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Estimation of Heritability, Genetic and Phenotypic Correlation of Head and Neck Traits of Egyptian Arabian Colts

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ABSTRACT

Morphometric characteristics of the head and neck are distinctive breed features in Egyptian Arabian horses, yet their heritability patterns remain incompletely characterized. This study investigated ten morphometric traits in 91 purebred Egyptian Arabian colts, one year old, at El Zahraa stud. The colts were progeny of 13 sires that were also found in El Zahraa stud. The measurements of the head and neck were obtained using calibrated tape to estimate ten measurements, encompassing seven head measurements (head length, muzzle circumference, left ear length, forehead length, eye-to-mouth length, jaw length, and jaw width) and three neck measurements (neck length, throat latch, and neck base circumference). This study aimed to investigate the influence of Arabian sires on the inheritance of head and neck traits in their foals and to estimate some genetic parameters such as heritability, genetic and phenotypic variance, and correlation among different head and neck traits of yearly Arabian colts. Results revealed a significant effect of sire component on specific morphometric traits, which allowed the identification of better breeding stock for specific trait improvement. These findings provide valuable insights for developing selective breeding strategies aimed at preserving and enhancing characteristic head and neck features in Egyptian Arabian horses. Moreover, this approach will further enhance understanding of Arabian horse genetics and improve breeding program outcomes.

Keywords: Arabian horse beauty, Body measurements, Egyptian Arabian horse, Genetic parameters, Sire effect.

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INTRODUCTION

The Arabian horse is widely recognized as one of the most ancient horse breeds in human history **(International Museum of the Horse, 2010; Olsen, 2013; Machmoum *et al.*, 2020; Remer *et al.*, 2022)**. Environmental considerations, as well as new uses for horses, impacted the selection programs, resulting in the development of a novel categorization for Arabian horses that is mostly based on the geographical origin of the subpopulation, for instance, Straight Egyptian, Polish Arabian, Spanish Arabian, Syrian Arabian, and Iranian Arabian. All of these Arabian horses are registered in the stud books that are officially recognized by the World Arabian Horse Organization (WAHO) **(Machmoum *et al.*, 2020).**

Equine conformation is considered an assessment of the level of correctness in a horse's skeletal structure, muscular development, and body proportions in relation to one another **(Staff, 2014; Duberstein, 2016; "ECAHO Judges Training Manual" 2023).** Modern Arabian horses have distinctive conformational traits, including high tail carriage, an arching neck, wide-set eyes, and a dish-shaped face profile **(Nagel, 2013).** Moreover, the Arabian horse is widely recognized for its exceptional heat tolerance and remarkable athletic endurance **(Ricard *et al.*, 2017; Cosgrove *et al.*, 2020).**

Head shape in domesticated horses exhibits significant variation, particularly in terms of ear shape, nasal profile, and jaw conformation **(Stock *et al.*, 2016),** while one of the most noticeable exceptions in the heads of purebred Arabian lines, such as Egyptian Arabian horses, is the dished-faced profile **(Stock *et al.*, 2016; Cosgrove *et al.*, 2020).** The head of an Arabian horse from the side should possess a triangular shape, accompanied by prominent and strong jaws that gradually narrow towards the muzzle. From a cranial

perspective, the frontal head profile of the horse has a short face and the forehead should appear broad between the eyes **(Lawrence, 2001; Sañudo Astiz, 2009; Salamanca-Carreño *et al.*, 2022).**

The head's attachment to the neck should allow for a full range of motion without restricting airflow. A clean, trim, well-defined, and highly flexible throatlatch is ideal. Short, thick neck is sometimes associated with a thick, rigid throatlatch that is unable to bend. Whereas a slight arch or crest on the neck is considered acceptable in certain breeds, an excessive crest, thick upper neck, or broken crest (lop neck) are considered undesirable as they might impede flexibility **(Lawrence, 2001).**

Beauty confirmation plays a crucial role in horse breeding operations **(McManus *et al.*, 2002). S**how competitions for Arabian horses primarily focus on the horses' attractiveness, which is determined by a number of facial characteristics of Arabian horses, which is the hallmark of the breed, including the horses' length and breadth of head, jaws, ears, eyes, and general face profile **(Klecel *et al.*, 2023).**

The European Conference of Arab Horse Organizations (ECAHO) is responsible for regulating the rules for the majority of European and Middle Eastern horse shows. When the ratings in these shows were examined, they revealed that the head and neck scores substantially affected the overall impression **(Klecel *et al.*, 2023).** Therefore, the head and neck are very important in judging Arabian horses in beauty show competitions. However, the ideal head has not been identified yet. Thus, the analysis of quantitative traits related to head morphology might provide insight into this matter.

