THE GENETIC HISTORY OF THE ARABIAN HORSE

IN AMERICA

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INTRODUCTION

Historical

The immediate ancestry of the horse as well as his domestication is still a matter of dispute. Horses of the world can be geographically divided into:

1. Equus Caballus Frigidus
2. Equus Arabicus

The first is cold blooded and belongs to the North and Northwestern countries. It is characterized by strong, slow moving action, convex nose, and thick skin. The second is the hot blooded horse which belongs to the South and East and is characterized by concave head, speed, and quality.

The Arabian horse is probably the world's oldest hot blooded stock. Much credit has been given to it by historians as being the tap root or the fountain of all light horse breeds existing in the world. The origin of the Arabian horse has been argued over by scientists and historians who devoted much of their time to the study of the Arab. It is very difficult, however, to get authentic information regarding how and where the Arabian horse originated. Archaeological findings have always been studied by the Arabian horse enthusiasts with the hope that they might throw more light on its origin.

While some scientists and historians claim that the Arabian horse has existed in the same conformation as to-day for the past 25,000 to

40,000 years, others believe that there were no typical Arabian horses in Arabia before Mohammed's time. Some authors used to claim the support of the Bible and Egyptian records for their statements about the origin of the Arab, but others claimed their unreliability.

According to Osborn, in the Grotto of Combarelles in Southern France are represented hundreds of small horses of the Arabian type intermingled with outlines of those of coarser blood and heritage, which we now call either the Nordic type or the Steppe type. In these outlines the striking characteristics of the Arabian are plainly discernible. Professor Osborn is inclined to believe that in Southeastern Eurasia, somewhere between the Nile and the Indus, is the original desert home of the prehistoric Arabian.

Professor William Ridgeway was inclined to trace the Arabian back to the desert regions of Arabia, the traditional home of the Arab.

Those that abstracted the information about the Arabian horse from the Bible and the old Egyptian records and believed in its validity mention that the Prophet Job, himself a Bedouin who lived about forty centuries ago meant the Arabian horse when he said "He paweth in the valley and rejoiceth in his strength; he goeth on to meet the armed men. He mocked at fear, and is not affrighted; neither turneth he back from the sword."

The first Egyptian records of the horse are very ancient. A wall painting showing an Egyptian hunter was drawn about 1400 B.C. The horse has a good many of the original, desirable characteristics of the Arabian such as the dished face, the large eye, the sensitive muzzle, the long swan neck, the well rounded rump, and the cocked tail, all of which are still highly esteemed in the Arabian horse.

Before the rise of Mohammedanism the famous Arabian poets, Imro-olkais, Amr Ibn Abi Rabeah, and Antara wrote their masterpieces of Arabic verse. In these they described many of the characteristics, colors, and habits of the Arabian horse. From their description one can tell that they were writing of the horse of the desert.

The Bedouins of Arabia had the Arabian horse, loved it, and it played an extremely important role in their lives.

The Arabian horse is the oldest species of the genus Equus domesticated and bred up by man. The best breeds now existing owe their valuable qualities to it.

The Arabian horse can be described shortly by the words of U. S. D. A. Bulletin as follows:

"A typical Arabian horse has a wedge-shaped head; small nose; dish face; wide, deep jaws; eyes set low, wide apart, and near the middle of the head, a relatively large brain capacity; one less lumbar vertebra than most other horses, giving a short, weight-carrying back; one or two fewer vertebrae in the tail, which is set up on a high croup and gaily carried; ribs sprung wide and deep; large knee, hock, tendon, and hoof; dense bone; small stomach capacity, with small feed requirements and the ability to assimilate rough feed; and a marked prepotency in the stud."

Generally the Arabian horse in action shows only the walk, trot, and canter. The usual height is from 14 to 15:1 hands and the weight from 850 to 1,100 pounds. Bay, grey, and chestnut are the predominating colors with an occasional white or black. White marks on the head and legs are common, but pure-bred Arabians are never piebald or spotted, notwithstanding an erroneous impression created by circus horses that are commonly called Arabians.

The History of the Arabian Horse in America

The Arabian horse had a strong influence on the Spanish horse. Many Arabian horses were brought to North Africa and then to Spain by the Arabian conquerors. It is believed that when the Spaniards came to America there were no horses on the continent. Antonio De Herrera (1824) described the journey of Ogeda (one of Columbus' men) into the country of Caunabo and mentioned that, "The natives were amazed to see him and his attendants on horseback, believing the man and horse to be one animal." Americos Vespucius (1497) discussed the situation of animals in America at the time of his first voyage saying, "They have no lions, bears, deer, swine or goats, neither have they any horses . . . , etc."

Apparently, the Spaniards' horses had much Arabian blood which is considered now to be the origin of the present-day American Mustang.

It is recorded that Arabians were imported to America before the revolution. One of the earliest horses of Arab breeding was Lord Lonsdale's Monkey which was imported in 1747 by Nathaniel Harrison of Brandon, Va. A desert bred horse called Ranger was imported to Connecticut then taken to Virginia where he took the name "Lindsey Arabian." President Washington's chestnut "Magnolio" was his son.

The first ten volumes of the American Stud Book reported the importation of 45 Arabian stallions and 21 Arabian mares of pure blood between 1760 and 1906 to the United States and American Colonies. Colonel Swan of Massachusetts imported "Day of Algiers" in 1798. J. C. Morgan of Philadelphia imported two Arabians in 1816. In 1820, "Selladin" was imported from Tripoli. President Jefferson received a gift of Arabian stallions and mares which he sold and turned the money over to the United States treasury. "Baghdad" in some references and "Scham" in others, was imported from France in 1824 by a company of Nashville men. Another Arabian called "Croucher" was imported into Virginia in 1825. Kochlani, Stamboul, Yemen, Zilcaadi were imported in 1831 by Mr. Rhind, U. S. Minister to Constantinople. These horses had some influence in producing fast race horses and also as producers of Tennessee Walkers. Cardoza and Lady Mary were imported in 1832, but records did not mention the name of importers. In 1838 a large consignment of both stallions and mares was brought to the United States by Commodore J. D. Elliot of the United States Navy.

About 1855, A. Keene Richard of Kentucky made two trips to the desert, his first in 1851-53 and the second in 1855-56. He was the first citizen of the United States to go to the desert, personally select and import Arabians direct to his native country. He made himself acquainted with the modern importations by going to England, France, and Spain and examining the best Arabs these governments had, then went to Morocco, Algeria, Tunis, Egypt through to the Arabian desert where he selected two stallions, Mokhladi and Massaoud, and a grey mare. On his second trip he imported Sacklowie, Hamdan, and Fysaul. Keene Richard horses were lost during the Civil War, but they are believed to be the origin of the American saddle horse. "Calif" of Cairo was given as a present to the U. S. Consul for Egypt by Abbas Fasha and was imported to America in 1860.

In 1879, General Grant brought to America two famous stallions, Leopard and Linden Tree, which were presented to him by the Sultan Abdel Hameed of Turkey. Randolph Huntington of Oyster Bay, L. I. imported Naomi and Maidan. In 1893 a company of men called "Hamidie Society" brought several stallions and mares from near Damascus and exhibited them at the World Columbian Exposition at Chicago. Most of these horses later were lost in a fire.

In 1906 Homer Davenport imported 10 mares and 17 stallions. W. R. Brown, Albert Harris, Roger Selby, W. K. Kellogg, J. M. Dickinson, L. W. VanVleet, Henry B. Babson and some other interested breeders made importations from different countries.

In 1908, the first Arabian National Stud book was published by "The Arabian Horse Club of America which was formed for investigating, ascertaining and keeping a record of the pedigree of Arabian horses. To-day, there are hundreds of Arabian horse breeders in all parts of the country. The Arab has found its place on the big ranches of the west as a stock horse, in the hunting fields as a pleasure horse, and on the bridle paths and roads of the cities and towns everywhere.

