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Hoof quality of Anglo-Arabian and Haflinger horses

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Abstract

Introduction: Foot quality is essential to the horse's movement. The barefoot approach favours the animal's welfare. Environment and selection determine hoof characteristics. **Material and Methods**: Hoof characteristics of eight Anglo-Arabian (AA) and nine Haflinger (HA) horses were studied. After a preliminary visual analysis of feet, nail samples were collected after trimming for physico-chemical analysis. The parameters were submitted to analysis of variance. A principal component analysis and a Pearson correlation were used to compare mineral contents. **Results:** The hooves of both breeds were healthy and solid. The hooves of HA horses were longer than those of AA horses (14.90 ±0.30 cm *vs* 13.10 ±0.60 cm), while the AA hoof was harder than the HA hoof both in the wall (74.55 ±2.95 H *vs* 60.18 ±2.67 H) and sole (67.00 ±5.87 H *vs* 43.0 ±4.76 H). In comparison with the sole, the AA hoof wall also had a lower moisture percentage (12.56 ±0.67% *vs* 20.64 ±0.76%), while crude protein and ash contents were similar in both regions. The AA hoof showed a higher Se content, while the HA hoof had a higher level of macroelements. The negative correlations of K with Cu, Fe, Ni, Pb, and Zn in the AA hoof may indicate osmoregulation activity. **Conclusion:** The hoof morphology of AA and HA horses met the literature parameters for mesomorphic horses. Both breeds had healthy and well-conformed hooves, useful for sport and recreation activities.

Keywords: horse, Anglo-Arabian, Haflinger, hoof, physico-chemical properties.

Introduction

Horse movement is governed by the hooves (5). A good foot condition is important in particular in equestrian activities. To promote their animals' welfare, many farmers have kept horses barefoot in recent years. Equine hoof characteristics are an index of environmental adaptability (29). The environment and selection determine the hoof characteristics.

The hoof region stores waste materials, so the nail growth can be considered as a system that works in parallel with other excretory organs and tissues such as the kidneys, skin, and mucous membranes (28). Due to the small surface in contact with the ground, hooves are subjected to heavy loads, and malformations of the keratin structures of the hoof can cause serious motion problems (17). The quality of the keratinised structures of the hoof depends on the availability of necessary minerals, such as calcium, zinc, or copper (17). The horny products of the skin also have the ability to bind heavy metals (23). Previous studies claimed that the soundness of a hoof depends on the arteriovenous activity and on the capacity of the nail to accumulate and excrete waste materials through consumption (19, 21, 30). Amiata donkey, Anglo-Arabian horse, and Monterufoli Pony hooves act as bio-accumulators and as emunctory organs of harmful elements. Because of their relative softness, Monterufoli Pony hooves quickly remove the minerals through nail consumption (21, 30).

The aim of this study was to compare the morphological, physical, chemical, and mineral characteristics of hooves of Anglo-Arabian and Haflinger horses reared in Tuscany. The Anglo-Arabian (AA) is a widespread breed used for endurance (15); the Haflinger (HA) horse is a breed native to South Tirol, and it is one of the most common Italian breeds (1). The horses, which were once used in agriculture, are now used as saddle horses. The Haflinger horse was known in the past as a medium

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sized workhorse. In 1873, the breed was improved by introducing Oriental blood and from 1973 there has been a stud book for this breed (1).

Material and Methods

Animals and experimental design. All experimental procedures were carried out according to Italian law on animal care. This study was performed in the "Corpo Forestale dello Stato" Tuscan farms, and it involved eight (four males and four females) AA horses (9.0 ±4.2 years of age and 543.4 ±17.9 kg of live weight) and nine (four males and five females) HA horses (6.0 ±0.8 years of age and 515.7 ±20.4 kg of live weight). The horses were reared in boxes with paddocks and were fed with local hay and straw, a mixture of barley and maize, and received water *ad libitum*. The trial was performed during the autumn and winter. The horses were trained on ground for two hours a day.

Morphological and physical analysis. During hoof shaving, a visual analysis was performed in order to check the nail characteristics. The morphology of the front left hoof was evaluated. The circumferences of the coronet and the bottom edge of the foot were measured and their relationship was calculated as the conicity index (CI) (5, 21). The hardness (H, kg/mm^2) of the wall, white line, and sole were measured following the methodology used by Tocci *et al.* (30).

Chemical analysis. Samples of wall and sole were taken from both breeds during the hoof shaving. Eight wall samples and six sole samples from AA horses, and nine wall samples and nine sole samples from HA horses were obtained and analysed.