Information about genetic parameters is population-specific, and it is essential for designing animal breeding programs and predicting response to selection **(Olasege *et al.*, 2019).** Accurate estimation of the genetic parameters is important to fulfill optimum genetic progress in any selection program (Ekiz and Koçak, 2007). Hence, the traits used in breeding programs need to be measured accurately and early in the life of the animal and associated with their breeding aim **(Holmström *et al.*, 1994; Solé *et al.*, 2014).**

It's so important to study sire effects on colts' head and neck traits with caution to avoid excessive use of certain sires in breeding programs, especially since the El Zahraa stud suffers from a high inbreeding coefficient based on microsatellite molecular markers **(Sargious *et al.*, 2021a, 2021b, 2021c).** The impact of inbreeding can be noticed as a decline in performance and useful traits, especially in the Egyptian Arabian horse breed, where the mating of closely related individuals occurs **(Molina *et al.*, 1999; Sadek *et al.*, 2006; AL-Khauzai *et al.*, 2021).** This study was carried out to investigate the sire effect on their colt's head and neck traits. In addition, to estimate genetic and phenotypic parameters for head and neck traits of the pure Arabian Egyptian colts in El Zahraa stud.

MATERIALS AND METHODS

Ten head and neck measurements were collected from 91 purebred Egyptian Arabian colts of about 1 year old, progenies of 13 sires. Both sires and colts are found and registered in the El Zahraa stud, which is one of the largest studs of registered Arabian horses in Egypt. It is a member of the World Arabian Horse Organization (WAHO). All the colts had the same quantity and quality of food with water available all day, as well as daily regular exercise.

Measurements were taken from the left side of the colts while standing with all feet on level and solid ground and restrained by a halter and rope. Moreover, measurements were taken using a tape measure that was calibrated at the National Institute of Standards (NIS) and were recorded in units of cm, which is familiar in Egypt with this system of units.

Genetic parameters estimation

The pedigreemm package in R serves as an extension of the lme4 package, enabling the fitting of mixed models with correlated random effects for Gaussian, binary, and count responses. A correlation between the amounts of the grouping component (e.g., sire).

The estimation methods provided in pedigreemm encompass approximations to maximum likelihood and restricted maximum likelihood (REML). Genotypic, phenotypic, and environmental variance, in addition to genotypic, phenotypic, and environmental coefficients of variance; heritability (broad sense); phenotypic and genotypic correlations were calculated.

Statistical analysis

One-way analysis of variance (ANOVA) and descriptive statistics were used for analysis between sires and significance at $p < 0.05$ (IBM SPSS Statistics 25).

Statistical Model

To analyse the effect of 13 sires of purebred Arabian stallions on the head and neck measurements of their 91 pure Egyptian Arabian colts, we used a Linear Mixed Model (LMM) (IBM SPSS statistics 25). This model accounts for both fixed and random effects as follows:

Mathematical Model

The model for each measurement (e.g., head or neck) is expressed as:

$$Yij=\beta 0+\gamma i+\epsilon ij$$

Yij: The head or neck measurement for foal **j** from sire **i**

β0: Fixed effect (overall mean for the measurement across all sires).

γi: Random effect for sire i, accounting for differences between sires. This is assumed to follow a normal distribution: γi∼N (0, σγ2).
ϵij: Residual error for foal j, assumed to follow a normal distribution: ϵij∼N (0, σϵ2).

Model Components

1-**Fixed Effect** (β0): Represents the overall mean measurement for all foals, regardless of sire.

2-**Random Effect** (γi): Captures the variability in measurements due to differences among sires. Each sire is treated as a random effect.

3-**Residual Error** (ϵij): Represents the variability within each sire group (differences between individual foals within a sire.

For each horse, the following 10 quantitative traits for head and neck were measured as shown in **table 1 and fig.1:**

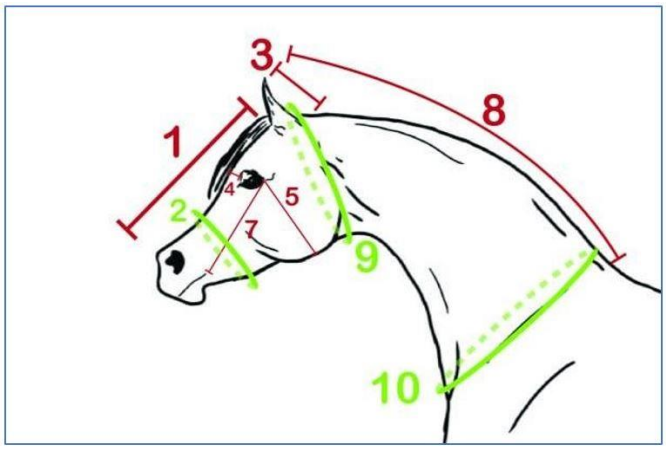

Fig.1: The quantitative traits for head and neck of horse

Table 1: The quantitative traits for head and neck of horse

Measure	Description
Head and Neck traits	
Head length	Measure from poll straight to between the top corners of the two nostrils.
Muzzle circumference	Measure the circumference of the muzzle directly in front of the cheekbones underneath the halter.
Left ear length	Measure from the base to the tip of the left ear.
Forehead length (Eye to eye width)	Measure between the inner canthus of the two eyes across the forehead while standing in front of the horse. Keep the tape taut and straight.
Jaw length (Left eye to jaw length)	Measure from the outer corner of the left eye to the highest point in the cheek curve.
Jaw width	Measure the head from underside at the widest region between 2 rami of the mandible bones. Keep the tape taut and straight.
Left eye to mouth corner length	Measure from the outer corner of the left eye to the corner of the mouth at the mouth commissure.
Neck length, head level with withers	Measure from the poll to the withers when poll and withers are at the same level.
Throat latch Circumference	Measure the circumference of the neck where the throat latch of the bridle goes, at the point where the neck is connected to the head.
Neck base circumference	Measure the circumference of the neck in front of the withers at the point where the neck is connected to the body. The tape should rest on the chest and curve comfortably around the base of the neck.

