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Role of sex as evolutionary factor from genotype to phenotype

Bruno Riccardi [1,*], Sergio Resta [2], Giacomo Resta [3] and Caterina Mondovecchio [4]

[1] *Biologist freelance, Pisa, Italy.*
[2] *Surgeon freelance, Siena Italy.*
[3] *Department of Pharmaceutical sciences Faculty of Farmacy, Perugia University, Italy.*
[4] *Faculty of Biology Perugia University, Italy.*

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Abstract

We know different forms of reproduction adopted by living beings, from the simple division of the protozoa, to the complex and modalities of the vertebrates that contemplate codified rituals and preliminary preparations before arriving at the mating.

In nature there is a wide range of reproductive modalities, which is as numerous as the living species. Every reproductive system has a specific procedure and a sexual dimorphism finalized to favor the coupling and strictly suitable for the ecosystem where the union of the sexes takes place.

Such a close relationship between living and environment is a consequence of the evolutionary process in which both share. But the ability to respond to random environmental variations for adapting and evolving with them is an exclusive characteristic of the living, thanks to the reproductive process mediated by sex.

So sexual reproduction is the real engine that promotes evolution.

The infinitely complex way in which sex acts is a subject that always has attracted biologists, and Darwin, with his work on the evolution of the living, was the first to investigate this phenomenon, inaugurating research, which still today has many obscure points.

By this manuscript we are going to try to contribute to the solution of this intriguing mystery.

Keywords: Reproduction; Gametes; Sexual evolution; Sexual dimorphism; Gender behavior

1. Introduction

Reproduction is the primary purpose of life for all living organisms.

The peculiarity of the reproductive function is such as to ensure, within each species, the achievement of the characteristics best suited to their survival and reproduction in each environment.

By the reproduction every living form can modify and experiment infinite possible solutions, for adaptation to its own ecosystem [1-2].

* Corresponding author: Bruno Riccardi

This has been possible because living matter has been able to select, among the infinite forms produced by evolution, those capable of reproducing and modifying genetic heritages.

The achievement of reproductive efficacy and diversification has occurred with the transition from elementary to more complex forms of life with the formation of the reproductive systems and the separation of the sexes, and with the acquisition of specialized reproductive strategies.

Thus, in vertebrates' sexual reproduction follows complex stages and rituals that precede mating, and are as follows:

- Mark the territory.
- Struggle and competition between mature individuals for the exclusive conquest of the sexual partner.
- Choice and selection of the partner, with the ritual of courtship.
- Mating and fertilization.

Finally, parental care, this stage ensures the survival of the offspring after conception.

Then someone understands the importance of sexual reproduction, if someone considers that on it depends on the possibility of recombination of the genotypes and their transmission to subsequent generations, which is achieved by mating.

Natural selection includes all living forms, animals and plants that share the same ecosystem, and has favored the strategy for the diffusion of gametes, with which plants and animals benefit from each other (Interspecific Mutualism).

In nature there are countless examples of this cooperative bond aimed at reproduction, and it is so specialized and indissoluble, that the extinction of an animal species, involves the extinction of the related plant species. Typical is the case of the massacre of bees produced by pollution and pesticides introduced into agriculture, which puts at risk the survival of many plant species.

At the same time there has been a specialization in animals and plants, in the manifestation of individual stages and reproductive modes that we will describe later.

Each living species adopts its own strategy for reproductive purposes that, with the help of natural selection, adapts to environmental variations; it is in this sense that reproduction has played a primary role in the evolution of the living.

In this context all other vital essential activities such as nutrition are functional to the achievement and completion of reproduction.

2. The differentiation of the sexes

Sex is the result of the interrelation of various components: chromosomal, gonadic, phenotypic, hormonal and behavioral, we are going to describe these aspects better in the rest of the article.