After a water and ethyl alcohol wash (9), the samples were pre-dried (60°C/24 h) following the methods of Tocci *et al.* (30). The samples were crushed with an electric mill (21). The moisture of both hoof regions was determined through drying in a stove (105°C/4 h). The EU official methodologies (First Commission Directive 71/250 EEC of 15 June 1971 OJ L 155/20, 12.7.1971) were used to determine the ashes. The total crude protein (CP) was determined with the Kjeldahl CEE-ASPA method (16).

Mineralogical analysis. The hoof mineral quantitative analyses were performed in the Florence University laboratories (30). Calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), phosphorous (P), copper (Cu), iron (Fe), manganese (Mn), selenium (Se), zinc (Zn), nickel (Ni), aluminium (Al), lithium (Li), lead (Pb), and strontium (Sr) were determined

Statistical analysis. Data were analysed with JMP 10 statistical software (22). The hoof morphological and physical characteristics were submitted to one-way ANOVA for unbalanced data, considering the breed as fixed effects. The chemical and mineralogical composition results were submitted to two-way ANOVA, considering as fixed effects the breed, hoof region, and their interaction. Differences among means were calculated with Student's *t*-test. The Pearson correlation coefficients were used to measure the strength of a linear association between the mean hoof H and the mean hoof moisture content. The reciprocal correlation between minerals in AA and HA hooves was also calculated.

Principal component analysis (PCA) was applied in this study. PCA is a procedure for identifying a smaller number of uncorrelated variables, called "principal components", from a large set of data. This method was used to determine the degree of similarity between the mineral content of the hooves of AA and HA horses, and between the mineral content in the wall and sole of both breeds.

The Kaiser criterion was applied. This method retains only factors with eigenvalues greater than 1. This criterion was proposed by the psychometrician whose name it bears (11), and is probably the one most widely used. The Varimax rotation was carried out. This method is a way of transforming the solution so that the rotated component matrix is relatively easy to understand (11). The loading and the score plots were also performed in order to visualise the mineral distribution in the hooves of both breeds and in both hoof regions.

Results

Visual and morphological analysis and physical characteristics. AA and HA horses showed well conformed and healthy hooves. Their hooves were solid and the nail integrated. The CI, wall, and white line thickness were similar in both breeds. The foot length was greater in HA horses. The sole and wall were harder in AA hooves (Table 1).

Chemical composition. The chemical composition of the nail (Table 2) showed how all the considered parameters were in ranges defined by hoof region and not by breed. Moisture content was higher in the sole, while CP and ash contents were higher in the wall. No significant interactions were found among chemical parameters. The correlation between moisture content in the wall and sole and their respective H was not significant (correlation coefficient in wall P = 0.34, P = 0.13, n.s.; correlation coefficient in sole P = 0.13, P 0.65, n.s.).

Mineral composition. Se content was higher in AA hooves, while K, Mn, Li, P, and Sr contents were higher in HA hooves (Table 3). In the hoof regions, only Al content was higher in the sole, while the rest of the elements' contents were heavier in the wall. Ca, K, Li, Mg, and Mn contents were different in the interactions between breed and hoof region (Table 3).

The HA hoof wall yielded the highest content of all the studied minerals, while the AA hoof wall often returned lower values (Table 4). The HA sole held

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lower mineral content with only the content of Li higher and similar to that of the wall. The AA sole concentrated minerals more sparsely.

The Kaiser test arrived at five eigenvalues that reached more than 79% of the total variability; Principal Component 1 (PC1) showed 33.54%, while Principal Component 2 (PC2) was next highest at 19.8% (Table 5).

Using Varimax rotation the following elements were identified in factor 1: Ca, K, Mg, Fe, Mn, Ni, and Sr. Rotation for factor 2 provided P, Cu, Fe, Se, Ni, Pb, and Sr (Table 6).

In the loading and score plots of the mineral content in the hooves of both breeds, PC2 discriminated AA from HA breed better than PC1 (Fig. 1). The AA hoof was identified mainly by Cu, Fe, Se, and Pb, while the HA hoof was identified by Ca, K, Mg, and P.

In the loading and score plots of content by hoof regions (Fig. 2), wall and sole were quite distinct in PC1; most minerals identified the wall, and only Al identified the sole.

