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La biología molecular, su situación en la educación y el ejercicio del médico veterinario en México

Molecular biology its situation in veterinary education and practice in Mexico

Biologia molecular, sua situação na educação e prática da medicina veterinária no México

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Resumen

La biología molecular está adquiriendo mayor relevancia en el campo de la medicina veterinaria. De hecho, cada vez son más las asignaturas, tanto en ciencias básicas como en ciencias aplicadas, que abordan el conocimiento de esta disciplina. Por ello, es necesario que el currículo de la carrera incluya cátedras como biología molecular o disciplinas afines, como la genómica o la biotecnología, "si las escuelas de esta profesión desean aprovechar las oportunidades emergentes y orientar su desarrollo hacia una formación que permita aportar soluciones a los problemas sociales que afectan a una sociedad global". En esta revisión se exploran los orígenes de la educación veterinaria, el surgimiento y avance de la biología molecular, las herramientas tecnológicas generadas a partir de esta disciplina, su impacto social y económico y se discute su integración en la formación del médico veterinario actual.

Palabras clave: Educación, Medicina veterinaria, Biología, molecular, México.

Abstract

Molecular biology is gaining increasing relevance in the field of veterinary medicine. There are many subjects in basic sciences, medicine, and veterinary clinics where the knowledge of this discipline is applied; therefore, subjects such as molecular biology or related knowledge such as genomics or biotechnology must be involved in the curriculum of veterinary medicine students; "if the schools of this profession want to capitalize on the opportunities that are emerging in this field and direct its development towards a profession with the knowledge that allows providing solutions to the social problems that currently affect a society globally". In this review, we address the origins of veterinary education, the birth, and progress of molecular biology, as well as the technological tools that have been generated from this discipline, the social and economic impact it has generated, and we also discuss its insertion in the training of the current veterinarian.

Keywords: Education, Veterinary medicine, Biology molecular, Mexico.

Resumo

A biologia molecular está se tornando cada vez mais relevante no campo da medicina veterinária. Na verdade, há cada vez mais disciplinas, tanto nas ciências básicas como nas ciências aplicadas, que abordam o conhecimento desta disciplina. Portanto, é necessário que o currículo da carreira inclua cursos como biologia molecular ou disciplinas afins, como genómica ou biotecnologia, "se as escolas desta profissão pretendem aproveitar as oportunidades emergentes e direcionar o seu desenvolvimento para uma formação que lhes permita fornecer soluções. aos problemas sociais que afectam uma sociedade global" Por este motivo, esta revisão explora as origens da educação veterinária, o surgimento e avanço da biologia molecular, as ferramentas tecnológicas geradas a partir desta disciplina, o seu impacto social e económico e, em seguida, discute a sua integração na formação dos médicos veterinários atuais.

Palavras-chave: educação, medicina veterinária, biologia molecular, México.

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Introduction

According to the World Trade Organization, about to sanitary and phytosanitary measures, "one of the most significant impacts of globalization is the need for states to strengthen their official veterinary services to promote and protect animal and human health, and ~~at~~ the same time facilitate international trade" (Pan American Health Organization [PAHO] and Association of Veterinary Surgeons [AAS]). Of American Veterinary Medical Colleges [AAVMC], 2007).

The word *veterinarian* has a controversial etymology, since, on the one hand, it is believed to come from the Latin *veterinarius*, which means 'relating to pack animals' or beasts of burden, but it could also derive from *vetus*, which means 'old', in which case the etymology would refer to the care of old animals. The first to use the word *veterinarian* was Lucius Junius Moderatus Columela, a Roman patrician of the 1st century, who used it to refer to the shepherd who performed functions related to knowledge in animal medicine (Díaz and Gerard, 2016).

The importance of the social role of the veterinarian dates back to ancient Egypt, Mesopotamia and ancient Rome, where there were already people dedicated exclusively to the care of animals destined for the production of food, clothing and cargo, as well as the cavalry of their armies. In pre-Hispanic Mexico, the letters of account of Hernán Cortés on the conquest of Mexico mention that among the Mexicas there were men and women dedicated to treating bird diseases. In this regard, it is worth remembering that before the arrival of the Spanish, there were no cattle, horses, pigs, sheep or goats in Mesoamerica. However, there was an intense activity of reproduction and breeding of mammals such as the white-tailed deer and the dog, as well as birds such as the macaw and the turkey, among other species. In the writings of Friar Bernardino de Sahagún, it is mentioned that there was the profession of butcher, seller of birds and eggs, among the Mexicas, and that they were in charge of raising birds and hunting animals such as deer to be consumed by the population (Mendoza, 2015).

