



## Use of *in vitro* Fertilization Technique in the Last Decade and its Effect on Brazilian Embryo Industry and Animal Production

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### ABSTRACT

**Background:** Based on the evaluation of embryo production and transfer numbers, as well as of market changes and trends, we can estimate the impact of the advances in reproductive biotechnology research and development on the productive sector. The aim of the present study was to retrieve the figures and critically evaluate the bovine embryo market in Brazil, considering also the world context and livestock production scenario.

**Methodology:** Data recovered from different breeders associations and related to the number of bovine embryos produced and transferred in 2009 were used. Data of relative efficiency of the embryo biotechnologies were obtained from private companies. Information of the world embryo industry was provided by the International Embryo Transfer Society (IETS). Context analysis was performed using different indexes from Brazilian government institutes.

**Results and discussion:** According to data retrieved by the Brazilian Embryo Technology Society (SBTE) there was a significant increase in bovine embryo production in Brazil in the last decade. This increase was directly related to the expansion in the use of *in vitro* embryo production (IVEP), which became the technique of choice to increase the number of offspring from genetically superior animals, mainly in zebu breeds. The growth in the adoption of IVEP resulted in an increased participation of the country in the total of embryos produced in the world and set some of the national market features, such as the low use of cryopreservation and the predominance of beef breeds in this industry. The emergence of semen sexing technology allowed an improvement in the use of IVEP in dairy breeds and was the key for the increase in the total of embryos produced in the last five years. The commercial outcome of IVEP in Brazil is related to a complex interplay of biological and market features including reproductive physiology characteristics of zebu cows, scale of use, and the previous experience with conventional embryo transfer. The association of these features produced a scenario favorable for the IVEP expansion, differently from what was observed in other countries with tradition in the use of conventional embryo transfer. Embryo production in Brazil is positively correlated to different research and development and livestock production indexes, but the association showed a pattern different from the one observed for other reproductive biotechnologies. The new figures of the Brazilian embryo industry and the indirect consequences on genetic progress of the herds and on animal production indicate that IVEP can be a model to study innovation in livestock production, once the advances in the state of the art were followed by the use of new technologies and consequent gains in market values of the products.

**Conclusion:** The use of bovine IVEP technology caused a significant change in the scenario of the Brazilian embryo industry and demonstrated the importance of innovation in livestock production and, consequently, of the investment in science and technology.

**Keywords:** Statistics, innovation, embryo technologies, animal breeding

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## I. INTRODUCTION

## II. METHODOLOGY

## III. RESULTS AND DISCUSSION

## IV. CONCLUSION

### I. INTRODUCTION

The jargon *in vitro embryo production* (IVEP) is generally used to refer to a number of procedures performed in laboratory which includes the maturation, fertilization, and culture steps required to produce embryos from immature oocytes. The IVEP emerged as an alternative to the *in vivo* embryo production by superovulation, also known as conventional embryo transfer (ET). Until the end of the 90's, IVEP in Brazil was performed almost only for research purposes and, consequently, had no commercial impact. The IVEP was a technically complex process and had a high implementation cost, so it was formerly expected to increase slowly, focused in specific market demands. In a period of only five years, however, the country became the world largest bovine embryo producer and reference in the use of IVEP technologies in a commercial scale. This performance was a result of the association of different factors which can now be better understood by the retrospective analysis of the ET and IVEP scenarios in the last 10 years.

Reproductive biotechnologies are tools to increase the number of offspring from genetically superior animals, therefore there is a natural relationship (and interplay) of the use of such technologies and the identification of better sires and dams, herd genetic progress, increases in productivity and reduction in production costs. Differently from techniques such as artificial insemination and conventional embryo transfer, the IVEP use in a commercial scale is still a recent phenomenon, and the measurement of its impact on animal production is not feasible yet. Nevertheless, the IVEP is likely to have a greater effect on genetic improvement and animal production than ET, due to the higher number of embryos produced per donor in the same period [16].

The aims of the present study were to characterize the bovine IVEP industry in Brazil, analyzing the background for its expansion and some possible implications for beef and dairy production, and to study IVEP as a model of innovation in livestock production.