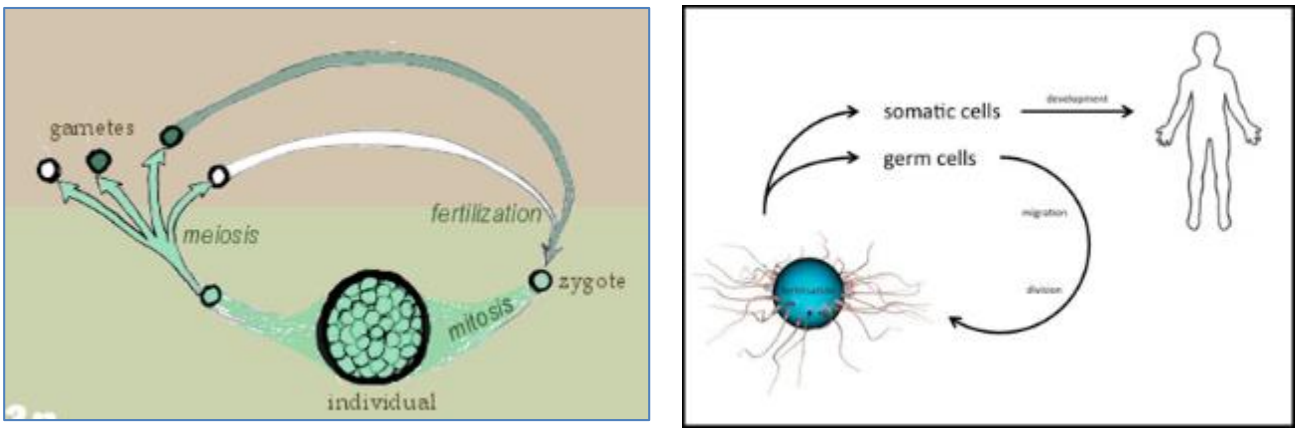
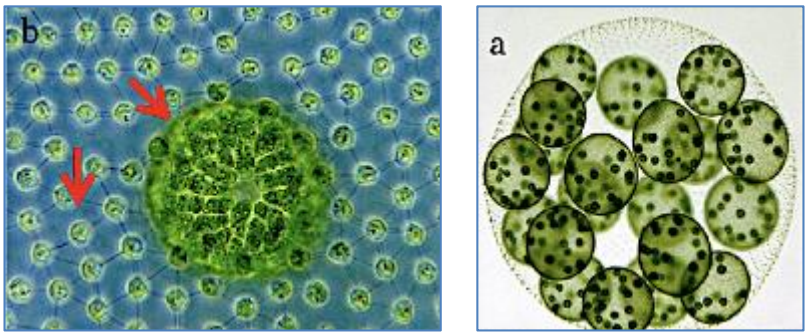


Figure 1 Subdivision scheme between somatic and germinal line

In the early stages of evolution there was a specialization and differentiation between the cells that form the soma and the cells that form the gametes, that is between the somatic line (the phenotype), formed by the organs that make up the body, and germinal line, represented by the reproductive organs Fig.1

In eukaryotic organisms (with nucleus) the two cell lines belong to the same individual, and in the primitive eukaryotic forms it is difficult to distinguish them from each other Fig.2-.



A B

Figure 2 A) Colonies of Volvox mature, B) somatic cells connected by cytoplasmic bridges and gonidium (reproductive structure) indicated by arrow. From www.astrobio.net, www.microscopy-uk.org.uk

As evolution progressed, differentiation took place between the phenotype apparatuses, also called vegetative, and reproductive apparatuses, up to the separation of the sexes in male and female individuals, having distinctive sexual dimorphism characteristics. Fig.3.

