Effects of dietary clinoptilolite-rich tuff on the performance of growing-finishing pigs

Chapter · January 2000

7 authors, including:

Ananias Tsirambides
Aristotle University of Thessaloniki
85 PUBLICATIONS **445** CITATIONS

Anestis Filippidis
Aristotle University of Thessaloniki, School of Geology
285 PUBLICATIONS **2,543** CITATIONS

Natural Zeolites for the Third Millennium - *C. Colella and F. A. Mumpton, eds.*, pp. 471-481.

EFFECTS OF DIETARY CLINOPTILOLITE-RICH TUFF ON THE PERFORMANCE OF GROWING-FINISHING PIGS

ATHANASIOS YANNAKOPOULOS[1], ANGELIKI TSERVENI-GOUSI[1], ANNA KASSOLI-FOURNARAKI[2], ANANIAS TSIRAMBIDES[2], KLEOPAS MICHAILIDIS[2], ANESTIS FILIPPIDIS[2], AND ULRICH LUTAT[3]

[1]*Department of Animal Husbandry, Aristotle University of Thessaloniki, Thessaloniki 540 06, Greece*
[2]*Department of Mineralogy-Petrology-Economic Geology, Aristotle University of Thessaloniki, Thessaloniki 540 06, Greece*
[3]*Silver and Baryte Ores Mining Co. S. A., Amerikis 21A, Athens 106 72, Greece*

ABSTRACT

The effects of a Greek clinoptilolite-rich volcanic tuff fed at the 6% level in practical pig diets on the performance of growing-finishing pigs were examined. The zeolitic rock material used contained 77% Ca-rich clinoptilolite, 13% feldspar, 8% mica + clays, and 2% quartz. The experimental results showed improvement in body-weight gains and feed-conversion ratios and reduced fat deposition in both sexes of pigs. At the end of the experiment (162 days of age), the body weight increased by 3.34% for zeolite-fed pigs. The mean back-fat thickness was 2.9% less for pigs fed the zeolite diet. The reduction of total feed consumption was 5.69%. No deaths were recorded during the experiment for either treatment group. Loin and leg yields were greater in zeolite-fed pigs than in control pigs by 12.08% and 4.79%, respectively. Kidneys, liver, and heart weights were reduced by 8.41%, 10.36%, and 5.77%, respectively, by the zeolite diet. Percentage of fat was lower by 33.87% in zeolite-fed pigs. The results indicate that the utilization of zeolites in pig growing-finishing diets is economically advantageous. The total gross margin was estimated to be around 3000 drachmas per zeolite-fed pig, compared with a pig of the control group.

INTRODUCTION

The significant effects of zeolitic volcanic tuff on the performance of pigs have been noted by many workers. Increased weight gain, feed efficiency, and reduced severity of diarrhea have been reported by the addition of 1 to 5 wt. % clinoptilolite-rich tuff (Cp) to the diet of pigs and other animals (Mumpton and Fishman, 1977; Pond and Yen, 1984; Vrzgula and Bartko, 1984; Kovac *et al.*, 1988; Lindemann *et al.*, 1993; Pond, 1995; Bartko *et al.*, 1995). According to Froseth (1982), zeolites in the diet of young pigs resulted in a reduction of the incidence and severity of scours. Pond and Yen (1982) observed different growth response of growing pigs for diets containing Cp-rich tuff supplements of various particle sizes from two different deposits, indicating the importance of particle size and composition. Beneficial effects of feeding clinoptilolite on embryo survival in swine were reported by Ma *et al.* (1979, 1984). Mumpton (1988) emphasized that most of this research does not reveal the physiological effects of zeolites on these animals.

In the present paper the effects of dietary

Cp-rich tuff from Pentalofos, Thrace, Greece, fed at the 6% level, are reported on the performance of growing-finishing pigs.

MATERIALS AND METHODS

Zeolitic tuff

The Cp-rich tuff added to the swine rations was obtained from the Pentalofos Paleogene zeolite-rich tuffs of Evros County (Thrace), northeastern Greece. The Pentalofos clinoptilolite deposit, located in the Orestias basin, has economic potential with geologically indicated reserves of ~5 million tons (Kassoli-Fournaraki *et al.*, 1999). The middle sequence of the deposit contains two zeolite-rich layers containing as much as 95% clinoptilolite.