LITERATURE

Several studies of the genetic history of livestock breeds have been carried out using the "approximate method" developed by Wright (1925).

Dickinson and Lush (1933) studied the inbreeding and genetic history of the Rambouillet sheep in America, and found that the inbreeding coefficient rose to 5.5% in the 34 years ending 1926. The average coefficient of relationship between random animals born in 1926 was 2.6%. They stated that no one ancestor has ever had a very dominant influence on the breed. The maximum relationship found between one animal and the breed was 14.4%. No other animal exceeded 8.7% and few exceeded 6.07%.

Lush, Holbert and Willham (1936) studied the genetic history of the Holstein-Freisian cattle in the United States. Two hundred pedigrees of bulls and 200 pedigrees of cows were chosen systematically from each of Volumes 7, 18, 29, 43, and 64 of the herd book of the Holstein-Freisian Association of America. The modal birth dates of each sample of 400 were 1889, 1899, 1909, 1919 and 1928. They found that the coefficient of inbreeding had risen to a little over 4.0% in the ten generations from 1881 to 1928 or 1931. In the same period the average inter se relationship rose to 3.4%, and there was a faint tendency for the breed to form into separate families but this family separation was not carried far. Their interpretation to this was that the more popular families were soon used for outcrossing on the others and the less popular ones were discarded entirely or were outcrossed with sires from other families. Discussing the influence of certain individuals, they showed that one cow, De Kol 2nd, exerted more influence on the breed than any other individual and that she furnished about one-tenth of the genes of the breed. Her highest total relationship to the breed was 12.2% in 1928. As a result of comparing the breeding of outstanding show specimens to the breed, it was found that the winners did not differ much from the breed average in their inbreeding or in their relationship to certain remote ancestors.

Yoder and Lush (1937) stated that no one animal ever dominated the whole Brown Swiss breed in the United States. Systematic samples of 400 pedigrees to represent the whole breed at different dates were selected from the herd book. The highest relationship coefficients found between individual animals and whole groups were in the show group where sires had values of 14.9 per cent and 14.2 per cent and cows were as high as 13.5% and 9.5%. The highest relationship coefficients between single animals and the general breed samples were 9.2% for William Tell in 1909 and 9.1% for College Boy in 1929. The coefficients of inbreeding were 5.0 ± 0.7 in 1909 sample, 4.0 ± 0.6 for 1919, 3.8 ± 0.6 for 1929 and 4.7 ± 0.8 for the sample taken from show winners. The inbreeding found was equivalent to a loss of about one-half of one per cent of the existing heterozygosis per generation. There were some indications of family formation, which however, rarely went far.

It was found that the show group was composed of relatively unrelated animals and did not show any tendency to be a distinct family within the breed. The early history of the breed in the United States indicated high heterogeneity because the groups were rather isolated.. This decreased when the breeders began to exchange breeding stock over a broader area.

Willham (1937), using specimens of 250 bulls and 250 cows found that the inbreeding coefficient for the Hereford breed in the United States rose to 8.1% $\pm$ 0.8 from 1860 to 1930. The inter se relationship in the breed was 8.8% $\pm$ 1.2 in 1930. He states that this would have resulted in an inbreeding coefficient of about 4.6 if random mating had been practiced in the group. The fact that the actual inbreeding coefficient was higher than this, indicated a tendency toward the formation of separate families. It was stated that nearly all of the animals which had unusually high relationships to the breed at the various periods were either the ancestors, descendents, or mates of Anxiety 4th. The breed was 18.5% related to Anxiety 4th in 1930. One of Anxiety 4th's grandons (Beau Brummel) had the highest relationship to the breed of any of the animals in the study. He was 24.6% related to the breed in 1930. The show winners and Register of Merit animals had higher coeffieients of inbreeding and inter se relationship than the contemporary random samples.

Lush and Anderson (1939) found that the average rate of inbreeding in the Poland China breed of swine from 1886 to 1929 was enough to lose about 0.6% of the existing heterozygosis per generation and that samples of the breed from 1900 to 1929 indicate little change in the average inbreeding rate. They stated that there was only a faint tendency for distinct families to be formed and kept free from interbreeding with each other. Ten foundation animals contributed 45% of the genes of the breed in 1929, 46% in 1920 and 30% in 1910. More than half of this came through three of them. It has been found that the principal plan of breeding seemed to have been selection and extensive use of the sons and daughters and granddaughters of the currently most famous sires and dams in the breed.

Carter (1940) made a study of the genetic history of the Hampshire sheep in America and found that the inbreeding which occurred in this breed since it was brought to the United States was 1.4% in 1925 and 2.9% in 1935 and that about 0.7 to 0.9% of the existing heterozygosis was lost per generation during the period studied. The inter se relationship found was zero in 1925 and 0.5 per cent in 1935. Only two animals had a relationship to the breed of more than 2%.

Stonaker (1943), used this method in studying the genetic history of the Aberdeen-Angus breed of cattle, and found that the average inbreeding percentage of samples of the breed in 1900, 1910, 1920, 1930 and 1939 were 8.9, 12.7, 10.8, 14.2 and 11.3 per cent. Inter se relationships in each of the five samples were 9.4, 16.3, 12.2, 6.1 and 13.3 per cent. The inbreeding expected from the inter se relationship was only about 62% of that actually found. About 10% of the average 0.3% rise in inbreeding per generation appeared to be the result of partial isolation between herds on account of distance. They found that Black Prince of Tellyfour was 24.1% related to the breed which is practically equivalent to his having been a grandsire of the whole breed. Over 60% of the genes in the breed were found to probably have come through foundation animals bred in only five herds.

ANALYSIS OF PEDIGREES

Coefficient of Inbreeding

Inbreeding increases the probability of receiving duplicate genes from the sire and dam. A measure of inbreeding is one which shows how much decrease in heterozygosis is to be expected from different kinds of mating.

Wright (1925) devised a coefficient for inbreeding which starts at zero for random mating and increases toward 100 per cent as the proportion of heterozygosis goes toward zero. The formula for the inbreeding coefficient is:

$$F_X = \Sigma\left[\left(\tfrac{1}{2}\right)^{n+n'} (1+F_a)\right]$$

Wright explains this formula in the following: "In this formula F_X is the required coefficient, and F_a is the similar coefficient for any common ancestor that makes the closest connecting link between a line of ancestry tracing back from the sire and one tracing back from the dam. The generations from sire and dam to such a common ancestor are designated n and n' respectively. The contribution of a particular tie between the pedigrees of sire and dam is $\tfrac{1}{2}^{n+n'+1}(1+F_a)$. There is a factor $\tfrac{1}{2}$ for every generation in the tie between the germ cells which unite to form the individual, reckoning the germ cells as each half a generation from sire and dam. The factor $(1+F_a)$ measures the effect of prepotency of a common ancestor that is himself inbred. The total coefficient is simply the sum of all such contributions.

"It is to be noted that the same animal may form the tie between many different pairs of ancestral lines of the sire and dam." Wright points out that this coefficient is not absolute, but a relative measure of the homozygosity of an animal.

Method:

Wright (1925) found that it is practically impossible to work out the average inbreeding coefficient for a breed by applying this formula, and therefore he devised a simple method, the results of which can be brought as close as desired to the complete method.

This method he has called "the approximate method." It rests on the tabulation of random samples of the pedigrees of the sire and dam. It is necessary that the sample lines be chosen wholly at random. It is well known that, in live stock breeding, common ancestors are more likely to be males. Thus straight male or straight female lines cannot give a fair basis for calculating the number of ties between two pedigrees. A truly random line of ancestry can be obtained by letting the sequence of sires and dams which is to be traced back in the herdbook be that of the heads and tails, respectively, in a coin tossing experiment. The sequence for each new line is begun when the last leaves off.

The simplest possible sample which can show a connection between sire and dam is obtained by tracing back two ancestral lines, one on the sire's side and one on the dam's side.

