) who, in balance trials by using the same or the double quantity of zeolite, found a slight and not significant improvement in organic matter digestibility.

The absence of effects on the reduction of blood urea nitrogen of clinoptilolite-treated pigs, could indicate that when dietary protein level is adequate (i.e. not excessive) the amount of ammonia produced and absorbed in the intestine does not contribute to BUN raising.

Second trial

Data concerning productive performances of suckling piglets are shown in table 8: no significant differences were detectable between groups. Mortality rate of newborns fell, in both groups, within the standard (about 10%) and was mainly due to crushing of piglets.

Regardless to dietary treatment and probably due to the high hygienic conditions, diarrhoea occurrences were low in both groups.

Growing parameters of piglets in the post-weaning phase (8-30 kg BW) are shown in table 9. As already observed in the previous phase, also during this second period no significant differences were appreciable between groups. On the whole, growing parameters, either regarding daily weight gain (547 *vs.* 549 g/d) or feed conversion rate (1.78 *vs.* 1.74), were highly satisfactory. These results agree with the findings obtained by Tassinari *et al.* (1999) on piglets of the same weight as those used in the present trials and receiving zeolite at 2%.

Beside the absence of mortality, also in the post-weaning period diarrhoea incidence was low; even if data were not significantly different, piglets receiving clinoptilolite had less diarrhoea occurrences (on the whole 13 *vs.* 21 cases; total absence of severe diarrhoea in treated group). These results agree with the findings of Kyriakis

Table 8. Second trial: performances of suckling piglets.

Groups		control	clinoptilolite	SEM
Sows	n.	6	6	-
Live born piglets	"	58	59	-
Weight at birth	g	1250	1215	22.7
Weaned piglets	n.	52	52	-
Weight at weaning	g	7950	7920	32.6
ADG	g/d	246	247	5.0
Mortality:				
- 0-7 d	%	6.9	8.5	-
-8-27 d	"	3.4	3.4	-
- 0-27 d	"	10.3	11.9	-
Diarrhoea occurrences (total)	n.	10	8	-

No significant differences were observed.

et al. (2000) that were obtained on piglets of 6 kg BW and receiving diets containing clinoptilolite at 2% and could indicate a better health-status of treated animals. According to Poulsen and Oksbjerg (1995) this fact could be related to intestinal ammonia binding properties of clinoptilolite that resulted in a lower damage on mucosa surface. A lower mucosa damage could also corresponds to a lower cellular turnover resulting in a sparing of nutrients which become available for growing process.

According to previous considerations on piglets' health, faecal dry matter content was significantly higher (P<0.05) in clinoptilolite-fed animals (33.27% *vs.* 31.21%); this result agrees with the findings obtained in digestibility trials on growing pigs (70-100 kg BW) by Monetti *et al.* (1996) and by Malagutti *et al.* (1997).

Conclusions

The inclusion of clinoptilolite at 2% in pig diets did not alter feed intake.

The addition of clinoptilolite did not influence

Table 9. Second trial: performances of weaned piglets.

Groups		control	clinoptilolite	SEM
Replications	n.	7	7	-
Piglets	"	42	42	-
Initial weight	kg	8.11	7.98	0.176
Final weight	"	33.27	33.23	0.446
ADG	g/d	549	549	8.8
FCR		1.78	1.74	0.028
Diarrhoea score:				
- mild	n.	15	10	
- medium	"	4	3	
- severe	"	2	-	
Faecal dry matter	%	31.21b	33.27a	0.552

a, b: P<0,05.

growing parameters (daily weight gain and feed conversion rate) all over the productive cycle of pigs, from birth to slaughter.

At slaughtering treated pigs showed a higher percentage of valuable cuts and an improvement in lean to fat cuts ratio.

The significant higher dry matter content of faeces observed during the post-weaning period, could indicate a positive role of this zeolite on intestinal pathologies that characterize this delicate phase.

From an economical standpoint, therefore, the use of clinoptilolite can result both in a reduction of the cost of the feed (notably during the first phases of breeding when ingredients are particularly expensive) and in an improvement of carcass quality (higher lean cuts yield) without inducing any modification of qualitative traits of meat (pH and colour).