The tuff was crushed in an industrial crusher, and the <0.8-mm fraction was homogenized. The screened material was studied by X-ray diffraction analysis and scanning electron microscopy. The mineral content was estimated by semi-quantitative examination using external standards produced from the volcaniclastic material for comparison. Ten samples were ground to fine powder and homogenized in an agate mortar. X-ray powder diffractograms revealed that they were rich in zeolite (Table 1), the clinoptilolite content ranging from 55% to 95%. Feldspar ranged from 3% to 22%; mica + clays, from 1% to 19%; quartz in most samples was not detectable. The different samples were mixed together to obtain an average sample. On average, the zeolitic tuff material added in the pig food by calculation contained 77% Ca-rich clinoptilolite, 13% feldspar, 8% mica + clays, and 2% quartz.

Scanning electron microscopy (SEM) of representative grains of the crushed zeolitic tuff material showed that they were subangular to round and microporous. The zeolite crystals occurred in lath or tabular shapes and were <200 μm in length (usually <20 μm).

The chemical composition of the tuff was determined from polished thin sections of selected samples using a Jeol JSM-840 scanning electron microscope equipped with a LINK-An 10000 microanalyzer. Representative chemical analyses of clinoptilolite are given in Table 2. Structural formulae are given in terms of 72 oxygen atoms. The zeolite belongs to the heulandite-clinoptilolite series, and, according to its Si/Al ratio, was identified as a Ca-rich

Table 1. Mineralogical composition (wt. %) of the samples estimated by X-ray diffraction.

Sample	Cp	Feldspar	Mica + Clays	Quartz
ZF1	68	22	6	4
ZF2	76	14	10	-
ZF3	86	13	1	-
ZF4	88	9	3	-
ZF5	95	3	2	-
ZF6	94	3	3	-
ZF7	76	16	8	-
ZF8	72	11	10	7
ZF9	55	15	19	11
ZF10	63	22	15	-
Average	77	13	8	2

Cp = Ca-rich clinoptilolite.

Table 2. Representative electron microprobe analyses (wt. %) of the clinoptilolite in the clinoptilolite-rich tuff used as an additive in the pig diet.

Oxide	1	2	3	4	5	6	7[1]
SiO_2	68.63	68.27	68.84	67.84	67.97	68.02	68.26
TiO_2	0.01	0.10	0.00	0.12	0.03	0.00	0.04
Al_2O_3	11.95	11.96	11.61	12.04	12.16	12.56	12.05
Cr_2O_3	0.00	0.00	0.10	0.06	0.00	0.06	0.04
Fe_2O_3	0.02	0.00	0.00	0.08	0.07	0.01	0.03
MnO	0.02	0.00	0.00	0.06	0.06	0.00	0.02
MgO	1.06	1.05	0.87	0.84	0.93	0.84	0.93
NiO	0.00	0.00	0.07	0.00	0.00	0.13	0.03
CaO	4.32	4.39	4.46	4.65	4.82	4.86	4.58
Na_2O	0.14	0.22	0.14	0.04	0.27	0.06	0.14
K_2O	0.59	0.69	0.69	0.63	0.59	0.44	0.60
Total	86.74	86.68	86.78	86.36	86.90	86.98	86.74
Structural formulae on the basis of 72 [O]							
Si	29.918	29.835	30.034	29.778	29.696	29.640	29.817
Ti	0.003	0.033	0.000	0.040	0.010	0.000	0.014
Al	6.140	6.160	5.970	6.229	6.261	6.450	6.202
Cr	0.000	0.000	0.034	0.021	0.000	0.021	0.013
Fe^{3+}	0.007	0.000	0.000	0.026	0.023	0.003	0.001
Mn	0.007	0.000	0.000	0.022	0.022	0.000	0.008
Mg	0.689	0.684	0.566	0.550	0.606	0.546	0.607
Ni	0.000	0.000	0.025	0.000	0.000	0.046	0.012
Ca	2.018	2.055	2.085	2.187	2.256	2.269	2.145
Na	0.118	0.186	0.118	0.034	0.229	0.051	0.123
K	0.328	0.385	0.384	0.354	0.329	0.245	0.338
Si/Al	4.87	4.84	5.03	4.78	4.74	4.60	4.81

[1]Average.

clinoptilolite. A cation-exchange capacity measurement of the clinoptilolite-rich tuff using the ammonium acetate method (Chapman, 1965) gave the value of 1.27 meq/g.

Experimental animals

Forty-four crossbred weanling pigs were assigned randomly to one of the following two treatments: (1) corn-soybean meal basal (A-treatment), and (2) corn-soybean meal basal + 6% Cp-rich rock (B-treatment) as replacement of some of the normal amount of rations. Each treatment was replicated two times (two pens) with 11 pigs per replicate. The average initial body weight was about 13 kg. The experimental period was 125 days (weanling stage = 42 days; growing stage = 42 days; fattening stage = 41 days). The pigs were kept in flat-deck pens.