Table 1 shows a full pedigree of the Arabian stallion "Sarjon" and table 2 shows the two column sample picked from the full pedigree

TABLE 1

A complete pedigree of the stallion SARJON 3861

SARJON 3861	SANAD 761	HANAD 489	DEYR 33	d.b.	-
					-
				d.b.	-
					-
			SANKIRAH 149	HAMRAH 28	d.b.
					URFAH 40
				MOLIAH 109	HAMRAH 28
					WADUDDA 30
		SABA 437	DEYR 33	d.b.	-
					-
				d.b.	-
					-
			HAFFIA 45	d.b.	-
					-
				d.b.	-
					-
	SHABRRA 1929	YBARRA 1096	ASIL 785	NAZEROUX 640	KILHAM 408
					HAYAH 385
				HEJAS 101	DEYR 33
					ABEYAH 39
			DOWHANA 858	HANAD 489	DEYR 33
					SANKIRAH 149
				DOMOW 267	ABUZEYD 82
					WADUDDA 30
		SHANTAH 1330	SAOUD 687	d.b.	-
					-
				d.b.	-
					-
			SHERAH 792	HAMRAH 28	d.b.
					URFAH 40
				SHERIA 110	ABBEIAN III
					URFAH 40

according to random sequences of S (sire) and D (dam). After recording the sire (Sanad) and the dam (Shabrra), the line of ancestry was traced back in the herd book, the sire being looked up where S occurs in the column and the dam for each D.

TABLE 2

A two line pedigree sample of the Arabian Stallion Sarjon (3861).

SARJON

Sanad	Shabrra
S - Hanad	D - Shantah
D - Sankirah	D - Sherah
S - Hamrah	S - Hamrah
D - Urfah	

It is clear that a single sample of that kind has practically no value in indicating the inbreeding of the individual. But when the average of a large number of such samples is taken, there will be no appreciable difference from the true value.

Wright and McPhee (1925) made a number of tests of the reliability of the approximate method of inbreeding coefficients and found that the approximate method gives sufficiently accurate measure. They found that the average coefficient of inbreeding of 64 Bates Duchesses, calculated from the complete pedigrees, was 40.9%. The random method gave 42.2% with a probable error of 1.1 per cent.

The two column samples of this kind fall at once into two alternative categories; those which show an ancestral connection, and those which do not. In the latter case the coefficient is zero as far as the sample indicates. In the former case a contribution of $(\frac{1}{2})^{n+n'+1}(1+F_a)$ is indicated if the common ancestor A is n generations back of the sire and n' back of the dam. The sire has 2^n ancestors in the $n^{\underline{th}}$ generation and the dam $2^{n'}$ in the $n'^{\underline{th}}$ generation. This sample pair of lines is thus only one among $2^{n+n'}$ possible pairs going back as far as the common ancestor. If the single pair of lines is a fair sample of the total, its contribution must be multiplied by $2^{n+n'}$ to obtain an estimate of the inbreeding of the whole pedigree. On carrying out this multiplication, n and n' disappear and the coefficient takes the simple form $\frac{1}{2}(1+F_a)$. Thus in calculating the inbreeding indicated by a two-column pedigree, it is not necessary to count the generations to the closest common ancestor, it is merely necessary to note whether there is a tie and what animal is responsible for it.

The coefficient merely takes the values 50% and zero under the two alternatives when we neglect the effect of inbred common ancestry. Such a determination means practically nothing as far as the individual is concerned. But by determining the proportion of such ties in a sufficiently large random sample of a family or breed a measure of the average degree of inbreeding of that family or breed can be obtained to as high a degree of accuracy as desired. Samples were taken at ten years intervals starting with 1907 and extending to 1946. No information of much value could be gained by taking samples from the animals before 1907 because the majority of them were either imported from the desert of Arabia with unknown pedigrees or had one or two generations only. The animals in the samples were chosen by picking at random sufficient males and females from each page of the supplement No. 1 to volume 5 of the Arabian stud book published by The Arabian Horse Club of America back to volume 5 itself so that enough animals were included to make a sample size of 100 males and 100 females for each of the four periods. The animal's name, breeder, or owner was not considered.

Two line pedigrees were traced at random for every animal in each of the samples, according to the methods described by Wright. The inbreeding and relationship coefficients from these pedigrees were calculated by use of the International Business Machines cards as described by Brandt and Marjorie McCrabb. One card is punched for each ancestor on the pedigree. A sample section of the tabulator tape is shown in figure 1.

In the first column appear the registration number of the ancestor, in the second the sex of the ancestor (0 stands for a female and 1 for a male); in the third, the family or line, that is, whether an ancestor of the sire or dam; (0 for dam and 1 for sire); in the fourth the sex of the subject (0 for female and 1 for male); in the fifth the registration number of the subject.

After the cards were all punched they were sorted first on subject then on ancestor and then listed.

Fig. 1

A sample section of the tabulator tape of International Business Machines showing two ties.

D	45	0	1	0	385	
D	45	0	1	1	422	
D	45	0	0	1	436	
D	45	0	0	0	437	
D	45	0	1	1	445	
D	45	0	0	1	445	
D	45	0	1	1	447	
D	45	0	1	1	449	
D	45	0	0	0	490	
D	45	0	1	1	505	
D	45	0	0	1	505	
D	45	0	1	1	553	12
D	48	1	1	0	366	
D	48	1	1	0	484	
D	48	1	0	0	516	
D	48	1	1	1	531	4
	49	1	1	0	366	
	49	1	1	0	481	
	49	1	1	0	484	
	49	1	1	0	512	
	49	1	0	1	514	
	49	1	0	0	516	
	49	1	0	0	576	7
	50	1	1	1	388	1
	51	0	0	0	342	
	51	0	0	1	406	2
	54	0	0	0	486	1
	57	0	0	0	318	1
	61	1	1	1	274	

Results

In calculating the average percentage of inbreeding for the breed, the animals which appear on both sides of a pedigree (and which therefore form a tie) were easily found from the tabulator tape. Thus in figure 1 ancestor No. 455 appears twice in the pedigree of subject No. 45, one in each line as shown by the 1 and 0 in the third column.

Four ties were found in the period 1907-1916, 8 ties for 1917-1926, 7 ties for 1927-1936 and 19 ties for 1937-1946.

The formula for calculating coefficient of inbreeding for each period is:

$$F_p = \frac{\text{No. of ties} \times 0.50\ (1+F_a)}{\text{No. of Pedigrees}}$$

F_p = Coefficient of inbreeding for each period

The average coefficient of inbreeding for the first period was calculated as follows:

$$F_x = \frac{4x.50}{200} = \frac{2}{200} = .01 \text{ or } 1.0\%$$

No animals among those which caused ties were inbred and therefore $F_a = 0$.

As there were no animals responsible for more than two ties in any other period, an average degree of inbreeding equal to that of the preceding period was assumed for them. Therefore, the second period $(1+F_a) = 1+0.01 = 1.01$. The coefficient of inbreeding for the second period (1917-1926) was therefore calculated as follows:

$$F_x = \frac{8 \times .50\ (1.01)}{200} = 0.02 \text{ or } 2.0\%$$

$(1+F_a)$ for the third period (1927-1936) will be $(1+.02) \doteq 1.02$ and the coefficient of inbreeding will be:

$$\frac{7 \times .50\ (1.02)}{200} = .018 \text{ or } 1.8\%$$

and $(1+F_a)$ for the fourth period (1937-1946) will be 1+.018 = 1.018 and the coefficient of inbreeding will be:

$$\frac{19 \times .50\ (1.018)}{200} = .048 \text{ or } 4.8\%$$

The standard errors for the inbreeding coefficients for the four periods were calculated. The standard error is the standard deviation of the mean. For example, if for one of the periods, we have an inbreeding coefficient of 2.0% with a standard error of ± 0.5, the ± 0.5 means that if we repeated our study using a number of samples, we would expect the coefficient of inbreeding in approximately two-thirds of the results to fall in the range from 1.5% to 2.5%.