The Pearson correlation of the mineral content in the AA hoof (Table 7) revealed that Al, Cu, Fe, Ni, Pb, and Sr had higher numbers of significant correlations. The significant correlations of Al were almost all negative, except with Na. In the HA hoof (Table 8) the elements with higher numbers of significant correlations were Ca, Cu, K, Mg, Mn, and Sr. Only Al had negative correlations, while usually the significant correlations among the elements were positive.

Table 1. Morphological and physical characteristics of hoof of AA and HA horses (means ±SEM)

	Unit	AA	HA
Foot length	cm	13.1 ±0.6 b	14.9 ±0.3 a
Foot width	cm	12.7 ±0.3	13.3 ±0.2
Width foot/length foot		0.94 ±0.02	0.89 ±0.01
Crown circumference	cm	36.0 ±1.38	38.7 ±0.6
Solar circumference	cm	42.0 ±1.28	44.2 ±0.77
CI		0.83 ±0.02	0.87 ±0.01
Sole H D	H	67.0 ±5.87 A	43.0 ±4.76 B
White line H D	H	26.55 ±3.82	31.55 ±3.82
Wall H D	H	74.55 ±2.95 A	60.18 ±2.67 B
Wall thickness	mm	10.6 ±0.4	12.4 ±0.7
White line thickness	mm	4.8 ±0.3	4.3 ±0.3

a, b – P < 0.05; A, B – P < 0.01

Table 2. Chemical composition of AA and HA hooves (means ±SEM)

		BREED		HOOF	
		AA	HA	WALL	SOLE
Moisture	%	16.89 ±0.77	16.7 ±0.64	12.56 ±0.67 B	20.64 ±0.76 A
CP	% on DM	97.14 ±0.44	97.87 ±0.95	97.14 ±0.44	98.41 ±0.44
Ashes	% on DM	1.43 ±0.13	1.18 ±0.15	1.17 ±0.13	1.44 ±0.14

A, B – P < 0.01

Table 3. Mineral composition (ppm) of hoof in relation to breed and hoof region (wall and sole) (means ±SEM)

	BREED		HOOF REGION		B x HR[1]
	AA	HA	WALL	SOLE	
Al	524.33 ±106.9	343.9 ±9.5	237.6 ±99.3 B	630.6 ±108.4 A	n.s.
Ca	1156.0 ±140.03	1216.5 ±108.3	1466.7 ±120.7 A	905.8 ±131.8 B	**
Cu	5.3 ±0.7	3.9 ±0.6	5.7 ±0. 6 a	3.6 ±0.6 b	n.s.
Fe	1620.4 ±452.0	1385.3 ±346.8	2509.0 ±388.9 A	496.6 ±494.8 B	n.s.
K	1348.2 ±214.8 B	2606.0 ±166.3 A	2201.4 ±175.3	1777.5 ±201.9	**
Li	0.41 ±0.04 B	0.61 ±0.04 A	0.7 ±0.04 A	0.4 ±0.04 B	***
Mg	305.6 ±39.9	322.8 ±31.0	373.0 ±32.7 A	255.4 ±37.5 B	***
Mn	99.6 ±40.0 B	246.1 ±31.1 A	325.9 ±34.4 A	19.8 ±37.6 B	**
Na	396.2 ±60.0	311.7 ±46.4	379.0 ±51.6	328.9 ±56.3	n.s.
Ni	3.6 ±0.7	3.1 ±0.5	5.5 ±0.6 A	1.1 ±0.7 B	n.s.
P	179.9 ±32.4 B	303.1 ±25.6 A	263.4 ±27.9	219.6 ±30.4	n.s.
Pb	2.2 ±0.4	2.2 ±0.3	2.7 ±0.3	1.7 ±0.3	n.s.
Se	1.2 ±0.2 a	0.5 ±0.2 b	1.2 ±0.2 a	0.4 ±0.2 b	n.s.
Sr	3.1 ±0.5 B	4.9 ±0.4 A	5.6 ±0.5 A	2.4 ±0.5 B	n.s.
Zn	126.4 ±6.9	107.3 ±5.7	131.5 ±6.3 A	102.1 ±6.9 B	n.s.