Later, in New Spain, data on animal care are found in the works of Suárez de Peralta, who wrote a treatise on the cavalry of the genet and bridle (printed in Seville in 1580) and a book on veterinary medicine (written between 1575 and 1580). Suárez de Peralta was an expert in the management and care of horses, as well as in the cure of their illnesses, applying his knowledge of indigenous herbal medicine (National Autonomous University of Mexico [UNAM], December 13, 2019).

Formal education in veterinary medicine began in France in the 18th century, with the creation of the first veterinary school in the city of Lyon in 1762. This institution was founded thanks to the initiative of the lawyer Claude Bourgelat (1712-1779), who, through his network of relations with the group of technocrats close to the court of Louis XV, managed to get the monarch to order the opening of the school. After the founding of the Lyon school, others began to emerge throughout Europe, including that of Alfort, from which Eugenio Bergeyre graduated, who collaborated in the founding of the veterinary career in 19th-century Mexico (Mendoza, 2015).

In Mexico, the professional teaching of veterinary medicine was founded in 1853 by decree of General Antonio López de Santa Anna. The Veterinary career was established at the National School of Agriculture in the former San Jacinto hospice facilities on Calzada Tacuba in Mexico City (Decree of the Ministry of Development, section 2, 1853). However, this school only lasted until 1914.

It was reopened two years later as the National School of Veterinary Medicine; in 1918, the term Medicine was added. This institution was attached to the Ministry of Development and Public Instruction until 1929 when it was incorporated into the UNAM. 1949, it was transformed into the National School of Veterinary Medicine and Animal

Husbandry. Later, in 1969, the school became the Faculty of Veterinary Medicine and Animal Husbandry, located in the facilities of the University City of the National Autonomous University of Mexico (Cervantes and Román, 2010).

In response to the increase in demand for this profession, the first school of Veterinary Medicine in the province, located in the state of Veracruz, was founded in 1957. Actually, more than 50 institutions in almost all states of the country offer study programs that include veterinary medicine and zootechnic careers.

In Mexico, universities award the title of Veterinary Zootechnician (MVZ). Professionals graduate after completing a bachelor's degree program of approximately five years, with training that covers medical aspects, veterinary public health, and animal production. However, the current profile of the MVZ graduates was analyzed and conceptualized by the Pan American Association of Veterinary Sciences (PANVET) in 1997. This study program has been around for almost 26 years since its conceptualization. In 2013, PANVET redefined the "profile of the MVZ with a vision to 2030", where it was established that said specialists must have a competency profile divided into two large groups: 1) general and 2) disciplinary.

The former include those complementary to professional practice, among which the capacity for scientific thinking stands out, that is, the ability to search for, analyze and synthesize scientific information, as well as participate in basic or applied research projects, following the appropriate methodology according to the scientific method. In addition, they must be able to use scientific methodology to identify and solve social problems, develop new technologies with available resources, and innovate in the field of biotechnology.

With this new approach, veterinary medicine schools in Mexico must update their curricula, taking as a reference to ad hoc training that allows students to acquire this profile of competencies from the first day of graduation (Zárate, 2016). This is essential for veterinary medicine professionals in our country to align themselves with the global trends of the profession, as has been considered by the Association of Veterinary Surgeons (Association of Veterinary Surgeons). Of the American Veterinary Medical Colleges, which maintains that veterinarians must be prepared to solve the problems that will emerge in the next 20 years. In other words, they must understand and have the skills to use emerging technologies.

In this regard, it is anticipated that some of the possible scenarios that veterinarians will face will include a world in which pandemic zoonoses will be persistent, so they will have to develop the necessary methods and measures to mitigate significantly the threats that these diseases represent for humanity. In addition, they must be trained to act in a world in which the genome of animal species is explored and exploited for genetic modification, cloning, drug development, the creation of genetically engineered pets, and the in vitro production of food for animal consumption. Likewise, a planet in which global warming and its consequences for domestic and wild animal populations drastically change the requirements for medical care and food supply would lead to new animal diseases. In short, new veterinary professionals must acquire, in addition to their disciplinary training, more specific knowledge in areas such as public health, laboratory animal medicine, wild animal medicine, biotechnology, and biomedical research (Prasse *et al*., 2007).