The standard error of inbreeding can be calculated according to the formula:

$$s_{\bar{X}} = \frac{1}{2}\sqrt{\frac{PQ}{N}}$$

where P is the observed frequency of the ties, Q = 1-P = the observed frequency of non-ties, and N = the number of cases (pedigrees). As the coefficient of inbreeding corresponds only to half of the percentage of ties the standard error should be rated down proportionally by the factor $\frac{1}{2}$. The NPQ formula, however, gives an asymmetrical distribution where the values for P and Q are so unequal. Applying the NPQ formula to obtain the standard error of the coefficients of inbreeding, the calculations for the first period (1907-1916) were as follows:

The formula for the standard error of coefficient of inbreeding is:

$$s_{\bar{x}} = \frac{1}{2}\sqrt{\frac{PQ}{N}}$$

$s_{\bar{x}}$ = standard error

p = observed frequency of ties = $\frac{4 \times 100}{200} = 2\%$

q = observed frequency of non-ties = 100 - 2 = 98%

Standard error = $\frac{1}{2}\sqrt{\frac{2 \times 98}{200}} = \frac{1}{2}\sqrt{\frac{196}{200}} = \pm\ 0.49$

The standard error of the inbreeding coefficients for the other three periods were calculated in a similar method. Coefficients of inbreeding and their standard errors are listed in table 3.

<u>Coefficient of Relationship</u>:

The coefficient of relationship is closely related to the coefficient of inbreeding. Measuring relationship is evaluating the probability that the two related individuals will have duplicate genes because they are related by descent. Relationship may be direct when one animal is the ancestor of the other - as parents and offspring or grandsire and grandson - or collateral when both animals are descended in part from some of the same ancestors - as half and full brothers, uncle and niece, cousins, etc.

The coefficient of relationship as defined by Wright (1925) is one which gives the degree of correlation to be expected between two individuals (X and Y) in characteristics which are entirely genetic and without dominance, conditions under which the correlation between parent and offspring, or between brothers in a random bred stock is +0.50.

Wright (1925) developed a formula for calculating the coefficient of relationship which is:

$$R_{xy} = \frac{\Sigma\left[\left(\frac{1}{2}\right)^{n+n'} (1+F_a)\right]}{\sqrt{(1+F_x)(1+F_y)}}$$

Where R_{xy} = the coefficient of relationship between x and y.

F_x and F_y = Coefficient of inbreeding of the two individuals x and y.

F_a = the coefficient of inbreeding for the closest common ancestor connecting a pair of ancestral lines in their pedigrees.

n and n' = the number of generations from x and y to this common ancestor along the lines in question.

For calculating the coefficient of relationship from random samples of pedigrees, Wright (1925) gave the following method:

"The presence of a tie between single random lines back of the two animals considered (X, Y) indicates a coefficient of:

$$\frac{1 + F_a}{\sqrt{(1 + F_x)(1 + F_y)}}$$

In calculating the relationship of a large group to a particular animal (Y), the coefficient of inbreeding of that animal (F_y) should of course be obtained with a high degree of reliability. The coefficient F_a of common ancestors that frequently recur should be calculated with considerable reliability. The coefficient F_x for the animals of the group should be calculated once for all, preferably by the two column method as described in the previous section on inbreeding."

TABLE 3

INBREEDING COEFFICIENTS.

PERIOD	Number of two line pedigrees sampled	Inbreeding Coefficients
1907-1916	200	1.0 ± 0.5
1917-1926	200	2.0 ± 0.7
1927-1936	200	1.8 ± 0.7
1937-1946	200	4.8 ± 1.1

Inter se Relationship:

Inter se relationship is the average relationship between random individuals of a breed. The subjects of each sample were listed by the tabulating machines with the ancestors appearing in the male and female line shown separately for each subject. Figure 2 shows the subjects listed with ancestors concerned. Male and female lines were given serial numbers. Each number indicates a male or a female line for certain subject in the sample. All numbers were recorded on small rectangular pieces of cardboard which were mixed thoroughly and put in a box. Two numbers at a time were drawn together randomly, recorded and returned back to the box. The lines which they represented were compared as to the presence of ties. One hundred pairs of lines were compared in each sample.

The presence of a tie between single random lines back of the two subjects considered indicated an inter se relationship coefficient of 1% according to the formula

$$R_{xy} = \frac{1+F_a}{\sqrt{(1+F_x)(1+F_y)}} \text{ ; if } F_a, F_x \text{ and } F_y \text{ each} = 0.$$

No inbreeding was found in the pedigrees of the subjects concerned, nor for the animals that caused the ties. The inter se relationship coefficients and their standard errors for the different periods are shown in table 4.

The standard errors for inter se relationship coefficients were computed according to the formula $s_{\bar{x}} = \sqrt{\frac{PQ}{N}}$, where P = the percentage of pairs that had ties and Q = the percentage of pairs that had no ties, and n = the number of pairs of lines examined in each sample.

Fig. 2

A sample section of the tabulator tape of International Business Machines showing subjects and their ancestors.

2151	0	1	0	815	
2151	0	1	1	1008	
2151	0	1	1	5017	G
2166	0	0	1	597	
2166	0	0	0	732	
2166	0	0	1	5017	G
2166	0	1	1	1450	
2166	0	1	1	5013	P
2171	1	0	0	596	
2171	1	0	0	615	
2171	1	0	1	708	
2171	1	0	0	1232	
2171	1	0	1	5011	G
2171	1	1	1	896	
2171	1	1	0	5006	E
2191	0	0	0	30	D
2191	0	0	0	267	
2191	0	0	0	487	
2191	0	0	0	589	
2191	0	1	1	597	
2191	0	1	1	1227	
2191	0	1	1	5017	G
2201	1	0	1	28	D
2201	1	0	0	203	
2201	1	0	1	575	
2201	1	0	0	956	
2201	1	1	0	13	
2201	1	1	0	90	
2201	1	1	0	203	
2201	1	1	1	244	
2201	1	1	1	575	
2201	1	1	1	1140	
2201	1	1	0	5074	G

TABLE 4

Coefficients of Inter se relationship

Period	No. of lines Sampled	Inter se relationship Coeff.
1907-1916	100	1.0 ± .9
1917-1926	100	4.0 ± 1.9
1927-1936	100	2.0 ± 1.4
1937-1946	100	4.0 ± 1.9

Prominent Individuals and their Relationship to the Breed.

This method of sampling pedigrees gives a measure of the importance of various individuals in the breed during the different periods. If an animal appears in many random lines as an ancestor, it had a better chance of scattering its genes throughout the breed. All of the stallions and mares that appeared 10 times or more in any one of the samples was considered comparatively important. Table 5 and 6 show the number of appearances of these animals in different periods. 200 pedigrees for the period (1907-1916) constitute 400 lines.

If an animal appears 13 times in 400 lines as the mare Nejdme #1 did for example, she would have a direct relationship of $\frac{13}{400} = .033$ or 3.3% to the breed at this particular time.

Two animals may have the same direct relationship to the breed at a certain period, but the breed may be more like one of them than the other. One of them may be the only connection between his ancestors and the breed while the ancestors of the other may have had many other offspring through which their genes were conveyed to the breed.

In this case, collateral relationship should be calculated. In this study there were not many collateral relationships. The most important ones found were the relationship of Sedjur #193, Antez #448, and Hanad #489, each one of them to the other through Hamrah #28 and Wadduda #30.

Next were Khaled #5 and Segario #249 through Nimr and Naomi; and El Sabok #276 and Khaled #5 through Naomi.

TABLE 5

NUMBER OF APPEARANCES OF STALLIONS IN DIFFERENT PERIODS.