[1] breed and hoof region interaction; a, b – P < 0.05; A, B – P < 0.01

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Table 4. Mineral content: breeds and hoof region interactions (means ±SEM)

	AA		HA	
	WALL	SOLE	WALL	SOLE
Macroelement				
Ca	1242.2 ±183.7 AB	1069.8 ±212.1 AB	1691.1 ±153.2 A	741.9 ±156.6 B
K	1242.9 ±281.2 B	1453.5 ±324.8 B	3110.5 ±239.8 A	2101.4 ±239.8 B
Mg	274.9 ±52.2 B	336.3 ±60.3 AB	471.0 ±44.5 A	174.5 ±44.5 B
Trace element				
Li	0.6 ±0.06 A	0.17 ±0.07 B	0.7 ±0.05 A	0.5 ±0.05 A
Mn	180.8 ±52.4 B	18.4 ±60.5 C	471.1 ±44.7 A	21.1 ±44.7 C

A, B – $P < 0.01$

Table 5. Results from the principal component analysis for the first five principal components

Number	Eigenvalue	Percentage	Cumulative percentage
1	5.03	33.54	33.54
2	2.97	19.8	53.34
3	1.69	11.25	64.59
4	1.19	7.94	72.53
5	1.01	6.76	79.29

Table 6. Correlation coefficient after Varimax rotation for minerals determined for AA and HA hooves and hoof region

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Al	-0.15	-0.17	-0.16	-0.41	0.72
Ca	0.7	0.09	0.27	0.48	0.11
Cu	0.03	0.85	0.15	0.16	0.05
Fe	0.5	0.42	0.52	-0.31	-0.2
K	0.63	-0.17	-0.28	0.31	0.24
Li	0.2	0.16	0.08	0.77	-0.1
Mg	0.91	-0.05	0.05	0.02	-0.09
Mn	0.91	-0.04	0.13	0.18	-0.13
Na	-0.04	0.22	0.08	0.04	0.88
Ni	0.63	0.54	0.25	-0.1	-0.1
P	0.32	-0.44	-0.27	0.58	-0.1
Pb	0.05	0.83	-0.001	-0.01	0.02
Se	-0.12	0.36	0.64	-0.17	-0.47
Sr	0.85	0.35	-0.03	0.3	-0.08
Zn	0.16	0.01	0.9	0.16	0.1

Table 7. Significant Pearson correlation coefficient among minerals in AA hoof

	Al	Ca	Cu	Fe	K	Li	Mg	Mn	Na	Ni	P	Pb	Se	Sr	Zn
Al	1.0														
Ca	-0.54	1.0													
Cu	-0.32	0.39	1.0												
Fe	-0.34	0.05	0.34	1.0											
K	0.09	0.03	-0.37	-0.30	1.0										
Li	-0.27	0.44	0.16	0.47	-0.14	1.0									
Mg	-0.38	0.54	-0.08	-0.30	0.10	-0.25	1.0								
Mn	-0.24	0.38	-0.11	0.39	0.26	0.55	0.12	1.0							
Na	0.49	0.00	0.36	-0.08	0.34	0.01	-0.34	-0.02	1.0						
Ni	-0.21	0.15	0.59	0.82	-0.30	0.58	-0.39	0.35	0.18	1.0					
P	0.05	-0.05	-0.56	-0.15	-0.14	-0.12	0.35	0.12	-0.35	-0.39	1.0				
Pb	-0.13	-0.09	0.61	0.45	-0.43	0.18	-0.47	-0.30	0.17	0.37	-0.45	1.0			
Se	-0.38	-0.25	-0.08	0.55	0.12	0.15	-0.11	0.46	-0.35	0.28	-0.12	0.21	1.0		
Sr	-0.45	0.48	0.83	0.53	-0.24	0.45	-0.09	0.22	0.27	0.68	-0.44	0.59	0.15	1.0	
Zn	-0.48	0.11	0.07	0.63	-0.38	0.37	0.06	0.56	-0.60	0.53	0.10	-0.01	0.60	0.32	1.0

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Table 8. Significant Pearson correlation coefficient among minerals in HA hoof

