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Demographic and Genealogical Analysis of the Population of Toulal (Meknes, Morocco): Family Structure and Inbreeding

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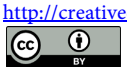

Abstract

This study presents a demographic and genealogical analysis of the Aït Saâdallah community of Toulal (Meknes, Morocco), composed of the Aït Messaoud and Aït Ouaârab factions. Genealogical data from 1533 individuals born between 1850 and 2015 were analyzed. Demographic parameters included family size, parental age at first birth, spousal age gap, intergenesic intervals, lifespan, kinship structure, and inbreeding coefficients. The mean number of children per individual was 4.17 ± 2.40. Men and women had similar average numbers of boys (2.43 ± 1.47) and girls (2.45 ± 1.50). The average age at first birth was 28.5 ± 5.6 years for men and 20.9 ± 3.6 years for women, with a mean spousal age gap of 8.95 ± 3.85 years. The intergenesic interval averaged 3.13 ± 1.96 years. Mean lifespan was 66.2 ± 18.9 years and was significantly higher in women than in men ($P < 0.05$). A total of 1099 kinship relationships were identified, reflecting a dense family structure. Endogamy was common, with 316 marriages between parallel patrilateral cousins and 21 between parallel matrilateral cousins; no cross-cousin marriages were observed. Inbred individuals represented 10.2% of the population. The mean inbreeding coefficient was 0.00346 ± 0.01372 for the total population and 0.03398 ± 0.02859 among inbred individuals. Inbreeding levels were significantly influenced by faction membership ($P < 0.001$) but not by sex. A gradual increase in inbreeding was observed across generations. Overall, the Aït Saâdallah population exhibits high fertility, sex-related differences in lifespan, strong kinship cohesion, and moderate but increasing inbreeding, reflecting long-standing demographic and matrimonial traditions within this Amazigh community.

Keywords

Sibling Size, Parental Age at First Child, Age Gap between Spouses, Lifespan, Family Relationships

1. Introduction

Reconstructing family histories and analyzing kinship structures are essential tools for understanding the demographic, social, and genetic dynamics of human populations (Bittles & Black, 2010). The study of communities characterized by strong social cohesion, marked endogamy, and specific migratory history makes it possible to assess the impact of marriage practices and kinship relations on the genetic structure of the population.

The population of Toulal, located on the southwestern peripheries of Meknes, Morocco, is a particularly relevant example for this type of analysis. Its inhabitants originate from Haut-Guir, in southeastern Morocco, and more specifically from the Gourrama region. This Amazigh community was forced to leave its ancestral territory around 1850, following a conflict with the local caïd (chief) over taxes deemed excessive. Their refusal to submit led to persecution, expulsion, and forced displacement, first to Fez, then to Meknes in 1865, where they were integrated into the Guich military system. In 1882, the sultan of the time had built the kasbah of Toulal for them and reorganized their original factions (Aït Messaoud, Aït Ouaârab, Aït Mechtaq, Aït Touasselt, and Aït Ali Ouhsain) into distinct spatial units, thereby promoting the reconstitution of their ancestral social structures (Boujenane, 2024).

This particular history shaped a population that was long characterized by high levels of endogamy. Until the mid-20th century, marriages took place almost exclusively within the community, sometimes between close relatives, while unions with outsiders were socially prohibited. This mode of social organization led to the formation of very dense family networks and close kinship ties, promoting high consanguinity and stability of lineages.

Consanguineous unions were common, and genetically speaking, they reduce genetic variability and increase homozygosity. Close relatives are more likely to share the same alleles inherited from their common ancestors, which increases the proportion of children who are homozygous for a given allele, including deleterious alleles, thereby increasing the risk of autosomal recessive diseases. Furthermore, inbreeding can have negative effects on reproduction (fertility and fecundity) and on the health of offspring (mortality and morbidity) (Talbi et al., 2007; Cheffi et al., 2022; El Khair et al., 2023).

The objectives of this study were to:

- Characterize family structure by examining sibling size, parents' age at first child, birth intervals, and age difference between spouses;
- Calculate the lifespan of men and women;
- Assess kinship relationships and levels of inbreeding in relation to the historical endogamy of the population.

By adopting a demographic, historical, and genetic approach, this study aims to provide a comprehensive overview of family dynamics in Toulal, while highlighting the social and historical processes that have shaped the current structure of this Amazigh population.

2. Materials and Methods

2.1. Study Location

The study focused on the population of Toulal, located in the southwestern suburbs of the city of Meknes, approximately 5 km from the city center, on regional road R718 towards Rabat. Toulal is located on a plateau at an altitude of 489 meters, at geographical coordinates 33˚53'55" north latitude and 5˚36'15" west longitude, and covers an area of approximately 2723 hectares.

In terms of demographics, Toulal's population grew from 5654 inhabitants in 1131 households in 1971 to 26,970 inhabitants in 7215 households in 2024, reflecting rapid population growth over the last few decades (HCP, 2024). Initially a rural suburb on the outskirts of Meknes, Toulal was administratively attached to the rural commune of Ain Orma. Following the administrative reorganization of June 30, 1992, it acquired the status of an autonomous municipality (Boujenane, 2024).

2.2. Data Source

The study is based on the analysis of the ascendant and descendant family trees of the Aït Saâdallah community of Toulal, compiled by Boujenane (2026). This community mainly comprises two factions (membership group), namely the Aït Messaoud and the Aït Ouaârab.