NAME	Total appearances in 4 periods	Reg. No.	1907-1916	1917-1926	1927-1936	1937-1946
OBERAN d.b.	23	2	10	4	4	3
KHALED	37	5	15	14	5	3
*HALEB d.b.	35	25	18	14	3	-
*HAMRAH d.b.	113	28	30	33	22	28
*ELBULAD d.b.	34	29	7	11	10	6
*DEYR d.b.	52	33	6	18	15	13
*ABU ZEYD	52	82	15	22	7	8
LETAN	32	86	1	11	14	6
HARARA	28	122	-	12	8	8
SIDI	27	223	-	9	10	8
*NIMR	43	232	19	16	1	7
*GARAVEEN	31	244	8	14	5	4
SEGARIO	34	249	14	11	3	7
*KISMET	35	253	15	14	2	4
*RODAN	43	258	4	20	14	5
EL SABOK	20	276	-	5	10	5
*BERK	38	343	5	10	10	13
RIBAL	21	397	-	-	11	10
ANTEZ	17	448	-	-	7	10
HANAD	12	489	-	1	11	-
REHAL	21	504	-	2	9	10
*NURI PASHA	25	517	-	3	13	9
GULASTRA	17	521	-	-	5	12
*RASEYN	21	597	-	-	6	15
NASIK	25	604	-	-	9	16
FARANA	13	708	-	-	3	10
RIFNAS	16	924	-	-	1	15
*NUREDDIN II	24	974	-	2	11	11
*CZUBUTHAN	10	1499	-	-	-	10
RIJM	37		3	9	10	15
SKOWRONEK	26		-	-	7	19
MESOUD	34		10	12	4	8
YATAGHAN	27		12	5	6	4
HARB	21		3	10	7	1

TABLE 6

NUMBER OF APPEARANCES OF MARES IN DIFFERENT PERIODS.

NAMES	Total appearances in 4 periods	Reg. No.	1907-1916	1917-1926	1927-1936	1937-1946
*NEJDME d.b.	40	1	13	12	11	4
SHEBA	24	19	11	4	4	5
*WADDUDA d.b.	51	30	13	8	18	12
*URFAH d.b.	74	40	25	25	13	11
*HADBA d.b.	16	43	10	2	3	1
*HAFFIA d.b.	34	45	6	12	12	4
DAHURA	32	90	4	6	14	8
SEDJUR	19	193	-	4	10	5
*NAOMI	57	230	23	13	12	9
*NAZLI	31	231	14	10	3	4
ROSE OF SHARON	34	246	7	13	7	7
GUEMURA	17	277	-	4	3	10
*FERDA	25	596	-	-	10	15
*FARASIN	22	615	-	-	8	14
HAIDEE	30		11	8	6	5
NARGHILEH	35		4	3	13	15
ROSE DIAMOND	27		9	12	4	2

In order to have their total relationship to the breed their full pedigrees were worked out and the total relationship was calculated by the formula: Total relationship = direct relationship of one of the animals to the breed + (their collateral relationship x the direct relationship of the other animal to the breed.)

Sedjur #193 was collaterally related to Hanad #489. Their collateral relationship coefficient was 21.87%. The direct relationship of Sedjur to the breed in (1927-1936) was 2.5% and the direct relationship of Hanad to the breed in the same period was 2.7%. According to the formula the total relationship of Sedjur to the breed will be:

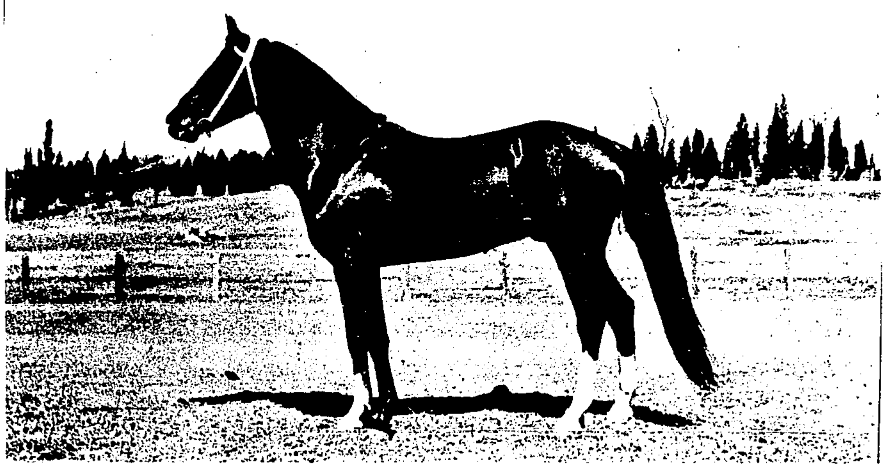
$$.025 + (.218 \times .027) = .031 = 3.1\%$$

The total coefficients of relationship were calculated and are shown in table 7 for stallions and table 8 for mares. Rather than calculating the standard error by the "NPQ formula" for each relationship, a standard scale for different levels of relationship with N = 400 is given in table 9.

It goes without saying that some of those with considerable collateral relationship may have been missed by this method of selecting them primarily on the size of their direct relationship.

It can be seen from table 7 that Hamrah #28, (Figure 3) a stallion foaled in 1903 in the desert and bred by an Arab tribe, maintained the highest relationship to the breed from 1907 to 1946. He had a relationship to the breed of 7.5% in the period 1907-1916, 8.3% in 1917-1926, 5.5% in 1927-1936 and 7.0% in 1936-1947.

Figure 3



Hamrah #28, a bay stallion bred by Ibn Badan El Awagi of the Anazeh tribe, Arabian Desert. Foaled in 1904 and imported to the United States by Homer Davenport in 1906. His relationship to the breed was 7.5% in 1907-1916, 8.3% in 1917-1926, 5.5% in 1927-1936 and 7.0% in 1937-1946.

Hamrah was sired by a Hamdani Simiri stallion and was imported with his dam Urfah #40 in 1906 by Homer Davenport and was owned by Hingham Stock Farm, Hingham, Massachusetts.

Descendants of Hamrah that had an influence on the breed were: Sedjur #193, foaled in 1916, bred by Hingham Stock Farm; Antez #448, foaled in 1921 and bred by F. E. Lewis II; Hanad #489, foaled in 1922 and bred by Hingham Stock Farm.

On account of the limited number of offspring it is difficult for a mare to attain as high a relationship to the breed as is possible for a stallion. Urfah #40, a mare imported in 1906 by Homer Davenport had a direct relationship of 6.3% in 1907-1916 and 6.3% in 1917-1926. Almost all of her influence has come through her son Hamrah #28.

Another mare was Naomi #230, which had a relationship of 5.8% to the breed in 1907-1916. This mare was the sole result of the two-years' trip (1875-6) by Major Upton to the desert to secure new blood for the English turf. She was imported to America by Randolph Huntington of Oyster Bay, Long Island, New York in 1888. Almost all of her influence on the breed came through her grandson Nimr #232, who had a direct relationship of 4.8% in the 1907-1916 period. Another important offspring of her was Khaled #5, who was the result of mating her to her grandson, Nimr. Khaled had a total relationship to the breed of 5.1% in 1907-1916. Segario #249, Naomi's great grandson, had a total relationship of 4.9% to the breed in 1907-1916. El Sabok #276, her grandson, was less important than any of her other descendents.