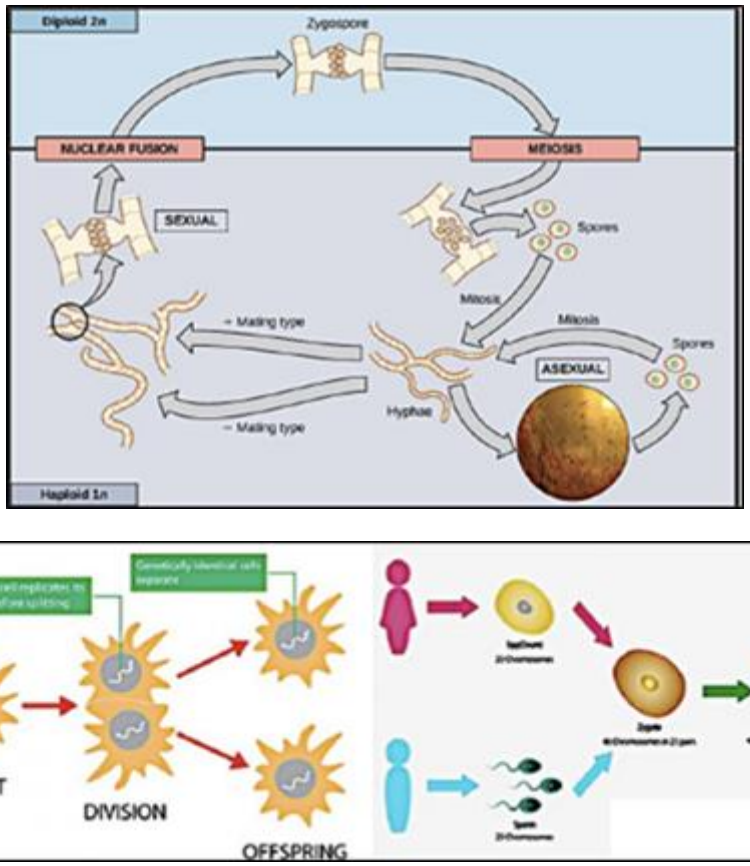


Figure 3 Reproductive cycle between asexual phase and sexual phase with the intervention of gametes

How has sexual reproduction affected the evolution of the living?

An important factor influencing evolution is closely linked to the random variability inherent in the genetic heritage of the living and its ability to adapt to the environment.

To this was added the variability produced by the recombination of genes resulting from sexual reproduction. In this way exponentially multiplied the effects obtainable with the only spontaneous variations, mutations.

The adaptation to the environmental transformations by the living is not unidirectional, in the sense that the adaptive variations take place not only in the realm of the living, but also the living have an active role in environmental transformations. There is a two-way reciprocal correspondence between living and environment within an ecosystem.

The powerful influence that the environment has on living beings has been known for centuries and the work of Charles Darwin "On the origin of species" has masterfully documented the fundamental role that the environment plays in the selection and natural evolution of life [3].

In an ecosystem, there are always three physical quantities, which in addition to exerting an effect of mutual transformation between them, at the same time modify the environment in which they operate: matter, living been and environment, which are schematically represented in the following diagram Fig.4.

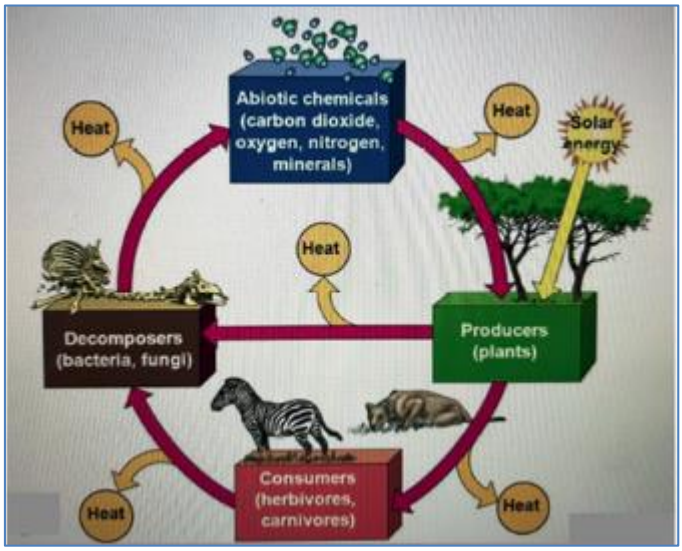


Figure 4 Flow between living beings matter and environment

Let us think of the importance of cyanobacteria and primordial algae in the production of atmospheric oxygen in the primordial stages of terrestrial evolution, or the activity of corals in the formation of coral reefs, and the infinite other environmental modifications resulting from the activity of living beings.

An index of this close bond is detectable in the evolution of the parasitic forms and their hosts, so that the transformations of the host, determine the adaptive modifications of the parasites. Bacterial resistance to antibiotics is currently a major health problem.