These genealogies were reconstructed using a qualitative, community-based approach based on oral interviews with community elders and family descendants. There was no fixed number of informants. For each family, information was obtained from multiple respondents recognized for their knowledge of local genealogies, through open-ended oral discussions without a formal interview protocol. The survey focused mainly on older generations not covered by civil registration, which only began in Meknes in 1953 and did not become widespread until the 1960s; recent generations were explored less, as civil registration records provided the necessary information.

Given that these genealogies rely on the memory of current residents, the data were systematically cross-checked and compared between several witnesses, and only consistently reported information was retained in order to correct biological and filiation inconsistencies and ensure data reliability.

2.3. Information Collected

Each individual, male or female, is uniquely identified by the combination of its surname, first name, and father's first name. This method of identification avoids duplication and ambiguity, as the first names of ancestors are often reused for descendants within the same lineage.

For each individual, the information collected includes: its identifier, its father's and mother's identifiers, its gender, its membership faction (Aït Messaoud or Aït Ouaârab), its year of birth, its year of death, the total number of children, the number of boys and girls, and its birth order among their siblings.

In the absence of systematic records, reconstruction based on informants'

memories, the dates of birth and death of older generations remain approximate. A validation and standardization process was therefore applied to correct chronological inconsistencies, harmonize spelling variations in names, and verify the biological plausibility of parentage (parent-child age differences, incompatible repetitions, generational anomalies, etc.).

2.4. Data File

The initial file included 1721 individuals, of whom 54.7% were male and 45.3% were female. Among them, 1533 individuals belonged to the two constituent factions of the Aït Saâdallah community (Aït Messaoud and Aït Ouaârab). The remaining 188 individuals were people whose mothers were from this community, while their fathers belonged to other factions of Toulal (Aït Mechtak, Aït Touasselt, Aït Ali Ouhsain) or were from outside the locality.

In this patrilineal community, descent is traced only when the father belongs to the Aït Saâdallah community. Thus, children born to an Aït Saâdallah woman and a man from outside the community are not included in the genealogy, unlike children born to a man from the community and a woman from outside, who inherit the name and paternal lineage.

Consequently, all individuals whose fathers did not belong to the Aït Saâdallah community were excluded from the demographic analysis. However, they were retained in the study of kinship and inbreeding to account for certain marriages involving a man from the community and a woman related by family ties but whose father was outside the community. These individuals were treated as pedigree founders and assigned an inbreeding coefficient of zero ($F = 0$).

The final analysis was conducted exclusively on the Aït Saâdallah community. The data file selected includes 1533 individuals, of whom 55.5% are male and 44.5% are female. Among them, 58.9% belong to the Aït Messaoud subgroup and 41.1% to the Aït Ouaârab subgroup.

All of the individuals analyzed, born between 1850 and 2015, are descended from 358 fathers and 338 mothers and are divided into 43 families, including 22 Aït Messaoud families and 21 Aït Ouaârab families, each descended from a founding ancestor, identified as the individual without a father or mother in the file. The majority of these individuals currently reside in Toulal; the others live in various cities in Morocco or abroad, while most maintain close ties with their village of origin.

2.5. Variables Studied and Statistical Analyses

The data collected were initially entered into an Excel spreadsheet, then subjected to genetic and statistical analyses using PedigreeViewer software (Kinghorn & Kinghorn, 2010), which allows the visualization and exploration of kinship relationships across several generations, SAS software (SAS, 2002) with various procedures, and R software (version 4.4.0; R Core Team, 2024) with various specialized packages. The following variables were then calculated:

- the size of the family and gender distribution of children, i.e., the number of children, the number of boys, and the number of girls;
- the age of the parents at the birth of their first child, i.e., the age of the parents (mother and father) at the birth of their first child when the years of birth are known;
- the age gap between spouses, i.e., the difference in age between the husband and wife;
- the birth intervals for women with at least two children, i.e., the number of years between two successive births (between two full-term pregnancies);
- the lifespan of an individual, i.e., the difference between its year of death and its year of birth;
- kinship relationships. In the present study, the term "kinship relationships" does not refer to all family ties within the community, nor to consanguineous loops or complete descent links across the pedigree. Instead, it specifically denotes parental unions in which both spouses had known parentage and shared at least one common ancestor;
- the inbreeding coefficient of each individual, which corresponds to the probability that two alleles at a given locus are identical by descent, i.e., derived by Mendelian descent from the same ancestral allele (Falconer & Mackay, 1996).

Demographic parameters, coancestry coefficients between all individuals, and individual inbreeding coefficients were calculated for the entire Aït Saâdallah community. These analyses were also performed according to sex (male or female), membership faction (Aït Messaoud or Aït Ouaârab), and birth cohort (before 1920, 1920-1950, 1950-1980, after 1980), when relevant. The effect of gender and faction was tested statistically.

For demographic analyses, individuals whose date of birth and/or death was unknown were excluded. Changes in inbreeding coefficients were examined by birth cohort in order to assess historical trends related to traditional endogamy in the population. Variations observed during the study period (1850-2015) were quantified using the regression coefficient of the inbreeding coefficient on the birth cohort.

3. Results and Discussion

3.1. Sibling Size

The frequency distribution showed that the number of children per individual ranged from 1 to 17, suggesting potential challenges for larger families. Individuals with 1, 2, 3, 4, and 5 children represented 9.33%, 20.1%, 17.6%, 14.6%, and 12.0% of the population, respectively, while those with 8 or more children constituted 10.4% (**Figure 1**).