### II. METHODOLOGY

Data retrieval of the Brazilian ET and IVEP activities shown in the present study was performed by the Brazilian Embryo Technology Society (SBTE). The data concerning activity in the world, including numbers provided by the SBTE, were published by the *Data Retrieval Committee* of the International Embryo Transfer Society [22]. The SBTE data retrieval methodology was based on the records of embryo transfers provided by breeders associations, and do not take into account embryos produced for research purposes. Consequently, figures obtained may underestimate the real number of embryos produced. This methodology, however, allows an estimation of the real impact of the embryo biotechnologies on the production systems, once the number of embryos produced by commercial companies directly reflects the number of embryos effectively transferred. Other countries report the total number of embryos produced to the IETS, irrespectively to their destination, what shall be considered for analysis and comparisons. Brazil accounted, in 2008, for 26.9% of the embryos produced in the world, but for 30.6% of the embryos transferred. For *in vitro* produced embryos, this difference is even greater (66.6% vs. 86.5%, respectively). In the present study, the main reference chosen to evaluate the activity both in the world and in Brazil was the total number of produced embryos by year and by technique (ET or IVEP).

Data from different sources were used for context analysis. The number of semen straws sold in Brazil [2] was used as a reference of reproductive biotechnologies adoption in the country. The values of grants and funding were provided by the statistic department of the National Council for Scientific and Technological Development [CNPq, personal communication, 2010]. Genetic progress index in the Gyr breed were provided by the National Program of Dairy Gyr Breed Genetic Improvement [Peixoto, personal communication, 2010]. Statistics of dairy and

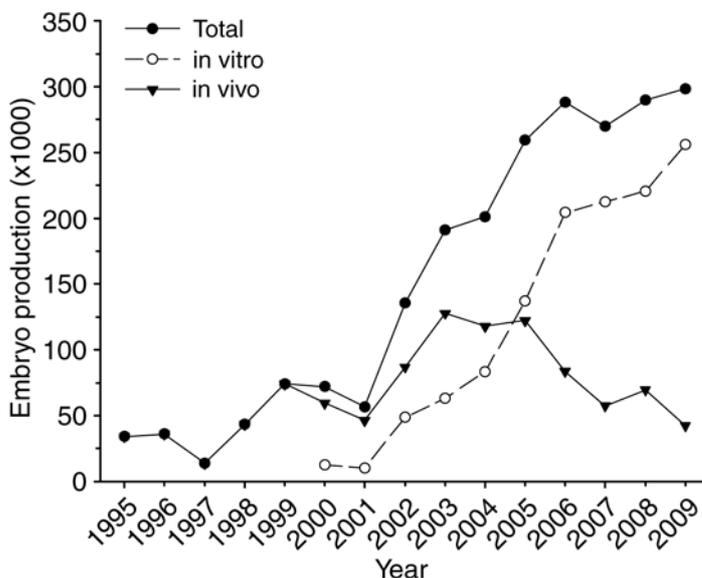
beef activities were obtained from Embrapa Dairy Cattle Research Center [11] and Brazilian Institute of Geography and Statistics [21] databases, respectively.

The embryo production rates among bovine subspecies were compared by the Chi-square method. The association between embryo production and different context references were calculated by the Pearson's correlation method. The analysis of the evolution in use of different biotechnologies was performed by curve regression adjustment. Statistical analyses were performed using the software SAEG.

### III. RESULTS AND DISCUSSION

#### IVEP activity in Brazil and in the world

The adoption of any technology is related to a number of causes, including market and economy context, showing therefore fluctuations over time. After a decade of commercial use of IVEP, however, an analysis of its impact on embryo industry can be performed, and consistent trends and occasional fluctuations identified. The ET and IVEP numbers in the last 15 years (Figure 1) show distinct periods according to the adoption of each technique. Until the year 2000 there was a trend for the increase in the *in vivo* embryo production, which was the only embryo technology commercially available in scale. This trend persisted in the earliest years (2000-2003) after the onset of the first IVEP companies, indicating a positive scenario for embryo technologies in general. The stabilization and latter reduction in ET activity in the subsequent years, however, suggest that, despite this scenario, the limitations inherent to the superovulation process, mainly in zebu breeds [4], prevented a greater expansion in ET use. The IVEP overcame some of these ET problems and allowed a significant increase in embryo industry, turning out to be the technique of choice for embryo production in zebu breeds after 2004 and bringing embryo numbers in Brazil to a new level (>200.000 embryos produced/year).



**Figure 1.** Production of bovine embryos in Brazil, according to the technique employed, in the period 1995-2009. (*in vivo*: embryos produced by superovulation [conventional ET]; *in vitro*: embryos produced in laboratory [IVEP]).