RESULTS

Table 2a: Descriptive statistics of head length, muzzle circumference and ear length of the Egyptian Arabian colts.

	Head Length	Muzzle Circumference	Ear Length	Mean of Head Muzzle Ear
Mean	46.62	49.82	15.84	37.43
Std. Error of Mean	0.26	0.29	0.17	0.15
Median	46.50	50	16	37.33
Mode	47	50	17	36.33
Std. Deviation	1.64	1.82	1.08	0.96
Variance	2.70	3.34	1.17	0.93
Skewness	0.01	0.74	-.23	0.009
Kurtosis	-0.02	1.16	-.87	-0.043
Range	7	9	4	4.33
Minimum	43	46	14	35
Maximum	50	55	18	39.33
Coefficient of variance	3.52	3.67	6.83	2.58

Table 2b: Descriptive statistics of forehead length, jaw length and width and eye to mouth corner of the Egyptian Arabian colts.

	Forehead Length	Jaw Length	Jaw Width	Mean of Forehead Jaw Width and Length	Eye to Mouth Corner	Ratio from Poll to Eye to Eye to Mouth Corner	Ratio from Poll to Eye to Head Length
Mean	16.57	20.79	9.75	15.70	25.74	0.64	0.35
Std. Error of Mean	0.12	0.13	0.20	0.10	0.16	0.007	0.002
Median	17	21	10	15.66	26	0.64	0.35
Mode	17.0	21.0	10.0	15.67	26.0	0.65	0.35
Std. Deviation	0.76	0.86	1.29	0.66	1.04	0.04	0.01
Variance	0.58	0.74	1.66	0.43	1.09	0.002	0.000
Skewness	-0.27	-0.06	0.24	0.34	-0.63	0.42	0.06
Kurtosis	-0.13	0.55	2.42	1.24	-0.06	0.04	0.09
Range	3	4	7	3.33	4	0.19	0.08
Minimum	15	19	7	14.33	23	0.56	0.31
Maximum	18	23	14	17.67	27	0.75	0.40
Coefficient of variance CV	4.61	4.15	13.24	4.21	4.05	6.88	4.88

Table 3a: The influence of genotype (sire effect) on head length, muzzle circumference and ear length of the Egyptian Arabian colts.

Genotype	Head Length	Muzzle Circumference	Ear Length	Mean of Head ,Muzzle and Ear
Sire1	45±1.15[a]	50.5±1.44[a]	14.5±0.28[a]	36.66±0.96[a]
Sire 2	49±0.32[b]	51.5±0.86[a]	15.5±0.28[a]	38.66±0.38[a]
Sire 3	46±0.57[a]	48.5±0.28[a]	16.5±0.28[a]	37±0.38[a]
Sire 4	46.33±0.66[a]	49±0.41[a]	15.66±0.88[a]	37±0.33[a]
Sire 5	46.5±0.28[a]	49.5±0.86[a]	17±0.56[a]	37.66±0.38[a]
Sire 6	45±0.43[a]	49±1.15[a]	15.5±0.86[a]	36.5±0.09[a]
Sire 7	47.33±0.88[a]	52.66±1.85[a]	15.33±0.66[a]	38.44±0.72[a]
Sire 8	45±1.15[a]	50±0.38[a]	15±0.38[a]	36.66±0.38[a]
Sire 9	46.5±0.28[a]	49.5±0.28[a]	16.5±0.28[a]	37.5±0.09[a]
Sire10	46.5±0.86[a]	50±0.57[a]	16±0.57[a]	37.5±0.28[a]
Sire11	46.5±0.28[a]	49±0.53[a]	16±0.57[a]	37.16±0.48[a]
Sire12	47±0.57[a]	50.5±0.28[a]	17±0.57[a]	38.16±0.09[a]
Sire13	49.5±0.28[b]	48±1.15[a]	15.5±0.86[a]	37.66±0.76[a]
Total	46.62±0.26	49.82±0.29[a]	15.84±0.17[a]	37.43±0.15[a]

Superscription of means with different small letters means there is a statistically significant difference within groups at $p< 0,05$.

Table 3b: The influence of genotype (sire effect) on forehead length, jaw length and width and eye to mouth corner of the Egyptian Arabian colts.