The number of boys per individual ranged from 1 to 11, and the number of girls from 1 to 8, with 77.7% of individuals having 1 to 3 boys and 80.6% having 1 to 3 girls (**Figure 1**). Among siblings, 18.0% were composed exclusively of boys, with those with 1, 2, or 3 boys representing 6.34%, 5.99%, and 2.46%, respectively,

while 10.2% of siblings were composed exclusively of girls, with 1, 2, or 3 girls representing 2.99%, 3.87%, and 1.58%, respectively.

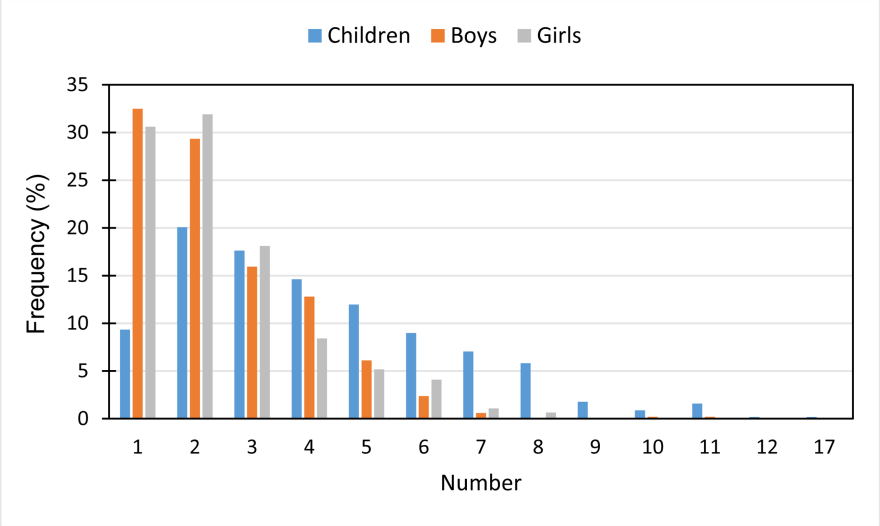

Figure 1. Frequency distribution of the number of children, boys and girls per individual among the Aït Saâdallah.

Finally, the number of children exceeding 11 was observed among men who had married more than one woman, at a time when contraceptive methods were non-existent.

Among the Aït Saâdallah, the average number of children per individual was 4.17 ± 2.40, with a minimum of 1 and a maximum of 17 children. The offspring showed an overall balanced gender distribution: the average number of boys per individual was 2.43 ± 1.47 and the average number of girls per individual was 2.45 ± 1.50 (**Table 1**). These results indicate a family structure characterized by large sibling groups, which is common in historical contexts with high fertility rates.

Table 1. Average number of children, boys, and girls per individual among the Aït Saâdallah*.

Variable	Number	Arithmetic mean	Standard deviation	Minimum	Maximum
Children	568	4.17	2.40	1	17
Boys	508	2.43	1.47	1	11
Girls	464	2.45	1.50	1	8

*Children: number of children; Boys: number of boys; Girls: number of girls.

The number of children, as well as the number of boys and girls per individual, is not significantly influenced by the sex of the individual or by the membership faction ($P > 0.05$). Among the Aït Messaoud, the average number of boys per individual (2.51 ± 1.42) was higher than that of girls (2.42 ± 1.41), while the opposite was observed among the Aït Ouaârab (2.34 ± 1.54 versus 2.50 ± 1.61).

The average size of the offspring observed among the Aït Saâdallah (4.17 chil-

dren per individual) is consistent with historically reported fertility levels in Morocco, particularly in rural areas, where the total fertility rate was estimated at between 4 and 6 children per woman for generations prior to the demographic transition (Direction de la Statistique, 2005). The overall balanced gender distribution of offspring is also consistent with Moroccan data, which indicates a sex ratio close to unity, with no systematic imbalance between boys and girls.

3.2. Parental Age at Birth of First Child

The distribution of parental ages at birth of first child showed that the modal age was between 24 and 26 for men and between 21 and 24 for women (Figure 2). For women, this age range corresponds to the most medically favorable period for reproduction. However, 8.70% of women gave birth to their first child before the age of 15, which could have led to significant health risks, such as difficult deliveries, anemia, or hypertension.

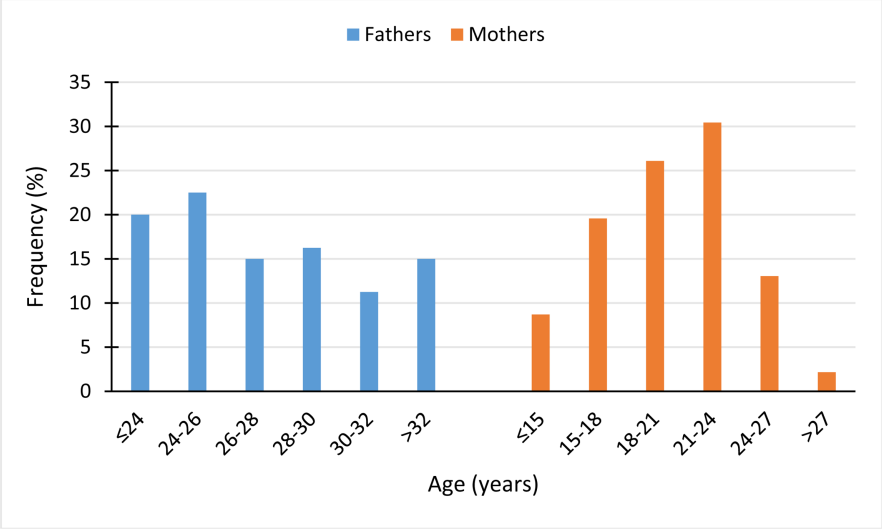

Figure 2. Frequency distribution of parental age at first childbirth among men and women of the Aït Saâdallah.