Diets (Table 3) were formulated to meet the nutrient requirements of pigs (N.R.C., 1994) during the different stages (for weanling, stage I; for growing and fattening, stage II). Water and diets were available *ad libitum* throughout the experiment. At the end of the weanling stage (42nd day), all 44 pigs were moved to a non climate-controlled fattening room and housed in four pens.

Measurements on live pigs, feed, and climate conditions

The pigs were individually weighed at the start of the experiment and biweekly throughout the experiment in order to calculate the average daily gain for each pig. Feeders were also weighed biweekly and feed added to feeders in each pen was recorded in order to calculate the average daily feed per pen or per pig and the feed consumed per unit of gain (kg feed/kg body weight).

Nitrogen, fat (ether extract), ash, Ca, and P analyses of the rations were carried out according to methods of the Association of Official Analytical Chemists (A.O.A.C., 1980). Blood samples (5 to 10 ml) were collected on the 90th day in 10-ml tubes containing lithium heparin in order to measure the plasma Ca and P concentration. Back-fat thickness was measured by a digital back-fat grader (Medata Systems Ltd, United Kingdom). Back-fat was measured at three different points opposite the last rib. Back-fat depth is often the major criterion of assessment of quality in pig carcasses at the point of payment to producer.

Temperature and humidity were recorded daily. The mean temperature for the whole experimental period was 13.6 ± 4.1°C, and the mean relative humidity was 78% ± 4%. The air ammonia level in the pens was measured weekly at 10-cm height from the ground by the Drager detector (Dragerwerk, A.G., Lubeck, Germany). The NH_3 concentration in the air was 3 to 5 ppm.

Measurements of carcass characteristics

At the age of 162 days, all experimental pigs were starved for 12 hr, weighed, and slaughtered at a local slaughterhouse, where carcass measurements on the warm carcasses were made. The slaughter procedures were those of a commercial method in a Greek market. Thus, one day after the end of the performance test and 4 hr after slaughter, the following traits on each hot carcass were recorded:

- Carcass weight in kilograms (carcass with head but minus skin, visible fat tissue, feet, alimentary tract, and blood).
- Killing-out percentage (carcass weight/live weight at slaughter).
- Carcass length in centimeters (the distance between the anterior edge of the symphysis pubis to the vascular impression on the anterior edge of the first rib).

Eight pigs (2 pigs/sex/replicate = 8 pigs/ treatment) from the experimental group were selected for further carcasses measurements and chilled (1°-2°C) overnight. Each side of each carcass was cut into the following wholesale parts: (1) head, (2) picnic shoulder, (3) loin (bone in with less than 5 mm external fat), (4) belly (single ribbed), and (5) legs excluding feet. These parts were weighed separately. Additionally, some non-carcass parts, as stomach, liver, spleen, kidneys, heart, and intestine, were measured. Twenty-four hours after slaughter a chop (2 cm cross section thick) of the 10th rib was removed and the length and width of the longisimmus muscle were measured. From each cold carcass the picnic-shoulder was taken. After removal of the bone, the remaining tissues (meat) were ground three times, stored in sealed polyethylene bags, and chilled at -12°C. The chemical composition of meat was determined according to the procedure of A.O.A.C. (1980).

Statistical analysis

Data were elaborated by an analysis of variance procedure appropriate for factorially (2x2) arranged treatments (Steel and Torrie, 1980). Differences between treatment means were assessed by least significant difference test (Cochran and Cox, 1957).

RESULTS AND DISCUSSION

Body weight and daily gain

The two diets used were somewhat different in terms of ingredients and also chemical composition. In particular (Table 3), the crude fiber content of the experimental diet was 22% lower in the first stage and 10% less in the second stage, compared with the control diet. Furthermore, the fat content was higher in the treatment B diet (+ 14% in the first stage and + 36% in the second stage). Of

Table 3. Composition of experimental diets (kg).

Ingredients	Treatment A (Control)		Treatment B (Zeolite)	
	Stage I	Stage II	Stage I	Stage II
Maize	520	260	500	245
Soybean meal 44%	160	87	165	110
Barley	100	313	80	300
Wheat bran	100	260	75	190
Premix	120	80	120	80
Zeolite[1]			60	60
Poultry fat				15
Analyzed nutrient composition (%)				
Crude protein	19.43	16.50	18.63	16.21
Crude fiber	4.06	5.25	3.17	4.71
Ether extract	3.41	3.17	3.91	4.32
Lysine	1.10	0.85	1.08	0.87
Ca (total)	1.14	0.78	1.14	0.78
P (total)	0.79	0.73	0.77	0.72
Salt	0.36	0.28	0.36	0.28

[1]Clinoptilolite-rich tuff from Pentalofos, Thrace, Greece.