In the last five years (2005-2009), the total embryo production had a trend to stabilization, with the increase in IVEP being, at least partially, counterbalanced by the reduction in ET activity. The national embryo industry scenario was reflected in the Brazilian percentage in world numbers. The overall participation of the country increased until 2005, with a trend to stabilize thereafter, as a consequence of the balance between the growing participation in the total number of *in vitro* produced embryos, which was greater than half of the world total in 2008, and a decreasing participation in the *in vivo* activity after 2003-2004 (Table 1). In general, there is a world trend towards not to increase

but to the polarization of the embryo industry, with North America (EUA and Canada) accounting for most of the ET activity, and Brazil being consolidated as a reference in IVEP.

**Table 1.** Brazilian participation (percentage) in the total of bovine embryos produced *in vivo* and *in vitro* in the world, during the period 2000-2008.

	<i>In vivo</i>			<i>In vitro</i>			Total		
	Brazil	World	%	Brazil	World	%	Brazil	World	%
<b>2008</b>	69,527	746,250	9.3	220,425	330,953	66.6	289,952	1,077,203	26.9
<b>2007</b>	57,368	763,467	7.5	212,441	434,581	48.9	269,809	1,198,048	22.5
<b>2006</b>	83,741	777,747	10.8	204,402	441,364	46.3	288,143	1,219,111	23.6
<b>2005</b>	122,210	789,972	15.5	137,042	330,647	41.4	259,252	1,120,619	23.1
<b>2004</b>	117,815	691,545	17.0	83,291	319,086	26.1	201,106	1,010,631	19.9
<b>2003</b>	117,829	693,787	17.0	63,164	330,848	19.1	180,993	1,024,635	17.7
<b>2002</b>	86,858	629,687	13.8	48,670	160,695	30.3	135,528	790,382	17.1
<b>2001</b>	46,301	580,077	8.0	10,198	109,205	9.3	56,499	689,282	8.2
<b>2000</b>	59,453	664,320	8.9	12,527	139,372	9.0	71,980	803,692	9.0

### Features of the bovine embryo production in Brazil

Embryo technologies were first used in Brazil in European dairy breeds, and the very first transfers were performed with Holstein embryos [31]. During these 30 years of activity, the national embryo activity underwent significant changes. Embryo transfer turned out to be increasingly important for beef breeds which, after the onset of IVEP companies, accounted for 88.0% of all embryos produced in 2006 in Brazil. Data from 2009 indicate that zebu breeds are still the most important in Brazilian numbers, with 92.4% of the total (Table 2). The predominance of zebu breeds is also reflected by the greater percentage of embryos produced *in vitro* than *in vivo* (85.5% and 14.2%, respectively). In both beef and dairy breeds, IVEP is the main option for zebu animals, while in European breeds ET is still the most used technique (91.2% and 79.4% of produced embryos, respectively).

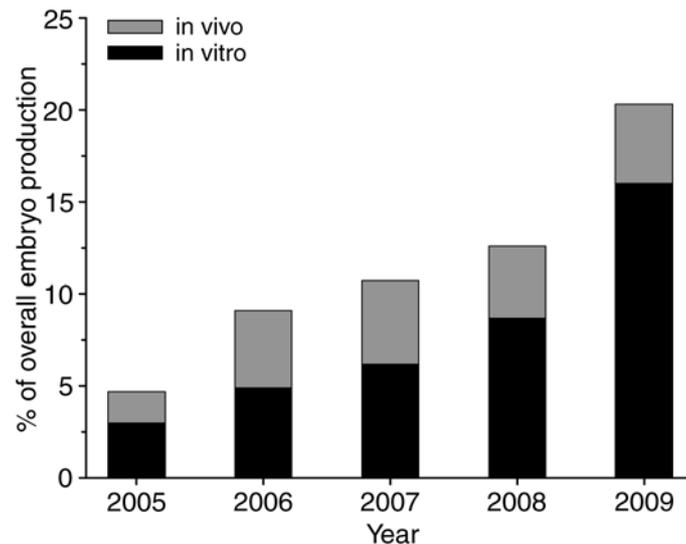
The predominance of zebu breeds and, consequently, of IVEP directly affected the scale of use of cryopreservation. The increase in the number of frozen embryos observed in 2008 was not kept in 2009 and it seems to be related only to a transient increase in the use of ET in that year. Since IVEP turned out to be the main choice for bovine embryo production in Brazil, in 2005, the percentage of frozen embryos ranges from 5 to 6% of the total, and recent developments in cryopreservation had still no effect on the activity in general. The low efficiency of cryopreservation procedures for *in vitro* produced embryos in Brazil seems to be directly related to inherent characteristics of *Bos indicus* embryos, once similar pregnancy rates have been reported for frozen-thawed *in vitro* and *in vivo* produced embryos in *Bos taurus* [15, 42]. The reasons for this difference are not fully understood, and comparative studies between *Bos taurus* and *Bos indicus* embryos were only performed using *in vivo* produced ones [47].