Genotype	Forehead Length	Jaw Length	Jaw Width	Mean of Forehead Jaw Width and Length	Eye to Mouth Corner	Ratio from Poll to Eye to Eye to Mouth Corner	Ratio from Poll to Eye to Head Length
Sire1	16±0.57	19±0.62	9.5±0.28	14.83±0.28	25±0.57	0.63±0.008	0.35±0.003
Sire 2	17±0.71	21±0.45	9.5±0.28	15.83±0.09	26±0.73	0.65±0.71	0.34±0.55
Sire 3	16.5±0.28	20.5±0.28	9.5±0.28	15.5±0.09	25.5±0.28	0.64±0.004	0.35±0.001
Sire 4	17.66±0.33	21±0.76	9.66±0.88	16.11±0.29	25.66±0.88	0.69±0.03	0.38±0.001
Sire 5	16±0.64	21±0.57	10.5±0.28	15.83±0.28	27±0.61	0.59±0.48	0.34±0.002
Sire 6	16.5±0.28	21±0.48	9.5±0.28	15.66±0.46	26±0.48	0.63±0.01	0.36±0.006
Sire 7	16.33±0.33	21.33±0.88	11.66±1.20	16.44±0.61	27±0.67	0.60±0.01	0.34±0.012
Sire 8	16±0.57	20.5±0.28	7.5±0.28	14.66±0.19	25.5±0.86	0.62±0.03	0.35±0.01
Sire 9	17.5±0.28	22±0.66	10.5±0.28	16.66±0.57	24.5±0.28	0.71±0.003	0.37±0.003
Sire10	15.5±0.28	20.5±0.28	10±0.75	15.33±0.61	26±0.57	0.59±0.02	0.33±0.012
Sire11	16.5±0.28	20±0.71	11±0.64	15.83±0.09	25.5±0.28	0.64±0.01	0.35±0.004
Sire12	17±0.87	21.5±0.28	10±0.39	16.16±0.09	25±1.15	0.68±0.03	0.36±0.004
Sire13	17±0.35	21±0.84	8±0.57	15.33±0.19	26±0.54	0.65±0.63	0.34±0.002
Total	16.57±0.12	20.79±0.13	9.75±0.20	15.70±0.10	25.74±0.16	0.64±0.007	0.35±0.002

Table 4: Descriptive statistics of neck traits of the Egyptian Arabian colts.

	Neck Length	Throat Lash Circumference	Neck Base Circumference	Ratio of Neck Base to Throat Lash
Mean	86.62	70.97	88.30	1.24
Std. Error of Mean	0.56	0.82	0.65	0.014
Median	86	71	89	1.24
Mode	90	65.0[a]	90.0[a]	1.11[a]
Std. Deviation	3.55	5.13	4.09	0.09
Variance	12.62	26.38	16.75	0.008
Skewness	0.53	-0.18	-0.42	0.66
Kurtosis	-0.08	-0.63	-0.86	0.55
Range	14	19	15	0.40
Minimum	81	61	80	1.11
Maximum	95	80	95	1.51
Coefficient of variance CV	4.10	7.23	4.63	7.25

Table 5: The influence of genotype (sire effect) on neck traits of the Egyptian Arabian colts.

	Neck Length	Throat Lash Circumference	Neck Base Circumference	Ratio of Neck Base to Throat Lash
Sire1	84.5±0.28[a]	66.5±0.86[a]	82.5±0.86[a]	1.24±0.02
Sire 2	83.5±0.86[a]	69±0.47[a]	91±2.30[b]	1.31±0.03
Sire 3	83±1.15[a]	70.5±0.28[a]	86±3.46[a]	1.21±0.04
Sire 4	87±3.46[b]	67.66±2.18[a]	86.33±2.33[a]	1.27±0.04
Sire 5	85.5±2.02[a]	76.5±0.86[b]	88.5±0.28[b]	1.15±0.01
Sire 6	85±0.57[a]	69±2.30[a]	90.5±0.28[b]	1.31±0.03
Sire 7	90.66±4.33[b]	75±1.73[b]	91.66±0.33[b]	1.22±0.02
Sire 8	87.5±1.44[b]	70.5±3.17[a]	89±2.30[b]	1.26±0.02
Sire 9	90±0.57[b]	79±0.57[c]	91.5±0.86[b]	1.15±0.002
Sire10	84±0.36[a]	74±0.57[b]	82.5±0.28[a]	1.11±0.004
Sire11	87.5±0.28[b]	61±0.29[a]	87.5±2.59[a]	1.43±0.04
Sire12	88±0.48[b]	74.5±2.02[b]	93±1.15[b]	1.24±0.01
Sire13	90±0.65[b]	69.5±0.86[a]	88±1.15[b]	1.26±0.00
Total	86.62±0.56[a]	70.97±0.82[a]	88.30±0.65[b]	1.24±0.01

Table 6a: Estimation of variances, coefficient of variances and heritability (broad sense) of head length, muzzle circumference and ear length of the Egyptian Arabian colts.

Traits	Environmental Variance	Genotypic Variance	Phenotypic Variance	Environmental Coefficient of Variance	Genotypic Coefficient of Variance	Phenotypic Coefficient of Variance	Heritability (Broad Sense)
Head length	1.2233	1.5096	2.7329	2.3720	2.6350	3.5454	0.5524
Muzzle circumference	2.8365	0.6538	3.4903	3.3805	1.623	3.7499	0.1873
Ear length	0.9882	0.2329	1.2211	6.2735	3.0455	6.9735	0.1907
Mean of head muzzle ear	0.695	0.2427	0.9377	2.2273	1.3161	2.587	0.2588

Table 6b: Estimation of variances, coefficient of variances and heritability (broad sense) of forehead length, jaw length and width, eye to mouth corner of the Egyptian Arabian colts.