Among men, the age at which they have their first child is mostly within a range considered optimal, as genetic risks and certain complications in children are generally only significant after the age of 40 - 45, a situation that does not apply to the Aït Saâdallah population.

Information regarding the age of parents at the birth of their first child was relatively limited, with 161 observations for men and 46 for women. The average age at the birth of the first child was 28.5 ± 5.60 years for men, with values ranging from 20 to 57 years, and 20.9 ± 3.57 years for women, ranging from 15 to 28 years (Table 2).

These results reveal a notable difference between the ages of parents at the birth of their first child, which corresponds to the marriage practices of the population, with men generally marrying later than women. Furthermore, the membership

faction has no significant effect ($P > 0.05$) on the age of men and women at the time of the birth of their first child.

Table 2. Average parental age (in years) at the birth of their first child among the Aït Saâdallah.

	Number	Arithmetic mean	Standard deviation	Minimum	Maximum
Fathers	161	28.5	5.60	20	57
Mothers	46	20.9	3.57	15	28

The average age of women at first birth observed in this study is higher than that reported by Baali (1994) among the Amazigh population of the Azgour Valley, near Marrakech, which was 19.25 ± 2.66 years. Furthermore, Dahbi et al. (2024) showed that, in the Souss population, the average age at first marriage is significantly lower in consanguineous unions than in non-consanguineous unions: 19.84 ± 0.38 years for women and 27.16 ± 0.51 years for men in consanguineous unions, compared to 21.34 ± 0.32 years for women and 29.81 ± 0.49 years for men in non-consanguineous unions. These results therefore, suggest that the age of parents at the birth of their first child in these populations is similar to that observed in the present study.

3.3. Age Gap between Spouses

The distribution of age gaps between spouses showed that 12.2% of couples had an age gap of less than 4 years, while 51.3% had an age gap of more than 8 years, suggesting that marriages in Toulal were more often arranged than chosen (**Figure 3**). The average age difference between spouses was 8.95 ± 3.85 years, with values ranging from 3 to 20 years. This asymmetry reflects the community's traditional marriage norms, in which the husband is generally older than his wife. Furthermore, this age gap is not significantly influenced by membership faction ($P > 0.05$).

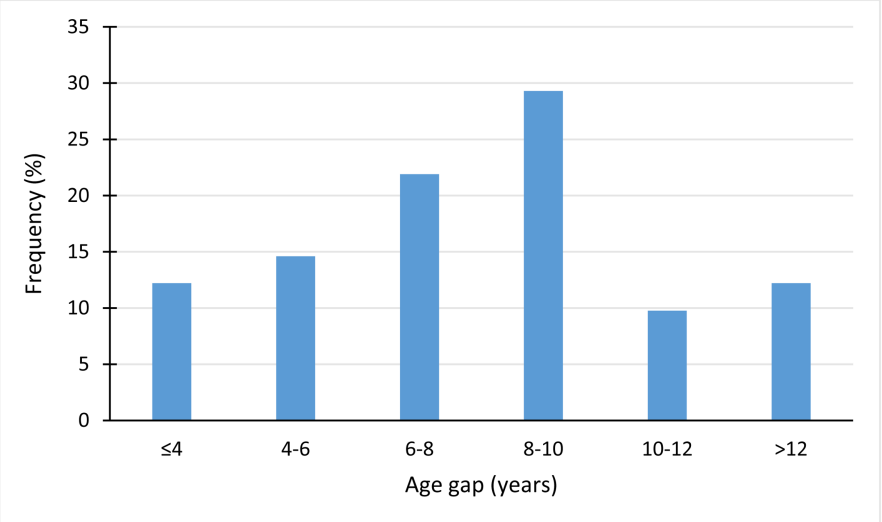

Figure 3. Frequency distribution of age gap between spouses among the Aït Saâdallah.

Hami et al. (2006), Sbii et al. (2008) and Hajjaji et al. (2018) reported an average age gap of approximately seven years between spouses in different Moroccan populations, respectively in the regions of Gharb-Chrarda-Béni Hssen, Souss-Massa-Drâa, and Tetouan-M'diq-Fnideq. Furthermore, Baali (1994) showed that, among the Amazigh population of the Azgour Valley, women in consanguineous couples marry slightly earlier than those in non-consanguineous couples, and that the average age gap between spouses is 7.34 ± 5.38 years for consanguineous couples compared to 10.22 ± 8.75 years for non-consanguineous couples.

The age gap observed in this study is greater than in those studies, which can be explained by the fact that these individuals are not necessarily marrying for the first time. According to Talbi et al. (2006), in the Moroccan population, the younger the bride, the more she tends to be tolerant, flexible, attentive, and permissive towards her husband and in-laws, thus reflecting traditional social and marital norms.

3.4. Intergenesic Intervals

The distribution of intergenesic intervals, defined as the time between two successive births of the same woman, showed that 53.5% of intervals are between 1 and 2 years, 19.1% between 2 and 3 years, 13.7% between 3 and 4 years, and 4.58% between 4 and 5 years. Intervals of more than 5 years were rare and accounted for only 9.12% of the total (**Figure 4**).