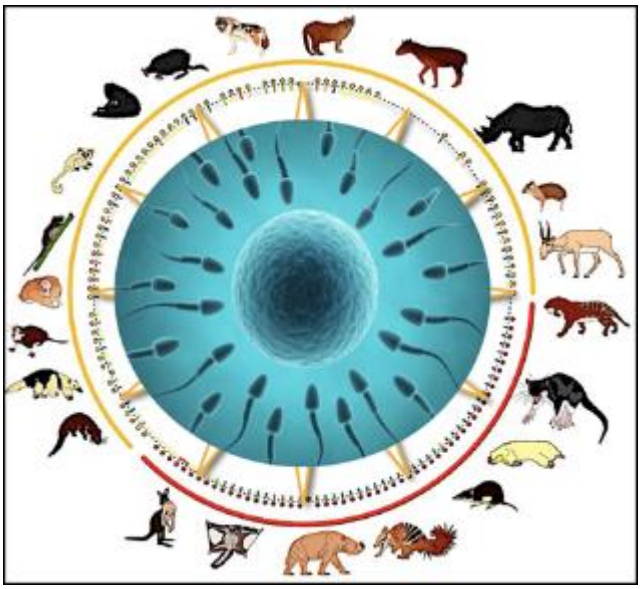
In fact, the very close link between living beings and their ecosystem is indissoluble and every transformation that takes place in one of the livings has heavy repercussions on the other.

Today we are experiencing in all its drama, the negative effects of the environmental changes produced by pollution, on the survival of many animal species.

3. Role of sex in animal and human evolution

The evolution of living organisms is a continuous process, and is the result of the infinite reproductive, asexual and sexual modes experienced by the living [5].

The freedom to go all the way to achieve reproductive effectiveness, in all its forms, probably has not expressed the best possible solution yet. However, the immanent search for the optimal solution involves all the living, to amplify and accelerate to the maximum degree all the possible combinations Fig.5.



From : https://twitter.com/grumpyDrFabre/status/1387305198557794304 Anne-Claire Fabre grumpy DrFabre fediscience.org

Figure 5 Differences in reproductive strategies in mammals have influence the morphological evolution.

A first fundamental step occurred with the birth of the favored sexual reproduction compared to the simple asexual reproduction that does not involve the union of two gametes and the genetic recombination.

In addition to the separation of the sexes, an important factor that contributed to evolution was the type of fertilization, which occurred with the transition from external fertilization to internal fertilization.

In the most primitive forms of life, reproduction occurs with the emission of thousands of gametes in the external environment, and their union is entrusted to chance.

This entails a greater risk that the reproduction of the offspring will be successful but is compensated by the high number of fecundated eggs and the possibility that a substantial number of offspring will survive.

In any case, the consequence of this mechanism is the fact that the high number of gametes produced, and the resulting fertilizations increase the assortment and recombination of genes, a decisive factor for evolutionary purposes.

It should be noted that the contribution of both sexes to the assortment and the number of gametes is equal.

The evolution towards more complex organisms has involved a radical modification in the type of fertilization, which has taken the safest and most effective form of internal fertilization.

But also in this case there has been a transformation, especially as regards the number of the male and female gametes involved in the fecundation.

In fact, females normally produce only one egg, while males produce billions of sperm, which will have to compete to reach and fertilize the egg. On a microscopic scale, the eternal struggle for the survival of the most suitable through selection is proposed again.

3.1. Sex determination

Historically, sex determination has been defined as Progamica, Singamica, or Epigamica, depending on whether sex was determined before, during, or after fertilization. This distinction retains only a descriptive meaning but has lost value with recent acquisitions on the subject.

In the meantime, we must say that sex is subject to numerous influences in its determinism and may or may not manifest distinctive morphological characteristics. When these characteristics are evident, we speak about secondary sexual manifestations or characters, for which it is possible to distinguish the males from the females, according to the shape of the reproductive apparatuses or other phenotypic manifestations (sexual dimorphism).

But what are the determinants of sex?

The determination of the sex in the various species can take place with multiple mechanisms, which vary according to the species and the stage of development of the individuals.

3.2. Chromosomal and genetic factors

The first recognized causes for the determination of sex resulted from the observation that the sexes depended on the different presence and shape of the chromosomes, of which only one pair, the heterosomes or sex chromosomes, present different in the two sexes, while the others, called autosomas, are implicated in other phenotypic expressions [6]

In most vertebrates, including men, sex chromosomes are distinguished in X and Y, the presence of two equal X chromosomes, or XX, determines the female sexual character, while the presence of two different XY chromosomes, determines the male sexual character.