Traits	Environmental Variance	Genotypic Variance	Phenotypic Variance	Environmental Coefficient of Variance	Genotypic Coefficient of Variance	Phenotypic Coefficient of Variance	Heritability (Broad Sense)
Forehead length	0.3152	0.2959	0.6111	3.3866	3.2815	4.7158	0.4842
Jaw length	0.2949	0.4487	0.7436	2.6113	3.2212	4.1468	0.6034
Jaw width	0.5983	1.0395	1.6378	7.9280	10.4501	13.1172	0.6347
Mean of Forehead Jaw Width and Length	0.1178	0.3003	0.4181	2.1846	3.4883	4.1160	0.7182
Eye to Mouth Corner	0.9103	0.2179	1.1282	3.7061	1.8133	4.1259	0.1931
Ratio from Poll to Eye to Eye to Mouth Corner	0.0011	0.009	0.0020	5.2353	4.6539	6.9377	0.4500
Ratio from Poll to Eye to Head Length	2e/04	1e/04	3e/04	4.1916	2.8078	4.8632	0.3333

Table 7: Phenotypic (above the diagonal) and genetic (below the diagonal) correlations of head traits of the Egyptian Arabian colts.

Genotypic Correlation	Head Length	Muzzle Circumference	Ear Length	Mean of Head Muzzle Ear	Forehead Length	Jaw Length	Jaw Width	Mean of Forehead Jaw Width and Length	Eye to Mouth Corner	Ratio From Poll to Eye to Eye to Mouth Corner	Ratio From Poll to Eye to Head Length
Head Length	1**	0.289	-0.004	0.753**	0.303	0.249	0.023	0.248	0.401*	-0.0617	-0.445**
Muzzle Circumference	-0.175	1 **	-0.188	0.736**	-0.014	-0.019	0.372*	0.232	0.106	-0.074	-0.2144
Ear Length	0.376	-0.399	1 **	0.256	0.157	0.294	0.2406	0.353*	-0.051	0.1495	0.1168
Mean of Head Muzzle Ear	0.858**	0.270	0.421	1 **	0.223	0.241	0.344*	0.425**	0.277	-0.026	-0.347 *
Forehead Length	0.461	-0.524	0.276	0.185	1 **	0.288	-0.078	0.482**	-0.222	0.786**	0.701**
Jaw Length	0.523	0.238	0.965**	0.879**	0.813**	1 **	0.236	0.718**	0.158	0.102	0.076
Jaw Width	-0.009	0.514	0.610*	0.4724	0.087	0.158	1 **	0.734**	0.074	-0.077	-0.114
Mean of Forehead Jaw Width and Length	0.3610	0.241	0.862**	0.712**	0.719**	0.777**	0.713**	1 **	0.029	0.312	0.243
Eye to Mouth Corner	0.108	0.682*	0.094	0.493	-0.645*	0.027	0.475	0.091	1 **	- 0.772**	-0.506**
Ratio From Poll to Eye to Eye to Mouth Corner	0.237	-0.617*	0.205	-0.074	0.945**	0.563*	-0.095	0.485	-0.856**	1 **	0.771**
Ratio From Poll to Eye to Head Length	-0.334	-0.325	-0.162	-0.511	0.684**	0.456	0.073	0.461	-0.690**	0.770 **	1 **

Table 8: Estimation of variances, coefficient of variances and heritability (broad sense) of Neck traits of the Egyptian Arabian colts.

Traits	Environmental Variance	Genotypic Variance	Phenotypic Variance	Environmental Coefficient of Variance	Genotypic Coefficient of Variance	Phenotypic Coefficient of Variance	Heritability (Broad Sense)
Neck length	8.7692	3.8184	12.5876	3.4184	2.2557	4.0955	0.3033
Throat lash circumference	6.9968	20.4679	27.4647	3.7269	6.3743	7.3839	0.7452
Neck base circumference	9.8024	7.8568	17.6592	3.5454	3.1741	4.7587	0.4449

Ratio of neck base to throat lash	0.0027	0.0058	0.0085	4.1432	6.0976	7.3817	0.6824

Table 9: Phenotypic (above the diagonal) and genetic (below the diagonal) correlations of neck traits of the Egyptian Arabian colts.