Table 4. Body weight (kg) during the whole experimental period ($\overline{X}$ ± SD).

Treatment	Sex	Body weight: Start of experiment (37 days of age)	Body weight: (79 days of age)	Body weight: (121 days of age)	Body weight: End of experiment (162 days of age)
Control	Male	13.13 ± 2.45	30.79 ± 5.37	63.30 ± 10.08	99.20 ± 11.86
Control	Female	12.54 ± 2.52	30.76 ± 7.19	61.90 ± 6.35	96.75 ± 7.82
Control	Average	12.83 ± 2.44	30.77 ± 4.35	62.95 ± 8.23	97.98 ± 5.82
Zeolite[1]	Male	13.85 ± 2.59	32.23 ± 5.36	63.95 ± 3.73	104.0 ± 9.42
Zeolite[1]	Female	13.55 ± 3.22	33.83 ± 7.16	66.40 ± 5.03	98.50 ± 7.19
Zeolite[1]	Average	13.60 ± 2.86	33.03 ± 6.20	65.17 ± 4.49	101.25 ± 4.56

Analysis of variance	Test of significance			
	Treatment (T)	Sex(S)	Age (A)	TxS
End of experiment	*	*	*	NS

[1]Same as in Table 1. NS = not significant (P >0.05); * = P <0.05; P = level of significance.

course, it was difficult to obtain from different materials the same diets in terms of chemical composition, and the differences may have been important, because the fiber fraction is responsible for the digestibility rates and because the added poultry fat in the second stage was probably more digestible than the ether extract normally present in raw materials. On the contrary, the differences in the protein content are acceptable: - 4% and - 1.75% in the two stages. The somewhat different composition of the two diets meets the nutrient requirements of pigs of N.R.C. (1994).

The effects of supplemental Cp-rich tuff on body weight are summarized in Table 4 by sex along with the level of significance for the main effects and the interaction. Body

Table 5. Effect of sex and diet on body weight (kg) at the end of the experiment and body weight gain during the experiment ($\overline{X}$ ± SD).

Sex	Diet	Body weight at the end of the experiment	Zeolite[1]/Control (%)	Body weight gain during the experiment	Zeolite[1]/Control (%)
Males	Control	99.20 ± 11.86		84.20 ± 8.35	
Males	Zeolite[1]	104.0 ± 9.42	+4.84*	86.08 ± 16.41	+2.23**
Females	Control	96.75 ± 7.82		85.15 ± 7.45	
Females	Zeolite[1]	98.50 ± 7.19	+1.81**	90.15 ± 10.21	+5.87*

[1]Same as in Table 1. *P <0.05; **P <0.10.

weight was affected ($P < 0.01$) by age as expected, and by diet ($P < 0.05$). Body weight was less in pigs fed the basal diet. The mean body weight at the end of stage I, was 30.77 and 33.03 kg for treatments A and B, respectively. The difference, +2.26 kg/pig, for the zeolite treatment is significant ($P < 0.05$). The mean body weight at the end of stage II was 62.95 and 65.17 kg for treatments A and B, respectively. The difference, +2.22 kg/pig, for the zeolite treatment is significant ($P < 0.05$). In addition, at the end of the experiment, the mean body weight was 97.98 and 101.25 kg for treatments A and B, respectively. The difference in average was 3.27 kg or 3.34% for zeolite-fed pigs.

Body weight at the end of the experiment and body weight gains (Table 5) were affected by sex. Although at the end of the experiment no significant zeolite sex interaction was noted for body weight, the data for body weight gain showed a reduced zeolite effect in males and a positive zeolite effect in females during the entire fattening period, except the last stage. The change in body weight gain was greater for the zeolite-fed female pigs than for female pigs in the control group. The well-known phenomenon of compensatory growth was evident in the last stage of fattening period when feed included 6% Cp-rich tuff.

Body weight at the end of the experimental period was related to daily growth rate (Table 6). Differences in daily gain, an indirect measure of body growth, between the two treatments may be attributed to the influence of body weight at the end of the fattening period. The final body weight in pigs with the same daily gain (e.g., 0.7 kg), can be predicted as 93.16 and 94.43 kg/pig for treatments A and B, respectively.