According to these observations, males determine sex because they can form, during meiosis, two different gametes (spermatozoa) containing only the X chromosome or only Y, while females produce only gametes (oocytes) of a single type containing X chromosomes. In some animal species the sex chromosomes are indicated differently, with ZW males and with ZZ females, Fig.6.

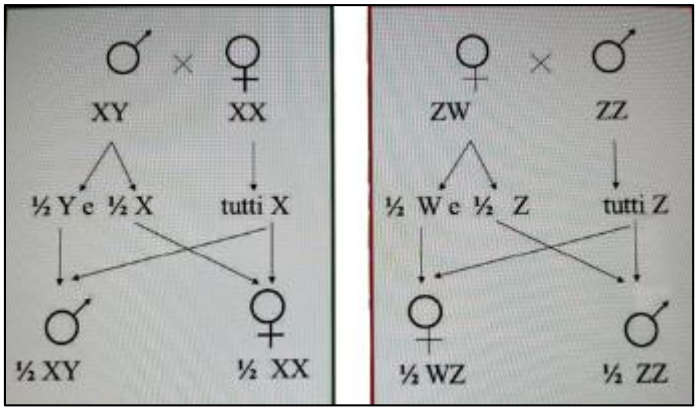


Figure 6 Chromosomal determination of sex

To put this hypothesis in crisis have been the observations of individuals in which the presence and the distribution of the chromosomes turned out different from the normal, of type XXY, X0, XXX, that determine dysfunctions not only in the expression of the sexual dimorphism, but also on other important phenotypic characters.

The presence of several abnormalities in sexual characteristics, not directly related to the karyotype, according to the classical concession, has led to the search for other factors responsible for sexual differentiation [7].

In addition, sex hormones also have an important role in directing the morphological or functional differentiation of the gonads, both in the embryonic phase, and in the pubertal and adult phase.

To complicate the understanding of the role of the two sexes in reproduction, there are observations that some animals can generate offspring without the need for sexual union. In this case the female can perform perfectly the reproductive task. This process, which is called parthenogenesis, consists in the fact that the egg does not undergo meiosis, with the halving of the chromosomes, and produces diploid oogons from which the whole organism develops. Typical examples are found in Comodo dragons that reproduce predominantly in this way. In these cases, the contribution to the evolution of the species is almost nil. In fact, the dragons of Comodo are considered ancestral organisms, real living fossils that have maintained the same characteristics they had in the Paleozoic ages.

In recent years, molecular biology studies have contributed to a thorough knowledge of the biochemical aspects involved in sex determination. They have revealed the presence of numerous genes, which, acting on the DNA of the sex chromosomes, control their functioning and consequently the epigenetic modifications at the embryonic level, during the differentiation of the gonads, and at the phenotypic level after birth [8-9].

This is not the place to delve into the description of all the genes and gene determinants involved in the differentiation of the sexes, for example we report a table that lists the most important genes that come into play in various animal species, Tab. 1.

Table 1 Sex-determining genes in vertebrates and insects, and their paralogs

Species	Master sex determining gene	Sex-determining mechanisms	Gene paralog	Paralog function
mammals	*Sry*	sex-determining Y	*Sox3*	HMG-box transcription factor
chicken (*Gallus gallus*)	*dmrt1*	dose-dependent Z	-	SD pathway transcription factor
African clawed frog (*Xenopus laevis*)	*dmW*	sex-determining W	*dmrt1*	SD pathway transcription factor
medaka (*Oryzias latipes*)	*dmrt1Y*	sex-determining Y	*dmrt1*	SD pathway transcription factor
(*Oryzias luzonensis*)	*gsdfY*	sex-determining Y	*gsdf*	secretory protein in SD pathway
Patagonian pejerrey (*Odontesthes hatcheri*)	*amhY*	sex-determining Y	*amh*	anti-Mullerian hormone
rainbow trout (*Oncorhynchus mykiss*)	*sdY*	sex-determining Y	*Irf9*	interferon regulatory factor
tiger pufferfish (*Takifugu rubripes*)	*amhr2*	dose-dependent X	*amhr*	anti-Mullerian hormone receptor
smooth tongue sole (*Cynoglossus semilaevis*)	*dmrt1*	dose-dependent Z	-	SD pathway
fruit flies (*Drosophila*)	*Sxl*	dose-dependent X	*CG3056*	mRNA splicing, non-sex specific
housefly (*Musca domestica*)	*F*	sex-determining W	*tra*	SD pathway switch splice factor
silkworm (*Bombyx mori*)	*Fem*	sex-determining W	-	piRNA
honeybee (*Apis mellifera*)	*csd*	haplodiploid	*tra*	SD pathway switch splice factor
wasp (*Nasonia vitripennis*)	*Nvtra*	haplodiploid	*tra*	SD pathway switch splice factor