TABLE 7

Total relationship of Prominent Animals to the Various Samples

Stallions

Name	Reg. No.	1907-1916	1917-1926	1927-1936	1937-1946
OBEYRAN	2	2.5	1.0	1.0	0.8
KHALED	5	5.1	4.3	1.5	1.2
HALEB	25	4.5	3.5	0.8	-
HAMRAH	28	7.5	8.3	5.5	7.0
E. BULAD	29	1.8	2.8	2.5	1.5
DEYR	33	1.5	4.5	3.8	3.2
ABU ZEID	82	3.8	5.5	1.8	2.0
LETAN	86	0.2	2.8	3.5	1.5
HARARA	122	-	3.0	2.0	2.0
SIDI	223	-	2.3	2.5	2.0
NIMR	232	4.8	4.0	0.3	1.7
GARAVEEN	244	2.0	3.5	1.3	1.0
SEGARIO	249	4.9	3.8	1.2	1.9
KISMET	253	3.8	3.5	0.5	1.0
RODAN	258	1.0	5.0	3.5	1.3
EL SABOK	276	0.9	2.1	2.8	1.3
BERK	343	1.3	2.5	2.5	3.3
RIBAL	397	-	-	2.8	2.5
ANTEZ	448	-	-	2.1	2.5
HANAD	489	-	0.4	3.3	0.2
REHAL	504	-	0.5	2.3	2.5
NURI PASHA	517	-	0.8	3.3	2.3
GULASTRA	521	-	-	1.3	3.0
RASEYN	597	-	-	1.5	3.8
NASIK	604	-	-	2.2	4.0
FARANA	708	-	-	0.8	2.5
RIFNAS	924	-	-	.3	3.8
NUREDDIN II	974	-	0.5	2.8	2.8
CZUBUTHAN	1499	-	-	-	2.5
RIJM	GSB	0.8	2.3	2.5	3.8
SKOWRONEK	”	-	-	-	4.8
MESAOUD	”	2.5	3.0	1.0	2.0
YATAGHAN	D.B.	3.0	1.3	1.5	1.0
HARB	GSB	0.8	2.5	1.8	0.3

TABLE 8

MARES

NAMES	Reg. No.	1907-1916	1917-1926	1927-1936	1937-1946
NEJDME	1	3.3	3.0	2.8	1.0
SHEBA	19	2.8	1.0	1.0	1.3
WADDUDA	30	3.3	2.0	4.5	3.0
URFAH	40	6.3	6.3	3.3	2.8
HADBA	43	2.5	0.5	0.8	0.3
HAFFIA	45	1.5	3.0	3.0	1.0
DAHURA	90	1.0	1.5	3.5	2.0
SEDJUR	193	-	1.1	3.1	1.2
NAOMI	230	5.8	3.3	3.0	2.3
NAZLI	231	3.5	2.5	0.8	1.0
ROSE OF SHARON	246	1.8	3.3	1.8	1.8
GUEMURA	277	-	1.0	0.8	2.5
FERDA	596	-	-	2.5	3.8
FARASIN	615	-	-	2.0	3.5
HAIDEE	D.B.	2.8	2.0	1.5	1.3
NARGHILEH	GSB	1.0	.8	3.3	3.8
ROSE DIAMOND	"	2.3	3.0	1.0	0.5

TABLE 9

Standard Errors for Coefficients of Relationship

Coefficient of relationship	Standard error
2	0.7
4	0.9
6	1.2
8	1.4
10	1.6

Wadduda #30, an imported mare, had an almost steady influence on the breed from the time she was imported up to 1946. She had a direct relationship of 3.3%, 2.0%, 4.5% and 3.0% to the breed in the first, second, third and fourth periods, respectively. She was foaled in 1899 in the desert and imported to America by Homer Davenport in 1906 after which she was owned by Armstrong Bedouin Stud, Holmdel, H. J.

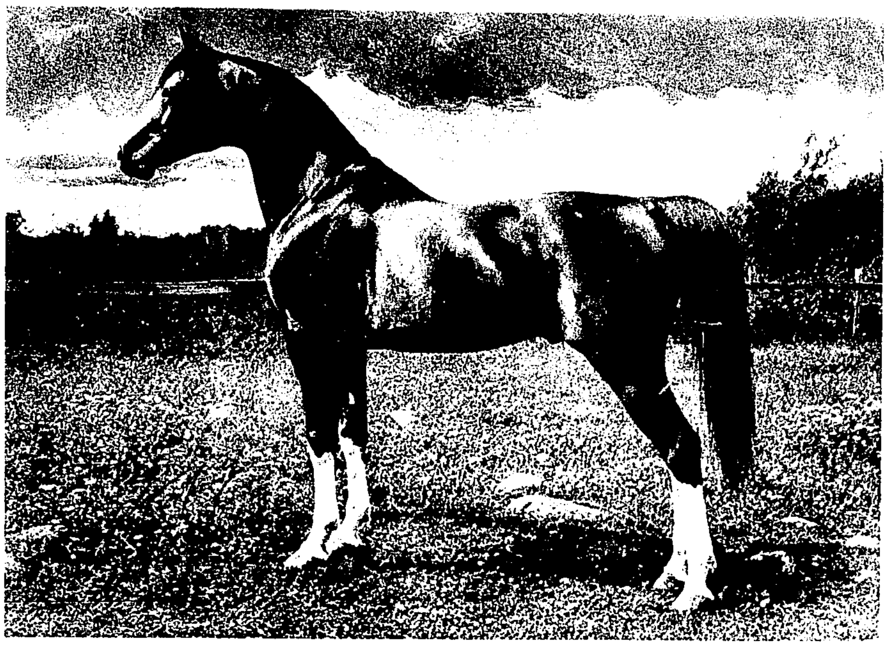
While Haleb #25 had a relationship of 4.5% after he was imported to America by Homer Davenport in 1906, he rapidly lost the influence on the breed and had a relationship to the breed of 0.0% in 1937-1946.

Deyr #33 was a comparatively influential stallion on the breed for a long time. He was imported by Homer Davenport in 1906 and owned by Hingham Stock Farm in Massachusetts, then owned by W. K. Kellogg in Pomona, California. He did not hold a high relationship in 1907-1916, but he had 4.5% in 1917-1926.

Abu Zeid #82 (Figure 4), foaled in 1904 and bred by Hon. George Savile of England, was imported to America in 1910 by Homer Davenport and owned by W. R. Brown, Maynesboro Farm, Berlin, N. H. Abu Zeid had a direct relationship to the breed of 3.8% in 1907-1916, and 5.5% in 1917-1926.

Rodan #258, a stallion which was imported in utero by Spencer Borden of Fall River from Crabbet stud, England, and was owned by U. S. Remount, Washington, D. C., had a direct relationship to the breed of 5.0% in 1917-1926. Apparently, he was not important later because he did not have more than 1.3% relationship to the breed in 1937-1946.

Figure 4



"Abu Zeyd" #82, a chestnut stallion, bred by Hon. George Savile, England. Foaled in 1904 and imported to the United States of America in 1910 by Homer Davenport. His relationship to the breed was 5.5% in 1927-1936.

Next to Hamrah #28 in influence upon the breed in 1937-1946 was Skowronek (Figure 5), a grey typical nice looking Arab which was not imported to America, but his influence came through his sons Raseyn #597, who was imported by W. K. Kellogg in 1926, and Raffles #952, imported by Roger Selby of Portsmouth, Ohio. Two daughters of Skowronek were also imported to America but they did not have much influence on the breed. One of them (Rossana #598) was imported by W. K. Kellogg in 1926, and the other was Rifala #815, who was imported by Roger Selby of Portsmouth, Ohio, in 1928. Rossana had twelve offspring while Rifala had only five. Raseyn had 85 offspring until 1946, while Raffles had only 39. Skowronek had a relationship of 4.8% to the breed while his son, Raseyn, had a relationship of 3.8% at this period. Raffles, although inbred to Skowronek, did not show up on the list of the animals that had considerable influence on the breed, probably because he was kept in Ohio, far from the Arabian horse center while Raseyn was kept in Pomona, California, where the Arabian horse had more enthusiasts and where more pure Arabian mares were located at that time.

Many of the get of Raseyn and Raffles in America were show winners, and, in fact, the majority of the prize winners in Los Angeles shows were related to him.

Skowronek was originated on the sire's side from Abbas stock, and he was of the Abbas type and size. He sired much winning stock of lovely type in England.

Figure 5

Skowronek (G.S.B.), a grey stallion imported from Poland by Crabbet Stud to England. Many of his sons and daughters were imported from England to the United States by W. K. Kellogg and Roger Selby. His relationship to the breed was 4.8% in 1937-1946.