Back-fat thickness is given in Table 7. The fat depth in millimeters, was 13.27 and 12.89 for control and zeolite pigs, respectively.

Table 6. Linear response equations for body weight at the end of the experiment (Y) with daily gain of body weight (X) (kg).

Treatment	Regression equations	R^2
A (control)	$Y = 9.9637 + 118.8539\ X$	0.9164, Se of b 8.4571***
B (zeolite[1])	$Y = 17.8866 + 109.3433\ X$	0.7250, Se of b 15.8700***

[1]Same as in Table 1. ***$P < 0.001$.

Table 7. Back-fat thickness for 100-kg live pigs ($\overline{X} \pm SD$).

Treatment	Body weight (kg)	Average back-fat thickness (mm)
A (control)	100.50 ± 8.84	13.27 ± 0.79
B (zeolite[1])	106.50 ± 7.33	12.89 ± 0.67
Differ. (%)	$+5.97^{NS}$	-2.86^{NS}

[1]Same as in Table 1. ^{NS}not significant ($P > 0.05$).

Table 8. Food consumption (kg/pig) during the last stage of fattenin period ($\overline{X} \pm SD$).

Treatment	Total feed consumption	Average daily feed consumption
A (control)	246 ± 4.71	1.984 ± 0.30
B (zeolite[1])	232 ± 3.10	1.870 ± 0.28
Differ. (%)	-5.69*	-5.75*

[1]Same as in Table 1; *P <0.05.

Thus, mean back-fat thickness was 0.38 mm (2.9%) less for pigs fed the zeolite diet. This trend for a reduction, although not statistically significant (P >0.05), may be of practical importance. The low variation for back-fat depths of zeolite-fed pigs will yield relatively few overthin and overfat animals. In general, the best eating quality is achieved at levels of fatness associated with back-fat depths at 100 kg live weight of between 8 and 14 mm. Most pigs in the United Kingdom with 65-70 kg carcass weight have back-fat measurements of 12 mm (Whittemore, 1993).

Feed consumption

Total feed consumption and daily feed intake decreased (P <0.05) if zeolite was part of the diet (Table 8). The recorded reduction of total or daily feed consumption was 5.69% and 5.75%, respectively. The less feed consumption by the zeolite-fed pigs is economically important. The zeolite-fed pigs have relatively less fat and more lean meat at any given empty body weight (Whittemore, 1993).

Substantial evidence indicates that increased weight gain and feed efficiency frequently resulted from the addition of 1 to 5 % zeolite in the diet of pigs (Mumpton and Fishman, 1977; Castro and Pastrana, 1988; Kovac *et al.*, 1988; Tsitsishvili, 1988). In these reports, feed supplemented with zeolite gave rise to feed efficiencies about 11% greater than those of normal rations, which was given to older animals (last stage of fattening period). Improved weight gain and feed efficiency in the presence of 6% added Cp-rich tuff almost agrees with the above observations in fattening pigs in the present experiment. Feed supplemented with zeolite gave rise to feed efficiencies about 9% greater than those of normal rations, which was given to older animals. Also, heavier weights at slaughter were associated with reduced efficiency of feed conversion. This is partly due to the fatness effect, i.e., 1 kg of fat gain requires about three times as much food as 1 kg of lean gain. For zeolite-fed pigs, however, heavier weights at slaughter were associated with improved efficiency of feed conversion.

Compared with pigs in the control groups,

Table 9. Effects of adding 6% zeolitic tuff to plasma Ca and P (mg/100 ml) ($\overline{X} \pm SD$).

Treatment	Ca	P
A (control)	8.90 ± 0.2	8.35 ± 0.6
B (zeolite[1])	8.50 ± 0.1	8.05 ± 0.3
Differ. (%)	-4.49^{NS}	-3.59^{NS}

[1]Same as in Table 1. ^{NS}not significant (P >0.05).

the zeolite-fed pigs had greater body weight and consumed less feed. Zeolite-fed pigs were apparently more efficient in converting feed to body weight than the control pigs. The physiological mechanisms for these improvements are unclear.

Table 10. Carcass characteristics ($\overline{X} \pm SD$).