Recent studies have also shown that not all sex chromosomes change in their activity on sexual dimorphism and what is even more surprising, many genes present on autosomal chromosomes contribute to the differentiation and definition of sex [10-11-12].

We should also note that chromosome and gene aberrations not only affect the primary and secondary aspects of sex, but more generally also produce degeneration and dysfunction on other organs and systems, demonstrating that living beings form a complex, unified and coordinated organism, and cannot be considered, reductively, as the expression of individual aspects, without altering their essence.

This completely changes the paradigm and view of sex differentiation as a result of the activity of individual chromosomes or genes, and suggests a holistic, unitary view of the phenomenon.

3.3. Sex in the evolution of man

We have previously described how sexual differentiation has been functional to the evolutionary process of the living, as regards the role of chromosomes and genes in the biological determinism of the genotypes of the two sexes.

One aspect that we must consider in order to complete the overall vision of the role of sex, are the behavioral implications following the biological differentiation of the sexes themselves, and of their relevant importance for the evolution and conservation of the species.

Apparently, the description of sexual behavior is easier to understand, and it would seem almost the direct derivation of innate genetic factors that guide the living in interactions with their fellow humans and with the environment.

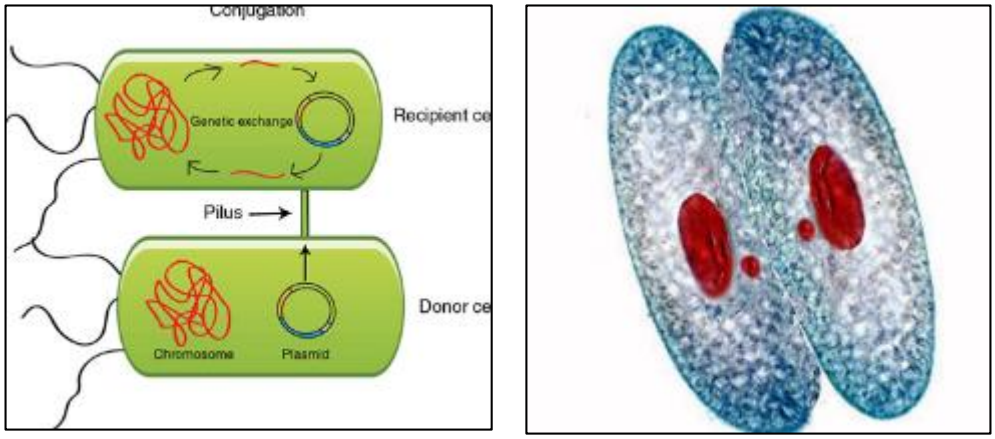
The behaviors that we observe in fact, follow codified rituals activated and stimulated by hormones that come into action with a frequency and repetitive temporal periodicity, influenced by seasonal or environmental variations.

Made the necessary distinctions for the different animal species, during the oestrum and the periods of fecundity the females produce hormones that stimulate the call and the irresistible attraction of the males that start the bloody competitions, even before reaching the reproductive territory, to win the fertile females.

Hormones are the same as in all mammalian and other animal species. Typically, they are testosterone in males and estrogen in females and together with pheromones help guide courtship and foreplay behaviors that precede actual mating.

How did the evolution of the reproductive mechanism take place, from the primordial presence of spermatozoa and of the egg, to a biologically differentiated system to favour the encounter of gametes?

In the simplest organisms, bacteria and protozoa, reproduction occurs asexually or by binary splitting, without the mediation of the gametes (except for the bacteria that use forms of gene exchange by means of plasmids), Fig. 7.