It can be seen from tables 7 and 8 that fifty-one animals had more or less influence on the breed in different periods. Apparently the influence of different individuals was changing according to the date of importation, their sex, whether they were located in an active Arabian horse center or not, and to the consideration of the Arabian breeders and the type they wanted in different times.

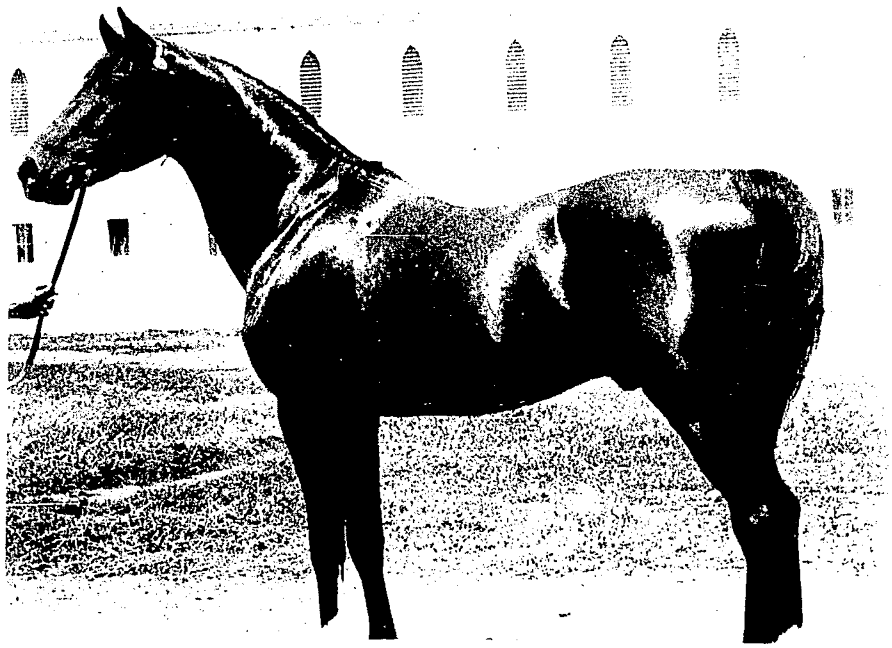
Our knowledge of the merits of the early importations is limited but it seems that American breeders used to like the big animals of more than normal height. Fragmentary information tells us that Naomi was 15-2 hands, and Khaled (Figure 6) was 15-2½ hands.

Animals that had the most influence on the breed can be classified according to their country of origin or to breeders, as follows:

	No.
Importations by Hamidie Society from the desert.	2
Importations by Davenport and those related to them (mostly from the desert)	15
Importations from English breeders by American breeders	8
Importations from Crabbet Stud of England and related.	18
Animals of mixed familes	5
Importation from Poland	1
Desert bred not imported to America	2

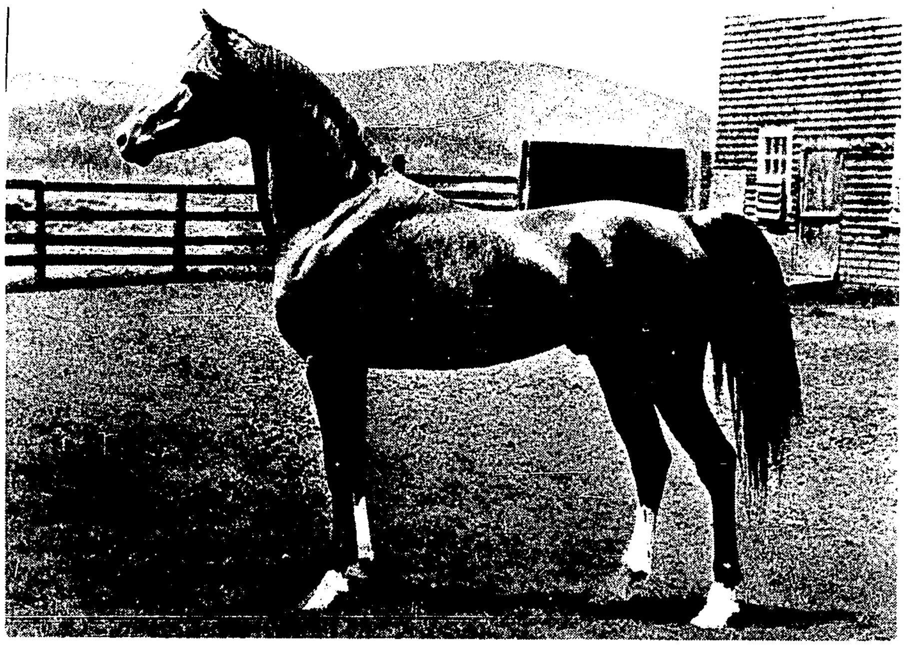
There are some animals among these which were not imported but their influence came through their imported offspring.

Figure 6



Khaled #5, a chestnut stallion foaled in 1895 and bred by Randolph Huntington, Oyster Bay, L. I. His relationship to the breed was 5.1% in 1907-1916.

Figure 7



Rodan #258, a chestnut stallion, bred by Crabbet Arabian Stud, Sussex, England. Foaled in 1906, imported in utero by Spencer Borden, Fall River, Massachusetts, in 1906. His relationship to the breed was 5.0% in 1917-1926.

DISCUSSION

The blood of the Arab horse was introduced to the United States of America through the horses of the Spaniards. As early as 1733-1747, pure Arabians were imported and were used for crossing with some other American mares found at that time. Importations were rather slow, and in small numbers until a little before 1906, when Huntington, Ramsdell, Spencer Borden, Hamidie Society and Davenport imported more stallions and mares and the Arabian Horse Club of America started registrations. Importations were more effective later when Brown, Kellogg, Selby, Dickinson, VanVleet, Babson and others were more interested in Arabians and imported several animals of good quality. Since then the Arabian horse population has been increasing rapidly every year.

The Arabian horse breeders did not have the opportunity of showing their animals and discussing their merits except recently. Three years ago, in California State the All-Arabian show started, guided by the Arabian Horse Breeders Association of California. Since then, merits of Arabian horse have been more thoroughly studied and discussed.

The merits to discuss and fix in the breed through breeding operations, however, were very few. As we mentioned before, the Arabian horse did not attain the status of a race horse in this country.

Today, there are hundreds of small breeders in all parts of the country. The Arab has found his place - on the ranches of the West, in the hunting fields, and jumping competition in the East, but nothing has been officially recorded to show what achievements were accomplished through systems of breeding, if there were any. The Arab took part in some endurance tests in early times, but now, there is no more of that.

The breeding operations are individually chosen by different breeders according to their own taste, and the colors and markings in California are on their way to being the main problem. These ideas combined with the results of this study show clearly that the Arabian horse, although imported to the country before any other breed of livestock, has not yet attained the same attention and organization as other breeds in this country have.

Apparently, selection was the main breeding plan, and the increasing coefficient of inbreeding from period to period shows that there is a drift toward homozygosity.

Although the coefficients for inbreeding in general are more or less lower than it was expected, comparing the first period (1907) with the fourth (1937) shows that there has been an increase in inbreeding.

Relatively fast progress is made with selection when it is first begun, but as the goal is approached, the progress becomes slower. The Arabian horse is the oldest breed of livestock in the world in which selection has been practiced.

Unless the American breeders are working for some other merits, rather than type and other characteristics which are already fixed, the breed will stay as it is and will not need any effort from the American breeders except that needed for the other characteristics that they want.

Only part of the quality selected for in the parents is actually gained in the offspring when selecting for a character which is much modified by environment. The Arabian horse which originated in the desert and lived for ages on limited amounts of feed averaged 14-14.2 hands in height in his home country, but owing to the excess of feeds, many individuals can be seen in the United States which are bigger and higher than the average.

As a result of the consistent work of an ever increasing number of Arabian horses in the United States, the perpetuation of the breed is becoming to be assured.