Treatment	Carcass yield (%)	Parts yield (% of body weight)					
		Head	Neck	Picnic sh.	Loin	Legs	Belly
A (control)	69.64±.36	5.17±.03	4.26±.15	11.38±.03	14.93±.20	20.70±.20	9.54±.23
B (zeolite[1])	70.30±.16	5.05±.40	4.57±.48	10.96±.56	15.53±.70	20.75±.40	9.89±.17
Differ. (%)	+0.95	-2.32*	+7.28*	-3.69*	+4.02*	+0.24	+3.67*
Cold carcass[2]							
Treatment	Carcass yield (%)	Parts yield (% of carcass weight)					
		Picnic shoulder		Loin		Legs	
A (control)	61.83±.25	17.46±1.56		22.19±1.76		31.72±1.15	
B (zeolite[1])	62.45±.17	17.55±1.24		24.87±0.58		33.24±2.14	
Differ. (%)	+1.02	+0.52		+12.08**		+4.79*	

[1]Same as in Table 1. [2]Without head. *P <0.05; **P <0.01.

Mortality and plasma composition

No deaths were recorded during the experiment for either treatment group. The plasma concentrations of Ca and P were not affected by diet (P >0.05) (Table 9).

Carcass characteristics

The yields of hot carcass and wholesale parts are given in Table 10. Carcass yield was greater for treatment B (zeolite) than for the control group (70.30% vs 69.64%). Zeolite-fed pigs had significantly (P <0.05) heavier neck, loin, and belly than the pigs fed the control diet.

The yields of cold carcass and parts (% of carcass weight) are shown also in Table

Table 11. Yields (% of body weight) of main organs ($\overline{X} \pm SD$).

Organ	A (Control)	B (Zeolite[1])	Difference (%)
Kidneys	0.452 ± 0.14	0.414 ± 0.06	-8.41*
Liver	1.689 ± 0.35	1.514 ± 0.04	-10.36*
Heart	0.416 ± 0.01	0.392 ± 0.09	-5.77*
Intestine	6.90 ± 1.05	6.83 ± 0.83	-1.01
Spleen	0.154 ± 0.53	0.161 ± 0.02	+4.54*
Stomach	2.00 ± 0.30	2.27 ± 0.15	+13.50*

[1]Same as in Table 1. *P <0.05.

10. Loin ($P < 0.01$) and leg ($P < 0.05$) yields were greater in zeolite-fed pigs than in control pigs. Consequently, zeolite diet apparently improved the yield of certain muscles.

The yields of some main organs of pigs are shown in Table 11. Kidneys, liver, and heart weights, expressed as percentage ($P < 0.05$) of body weight, were reduced by 8.41%, 10.36%, and 5.77%, respectively, by the zeolite diet. According to Pond *et al.* (1993), who also found similar reduction in relative mass of liver and kidneys, the physiological basis for this reduction is unclear. Changes in nitrogen metabolism associated with differences in amounts of ammonia processed by intestinal epithelium, liver and kidneys may have occurred in the presence of clinoptilolite, as a highly selective cation exchanger for NH_4^+ in the upper gastrointestinal tract. The reduction in relative mass of liver and kidneys, two metabolically active visceral organs, would allow diversion of nutrients to growth of other body tissues.

Chemical carcass composition

The chemical composition of shoulder tissues is summarized in Table 12. Percentages of water and protein were less ($P < 0.05$) and percentage of fat was greater ($P < 0.01$) in pigs fed the control diet (A) than in those fed zeolite (B). Whittemore (1993) reported that usually dissected lean tissue (muscle) contains 70-75% water, 5-15% fat, and 20-25% protein. The water content in the lean of a very young pig may be as much as 80% but in a mature animal the water content of lean may be substantially less than 70%. Fatty tissue contains 10-25% water, 2% protein, and 70-80% lipid.

The data suggest that the addition of 6% Cp-rich tuff in the diet of finishing pigs resulted in increased lean percentage and decreased fat percentage in the carcass.

Economic data

Grower settlement cost, which is an index of grow-out efficiency, was calculated using the general relation:

[(Number of pigs placed × pig cost) + (kg of feed × feed cost)]/(kg of live weight).

The settlement cost was lower (improved) in the zeolite treatment compared with control treatment. The cost of pig production in Greece varies considerably between breeding systems and farms. According to the results of the present experiment the feed cost (drs/pig) per zeolite-fed pig was reduced by 5.69%, whereas the gross margin from meat sales (drs/pig) was increased by 3.34%. The total gross margin per zeolite-fed pig was 3157 drachmas compared with a pig from the control group. Thus, the type of diet influenced the cost of production. Food intake in zeolite-fed pigs was lower, so the feed cost was also less. In addition, the gross margin from meat sale was more in zeolite-fed pigs, which were heavier compared to the control pigs.

SUMMARY AND CONCLUSIONS

The effects of Cp-rich tuff addition at a 6% level in the pig diets, gave the following results:

Table 12. Chemical composition of shoulder tissues ($\overline{X} \pm SD$).