For these reasons, in recent decades, knowledge of molecular biology has gained increasing relevance in veterinary medicine worldwide. If we want to take advantage of this trend in Mexico, the knowledge acquired in this discipline must begin to be reflected in the curriculum of veterinarians. The study plans imply developing new subjects related to molecular genetics, genomics, and medical biotechnology. In addition, the basic concepts of molecular biology must be widely addressed in subjects that are part of the structure of basic knowledge of the degree, such as Cell Biology, Biochemistry, Genetics, Virology, and Biotechnology.

After explaining the above, this review describes the current applications of molecular biology in veterinary medicine and discusses some of the difficulties associated with teaching this discipline in veterinary schools in our country.

Background

The origins and progress of molecular biology

Molecular biology is one of the most recent branches of biology. It is dedicated to explaining biological factors, processes and systems at the molecular level. As a discipline, it also encompasses the biophysical and biochemical techniques used to investigate phenomena of molecular origin (Marion *et al*., 2007).

Previously, these aspects of living beings were addressed by disciplines such as cell biology, biochemistry and genetics, which explains why molecular biology has its foundations in these areas. 1865 Gregor Mendel discovered biological inheritance laws, turning biology into an exact science, just like physics and chemistry. Mendel's four basic laws of genetics, formulated from meticulous experimentation, sparked a revolution in biology by providing biologists with a rational basis for quantifying observations and investigating cause-effect relationships. These laws were comparable to the fundamental laws of thermodynamics, which attracted many physicists to biology. An example is the German physicist Max Delbrück, who, after researching astronomy and quantum physics, moved to biology to study the basic rules of inheritance in simpler organisms, such as bacteriophages (viruses that can infect bacteria) (Kellenberger, 2004).

Although Mendel established the laws of inheritance, the most crucial question was how genetic information was stored in the cell. DNA was not seriously considered, as how could a heteropolymer of only four different monomers explain the high specificities of genes? Instead, with their 20 different amino acids, proteins seemed more suitable as the molecular structure storing genetic information. However, Oswald Avery and his collaborator Maclyn McCarty's research demonstrated that DNA is the material of genes and chromosomes.

Alfred Hershey and Martha Chase's experiments further supported the idea that DNA carries genetic information. As biological macromolecules (nucleic acids and proteins) became the focus of research, biology and biochemistry found a common ground for study. Researchers from both disciplines focused on studying these macromolecules to investigate how genetic information is stored, transmitted, and translated into phenotypes, giving rise to a new discipline called molecular biology.

Various researchers in chemistry, physics, and biology addressed the study of the structure of DNA. However, it was not until 1953 when the British physicist Francis Crick and the American biologist James Watson published the famous structure of the DNA double helix in a one-page article in the journal Nature. This publication established the shape and chemical composition of DNA and opened the doors to a large amount of research to define the bases of the genetic code (Travers and Muskhelishvili, 2015).

From then on, numerous researchers from different disciplines concentrated their efforts on studying the expression and regulation of genes, which constituted the beginning of an exceptional succession of discoveries in molecular biology during the 1950s and 1960s, among which the genetic code and the first model of regulation of gene expression proposed by François Jacob and Jacques Monod stand out. In this way, the “gene” became the work focus for many researchers for almost a century.

The discovery that several genes encode more than one protein and that retroviruses can synthesize DNA using RNA as a template (reverse transcription) changed the paradigm of molecular biology. From this point on, different groups of researchers focused on the study of gene sequencing, genetic engineering and genome integration.

However, it took almost 20 years for the basic knowledge of molecular biology to be applied to technology. Thus, in the 1970s and 1980s, genetic engineering experienced a significant boom: in 1973, a genetic recombination technique was patented for the first time in the United States; in 1977, a human hormone was successfully manufactured in a bacterium; in 1978, the human insulin gene was cloned; and in 1982, the "super mouse " was created by inserting the growth hormone gene from a rat into fertilized eggs from a female mouse.

On September 14, 1990, the FDA approved the first human gene therapy trial. Two children with adenosine deaminase deficiency (ADA-SCID), a single-gene disease causing severe immunodeficiency, were treated with white blood cells extracted from their blood and modified *ex vivo* to express the normal gene that produces adenosine deaminase (Wirth *et al.*, 2013).

In veterinary medicine, the first animal produced by genetic engineering was a model for the disease retinitis pigmentosa, created by Petters *et al*. (1997), this consisted of a line of pigs containing the rhodopsin gene with a P347L mutation, which generated a disease similar to that seen in humans. Likewise, Wilmut *et al*. announced in 1996 the birth of Dolly the sheep, the first cloned farm animal (Campbell *et al*., 2005).