**Table 2.** Distribution of bovine embryos produced in Brazil in 2009 according to subspecies (Zebu or European), economic activity (dairy or beef) and technique used (*in vivo* or *in vitro*).

Subspecies and activity	Production technique		Total by subspecies and activity
	<i>In vivo</i>	<i>In vitro</i>	
Dairy Zebu	1,932	43,622	45,554
Dairy European	10,943	4,097	15,040
<b>Subtotal</b>	12,875	47,719	60,594 (20.3%)
Beef Zebu	22,403	207,674	230,077
Beef European	7,119	600	7,719
<b>Subtotal</b>	29,522	208,274	237,796 (79.7%)
<b>Total by technique</b>	42,397 (14.2%)	255,993 (85.8%)	298,390

In spite of the greater percentage of beef breeds in the total number of embryos produced (79.7%), a retrospective analysis show an increasing importance of the activity in dairy breeds (Figure 2). Actually, the growth in the number of *in vitro* produced embryos after 2005 (Figure 1) was mainly a consequence of the increasing IVEP in dairy breeds. The use of IVEP in the main zebu beef breed, the Nelore, showed a negative variation in the period 2005-2009 (-11.9%), while in the main zebu dairy breed, the Gyr, it increased 637.5%. Figure 2 also shows that this expansion in embryo activity in dairy breeds was related to an increase in the use of IVEP, but not ET. This shift towards dairy breeds can be assigned in a great extent to the onset of the use of sexed semen, once the greater proportion of males born with conventional semen [7] was one of the main reasons impairing economic viability of IVEP in these breeds.

The increasing importance of embryo technologies in dairy breeds can be also noticed considering the proportion of embryos produced in relation to the number of births recorded (RGNs). Nelore and Gyr breeds, for example, accounted for 68.5% and 16.5% of the embryos produced, but for 83.0% and 4.9% of the RGNs among zebu breeds, respectively [3]. The Girolando, a dairy breed (Gyr x Holstein), is the only crossbred with significant participation both in ET and in IVEP, with 2.5% of the total. It is interesting to highlight that embryo technologies can be used in dairy breeds not only for the production of sires and dams, but also to produce replacement animals in production herds, such as the case of the F1 generation after crossbreeding, which opens a potential new market for IVEP.



**Figure 2.** Participation of dairy breeds in the total of embryos produced in Brazil in the period 2005 a 2009. (*In vivo*: embryos produced by superovulation; *in vitro*: embryos produced in laboratory).

### The background for IVEP growth in Brazil

Although the great progress in its use, analysis of the partial results for each step of the process shows that the IVEP is still characterized by a low efficiency. Different studies reported rates of approximately 70% in COCs recovery by follicle aspiration in non-stimulated animals [34,44], 10 to 40% in embryo production (including maturation, fertilization, and culture up to blastocyst stage) [23,30,43], pregnancy rates ranging from 30 to 40% [28,29,35], and higher incidence of abortion or stillbirths [28]. Consequently, even in the better systems the overall efficiency is hardly higher than 10% [43]. In spite of a great effort in the development of each of the steps involved, substantial gains are unlikely to occur, once they are limited by the quality of the recovered COCs [5,27]. Therefore, the efficiency and consequent economic viability of the IVEP are closely related to the number of follicles available for aspiration (OPU) on the donors ovaries, and to the quality and development potential of recovered oocytes.

Animals from zebu breeds are known to show many differences in ovarian physiology, including a greater number of follicular waves [14,45], lower persistency and diameter of the dominant follicle at deviation [33,46] and differences in the acquisition of ovulatory capacity [18]. The relationship among ovarian reservoir, follicle dynamics, and number of follicles available for aspiration between the sub-species *indicus* and *taurus* is still not clear and requires further investigation. It is clear, however, that the mean number of COCs recovered by commercial IVEP companies in Brazil, working mainly with zebu breeds (Table 3), is consistently greater than those reported by companies which perform OPU in European breeds (4-6 COCs) [9,24]. Reports on animals producing more than 50 COCs per OPU session are frequent, and there is a record of an aspiration that yielded more than 500 oocytes in a Nelore donor [32].