Treatment	Water	Protein	Lipid
A (control)	66.99 ± 0.17	19.26 ± 0.45	12.52 ± 0.17
B (zeolite[1])	70.53 ± 0.19	19.66 ± 0.26	8.28 ± 0.98
Difference (%)	+5.28**	+2.08*	-33.87**

[1]Same as in Table 1. *$P < 0.05$; **$P < 0.01$

- Feed conversion improved and feed costs were reduced.
- Feed utilization improved for both sexes.
- Continuous supplementation of natural zeolite at 60 kg/ton (6%) significantly improved the growth rate of both male and female fattening pigs.
- Fat content and composition of meat were changed by appropriate diet manipulation.
- Finishing pigs receiving Cp-rich tuff showed less fat deposition, but such reduced fat growth did not reduce overall growth rate.
- No deaths were recorded during the experiment for either treatment group.
- The results of our experiment indicate that the utilization of Cp-rich tuff in pig finishing diets may be economically advantageous.

REFERENCE CITED

A.O.A.C. (Association of Official Analytical Chemists) (1980) *Official Methods of Analysis:* 13th ed., Association of Official Analytical Chemists, Washington, D.C., 320 pp.

Bartko, P., Seidel, H., and Kovac, G. (1995) Use of clinoptilolite-rich tuffs from Slovakia in animal production: A review: in *Natural Zeolites '93: Occurrence, Properties, Use,* D. W. Ming and F. A. Mumpton, eds., Int. Comm. Nat. Zeolites, Brockport, New York, 467-475.

Castro, M. and Pastrana, M. (1988) The effect of different levels of zeolite on the performance of growing pigs: in *Occurrence, Properties and Utilization of Natural Zeolites,* D. Kalló and H. S. Sherry, eds., Akademiai Kiado, Budapest, 721-727.

Chapman, H. D. (1965) *Methods of Soil Analysis: Agronomy Series No. 9, Part 2,* A. Black, ed., Am. Inst. of Agronomy, Madison, Wisconsin, 891-901.

Cochran, W. G. and Cox, G. M. (1957) *Experimental Designs:* 2nd ed., Wiley, New York, 560 pp.

Froseth, J. A. (1982) Performance, scours, and metabolic measurements of pigs fed clinoptilolite: in *Program and Abstracts, Zeo-Agriculture '82,* Int. Comm. Nat. Zeolites, Brockport, New York, p. 18 (abstract).

Kassoli-Fournaraki, A., Stamatakis, M., Hall, A., Filippidis, A., Michailidis, K., Tsirambides, A., and Koutles Th. (1999) The Ca-rich clinoptilolite deposit of Pentalofos, Thrace, Greece: This Volume.

Kovac, G., Vrzgula, L., Bartko, P., and Prosbova, M. (1988) The addition of natural zeolite to feed and its effect on the state of health of pigs and the quality of meat products: in *Occurrence, Properties and Utilization of Natural Zeolites,* D. Kalló and H. S. Sherry, eds., Akademiai Kiado, Budapest, 737-745.

Lindemann, M. D., Blodgett, D. J., Kornegay, E. T., and Schurig, G. G. (1993) Potential ameliorators of aflatoxicosis in weanling/growing swine: *J. Anim. Sci.* **71**, 171-178.

Ma, C., Tzeng, C., Lai, M., and Tsai, A. (1979) The feeding of zeolite on the litter size at birth of swine: *Soc. Agric.* **27**, 189-193.

Ma, C., Yang, S., Tzeng, C., and Wu, H. (1984) Effect of feeding clinoptilolite on embryo survival in swine: in *Zeo-Agriculture, Use of Natural Zeolites in Agriculture and Aquaculture,* W. G. Pond and F. A. Mumpton, eds., Westview Press, Boulder, Colorado, 155-160.

Mumpton, F. A. (1988) Development of uses for natural zeolites: A critical commentary: in *Occurrence, Properties and Utilization of Natural Zeolites,* D. Kalló and H. S. Sherry, eds., Akademiai Kiado, Budapest, 333-367.

Mumpton, F. A. and Fishman, P. H. (1977) The application of natural zeolites in animal science and aquaculture: *J. Anim. Sci.* **45**, 1188-1203.

N.R.C. (National Research Council) (1994) *Nutrient Requirements of Pigs:* 9th ed., National Academic Press, Washington, D.C., 17 pp.

Pond, W. G. (1995) Zeolites in animal nutrition and health: A review: in *Natural Zeolites '93: Occurrence, Properties, Use,* D. W. Ming and F. A. Mumpton, eds., Int. Comm. Nat. Zeolites, Brockport, New York, 449-457.