On the other hand, advances in DNA sequencing were remarkably rapid. In 1988, the HUGO organization was created to carry out the Human Genome Project, the goal of which was to identify the total nucleotide sequence in the human genome, estimated at that time to be approximately fifty to one hundred thousand genes and three billion base pairs (Olson, 1993). In February 2001, the project published its results: a 90% complete sequence of the three billion base pairs in the human genome. The HGP Consortium published these data in the February 15, 2001, issue of *Nature*. Shortly afterward, in volume 438 of December 8, 2005, of the same journal, the canine genome was published, while that of the bovine was the first farm animal to have its complete genome sequenced and published in volume 324 of the journal *Science* in 2009. At present, all the genomes of domestic species have been published.

The discovery of PCR (polymerase chain reaction) significantly drove advances in genome sequencing. In 1986, Mullis and collaborators published a method for the enzymatic amplification of specific DNA sequences. This made it possible to identify short and highly specific sequences within the 3.3 billion base pairs that comprise the human genome and make millions of copies of these small DNA fragments in vitro for physical isolation (Mullis, 1989).

Among the various uses of PCR, one of the most notable was its application in diagnosing several diseases, both in humans and animals. Today, it is undoubtedly the most widely used technique for identifying viruses, bacteria, and other microorganisms (Figure 1).

It is worth noting, however, that molecular biology, biotechnology, and genomics could not have been understood without the use of bioinformatics, as the use of computers has become ubiquitous in biology, as well as in most natural sciences (physics, chemistry, mathematics, cryptography, in between others). Interestingly, however, only biology has a specific term to refer to the use of computers in this discipline: "bioinformatics." This may be because computers in biology required a particular understanding of the structure of macromolecules (nucleic acids and proteins), which led biology to be computerized later than other "hard" sciences such as physics and mathematics. This is not surprising, considering that the first computers were specifically designed to solve mathematical calculations in physics. Modern bioinformatics is believed to have emerged only recently to support genome sequencing data analysis.

However, the beginnings of bioinformatics date back more than 50 years, when DNA had yet to be sequenced. The foundations of this discipline were laid in the early 1960s with the application of computational methods for the analysis of protein sequences, including de novo sequence assembly (databases of biological sequences and substitution models). Before the sequencing of DNA, bioinformatics had its early beginnings over 50 years ago. The discipline was established in the early 1960s when computational methods were first applied to analyze protein sequences. This included de novo sequence assembly, creation of biological sequence databases, and development of substitution models.

Later, DNA analysis also began to develop thanks to parallel advances in (i) molecular biology methods, which allowed easier manipulation of DNA and its sequencing, and (ii) computer science, which saw the emergence of increasingly miniaturized and powerful computers and new software more suitable for handling bioinformatics tasks.

From the 1990s to the 2000s, there were significant improvements in sequencing technology and reduced costs, leading to an exponential increase in data. Indeed, the advent of big data presented new challenges in data search and management, which demanded more excellent computing expertise in the field; together with the growing number of bioinformatics tools, biological big data has (and continues to have) profound implications on the predictive power and reproducibility of bioinformatics results. To address this issue, universities fully integrate this discipline into the biology students' curriculum. Recent sub-disciplines such as synthetic biology, systems biology, and whole-cell modeling have emerged from the growing complementarity between computer science and biology (Gauthier, 2007).

The technological advances mentioned above have given rise to new research fields known as "omics," which refer to the comprehensive study of the relationships and actions of various molecules in an organism's cells. Beginning with genomics, new sequencing technologies allow for rapid and cost-effective sequencing of an entire genome and the study of all genes simultaneously rather than analyzing gene by gene.

In addition to genomics, a range of omics technologies have been developed, including transcriptomics (the study of the expression of all genes in a cell or organism), proteomics (the analysis of all proteins), metabolomics (the comprehensive analysis of all small molecules), and epigenomics (the study of genome-wide epigenetic regulation), among others. Other omics terms have also emerged, such as lipidomics, metagenomics, glycomics, connectomics, coelomics, and foodomics (Olivier *et al*., 2019).

It is worth mentioning that, since a detailed discussion of these omics technologies is beyond the scope of this review, we will not address their individual applications in human and veterinary medicine.

The socioeconomic impact of molecular biology

Investment in innovation and technology development should be a priority for countries that want to participate in the global economic competition. For example, the human genome project had an economic impact of $966 billion. According to a study by

United for Medical Research and Battelle, it generated $59 billion in federal tax revenue in the U.S., according to a study by United for Medical Research and Battelle[1].