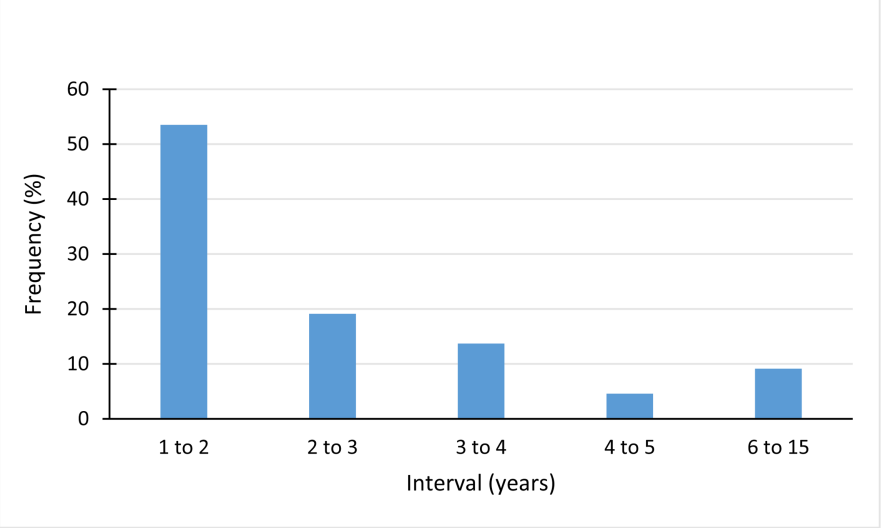

Figure 4. Frequency distribution of intergenesic interval among the Aït Saâdallah.

The high proportion of short birth intervals observed among the Aït Saâdallah, with nearly 60% of births spaced less than two years apart, corresponds to a reproductive profile frequently reported in rural Moroccan populations. National population and family health surveys show that in rural areas, the average birth spacing generally remains between 2.5 and 3 years, linked to high fertility and limited use of modern contraceptive methods (HCP, 2011).

Conversely, long intergenesic intervals could be associated with specific situations, particularly births resulting from remarriage, but also with social or biological factors such as widowhood, migration of the spouse, or secondary infertility.

The intergenesic interval was calculated based on 284 births. Its average value was 3.13 ± 1.96 years, with extremes ranging from 1 to 15 years (Table 3). This average corresponds to an intergenesic interval that is generally considered satisfactory, as it allows the mother sufficient time to recover physically after giving birth, helps reduce the risk of complications during the next pregnancy, and promotes better health for the newborn.

Table 3. Intergenesic intervals among the Aït Saâdallah according to membership faction.

Faction	Number	Arithmetic mean	Standard deviation	Minimum	Maximum
Aït Messaoud	171	3.10	1.84	1	15
Aït Ouaârab	113	3.17	2.15	1	14
All	284	3.13	1.96	1	15

Within the groups studied, the average intergenesic interval was slightly higher among the Aït Ouaârab (3.17 ± 2.15 years) than among the Aït Messaoud (3.10 ± 1.84 years). However, this difference is not statistically significant ($P > 0.05$), indicating homogeneity in reproductive behavior between the two groups.

3.5. Lifespan

The frequency distribution indicated that 21.8% of Aït Saâdallah die before the age of 50, with 22.7% among men and 18.9% among women. Conversely, 63.9% of individuals live beyond the age of 60, including 60.0% of men and 75.7% of women (Figure 5). The main factors influencing longevity include living conditions, access to healthcare, nutrition, and the environment.

The lifespan of individuals from the Aït Saâdallah tribe for whom birth and death years are available averaged 66.2 ± 18.9 years, with values ranging from 16 to 98 years, indicating a generally relatively long life expectancy (Table 4). This significant variability reflects both historical health conditions and the diversity of living conditions within different generations. Lifespan is significantly influenced by gender ($P < 0.05$), but not by membership faction ($P > 0.05$). Women had a higher lifespan than men, with an average difference of 6.9 years (Table 4), an observation consistent with general demographic trends.

The cohort-based analysis revealed a clear improvement in lifespan over time. Individuals born before 1920, between 1920 and 1950, and between 1950 and 1980 had mean lifespans of 55.4 ± 16.9 years, 69.0 ± 15.3 years, and 70.2 ± 20.6 years, respectively. This increase in lifespan likely reflects historical improvements in healthcare and living conditions. Before 1920, medical care relied largely on traditional medicine, whereas after this period, hospitals were progressively established in Meknes, initially during the French Protectorate and later by the Moroc-

can government following independence, facilitating access to modern medical treatments and contributing to reduced mortality.