Genotypic Correlation	Check length	Throat lash Circumference	Neck base Circumference	Ratio of Neck base to Throat lash
Neck length	**	0.0696	0.2507	0.0979
Throat lash Circumference	0.4824	**	0.3735 *	-0.7776 **
Neck base Circumference	.8611 **	0.3787	1 **	0.2879
Ratio of Neck base to Throat lash	0.0371	0.8723 **	0.1167	1 **

DISCUSSION

1. Colts head and neck traits

As a breeding objective, conformation traits should be prioritized **(Jakubec *et al.*, 2009).** Since the configuration of the head and neck plays a crucial role in the gait of the horse **(Moore, 2010).** The shape of the head, neck and the head-neck connection facilitate unrestricted mobility and flexion, which influence the athletic performance of the horse **(Bakhtiari and Heshmat, 2009).**

Head length is a crucial feature in identifying the breed traits that define horses. The head is essential for the horse's movement, as it plays an essential role in balance and motion. Although the head of the Arabian horse is regarded to be small and delicate, a longer neck is considered a compensatory characteristic for the small heads; in addition, a good muscular neck is considered essential for regulating the shoulder, arm, and thoracic limb muscles; hence it enhances the horse's agility **(Denoix, 2014; Farinelli de Siqueira, 2024).** The present study showed that the mean of head length in **Table 2a** from poll to upper corner of nostril is 46.628 cm, and the mean of neck length in **Table 4,** where poll and withers are at the same level, is 86.628 cm.

The results of the present study align with the linear measurement data obtained from previous studies, as a study that was performed on 168 adult purebred Arabian horses on a farm in the Brazilian state of São Paulo, the mean of head and neck length were 61.13 cm and 82.36 cm, respectively **(Farinelli de Siqueira, 2024).** Moreover, another study showed the mean of head length of Arabian horses is 64.10 cm and the mean of neck length is 75.58 cm **(Gharahveysi *et al.*, 2008),** but the study did not specify their age. Also, a study was conducted on Spanish Arabian horses; the mean of their neck length is 69.47 cm **(Cervantes *et al.*, 2009).** In addition, stallions of Western American breeds showed that the mean head length is 52.6 cm and the mean neck length is 81.46 cm **(Petlachová *et al.*, 2013).** Furthermore, a study was done on 95 Arabian thoroughbred horses that were born and raised in Algeria; the mean of the head length in horses that age starting from 3 years was 50.59 cm, and the mean of neck length was 67.09 cm **(Benia *et al.*, 2022).**

The present study investigation revealed the mean of the forehead length in **Table 2b** is 16.57 cm in accordance with a previous study that measured head traits of the 1-year-old colt. In the Žemaitukai breed, it was found that the average head length was 49.9 cm and forehead width was 21.7 cm **(Macijauskiene and Juras, 2003).**

In the present study, **Table 4** presents a throat lash circumference with a mean of 70.97 cm and a neck base circumference with a mean of 88.3 cm. Where a previous study that studied head and neck traits of 4 to 7-year-old Pura Raza Espanol horses revealed that the mean head length is 61.30 cm, the circumference at the junction of the neck and head is 89.81 cm, and the circumference at the junction of the neck and body is 146.35 cm **(José Sánchez *et al.*, 2013).** This may be attributable to variations in breed and age, as this study focused on Arabian yearling colts.

Following previous studies, a study was conducted to evaluate the body composition of 6–16-year-old stallions, revealing that the shortest head length recorded was 50.1 cm for the Lipizzaner (LH), which is comparable to our study's measurement of 46.6 cm presented in **Table 2a**. Additionally, the American Paint Horse (APH) exhibited the smallest jaw width at 10.8 cm, closely aligning with our study's mean jaw width of 9.75 cm, as shown in **Table 2b**. Furthermore, the American Quarter Horse (AQH) neck length mean is

86.2 cm, whereas our study indicates a mean neck length of 86.6 cm, which is similar to this study's mean neck length of 86.6 cm, as detailed in **Table 4 (Petlachová *et al.*, 2013).**

The results of the throat lash circumference in **Table 4,** which is 70.9 cm, follow another study where the throat lash circumference of 12-36-month Arabian Saklawi colts in Al-Diwaniyeh is 70.2 cm **(Munahi, 2016).** The results of the previous study on purebred Arabian horses in the Brazilian state average head and neck lengths were 61.13 cm and 82.36 cm, respectively **(Farinelli de Siqueira, 2024).** In addition to another study on the Egyptian Arabian purebred horses, the average neck girth was 104.6 cm **(Sadek, 2006).** Furthermore, the mean neck length of the purebred Arabian horses in 3 Polish horse farms was 78.2 cm **(Sobczuk and Komosa, 2012).**

The variations of the values between different studies and the present study might be due to the differences in the ages and breeds, as this study was performed only on yearling purebred Egyptian Arabian colts, as well as neck length maybe due to the difference in measuring method. Future research should extend to longitudinal studies tracking trait development beyond the yearling stage, examining environmental influences on trait expression and performance. The coefficients of variation obtained were moderate to low, all below 10%. Comparable outcomes were observed in the same breed as well as in other selected breeds. Consequently, the examined sample is adequately homogeneous for these traits **(José Sánchez *et al.*, 2013).**

2. Influence of Sire on Offspring's head and neck traits

The measurement of horses is the most objective and precise approach for evaluating them. Utilizing measures facilitates the selection of parental pairs for breeding desired offspring and upholding breed standards **(Petlachová *et al.*, 2013).** It's important to study sire effect on foals, and our concerns are related more to stallions because one stallion is used in breeding to give more than one foal in the year. Specifically, head-neck conformation significantly influences health, indicating that horses should not possess excessive weight in the forepart **(CavvySavvy and Wood, 2020).**

The facial features of Arabian horses are crucial to the breed, such that assessments in show competitions entail evaluating the head's length and width, jaws, ears, eyes, and overall facial profile **(Klecel *et al.*, 2023; Alhaddad *et al.*, 2024).** The head and the neck are the first things that catch the eye.