For its part, the Organization for Economic Co-operation and Development (OECD), in its report on bioeconomy 2030, points out that genomics will be a significant economic driver in the next 20 years and recommends establishing public policies that stimulate and guide innovation in life sciences as a new driver of the global economy. Likewise, in its May 2013 report, the McKinsey Global Institute classifies genomics as a disruptive technology that will change the world much more than computers. It predicts a global economic impact of trillions of dollars annually by 2025.

In addition, scientific research related to the genomics project generated nearly 53,000 direct jobs, resulting in more than $293 billion in wages. These figures underline how a technological branch derived from basic knowledge of molecular biology has been enormously beneficial for countries that invested in its development.

Although Mexico did not participate in developing the human genome project, a Mexican researcher chaired this project's genomics and bioeconomy committee, which links our country to the genomics scene. Our country, therefore, must focus on transforming itself into an economy based on knowledge and technological development, like the OECD member countries, which generate their wealth and jobs in high-tech industries, such as biotechnology.

In this regard, it is estimated that the knowledge-based industry contributes to more than half of the GDP in the main OECD economies, and global trends indicate that emerging economies with adequate infrastructure and competitive human resources, such as Mexico, can incorporate genomics as a key element for their prosperity and economic growth.

Biotechnology contributes significantly to the health of human and animal populations, in what is known as “one health.” Examples of this include the generation of new-generation vaccines, improved foods with high performance and nutritional value, and the development of pharmacogenomics, which allows for personalized medicine based on the genomic characteristics of patients. Being part of the knowledge economy is essential in a globalized and competitive economy, where the ability to translate scientific and technological knowledge into practical applications for the market is crucial. In the case of Mexico, the country has a notable potential to successfully integrate biotechnology into its

[1]https://unitedformedicalresearch.org/wp-content/uploads/2013/06/The-Impact-of-Genomics-on-the-US-Economy.pdf

economic strategy, which can be achieved by taking advantage of its capacity to develop and apply innovative technologies for the benefit to public health and economic growth.

In recent decades, Mexico has made significant progress in developing genomic sciences. In this regard, creating crucial infrastructure, such as the National Institute of Genomic Medicine, the National Laboratory of Genomics and Biodiversity, and the Center for Genomic Sciences, and training qualified human resources has been fundamental. However, the country needs a modern and robust State policy that promotes sustained investment in science and technology, as well as the generation of experts in the area to guarantee the effective transfer of scientific and technological knowledge to the productive sector and to strengthen global competitiveness and ensure its economic growth and social and cultural well-being (Jimenez, July 6, 2013).

Applications of molecular biology in technological development in veterinary sciences

Basic knowledge of molecular biology applied to veterinary medicine has focused mainly on so-called "genetically modified animals," with the aim of obtaining animals that are better adapted to the environment, more efficient in feeding, produce more, and are resistant to diseases.

Basic knowledge of molecular biology applied to veterinary medicine has focused mainly on so-called "genetically modified animals," with the aim of obtaining animals that are better adapted to the environment, more efficient in feeding, produce more, and are resistant to diseases.

The world's population, currently around seven billion, continues growing, especially in developed countries. It is expected to reach nine billion by 2050, so food production must double to meet global demand. Since conventional farming and animal husbandry systems will not be sufficient, the generation of genetically modified animals is presented as an innovative solution to the problem of global food security. However, for this to materialize, a more significant commitment from universities is needed to develop a new structure in veterinarians' education and professional practice.

In this regard, there are many examples in which the development of molecular biology and its technologies have applications in the modern era of veterinary medicine:

- Sex selection in the dairy and egg production industries: Allows for the directed breeding of primarily females, eliminating the need for castration and/or destruction of males.
- Generation of transgenic sows: Litters of piglets with a higher survival and growth rate are obtained, which increases pork production.
- Genetically modified pigs: They predominantly produce omega-3 fatty acids, rather than the nutritionally less valuable omega-6 variety.
- Genetically modified pigs: Excrete 75% less phosphorus into the environment.
- Genetically modified pigs with organs for xenotransplantation offer an alternative to stem cell therapy.
- Transgenic cows with mammary glands: They express antibacterial against the main infectious agents causing mastitis.
- Transgenic animals (often cows and goats): These function as bioreactors, as they can produce disease-specific therapeutic molecules in their milk, which would serve as therapies for humans or other species. This technology offers hope as a prophylactic for many enteric infectious diseases in children, especially in countries with emerging economies such as Mexico (McColl *et al*., 2013).
- In the field of veterinary biomedicine: Animal models of human diseases have been developed for the study of cystic fibrosis, diabetes, cardiovascular diseases, cancer, Huntington's disease, Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, ataxia-telangiectasia, Duchenne muscular dystrophy, polycystic kidney disease, hemophilia type A, retinitis pigmentosa, albinism, immunodeficiencies, among others (Table 1) (Rogers, 2016).
- The development of monoclonal antibodies: Has greatly favored the application of immunological techniques in the research of biochemistry and genetics, and especially in the diagnosis of a large number of infectious diseases, both viral and bacterial, in all animal species (Ciftci and Trovitch, 2000).