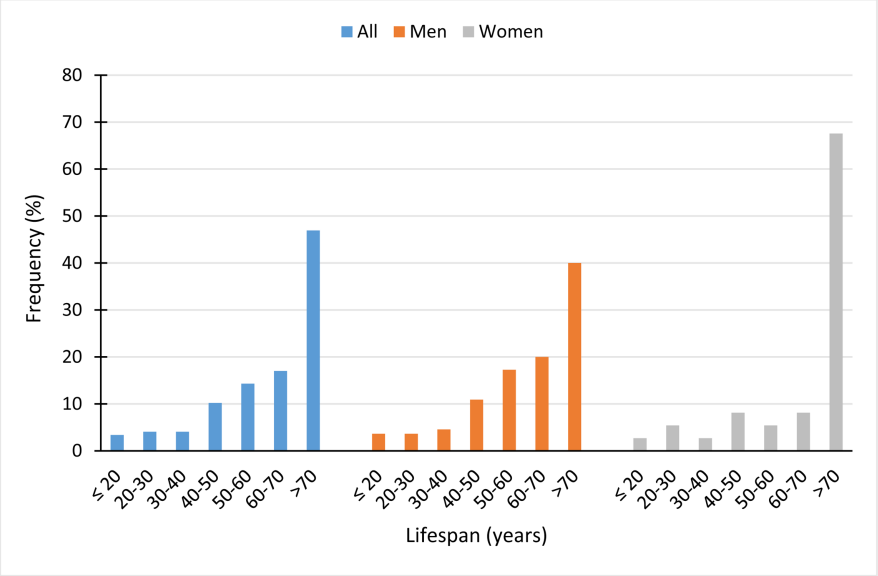

Figure 5. Frequency distribution of lifespan among the Aït Saâdallah.

Table 4. Average lifespan (in years) of individuals in Aït Saâdallah by gender.

Variable	Number	Arithmetic mean	Standard deviation	Minimum	Maximum
Men	109	64.4	19.0	16	98
Women	37	71.3	21.1	18	97
All	146	66.2	18.9	16	98

3.6. Family Relationships and Inbreeding Coefficients

Family relationships, which refer to all the ties that bind individuals of the same family through blood, marriage or filiation, were particularly strong within the Aït Saâdallah community (**Figure 6**). A total of 1099 kinship relationships, both close and distant, were identified among individuals with known parentage. This high density of ties can be explained by the community lifestyle; meals are often shared in the parents' home with all family members, and mutual aid prevails during agricultural work, as well as by the spatial grouping of houses belonging to the same large family (brothers, uncles, cousins, etc.). These conditions reinforce blood ties, which are highly valued and central to the culture of the Aït Saâdallah.

Family endogamy accounted for a significant proportion of marriages among the Aït Saâdallah, with 316 marriages between parallel patrilateral cousins and 21 between parallel matrilateral cousins, while no marriages between cross-cousins were observed. This trend can be explained by the fact that, from their settlement in Toulal around 1865 until the mid-20th century, marriages were mainly intra-family and intra-factional, and sometimes inter-factional within the locality. Ex-

ogamous marriages only began to appear in the second half of the 20th century. Intrafamilial and intra-factional unions were seen as a means of strengthening marital stability, ensuring compatibility between spouses, promoting a favorable family dynamic, providing emotional and financial security, and preserving land ownership by avoiding the division of land and concentrating inheritance within the same lineage.

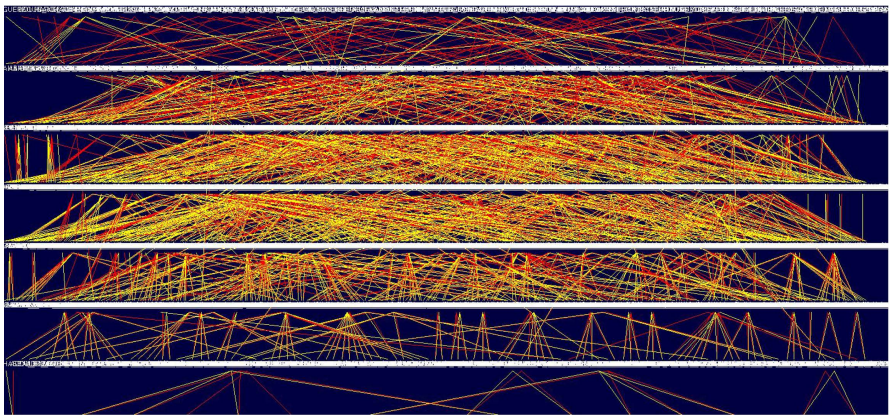

Figure 6. Family relationships among the Aït Saâdallah (male lines in red, female lines in yellow).

The proportion of inbred individuals, i.e., those whose father and mother share one or more common ancestors, whether close or distant, represented 10.2% of the total population of the Aït Saâdallah. The distribution of inbreeding coefficients (F) showed that 68.6%, 27.6%, 1.92%, and 1.92% of inbred individuals had an F ≤ 4%, between 4 and 8%, between 8 and 12%, or greater than 12%, respectively (Figure 7).

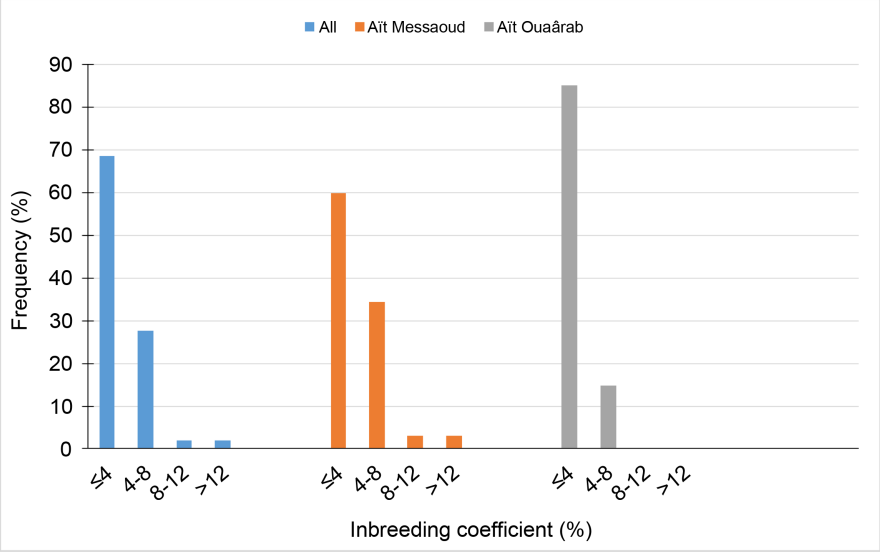

Figure 7. Frequency distribution of the inbreeding coefficient among inbred individuals in Aït Saâdallah.