Inbreeding:

The average coefficients of inbreeding found in the breed at various periods are shown in table 3. These inbreeding coefficients represent the increase in homozygosity in the breed since 1907. While the coefficient of inbreeding was 1.0% in 1907-1916, it was doubled in 1917-1926 and was almost the same in 1927-1936. In 1937-1946, there was a distinct increase. It rose to 4.8% in that period.

Generally, the amount of inbreeding found in the Arabian horse breed of America was more or less of the same level as the amount of inbreeding found in studies of other breeds.

The number of males used in a herd or a breed has a considerable effect on the heterozygosity lost each generation.

If a population is kept entirely closed to outside blood, about $\frac{1}{8M} + \frac{1}{8L}$ of the remaining heterozygosity will be lost per generation, In a stud where there are only 5 stallions and 50 mares this will be: $\frac{1}{8 \times 5} + \frac{1}{8 \times 50} = \frac{11}{400}$ = 2.8% of the remaining heterozygosis.

The number of males and females in this study in different periods was found to be as follows:

Period	Males	Females
1907-1916	107	121
1917-1926	118	166
1927-1936	249	371
1937-1946	1219	1373

Almost all the early importations of Arabians were of stallions. Mares were very hard to import owing to the old traditions of the Arabs of not selling mares.

As stated by Lush (1945) the average interval between generations in the horse is about ten years. Each of the periods listed in this study is therefore, approximately one horse generation.

If breeding were truly at random, and all the stallions of the breed were used in breeding through the different periods we would have expected coefficients of inbreeding similar to what we get by solving the formula $\frac{1}{8M} + \frac{1}{8L}$, which gives us a coefficient of inbreeding equal to:

$$\frac{1}{8 \times 107} + \frac{1}{8 \times 121} = 0.20\% \text{ for 1907-1916 period}$$

$$\frac{1}{8 \times 118} + \frac{1}{8 \times 166} = 0.18\% \text{ for 1917-1926 period}$$

$$\frac{1}{8 \times 249} + \frac{1}{371} = 0.08\% \text{ for 1927-1936 period}$$

$$\frac{1}{8 \times 1219} + \frac{1}{8 \times 1373} = 0.02\% \text{ for 1937-1946 period}$$

Comparing the results with the inbreeding actually found as in table 10, we can see that there was a big difference between the two:

TABLE 10

Coefficients of inbreeding actually found, and coefficients if mating was at random.

Periods	Pedigrees sampled	Inbreeding Coefficient	
		Actually found	If mating was at random
1907-1916	200	1.0%	0.20%
1917-1926	200	2.0%	0.18%
1927-1936	200	1.8%	0.08%
1937-1947	200	4.8%	0.02%

In animal breeding operations, the number of females (L) will be usually so much larger than the number of males (M) that the term $\frac{1}{8L}$ can be neglected without much error. Then, in a random mating population of M equally used males and many more females, the fraction of the existing heterozygosis lost per generation is approximately $\frac{1}{8M}$.

Using the actually found inbreeding coefficients in this study which gives the observed increase in inbreeding per generation and solving for M, we get values of:

$$\frac{1}{8M} = .01 = \text{12 stallions for 1907-1916}$$

$$\frac{1}{8M} = .02 = \text{6 stallions for 1917-1926}$$

$$\frac{1}{8M} = .018 = \text{about 6 stallions for 1927-1936}$$

$$\frac{1}{8M} = .048 = \text{about 3 stallions for 1937-1946}$$

Of course the actual conditions are not as simple or uniform as this. At all times many more than 12 stallions are actually used in breeding but they are by no means used equally. Sometimes fewer than 12 sire, most of the offspring in one period, and their descendants are used in large numbers to head studs throughout the country, and far more than twelve are used only a little and have most of their descendants used for grading on other breeds.

Almost all the early importations were of stallions. Mares were very hard to import owing to the old traditions of the Arabs of not selling mares.

Customs such as advertising and other sorts of salesmanship, and also the results of shows lately held in different parts of the country, might have caused a few individuals, mainly sires, to be more appreciated by breeders so that they tried to get sons or grandsons of theirs and use them as sires to head their studs.

Inter se Relationship:

If the foundation stock of a breed was of limited size — as it is in the case of the Arabian horse in America — one may expect a certain amount of inbreeding in the breed. The more closely related the animals of the breed are to each other, the more likely it is that the same ancestor will be found in the pedigrees of two individuals chosen at random.

In order to ascertain whether the mating was actually at random or there was a tendency for the breeders to favor inbreeding, the formula: $F = \frac{R}{2-R}$, used by Yoder and Lush (1937) for calculating inbreeding from the average inter se relationship, was used.

The factor (F) in this case equals the inbreeding which results merely because all members of the breed are related to each other.

Table 11 shows the inbreeding actually found, inter se relationship, and the average inbreeding expected from inter se relationship.

It can be seen from this table that in all samples except one, the observed or actually found inbreeding was more than what is calculated from inter se relationship. This indicates the tendency toward the formation of separate families.

Only in the sample of 1917-1926, was the inbreeding expected from inter se relationship the same as the observed.

It is clear that, at least in the other three periods, there was more inbreeding than is made necessary by the general average relationship of members of the breed to each other.

There may be several factors contributing to such a result. It does not seem that all breeders have favored inbreeding. Apparently there may be a few of them that were inclined to use inbreeding to some outstanding sires. In fact we have contacted some of those breeders and we

TABLE 11

Inbreeding and inter se relationship coefficients.

Period	Pedigrees Sampled	Coefficient of inbreeding: Actually found	Coefficient of inbreeding: Expected from inter se relationship	Inter se relationship coeff.
1907-1916	200	1.0 ± 0.48	0.5	1.0 ± 0.9
1917-1926	200	2.0 ± 0.69	2.0	4.0 ± 1.9
1927-1936	200	1.8 ± 0.65	1.0	2.0 ± 1.4
1937-1946	200	4.8 ± 1.06	2.0	4.0 ± 1.9

know from judging their animals and working out their pedigrees that they have used intensive inbreeding in some cases. There may be some other natural causes. It may be the result of the geographical situation of the studs in the country and the fact that most breeders prefer to purchase sires from nearby studs.

Perhaps there are other causes which cannot be perfectly ascertained.

Show Winners:

No samples were taken from the show winners as they were few and represented only the California State Arabian horses or horses from some other western states. Excluding the three all-Arabian shows made lately in California, there have been no shows for the Arabian horse since the start of this breed in America. It is true that some individuals participated in other shows, but this was among stock horses, or pleasure riding horses of different breeds.

The Arab did not attain the status of a race horse in America and, therefore, there were no available records to show the superiority of some individuals over the others in performance.

There were some endurance tests done to ascertain the power of the Arab, but even in these the Arab was competing with horses of different breeds so that it was difficult to gain any conclusion.

CONCLUSIONS

1. The inbreeding coefficient for the Arabian horse breed of America rose gradually from 1.0% in 1907-1916, to 4.8% in 1937-1946.

2. The inter se relationship in the breed was 1.0% in 1907-1916, 4.0% in 1917-1926, 2.0% in 1927-1936 and 4.0% in 1937-1946.

3. The actually found coefficients of inbreeding were higher than the expected inbreeding from inter se relationship. This indicates the tendency toward the formation of separate families.

4. The highest relationship to the breed was for Hamrah #28, who was imported by Davenport in 1906. His relationship was almost constant through the different periods (7.5%, 8.3%, 5.5% and 7.0%).

5. Skowronek, a horse owned by Crabbet stud in England and tracing back to Egyptian origin on his male line, had the next highest relationship to the breed in 1937-1946. His relationship to the breed came through some sons and daughters of his imported to America.

6. Due to the fact that there were not enough all-Arabian shows, there were no means to study the systems of breeding of the outstanding show animals.

7. The majority of the foundation animals were imported by Davenport from the desert and others imported from Crabbet Stud in England.

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