A B

Figure 7 Bacterial conjugation A) and division in protozoa B)

With the evolution towards more complex reproductive forms and the separation of sexes in males and females, it has become essential to devise a mechanism to facilitate their mating.

For this purpose, the evolutionary mechanism has produced specialized structures of neuronal networks, capable of responding to specific stimuli of the two sexes and facilitating their encounter.

From the biological point of view, the somatic component of the living functions only as carrier of the genetic codes contained in the gametes and must favor its fusion with the coupling.

From the biological point of view, the somatic component of the living functions only as carrier of the genetic codes contained in the gametes and must perform the task of favoring their fusion with the coupling.

This has been possible with the evolution of the neurosensory system able to produce an adaptive response to environmental changes, and above all suitable to promote the encounter and union between the sexes.

Among the stimuli present in the environment, those of a sexual nature are fundamental for the conservation and reproduction of the species, therefore the selection has favored the neuronal networks capable of perceiving them and translating them into suitable behaviors to favor the meeting of the gametes.

In addition, the contribution of neurosensory systems to reproductive purposes has been so important that it has produced nervous structures sensitive to sexual stimuli and able to translate them into mating behaviors.

In addition, the contribution of neurosensory systems to reproductive purposes has been so important that it has produced nervous structures sensitive to sexual stimuli and to translate them into behaviors aimed at mating.

The effective stimuli endowed with these properties are of a chemical nature (hormones and odors), of an electromagnetic type (the colors of the livery), or in the form of sound calls produced by the rituals of courtship.

In humans, the evolution of the brain has developed the ability to respond with very complex behaviors to sexual stimuli, which have played an essential role in the history of customs and social culture.

The infinite and varied ways in which men express normal or "deviant" sexual tendencies and behaviors has profoundly changed traditional habits, producing an extremely diverse socio-cultural evolution in the various countries.

There are several hypotheses formulated to understand what and what causes the sexual choices and behaviour in different societies [13].

There are learned arguments about the differences between biological and gender sex (the latter being the expression of biological sex in the many social and psychosexual behaviours), and about the causes that can modify and translate them into different external manifestations [14-15] Fig.8.

Figure 8 Scheme of difference of meanings between sex and gender

According to the Canadian Institutes of Health Research, sex' and 'gender' are often used interchangeably, despite having different meanings:

"Sex refers to a set of biological attributes in humans and animals. It is primarily associated with physical and physiological features including chromosomes, gene expression, hormone levels and function, and reproductive/sexual anatomy. Sex is usually categorized as female or male but there is variation in the biological attributes that comprise sex and how those attributes are expressed.

Gender refers to the socially constructed roles, behaviors, expressions and identities of girls, women, boys, men, and gender diverse people. It influences how people perceive themselves and each other, how they act and interact, and the distribution of power and resources in society. Gender identity is not confined to a binary (girl/woman, boy/man) nor is it static; it exists along a continuum and can change over time. There is considerable diversity in how individuals and groups understand, experience and express gender through the roles they take on, the expectations placed on them, relations with others and the complex ways that gender is institutionalized in society.

A heated debate is ongoing on the definition of sex as a binary phenomenon, i.e. as male and female, as various research reveals that there are several events that affect sexual differentiation and the way of being male, female, or both, not exclusively attributable to the different factors, genetic, hormonal, environmental described above [16-17].

The argument that sexes is not binary in man is supported by the widespread use in different parts of the world of surrogate motherhood and medically assisted fertilization, irrespective of traditional sexual mating [18].

However, it cannot ignore the union of the two biologically active male and female gametes.

If from a formal point of view this is true, however, there is a distinction of the sexes derisively from the point of biological life, and it is the classic definition of species to which all the interfecond subjects belong; that is, whatever the phenotypic aspect of the two sexes, these must be effective in the reproduction of fertile intraspecific generations.

Therefore, the discrimination between the two sexes could be defined from the point of view of reproductive effects, that is, there are two distinct sexual characteristics if two individuals are able to mate and give a fertile offspring capable of reproducing themselves.

Because in the end what matters from an evolutionary point of view is the ability to reproduce and preserve the species.

Ultimately, the multiple manifestations of the sexual phenomenon, in all its social forms, are the result of the millennial evolutionary process, which is not only biological but also cultural.