The last two categories are only found in the Aït Messaoud faction, indicating that very close intra-family unions are particularly frequent there. The distribution was heterogeneous, with some very high values (F ≥ 12%) corresponding to close unions, such as those between first cousins or even double first cousins. These individuals have loci containing identical alleles by descent, which constitutes an increased risk factor for the appearance of hereditary abnormalities and reduced biological capacities.

Overall, the existence of a significant level of endogamy is consistent with population genetics research, which shows that small, isolated rural communities tend to gradually accumulate moderate levels of consanguinity, even in the absence of recurrent marriages between close relatives, due to their small effective population size (Falconer & Mackay, 1996).

The average inbreeding coefficient for all 1533 individuals in the Aït Saâdallah population, calculated from genealogies, was 0.00346 ± 0.01372, with values ranging from 0 to 0.15625. For inbred individuals alone, this coefficient averaged 0.03398 ± 0.02859, ranging from 0.00391 to 0.15625 (**Table 5**), indicating the occasional occurrence of highly inbred marriages within the study population.

These results also reflect the traditionally endogamous family structure of the Aït Saâdallah, characteristic of many rural Moroccan communities, based on geographical proximity, lineage alliances, and socioeconomic constraints. The maximum coefficient of inbreeding was observed among children born to parents who were double first cousins and grandparents who were first cousins.

Table 5. Average coefficient of inbreeding among inbred individuals in the Aït Saâdallah according to membership faction.

Faction	Number	Arithmetic mean	Standard deviation	Minimum	Maximum
Aït Messaoud	102	0.03964	0.03099	0.00391	0.15625
Aït Ouaârab	54	0.02329	0.01955	0.00391	0.06250
All	156	0.03398	0.02859	0.00391	0.15625

The coefficient of inbreeding was significantly influenced by the membership faction ($P < 0.001$), but not by the sex of individuals ($P > 0.05$). Among the Aït Messaoud, where many intra-factional marriages were observed, the average inbreeding coefficient of inbred individuals was higher than among the Aït Ouaârab (0.03964 ± 0.03099 versus 0.02329 ± 0.01955, respectively) (**Table 5**). The relatively large standard deviations in both groups reflect a notable heterogeneity of unions, with the coexistence of weakly and strongly endogamous families.

Many authors have reported apparent inbreeding coefficients (Ca) calculated using the following formula:

$$Ca = 1/8\,Fdcg + 1/16\,Fcg + 1/32\,Fci + 1/64\,Fcig$$ (Talbi, 2008),

where Fdcg, Fcg, Fci and Fcig correspond to the frequencies of unions between double first cousins, first cousins, unequal cousins and second cousins, respectively.

Using the previous formula, the inbreeding coefficients reported in different regions of Morocco are as follows: 0.0399 in the population of Fritissa (Middle Atlas) (Latifi et al., 2004), 0.0114 in the High Atlas near Marrakech (Cherkaoui et al., 2005), 0.0075 in the Gharb-Chrarda-Beni Hssen region (Hami et al., 2008), 0.0166 in Doukkala (Talbi, 2008), 0.02033 in the Tangier-Tetouan region (Hardouz et al., 2014), 0.0564 in Tiflet (Zhour et al., 2016), 0.00804 in northern Morocco (Habibeddine et al., 2018), 0.01381 in Oriental (El Ouardani et al., 2019), 0.0122 in Chaouia (Cheffi et al., 2022), 0.0119 in Agadir (Bouadil & El Madidi, 2022), 0.019 in Doukkala (El Khair et al., 2023), 0.0117 in Souss (Dahbi et al., 2024), and 0.01459 in Settat (El Goundali et al., 2025).

The inbreeding coefficient reported in this study is also comparable to those obtained in other countries. It is 0.02265 in the population of the Riyadh region in Saudi Arabia (Al Husain & Al Bunyan, 1997), 0.0356 in the population of the Okara region in Pakistan (Nawaz et al., 2021), and varies between 0.0084 and 0.0216 in different regions of Tunisia (Mezzi et al., 2024).

Thus, the average coefficient of inbreeding observed among the Aït Saâdallah of Toulal ($F \approx 0.04$) falls within the range of values reported for other Moroccan and foreign communities with high levels of endogamy, even though, in general, the coefficient of inbreeding based on inbred marriages is higher than that based on genealogy (Latifi et al., 2004).

Furthermore, El Goundali et al. (2025) showed that levels of consanguinity were closely linked to traditional marriage practices, age at marriage, level of education, place of residence (rural or urban), and socioeconomic status. Similarly, Ossmani et al. (2018) reported that the inbreeding coefficient in northern Morocco reached 0.00890 in urban areas and 0.00766 in rural areas, highlighting the influence of the socio-spatial context on marriage behaviors.