**Table 3.** Results consolidated from four different IVEP companies in Brazil. Data shown below represents the sum of the partial results of each company during the period of one year [personal communication, 2010].

End point	Mean value (N)	Range
COC recovered per OPU	19.9 (528,743/26,598)	15.2-24.4
Embryo rate*	35.4% (123,624/348,957)	32.9-41.2%
Pregnancy rate*	38.5% (30,729/79,798)	36.0-41.0%

\* Only embryos and pregnancies which could be linked to the number of COCs in culture and to embryos produced, respectively, were computed.

Based on the partial results of different commercial IVEP companies in Brazil (Table 3), we can project a mean result of 2.7 pregnancies per donor/aspiration session. In contrast, the compilation of IVEP results in Europe from 2000 to 2003 [39,40,41] shows a mean production of 1.6 embryo per aspiration session (28,209 embryos/18,140 OPU), and even considering a hypothetical pregnancy rate of 50% it will end up with less than one pregnancy per aspiration, which means less than 1/3 of the result with zebu breeds in Brazil. The European mean number of embryos per aspiration indicates five to seven COCs recovered per donor, which is in agreement with the oocyte recovery reported in different studies with *Bos taurus* [9, 17, 19,24,26]. Coherently, IVEP is used nowadays in Europe mainly for donors with problems for *in vivo* embryo production [12].

Besides the greater number of recovered COCs, the results of commercial companies show higher embryo production rates for zebu breeds (Table 4). These results can be a consequence of an intrinsic better quality of the oocytes, or reflect the positive cooperation effect resulting from a greater number of COCs in culture [10, 13]. Regardless of the main reason, the greater number of oocytes recovered per aspiration session associated with the good embryo production rates in zebu breeds definitely contributed to the expansion of IVEP use in Brazil. This scenario was opposed to that observed in Europe and North America, where there is a predominance of *Bos taurus* breeds, and a reduction in the *in vitro* embryo production was observed after the 90's.

**Table 4.** Comparison of embryo production rates in a commercial IVEP company in Brazil (Adapted from Watanabe et al. [48]).

Subspecies	COCs	Embryos	Embryo rate
<i>Bos taurus</i> breeds	8,200	2,098	25.6%a
Sintetic breeds	30,496	8,408	27.6%b
<i>Bos indicus</i> breeds	763,344	245,123	32.1%c
<b>Total</b>	<b>802,040</b>	<b>255,629</b>	

a,b,c Values followed by different letters, in the same row, differ ( $X^2$ ,  $P < 0.001$ )

At least two other factors played key roles in the expansion of IVEP use in Brazil. The first was related to the scale effect, due to the great demand for genetically superior animals. Brazil has the second largest bovine herd in the world (170 million animals) and the first in commercial production [21]. Most of the Brazilian herd is composed by beef zebu breeds and crossbreds raised under extensive systems. Due to the characteristics of these production systems (large number of animals per herd, low availability of labor force, etc.), the use of artificial insemination is restrict (approximately 8%) [2] and, even with the development of fixed time AI, reproduction is still largely based in natural service. There was, consequently, a high demand for replacement bulls, stressed by a low offer of animals and by the necessity of productivity gains, creating an opportunity for the large scale use of IVEP. The commercial success of the technique was then more based on the production volume instead of on high prices of the embryos or pregnancies. Coherently, the greater number of offspring produced per donor in a period of time is one of the advantages of IVEP when compared to conventional ET [42,43].