As illustrated in **Table 3a,** the influence of sire genotype on offspring head length, with the shortest measurements recorded at sires 1, 6, and 8 at 45 cm and the longest at sire 13 at 49.5 cm. Hence, breeders and experts in the field may favour horses with shorter heads in order to obtain an optimal head-to-neck ratio. This results in the forelimbs being less heavy, so the animal's balance, cephalocervical equalizer movement, and walking are all improved **(Santiago *et al.*, 2016).** In addition, the Arabian horse head is always more favorable than other breeds, for it's a relatively small and refined, dished head with a clearly defined bone structure **(ECAHO Judges Training Manual" 2023).** Head length is important for balance, as if the neck is used as a lever, the length of the head counteracts **(José Sánchez *et al.*, 2013).** Therefore, it is preferable to use sires 1, 6, and 8 to further develop this trait.

The smallest muzzle circumference was 48 cm for sire 13, while the highest was 52.6 cm for sire 7, as shown in **Table 3a**. The head shape, when observed from the side, should possess a triangular shape, accompanied by prominent and strong jaws that gradually narrow towards the muzzle **(Forbis, 1976; Lawrence, 2001; "ECAHO Judges Training Manual - ECAHO," 2018).** Therefore, it is preferable to utilize sire 13 for this trait but without affecting air intake. As a short head with a small muzzle and large nostrils results in a horse with no issues in pulling in the air, an extremely dished face is one of the undesirable features, as it may affect air intake and result in misalignment of the teeth **(Mercedes, 2013; "ECAHO Judges Training Manual" 2023).** Moreover, the shortest ear length, as shown in **Table 3a,** was recorded for sire 1 at 14.5 cm, while the longest was observed for sires 5 and 12 at 17 cm. According **to AHA and ECAHO**, it is always desirable to have a short, small ear as sire 1 **(ECAHO Judges Training Manual" 2023).**

The forehead length was widest, as shown in **Table 3b,** in sire 4, which was 17.6 cm, and narrowest in sire 10, which was 15.5 cm. This width is crucial for providing a room for the brain, sinuses, tear ducts, and respiratory passages beneath the skull, while also ensuring aesthetic attractiveness **(Duberstein, 2016).** The wider the forehead length, the better, according to AHA **(Upton, 2007; "ECAHO Judges Training Manual - ECAHO," 2018).** Thus, using sire 4 is preferable for breeding.

Jaw length was longest, as shown in **Table 3b,** in sire 9, which was 22 cm, and shortest in sire 1, which was 19 cm; it is preferable to use sire 9 for this trait. While jaw width was the widest, as shown in **Table 3b,** in sire 7, which was 11.6 cm, and the narrowest in sire 8, which was 7.5 cm, it's better to use sire 7 for this trait. Furthermore, the eye-to-mouth corner was longest, as shown in **Table 3b,** in sires 5 and 7, which were 27 cm, and shortest in sire 9, which was 24.5 cm; it's preferable to use sires 5 and 7.

According to ECAHO, a desirable feature is that the jaw must be straight and align smoothly with a well-defined chin groove, with sufficient space between the branches at the throat to facilitate the unobstructed

passage of food and air, in addition to the lateral face profile, which should exhibit a wedge shape with a reasonably concave profile, which gives a longer length from eye to mouth corner **("ECAHO Judges Training Manual" 2023).** In accordance, the horse should possess sufficient breadth for airflow, allowing for the insertion of four knuckles of your fist between the jawbones **(Thomas, 2005).**

When it comes to neck traits, our study showed that in **Table 5,** the neck length was longest for sire 7, which was 90.6 cm, and shortest for sire 3, which was 83 cm; it's always preferred to have a long neck like sire 7. As the longer neck is considered a compensatory trait rather than a conformational fault in horses with smaller heads. The muscular neck musculature is crucial for controlling the shoulder, arm, and forelimb muscles, hence enhancing the horse's speed **(Denoix, 2014; "The Classic Arab Horse by Peter Upton," 1992).** Moreover, the neckline of the racehorse must be long enough to play its role of balancing correctly, especially at a gallop, without overloading the front hand **(Benia *et al.*, 2022).** Neck length should be the same length as the front legs, one-third of the horse's total length, and one and a half times the length of the head **(Thomas, 2005).**

The smallest throat lash circumference was for sire 11, as shown in **Table 5,** which was 61 cm, while the largest throat lash circumference was for sire 9, which was 79 cm, so it's better to use sire 11. As it should be sharply defined, free from excess fat or muscle that could restrict the range of motion at the poll, but lengthened to provide space for the windpipe when the head is pulled toward the chest **(Thomas, 2005).** In addition, the throat latch should be clean, trim, well-defined, and capable of great flexion **(Lawrence, 2001).**