Pond, W. G. and Yen, J. T. (1982) Response of growing pigs to dietary clinoptilolite from two geographic sources: *Nutr. Rep. Int.* **25**, 837-848.

Pond, W. G. and Yen, J. T. (1984) Physiological effects of clinoptilolite and synthetic zeolite A in animals: in *Zeo-Agriculture: Use of Natural Zeolites in Agriculture and Aquaculture,* W. G. Pond and F. A. Mumpton, eds., Westview Press, Boulder, Colorado, 127-142.

Pond, W. G., Ellis, K. J., Krook, L. P., and Schoknecht, P. A. (1993) Modulation of dietary lead toxicity in pigs by clinoptilolite: in *Program and Abstracts, Zeolites '93, 4th Int. Conf. Occurrence, Properties, and Use of Natural Zeolites,* Int. Comm. Natural Zeolites, Brockport, New York, 170-172 (abstract).

Steel, R. G. D. and Torrie, J. H. (1980) *Principles and Procedures of Statistics:* Hill Book Co, New York, 481 pp.

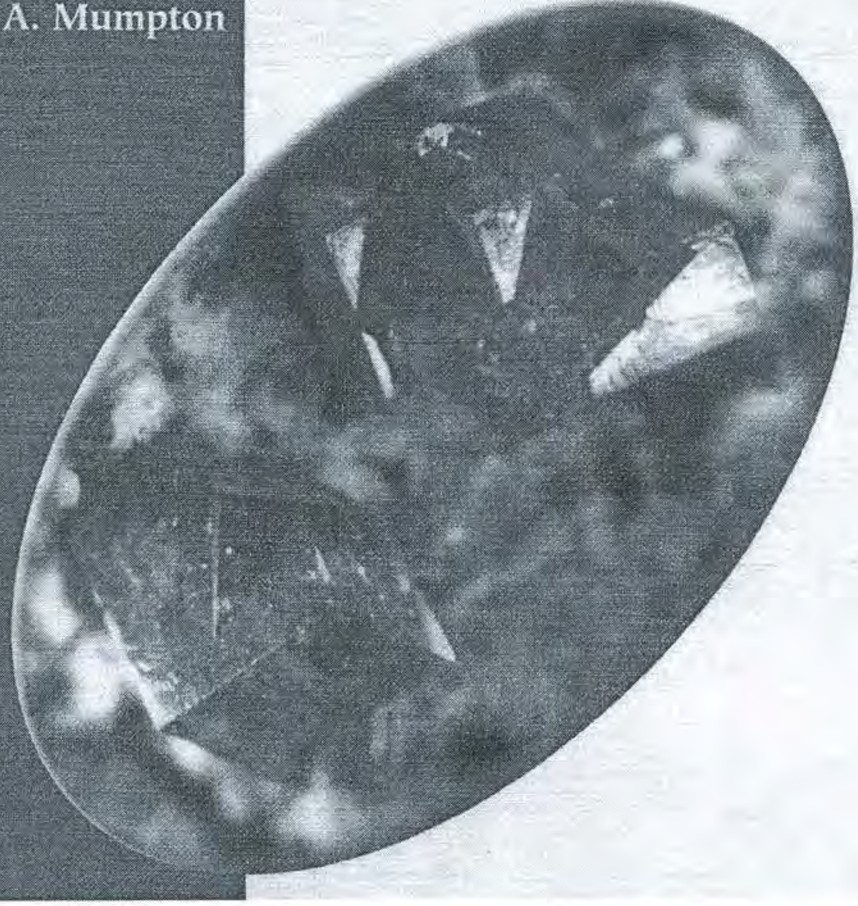
Tsitsishvili, G. V. (1988) Perspectives of natural zeolite applications: in *Occurrence, Properties and Utilization of Natural Zeolites,* D. Kalló and H. S. Sherry, eds., Akademiai Kiado, Budapest, 367-393.

Vrzgula, L. and Bartko, P. (1984) Effects of clinoptilolite on weight gain and some physiological parameters of swine: in *Zeo-Agriculture: Use of Natural Zeolites in Agriculture and Aquaculture,* W. G. Pond and F. A. Mumpton, eds., Westview Press, Boulder, Colorado, 161-166.

Whittemore, C. (1993) *The Science and Practice of Pig Production:* Longman Scientific and Technical, Essex, England, 661 pp.

NATURAL ZEOLITES FOR THE THIRD MILLENNIUM

edited by
Carmine Colella
and
Frederick A. Mumpton



De Frede
Editore
Napoli