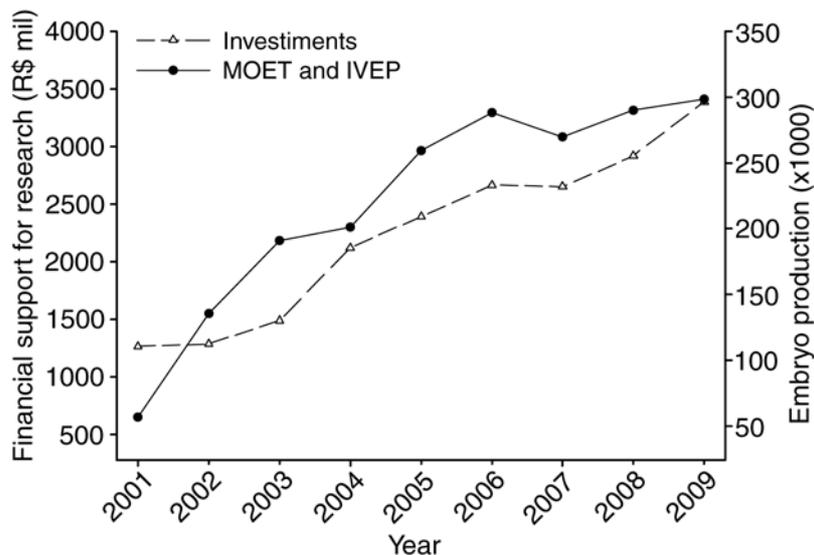
Additionally, the previous positive experience with the *in vivo* embryo production was important to support the IVEP expansion. When the first IVEP companies were established, Brazil presented an already significant participation in the world embryo production, and was ranked in 2000 in the 1st position among countries outside USA-Canada [39]. Since that time Brazil also has the largest national scientific society on embryo technologies, only smaller in the number of participants than the IETS [20]. The expressive use of ET allowed for the growth of a whole market of products and services related to embryo technologies including the supply of hormones, culture medium, disposables, recipients and technical assistance. This market adapted fast to meet the IVEP logistic needs, following the shift from ET to IVEP after 2004.

### **The embryo industry as a model of innovation in livestock production**

The expansion of commercial IVEP after 1999-2000 significantly affected the Brazilian bovine embryo industry. Could these changes be considered the result of innovation in this area? This is a relevant question even in the scientific context, once the innovation concept is being broadly used to establish goals and evaluate the impact of research results.

Innovation requires the conjunction of advances in science and technological development, as previously demonstrated in the "Pasteur's quadrant" [38]. Therefore, the generation of new knowledge shall be used to develop new products and services for the market. Research on IVEP has been performed in Brazil since the 80's in different universities and research centers [31]. Besides the development of protocols for *in vitro* maturation and fertilization, there was a great advance in the understanding and control of the reproductive physiology in zebu breeds [14], in the use of OPU [44] (which is the technique used to recover most of the oocytes used in IVEP in Brazil), and even in the development of the *in vivo* embryo production [4]. The convergence of all these research lines set not only the technical basis but also the human resources needed for the expansion of IVEP. The importance of funding for research and development can be inferred from Figure 3. Although a single databases (CNPq) was used and it was considered the total of grants in the sub-area animal reproduction as a whole, the association of funding and use of biotechnology was suggestive ( $R=0.91$ ;  $P<0.001$ ) and contributes to end up with the paradigm that sophisticated reproductive biotechnologies are of restrict use and, consequently, not worthy of research funding.

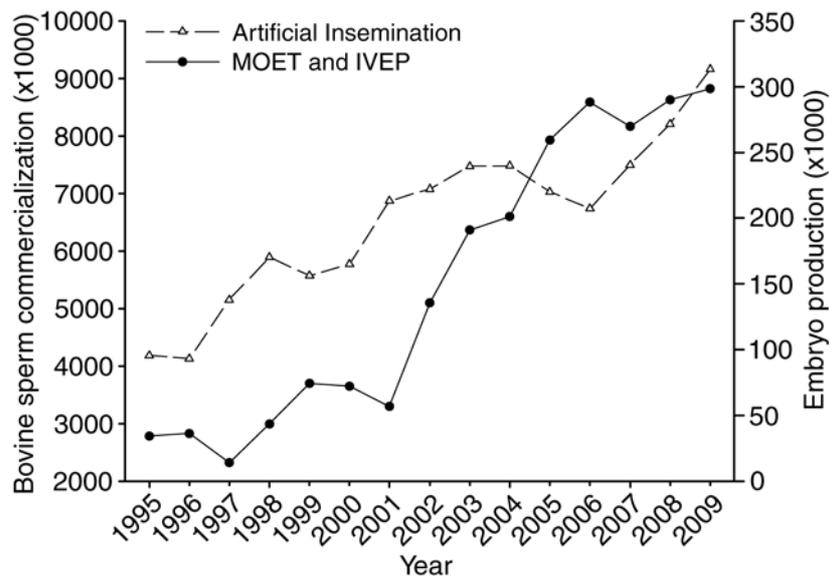
The history of the SBTE is closely linked to the embryo industry in Brazil [31]. Coherently, the support on research and development of reproductive biotechnologies is part of the mission of the society, as shown on its statement: "Art. 2nd - The SBTE is dedicated to education, research and diffusion activities in embryo technology in all branches and has the purpose of: § 1º - Stimulate research applicable to national conditions; § 2º - Disseminate technical and scientific information..." [37]. This mission naturally stimulates innovation, once it integrates science and commercial application of knowledge.