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REFERENCES

ASPA, 1991. Commissione metodologie di valutazione della produzione quanti-qualitativa della carne. Metodiche relative alla macellazione degli animali di interesse zootecnico e alla valutazione e dissezione della loro carcassa. ISMEA, Roma, Italy.

ASPA, 1996. Commissione di studio valutazione della produzione quanti-qualitativa della carne. Metodiche per la determinazione delle caratteristiche qualitative della carne. Università degli Studi, Perugia, Italy.

CONTESSI, A., 1995. Le ultime novità nel controllo degli artropodi che infestano il cereale grezzo immagazzinato. Molini d'Italia. 45(5): 25-30.

KYRIAKIS, S.C., ALEXOPOULOS, C., SAOULIDIS, K., PAPAIOANNOU, D., BALKAMOS, G.C., 2000. An experimental study on the effect of in-feed inclusion of a natural zeolite (clinoptilolite) on health status and performance of weaned, growing and finishing pigs. Page 381 in Proc. 16th Congr. International Pig Veterinary Society, Melbourne, Australia.

MALAGUTTI, L., D'ARDES, V., GIZZI, G., SCIARAFFIA, F., 1995. Prove sperimentali sul contenuto di NH_4^+ in liquami suini trattati con zeolite. Proc. 9th Nat. Congr. ASPA, Udine, Italy, 399-400.

MALAGUTTI, L., ZANNOTTI, M., SCIARAFFIA, F., 1997. Effetti di una zeolite nell'alimentazione del suino. Riv. Suinicolt. 38(8): 69-72.

MARTILLOTTI, F., ANTONGIOVANNI, M., SANTI, E., BITTANTE, G., 1987. Metodi di analisi per la valutazione degli alimenti di impiego zootecnico. Quaderni Metodologici n.8 CNR-IPRA, Roma, I.

MCLAREN, K., 1980. Food colorimetry. In: J. Walford (ed.) Developments in Food Colours. Applied Sci. Publ., London, UK, pp 27-45.

MELCION, J.P., 1995. Emploi des liants pour le pressage des aliments des animaux: aspects technologiques et nutritionnels. Prod. Anim. 8(2): 83-96.

MONETTI, P.G., TASSINARI, M., VIGNOLA, G., GONZ·LES VALDÈS, J.L., 1996. Bilancio azotato e digeribilità apparente di alcuni nutrienti in suini alimentati con diete contenenti una zeolite naturale. Zoot. Nutr. Anim. 22: 159-167.

MUMPTON, F.A., FISHMAN, P.H., 1977. The application of natural zeolites in animal science and aquaculture. J. Anim. Sci. 45: 1188-1203.

NOBLET, J., FORTUNE, H., DUBOIS, S., HENRY Y., 1989. Nouvelles bases d'estimation des teneurs en énergie digestible, métabolisable et nette des aliments pour le porc. INRA, Paris, France.

PARISINI, P., SARDI, L., PANCIROLI, A., COPPA, C., 1993. Effetti della sostituzione con sepiolite (silicato idrato di magnesio) di parte del mangime nell'alimentazione del suino pesante. Proc. 10th Nat. Congr. ASPA, Bologna, Italy, 459-464.

PIERSANTI, R., 1995. Zeoliti, le deiezioni diventano ecologiche. Riv. Suinicolt. 37(4): 67-69.

POULSEN, H.D., OKSBJERG, N., 1995. Effects of dietary inclusion of a zeolite (clinoptilolite) on performance and protein metabolism of young growing pigs. Anim. Feed Sci.Technol., 53: 297-303.

RAMOS, A.J., HERNANDEZ, E., 1997. Prevention of aflatoxicosis in farm animals by means of hydrated sodium calcium aluminosilicate addition to feedstuffs: a review. Anim. Feed Sci. Technol. 65: 197-206.

TASSINARI, M., VIGNOLA, G., GATTA, P.P., MARCHETTI, S., 1999. Effetti esercitati dalla somministrazione di mangimi contenenti zeoliti (clinoptilolite) sulle prestazioni produttive del suinetto appena svezzato. Proc. 25th Ann. Meet. SIPAS, Parma, Italy, 173-179.

THEOPHILOU, N., 2000. Clinoptilolite may help reduce ammonia. Feed Mix. 8: 14-16.