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Table 1. Animal models developed for the study of genetic diseases in humans

Human disease	Animal model	Modified gene
Cystic fibrosis	Domestic pig	CFTR-null
Diabetes	Domestic pig Domestic pig	Contains a dominant negative GIPR transgene Contains a HNF-1α transgene dominant negative
Cardiovascular diseases	Yucatan Miniature Pig Yucatan Miniature Pig Goat	Contains a PCSK9 transgene dominant negative LDLR- null Contains a human TGF-β1 transgene
Cancer	Domestic pig, Yucatan miniature pig	TP53-R167H, KRAS-G12D
Huntington's disease	Sheep, Tibetan miniature pig, Liběchov miniature pig	They contain a human HTT- transgene
Alzheimer's disease	Göttingen miniature pig	Contains a human APP695sw transgene
Parkinson's disease	Bama Miniature Pig	PARK2- and PINK1-null
Amyotrophic lateral sclerosis	Miniature pig from Tibet, miniature pig from Yucatan	Contains a human SOD1-G93A transgene
Ataxia telangiectasia	Minnesota Miniature Pig, Yucatan Miniature Pig	ATM-null

Duchenne muscular dystrophy	Domestic pig	DMDex52deletion
Polycystic kidney disease	Chinese pig	PKD1-null
Hemophilia type A	Domestic pig	FVIII-null
Retinitis pigmentosa	NIH Miniature Pig	Contains a human RHO-P23H transgene
Albinism	Bama Miniature Pig	TYR-null
Immunodeficiencies	Domestic pig Bama miniature pig , Minnesota miniature pig	IL2RG-null RAG1/RAG2-null RAG2-null

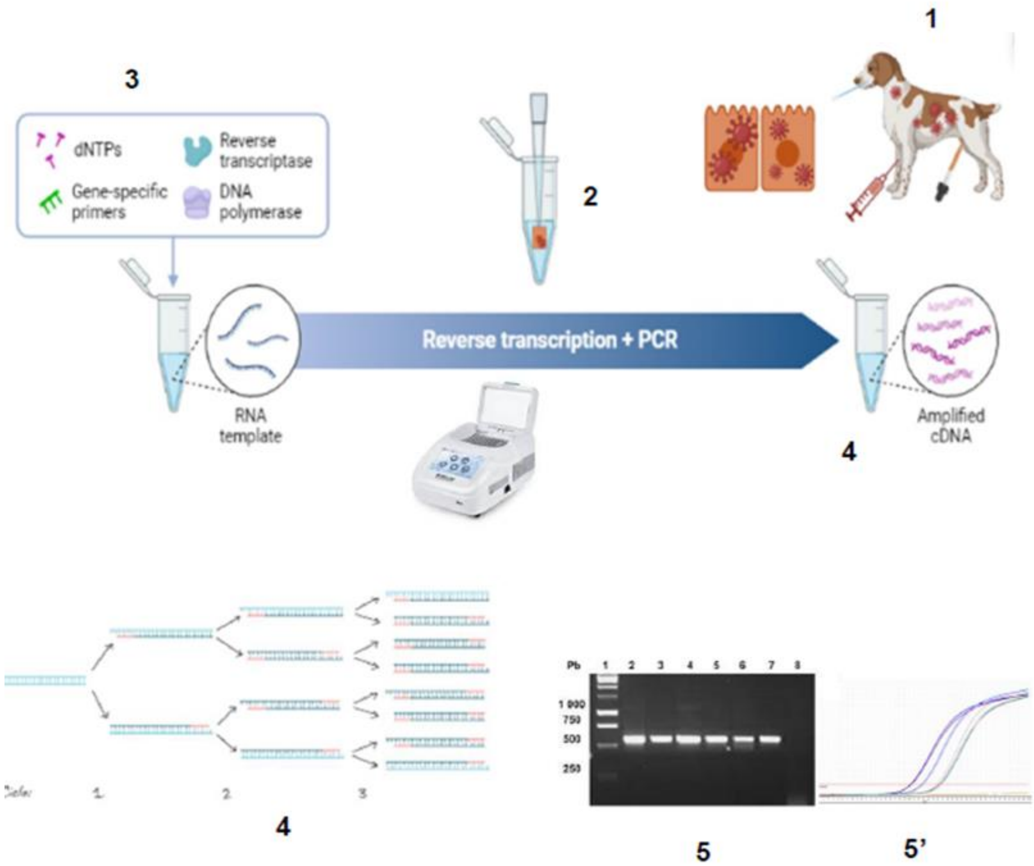
Source: Based on Rogers (2016)