And they have profoundly changed the perception and judgment of value, merit, approval or blame that we express on people with uncommon gender behavior, and we catalogue them with our not always objective assessments [19-20].

4. Conclusion

In conclusion, if the understanding of the biological and evolutionary aspects of sex seems complex and scientifically controversial, their effects on socio-cultural manifestations, which are the evolutionary epiphenomenon of the biological component, for the multiplicity of its manifestations, they still appear to us totally imponderable. We just must observe the natural phenomena and be enchanted by the show.

The only certainty we have is the indisputable role of sexual reproduction on the biological evolution of the living in all their manifestations.

Because the evolution of the living is the effect of the assortment and recombination of genotypes produced by sex.

Compliance with ethical standards

Disclosure of conflict of interest

Authors declare that they have no conflict of interest in this article.

References

[1] Otto, S. (2008) Sexual Reproduction and the Evolution of Sex. Nature Education 1(1):182

[2] Sarah P. Otto* and Thomas Lenormand; RESOLVING THE PARADOX OF SEX AND RECOMBINATION, Nature Publishing Group APRIL 2002 | VOLUME 3

[3] Darwin, Charles (1859) On the Origin of Species. John Murray, London

[4] Giuseppe Benagiano et al; Sex and reproduction: an evolving relationship , Human Reproduction Update, Vol.16, No.1 pp. 96–107, 2010

[5] Becks L, Agrawal AF (2012) The Evolution of Sex Is Favoured During Adaptation to New Environments. PLoS Biol 10(5): e1001317. doi:10.1371/journal.pbio.1001317

[6] Bachtrog D, Mank JE, Peichel CL, Kirkpatrick M, Otto SP, et al. (2014) Sex Determination: Why So Many Ways of Doing It? PLoS Biol 12(7): e1001899. doi:10.1371/journal.pbio.1001899

[7] Irene Miguel- Aliaga; Let's talk about (biological) sex, NAture Reviews | Molecular Cell Biology, volume 23 | April 2022 | 227

[8] Nathaniel P. Sharp and Sarah P. Otto ; Evolution of sex: Using experimental genomics to select among competing theoriesEvolution of sex: Bioessays 38: 751–757, 2016 WILEY Periodicals, Inc.

[9] Irene Miguel- Aliaga; Let's talk about (biological) sex , Nature com , April 2022 | volume 23

[10] Marianne J.Legato ; The Plasticity of Sex The Molecular Biology and Clinical Features of Genomic Sex, Gender Identity and Sexual Behavior, Academic Press 2020

[11] Panagiota Manolakou et al ; Molecular patterns of sex determination in the animal kingdom: a comparative study of the biology of reproduction, Reproductive Biology and Endocrinology 2006, 4:59

[12] Sarah P. Otto* and Thomas Lenormand ; RESOLVING THE PARADOX OF SEX AND RECOMBINATION, Nature Publishing Group, APRIL 2002 | VOLUME 3

[13] Silvia Manclossi ; Sex and gender within the context of data collected for the Sustainable Development Goals (SDGs), Office for National Statistics, 21 April 2023

[14] Claire Ainsworth ; Sex Redefined: The Idea of 2 Sexes Is Overly Simplistic, Nature Magazine October 22, 2018

[15] Sex and gender, Council of Europe , https://www.coe.int/en/web/gender-matters/sex-and-gender

[16] Colin Wright ; Understanding the Sex Binary , City Journal Mar 20 2023

[17] Agustin Fuentes ; Biological Science Rejects the Sex Binary, and That's Good for Humanity, ESSAY HUMAN NATURE, 11 MAY 2022

[18] MORENO NARANJO, Leonardo and GUTIERREZ, Germán ; How sex shapes the evolution of behavior: The case of preferences in human reproduction. Suma Psicol. [online]. 2021, vol.28, n.1, pp.25-36. Epub Jan 01, 2021. ISSN 0121-

[19] ROBERT LYNCH ; From Sex To Gender: The Modern Dismissal of Biology, Skeptic April 7, 2023 , https://www.skeptic.com/reading_room/from-sex-to-gender-modern-dismissal-of-biology/

[20] A. GRAZIOTTIN; Medical sexology: male and female , Clinical Sciences - Medical Gynecology, 10 October 2011