	Al	Ca	Cu	Fe	K	Li	Mg	Mn	Na	Ni	P	Pb	Se	Sr	Zn
Al	1.00														
Ca	-0.24	1.00													
Cu	-0.35	0.68	1.00												
Fe	-0.25	0.36	0.35	1.00											
K	0.01	0.65	0.44	0.22	1.00										
Li	-0.38	0.60	0.41	-0.16	0.38	1.00									
Mg	-0.28	0.72	0.37	0.54	0.61	0.32	1.00								
Mn	-0.36	0.71	0.36	0.56	0.56	0.35	0.96	1.00							
Na	0.45	0.06	-0.05	-0.04	0.34	0.17	-0.05	-0.01	1.00						
Ni	-0.25	0.58	0.51	0.65	0.49	0.09	0.81	0.80	-0.16	1.00					
P	-0.19	0.39	-0.13	-0.31	0.23	0.42	0.32	0.34	-0.09	-0.04	1.00				
Pb	0.01	0.29	0.36	0.51	0.39	-0.09	0.34	0.25	0.08	0.42	-0.38	1.00			
Se	-0.04	0.30	0.44	-0.03	0.19	0.32	0.05	0.13	0.31	0.30	-0.03	-0.03	1.00		
Sr	-0.30	0.85	0.56	0.56	0.62	0.42	0.90	0.90	-0.10	0.80	0.29	0.31	0.18	1.00	
Zn	-0.16	0.58	0.31	0.38	0.31	0.19	0.26	0.29	0.26	0.15	0.09	0.31	0.01	0.30	1.00