Neck base circumference in **Table 5,** the smallest neck base circumference was for sire 1 and 10, which was 82.5 cm, and the largest for sire 12, which was 93 cm. The positioning of the neck in relation to the shoulder is crucial for achieving proper balance; the base of the horse's neck should align with the shoulder point. The neck should connect relatively high on the chest to facilitate adequate flexibility **(Thomas, 2005).** Moreover, the proper head and neck positioning, as well as neck-body integration, are more critical than neck length for dressage proficiency **(Halo *et al.*, 2008).**

Proper head, neck, and body conformation in horses is considered important for good health; the genetic correlation between health and conformation can reach up to 0.75 **(Jönsson *et al.*, 2014).**

3. Genetic parameters

The genetic parameters for head and neck traits of the Egyptian Arabian colts have not been very well studied, and there is little information about these traits. However, traits such as withers height, heart girth, chest width, and cannon circumference are extensively researched. Conversely, there is scant evidence regarding many features, like head length, shoulder length, and cannon height **(Bakhtiari and Heshmat, 2009).** Further, heritability estimates for conformation traits in most of the breeds are moderate to high **(Jönsson *et al.*, 2014).**

The heritability estimates ranged from low, which is less than 0.2, or moderate, more than 0.2 to less than 0.4, to high, which is over 0.4 for body measurements. The current study showed that the estimates of heritability for head traits ranged from 0.18 to 0.63, where the highest heritability estimate was for jaw width, as shown in **Table 6b,** which was 0.63, and the lowest heritability was for muzzle circumference, as shown in **Table 6a,** which was 0.18. While for the neck traits, the study ranged from 0.3 to 0.74, the highest heritability estimate was for throat lash circumference, as shown in **Table 8** which was 0.74, and the lowest heritability was for neck length, as shown in **Table 8** which was 0.3. Our results are in agreement with **Sadek (2006)** who showed that the heritability of neck girth is 0.35, which agrees with our results shown in **Table 8** as the neck base circumference is 0.44, which is considered high heritability as mentioned by **Sadek (2006).**

In addition, the heritability estimation for the head profile of Old Kladrub' horses were 0.675 according to **Jakubec *et al.*, (2009)** and it was the highest in heritability estimation in his research, which agrees with our results in **Table 6a,** which displayed that the heritability of head length was 0.55, which is also high heritability. Also, it has been reported that in thoroughbred horses, the heritability of head length is 0.44 **(Oki, 1989),** while the heritability estimation for neck length was 0.11, as reported by **Jakubec *et al.*, (2009)** and in our results in **Table 8** was 0.30. Furthermore, **Ghavi Hossein-Zadeh (2021)** mentioned in his study that the heritability for the head is 0.445, head length is 0.30, and that for neck length is 0.14, which agrees with our results; the heritability for the head is high. Moreover, the estimated heritability for all morphometric traits evaluated in Mangalarga Marchador horses ranged from moderate to high magnitude, where the heritability of neck length is 0.40 (0.38; 0.43), as mentioned by **Maruch *et al.*, (2021).** It has also been reported that the heritability for head in Pura Raza Menorquina horses is 0.58, head length is 0.44, while the neck length is 0.37, as well as the upper neck line is 0.28 **(Perdomo-González *et al.*, 2022).**

Genetic parameters, including heritability, are affected by gene frequency, estimation methodology, statistical model, and the characteristics of the trait. Due to possible variations in the factors included in each study, the minor differences in values between the

current study and prior research may be ascribed to such differences. The medium to high estimated heritability for the traits in this study suggests that genetic enhancement could be achieved for these traits. This enables us to predict the potential for significant genetic advancement via the breeding program **(Perdomo-González *et al.*, 2022).**

The additive genetic correlation is a crucial factor in the genetic enhancement of animals **(Bijma and Bastiaansen, 2014).** Our results showed that there was a positive genetic correlation between muzzle circumference and eye to mouth corner with 0.68, as shown in **Table 7.** In addition, there was a positive genetic correlation between ear length with jaw length and width of 0.96 and 0.61, respectively. Also, a positive genetic correlation was found between forehead length and jaw length of 0.81, while it was a negative genetic correlation with eye to mouth corner -0.64. It has been shown that there was a positive phenotypic correlation between head length and eye-to-mouth corner with 0.40. In addition, there was a positive phenotypic correlation between muzzle circumference and jaw width with 0.37, as shown in Table **7.**

For neck traits, there was a strong positive genetic correlation between neck length and neck base circumference of 0.86, as shown in **Table 9.** Furthermore, there was a positive phenotypic correlation between throat lash circumference and neck base circumference with 0.37, as shown in **Table 9.**

CONCLUSION

These findings may provide guidance for the Arabian horse breeding programs through the identification of specific sires with desirable trait expressions and provide clear guidance for selective breeding. In addition, heritability estimates enable more precise prediction of breeding outcomes and genetic correlations, which facilitate efficient multi-trait selection strategies. This comprehensive approach will further enhance understanding of the Arabian horse genetics and improve breeding program outcomes.

Consent for publication

All authors read and approved the manuscript.

Availability of data and materials

The data that support the findings in our study is available from the corresponding author upon reasonable request.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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