The consequences of inbreeding on the health and reproduction of offspring are well documented. Consanguinity leads to a decrease in heterozygosity and an increase in homozygosity, including for deleterious recessive alleles, thereby promoting the expression of certain genetic abnormalities. In this study, 50% of individuals of both sexes belonging to the family with the highest inbreeding coefficient ($F = 0.15625$) are affected by a hereditary abnormality characterized by progressive locomotor impairment beginning in adolescence and leading to death between the ages of 30 and 40. The affected individuals are currently living and well identified within the community. Clinical information is based on concordant oral reports from the individuals' close relatives, in the absence of medical records, clinical examinations, or molecular analyses. Based on age at onset, symptom progression, apparent mode of transmission, and high consanguinity, the condition is compatible with an autosomal recessive hereditary ataxia. This interpretation remains provisional.

Other studies conducted in Morocco corroborate these observations. Cheffi et al. (2022) showed that the average number of pregnancies and spontaneous abortions was significantly higher in inbred unions than in non-inbred unions among

the Chaouia population. Similarly, El Khair et al. (2023) reported that inbreeding has deleterious effects on fertility and fecundity, while increasing the risks of congenital malformations, stillbirths, infant mortality, morbidity, and intellectual disability. It is also associated with impaired cognitive abilities and the onset of conditions such as deafness, congenital heart disease, various physical and psychological disabilities, and certain neuropsychiatric disorders, including epilepsy, schizophrenia, and bipolar disorder.

The average coefficient of inbreeding among the Aït Saâdallah population showed a gradual change over generations. It was zero among great-great-grandparents and great-grandparents (born before 1920), then reaches 0.295% among grandparents (born before 1950), 0.796% among parents (born before 1980), and 1.884% among individuals born after 1980 (**Figure 8**). The average increase observed over the entire period studied was 0.00490 ± 0.00057, indicating a gradual intensification of inbreeding from one generation to the next within the Aït Saâdallah community.

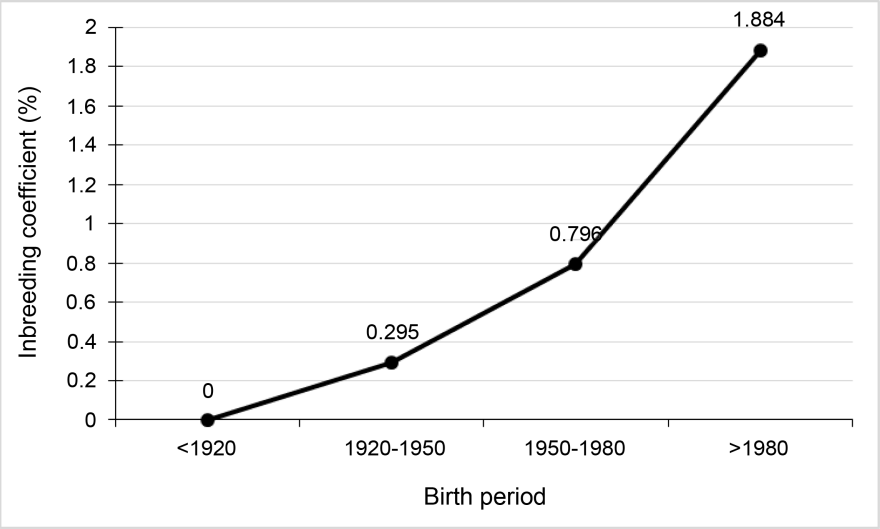

Figure 8. Evolution of the inbreeding coefficient in the entire population of the Aït Saâdallah.

Among inbred individuals, the average coefficient of inbreeding also showed a gradual increase over generations. It was zero among great-great-grandparents and great-grandparents (born before 1920), then rose to 2.399% among grandparents (born before 1950), to 3.195% among parents (born before 1980), and reached 5.388% among individuals born after 1980 (**Figure 9**). The average increase observed over the entire study period was 0.01329 ± 0.00393, reflecting a marked increase in inbreeding among the individuals concerned.

The average coefficient of inbreeding is a synthetic indicator of the level of genetic relatedness associated with inbred unions. In this regard, our results are consistent with those of Hajjaji et al. (2018), who, in an intergenerational analysis, found a significant increase in the proportion of inbred marriages, from 15.4% in the grandparents' generation to 25.4% in the couples studied, representing an increase of approximately 10%.

Figure 9. Evolution of the inbreeding coefficient among inbred individuals of the Aït Saâdallah.

However, our observations differ from those reported by Hami et al. (2005) and Talbi et al. (2007) in the Kenitra region, where the authors found a slight decrease in marriages between first cousins, offset by an increase in unions between more distant relatives. They also disagree with the findings of El Khair et al. (2023), who found a clear decline in the overall rate of inbred marriages in the Doukkala population, with a decrease of 6.73% between the periods 1924-1947 and 1996-2019, and a more marked reduction (24.18%) in recent periods (1972-1995 to 1996-2019).

These differences highlight the decisive role of local historical, social, and cultural contexts in the evolution of marriage practices and levels of inbreeding observed among Moroccan populations.

4. Conclusion

Analysis of the Aït Saâdallah population revealed a dense family structure, high fertility, gender-differentiated lifespan, and a moderate level of inbreeding. These characteristics reflect the demographic history, marriage practices, and traditional endogamy specific to this Amazigh community.

Furthermore, the coefficient of inbreeding showed a gradual increase from the generation of great-great-grandparents and great-grandparents to that of children, reflecting the persistence, or even strengthening, of an ancient matrimonial tradition based on unions between individuals who are closely or distantly related. As a result, the proportion of loci carrying identical alleles by descent tends to increase from one generation to the next among descendants of inbred marriages, suggesting an increased risk of abnormalities and hereditary diseases, as well as a possible reduction in fertility and reproductive lifespan.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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