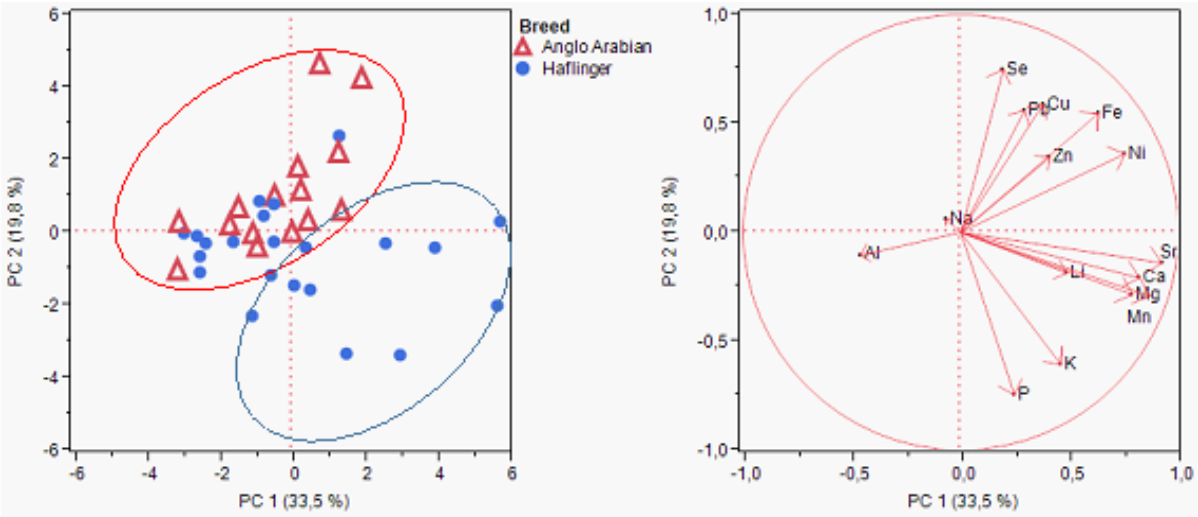

Fig. 1. Score and loading plot for PCA of AA and HA hooves

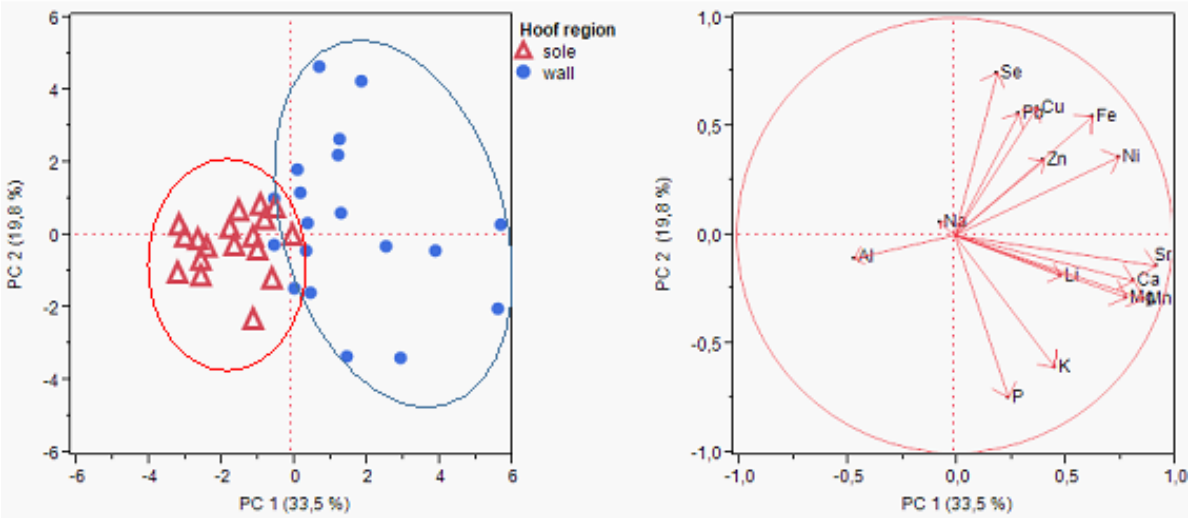

Fig. 2. Score and loading plot for PCA of wall and sole of both breeds

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Discussion

Visual and morphological analysis and physico-chemical composition. The AA hoof was solid and hard, because this breed derives from Arabian horses, adapted to the desert environment (24). The robustness of AA hooves in the current study did not concur with the results of Łuszczyński *et al*. (14), who found problems in the hoof of this breed, mainly in the white line. The same characteristics were found in the HA hoof as in the AA counterpart, as also in their Arabian ancestors (10). The CI was not different from the values of mesomorphic/dolicomorphic horses, indicating an ideal ratio of 5/6 (5). The wall thickness was measured at lower values than those found by Corley and Stephen (8). Wall thickness of both breeds was similar to values for this parameter found by Stachurska *et al*. (26) and Tocci *et al*. (30). The white line thickness was wider than the 3 mm claimed as the average value by Smith Thomas (24), but the line had uniform width all around the sole and was free from defects or damage.

The length and the width of the AA hoof were similar to those found by Stachurska *et al*. (27), while the width to length ratio and the wall thickness were a little lower in this study. The crown circumference of both breeds was larger than that of the Crioulo breed, having the same morphological characteristics (25). The AA wall H was in line with that found by Pütz (18).

The HA wall H supported the results found by Coenen and Spizlei (7) and by Pütz (18). Hardness in the sole of AA and HA hooves was lower than in the wall. The horn of the sole differed from the horn of the wall, but it was soft, moist, and elastic (6). The white line, the germinative layer of nail, was the softer region of the hoof. Narrowness of the white line is important for both breeds, because it represents the conjunction of wall, sole, and inner hoof, and is more susceptible to infections (4).

Moisture content affects the mechanical characteristics, influencing nail health and affecting its water-soluble substances. The absorption capacity of the sole is determined by its moisture, especially close to the white line. A low storage capacity is an attribute of the sole (3). The moisture content found in this trial was lower than results reported in the literature (18, 3). This study was performed in a Mediterranean area, where the dry periods can affect the water content of the nail. According to some authors, H is positively correlated to moisture (3), while an average water content leads to an elastic nail, and too dry or too wet nails are less elastic (3) and consequently more prone to damage (31).

The CP content was higher than literature results (9, 12). The nail ash evaluated in this trial was similar to that of equines raised in Tuscan farms (30), but lower than that of Brazilian horses (9).

Mineral composition. The Mn content in the soles of both breeds was similar to that found by Stachurska *et al*. (27), while AA and HA hooves presented higher Cu and Pb contents. The mineral content in both breeds was similar to the results of Ley *et al.* (13) for Thoroughbred hooves, and only Mn content was higher and P was lower in AA and HA hooves. Na and K are involved in cellular osmoregulation, having an active role in the Na/K pump (2, 20). K in the AA hoof probably played a role in the osmoregulation activity because the negative correlations with many elements are also dangerous. The Pearson positive correlation of mineral content in the HA hoof seemed to indicate low osmoregulatory activity.

In summary, the considered hooves were healthy and well conformed, with morphology that reflected the literature parameters for mesomorphic horses. Foot length in HA hooves exceeded that in AA hooves while hardness of the sole and wall in AA hooves surpassed that of HA hooves. The hooves of both breeds had lower moisture content than the hooves of North European horses studied by other authors. As expected, soles contained less moisture than walls, while walls contained more mineral traces, except for Al. The AA hoof was identified mainly by trace elements, while the HA hoof was identified by macroelements. The majority of the negative correlations of the AA hoof, especially for K, seemed to indicate high osmoregulatory activity. The hoof quality of AA and HA horses recommends the selection of both breeds for equestrian activities which test endurance.

Conflict of Interests Statement: The authors declare that there is no conflict of interests regarding the publication of this article.

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Animal Rights Statement: The authors declare that the trials on animals were conducted in accordance with local Ethical Committee laws and regulations as regards care of animals.

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