Without a doubt, the discovery derived from molecular biology that has had the most significant impact on biotechnology and has had a broad impact on society is PCR. This technique has spread to all research areas and is now part of the country's economic development. For example, real-time reverse transcription PCR is the gold standard for SARS-CoV-2 diagnostics and many other infectious and genetic diseases that affect both humans and domestic animals.

Today, PCR is a simple, fast and inexpensive diagnostic system, and its evolution will undoubtedly allow interaction with other developing technologies, such as the Internet of Things and artificial intelligence. In the near future, we will be able to see how microscopic samples, even those containing only the RNA of a single cell, can be amplified and analyzed on technological systems such as a *smartphone.*

In this scenario, the Android system could process the data and, through a wireless network, send it to a disease reference center to improve accurate recording and diagnosis for disease control (Zhu *et al*., 2020). *A schematic of the basic principle of this technology is presented in Figure 1.*

Figure 1. Basic aspects of the reverse transcription PCR procedure for the diagnosis of viral diseases caused by viruses with RNA genomes



Note: 1) The type of sample that can be collected from the infected animal is shown, as well as epithelial cells infected by a virus. 2) Viral RNA purification procedure. 3) Reagents needed to perform reverse transcription PCR that are placed together with the viral RNA and are processed in a thermocycler to carry out the amplification of the selected genomic region of the virus. 4) The selected genomic region is replicated exponentially and at the end of the process billions of copies are obtained as seen in 4 *bis*. 5) The amplified fragments can be visualized in electrophoresis using agarose gels using dyes intercalated in the amplified DNA molecules and ultraviolet light (end-point PCR) or as in 5' using probes labeled with a fluorophore and where the same thermocycler detects the signal emitted by the fluorophores as the amplification is carried out and shows it in a kinetics through a computer (real-time PCR).

Source: Own elaboration

Methodology

Integrating molecular biology into the veterinary education curriculum

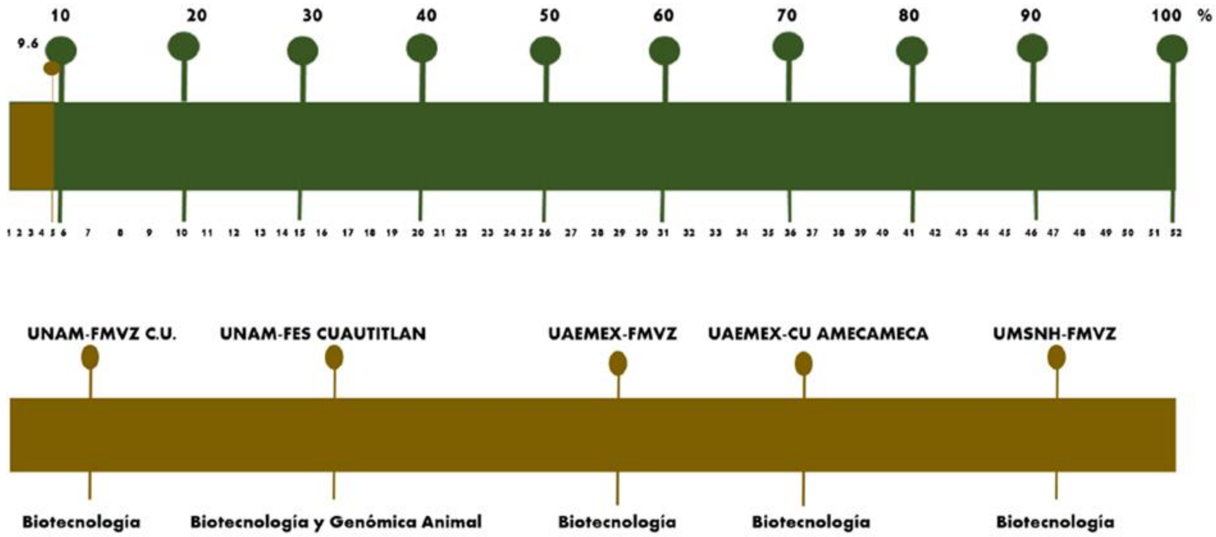
To determine the inclusion of molecular biology or related areas in veterinary education in Mexico, we analyzed the curriculum of 52 universities that teach veterinary medicine and animal husbandry in the country.