**Figure 3.** Evolution of bovine embryo industry and of the investments in human resources in Brazil from 2001 to 2009, as indicated by the total of embryo produced and by the value of grants from CNPq in the area of animal reproduction.

Innovation results in the appearance of new or improved goods, with potential impact when introduced in a market, and may occur in different contexts such as products, processes, marketing or organizational method. According to the Manual of Oslo [25], “if the innovation brings substantial improvement in the characteristics of the offered service and in the methods, equipments and skills needed to perform it, the innovation is both in the product and in the process.” Therefore, as the IVEP resulted both in new services (OPU, embryo production in laboratory) and in new methods (in vitro fertilization, maturation, and culture), innovation was characterized in these two contexts. The IVEP provided a range of applications which could not be done by conventional ET, such as the production of embryos from pre-pubertal heifers [1], pregnant [43] and problem cows [12], and even from dead animals [48]. There was also a specialization of the services, with OPU, embryo production, and embryo transfer being offered by independent companies, a segmentation that did not exist in the ET market.

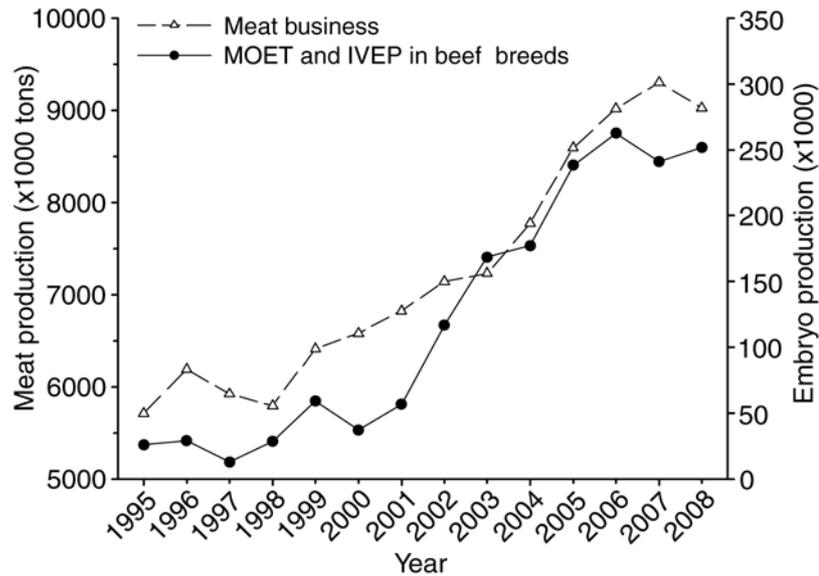
Either for products or for services, however, to characterize innovation the good, besides being new or improved, shall be effectively introduced in the market. The possibility of generating mammals by in vitro fertilization is known since the 50's [8] and the first in vitro produced calf was born in 1981 [6]. In Brazil, the first in vitro produced zebu calves were born in 1993 [31], but the large scale of use, which characterize innovation, only happened later. The growing adoption of IVEP after the year 2000 and its subsequent establishment as the technique of choice for bovine embryo production since 2004 were previously described (Figure 1) and shows that this so called “advanced” technology was fully accepted by the livestock production sector, formerly considered as very conservative. The question is: the increase in the bovine embryo industry was a consequence of the introduction of the new technology or just reflects the positive period of the sector? Figure 4 shows a parallel between the use of embryo technologies and artificial insemination (AI). In both cases, there is a market effect, more evident for AI. The negative fluctuations in semen straws commercialization observed in 1995-1996, 1998-1999, and 2004-2006 [2] were observed in embryo production in 1996-1997, 1999-2001, and 2006-2007, one year later. The analysis of the whole period from 1995 to 2009, however, shows a trend to a linear growth for AI ( $R^2=0.87$ ), while embryo production fits in a sigmoid curve ( $R^2=0.97$ ), with distinct pre- and post- IVEP introduction moments (Figure 4) which characterize the impact of the new technology in the embryo industry.



**Figure 4.** Evolution of bovine artificial insemination and embryo transfer markets in Brazil from 1995 to 2009, according the total of semen straws commercialized and embryos produced in this period. (R=0.83; P<0.0001).