Results

The analysis showed that only 5 (9.6%) universities have incorporated courses related to molecular biology. The Cuautitlán School of Advanced Studies at UNAM (FES-Cuautitlán UNAM) offers two related courses: Biotechnology and Animal Genomics. On the other hand, the School of Veterinary Medicine and Animal Science (FMVZ) at UNAM in Ciudad Universitaria only offers the subject of Biotechnology. Similarly, the FMVZ at the Autonomous University of the State of Mexico (UAEMex), the University Center of Amecameca in the same university and the FMVZ at Michoacana University of San Nicolás de Hidalgo (UMSNH) only offer the subject of Biotechnology (Figure 2).

In other words, it can be noted that academic institutions' efforts to incorporate one of the most developed areas of science today have been minimal, which will most certainly be reflected in the training of their graduates both now and in the future.

Figure 2. Current situation of the implications of teaching molecular biology and related subjects in the different veterinary medicine schools in the country



Note: The green bar represents the percentage of schools analyzed, while the embedded gold bar represents the 9.6% of schools that offer one or more courses with a specialization in molecular biology, genomics, or biotechnology in the bachelor's degree program. The enlarged gold bar specifies the five schools that offer these courses in their bachelor's degree curriculum.

Source: Own elaboration

Discussion

This paper analyzes molecular biology's impact on veterinary education in Mexico. The status of this discipline in the curricula of the different schools and faculties of veterinary medicine shows little interest on the part of the corresponding educational authorities. Less than 10% of these institutions have taken the initiative to incorporate these disciplines into their curricula, leaving recent graduates at a clear disadvantage when competing in the industry that develops products, diagnostic systems, and therapeutics in molecular biology and genomic medicine.

Furthermore, since knowledge and the global economy are changing rapidly, newly graduated professionals must have the necessary skills and tools to adapt to these new work environments. New graduates are, therefore, expected to have sufficient knowledge to act effectively in holistic and constantly changing environments, as they will be faced with many emerging issues, such as new diagnostic technologies, new modalities of pharmacological and antimicrobial therapies, and new forms of food production based mainly on biotechnology. Therefore, future graduates must have sufficient learning opportunities to develop in biomedical, genomic, and biotechnological areas (Prasse *et al.,* 2007).

In the basic training of the veterinary medicine student, molecular biology is relevant to a wide range of subjects within the curriculum, such as Cell Biology, Physiology, Embryology, Biochemistry, Genetics, Virology, Pathology, Microbiology, Parasitology, Immunology, Nutrition, Pharmacology and Clinical Diagnosis, among others. Since many aspects of molecular biology may seem redundant to students, teachers must focus on molecular biology's basic definitions and terms and demonstrate their application to real-world problems in the clinical field of veterinary medicine.

Depending on the area in which the veterinary educator has developed, we may need some help embedding molecular biology knowledge in the different areas of basic and applied teaching of the veterinary doctor's degree. For example, suppose the educator developed in the scientific area, and has no experience in clinical aspects. In that case, he or she might not have the context to explain the applications of molecular biology in solving clinical problems. On the other hand, if the educator has only specialized in clinical aspects, he or she might not touch in-depth on the necessary knowledge of molecular biology in each of the areas mentioned, which are part of the training of the veterinary medicine student.

Conclusion

In conclusion, veterinary schools must ensure that their teaching staff consists of veterinarians with specialized clinical training and research training with a biomedical or molecular component. This helps bridge the gap between clinical and basic science. By doing so, not only will awareness and knowledge of molecular biology be increased among veterinary physicians, but communication between clinical and basic science teaching staff will also be fostered.

In summary, collaboration through research will provide both parties with a more holistic view of molecular biology applied to veterinary medicine, which will positively impact both the teaching content and the veterinarian's professional practice.

Future lines of research

The study of molecular biology in the veterinary field is not a fad or a passing trend but rather an advance in science and technology that will continue to grow. Therefore, it is vital to include this type of study in the training of new generations of veterinarians so that they can apply this knowledge in their professional development.

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