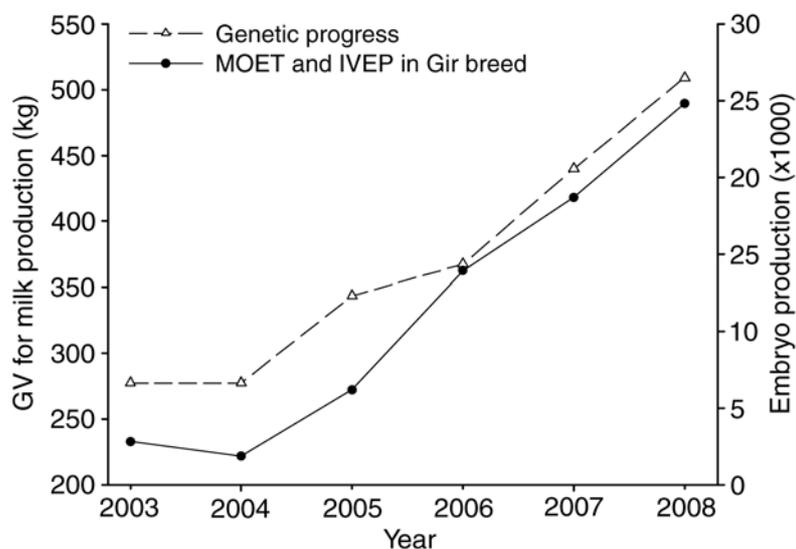
Another feature of innovation is that the new good (product or service) or process shall have an impact on efficiency, productivity or profitability of the company or sector of activity [25]. The measurement of innovation impact requires a complex analysis that is beyond the scope of the present study. A global view of Brazilian agribusiness in the period 1995-2009, however, shows a positive evolution not only for animal products (increases of 58.0% and 64.4% in beef and milk production, respectively) but also of the main agricultural commodities. Grain production, for example, increased 8.2% per year in this period, and this performance was related mainly to increase in productivity (+95.2%) but not in explored area (+27.7%) [11]. The gains in productivity are a strong indicative of technological evolution and, consequently, of innovation.

In animal production, increases in productivity are closely related to the results of the selection and genetic improvement programs, and subsequent introduction of genetically superior animals in the production systems. The use of reproductive biotechnologies such as ET and IVEP may accelerate genetic improvement, as occurs in MOET programs, and at the same time be required as a tool to increase offspring of superior animals [36]. Consequently, a positive association between the use of these technologies and production or productivity indexes is expected. Figure 5 shows the parallel for the beef market, with embryo production in beef breeds and meat production showing a significant correlation (R=0.97; P<0.0001).



**Figure 5.** Evolution of bovine beef and embryo production markets in Brazil from 2001 to 2009, according the number of embryos produced in beef breeds and the production of meat in this period.

The parallel observed between embryo industry and beef market (Figure 5) was not that evident for the dairy industry. It is noteworthy, however, that IVEP was initially used mainly for beef breeds. The increase in the participation of dairy breeds in the total of embryos produced is a recent phenomenon, as previously demonstrated (Figure 2), and was associated with the introduction of sexed semen, another innovation. If we consider the genetic progress in a dairy zebu breed [Peixoto, personal communication], for example, a linear relationship ( $R=0.98$ ;  $P<0.001$ ) between productivity and use of embryo technologies can be characterized (Figure 6). In Brazil, the use of embryo technologies accelerated genetic improvement, especially in Zebu beef and milk breeds, increasing the market prices of animals selected as genetically superior and stimulating a further increase in the use of ET and IVEP. Actually, commercial viability of IVEP is directly related to the possibility of higher genetic progress [36] and is consequently more likely to occur in developing countries with more heterogeneous herds [42].



**Figure 6.** Evolution in the use of embryo technologies and genetic progress in the Gyr breed from 2001 to 2009, according the total of embryos produced and the progress in genetic value (GV) for milk production in this breed.

In the future, it is expected that the great number of genetically superior animals produced by the intensive use of IVEP may cause a drop in their market prices and embryo industry stabilize in a certain level, as the trend observed for beef breeds. Therefore, the hypothetical possibility of producing a large number of offspring from a single donor, frequently highlighted as one of the main advantages of the IVEP [27], may be less important than the strategic use of the technique focusing in specific breeding targets and market opportunities.

## IV. CONCLUSION

The use of bovine IVEP technology caused a significant change in the scenario of the Brazilian embryo industry and demonstrated the importance of innovation in livestock production and, consequently, of the investment in science and technology.

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