



Brazilian embryo industry in context: pitfalls, lessons, and expectations for the future

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Abstract

The aim of this review is to provide a brief description of the current situation of the embryo industry in Brazil, in the context of the national and international livestock production scenario. Total number of embryos produced (375,894) declined in 2015 in comparison with the previous years. *B. taurus* dairy breeds and crossbreds accounted for 51.8% of the total embryo production. Moreover, the percentage of frozen-thawed embryos transferred reached 22.8% in 2015, the highest value in a decade. A greater proportion of embryos were produced *in vitro*, both in dairy (97.2%) and beef (90.2%) breeds. The use of embryo technologies in Brazil has remarkably increased 726.5% in the past 20 years, but still represents only 0.33% of the number of cows and heifers at reproductive age. Nonetheless, embryo transfer (ET) accounted for an estimated 19.7% of all purebred calves born and registered by the Brazilian Zebu Cattle Breeders Association in the period 2005-2015, highlighting the importance of ET for animal breeding and genetic improvement of the herd. In the world's context, Brazil is the largest producer of bovine *in vitro* produced (IVP) embryos, but is ranked only 11th based on an index of intensity of use of embryo technologies, below Canada, USA and various European countries. This scenario demonstrates a potential for further increases in embryo production in Brazil, mainly associated with the expected adoption of new technologies by a large proportion of dairy and beef farms; the use of embryo technologies for large scale production of crossbreds; and to eventual increases in the international embryo import/export activity.

Keywords: cattle production, embryo technologies, statistics.

Introduction

The Brazilian embryo industry underwent remarkable changes in the past 15 years, most of them associated to the adoption of *in vitro* technologies. In cattle, there was a >5-fold increase in embryo production, and *in vitro* fertilization/culture has almost fully replaced superovulation (MOET) as the technique of choice for embryo production. Development of IVP in Brazil was addressed in previous studies (Viana et al., 2010, 2012; Sartori et al., 2016), with a main focus on the technical aspects of the technology. The use of

embryo transfer, however, affects overall cattle production both by increasing genetic progress of animal breeding programs and by providing new alternative methods to produce crossbred animals.

Nevertheless, changes in dairy and beef production systems, induced by the pressure to increase productivity, reduce costs, or improve animal welfare will probably drive further demands for the development of embryo technologies. Thus, to understand the past contribution and the prospective expectations of Brazilian embryo industry, records and numbers must be analyzed in a context. In this study we present a brief description of the current situation of embryo production in Brazil, as well as some proposed indexes to characterize activities related to embryo technologies in the national and international scenario.

A summary of changes in the Brazilian embryo industry during the past decade

Data of Brazilian embryo production in 2015, discriminated by genetic group (*Bos taurus* and *Bos indicus*), industry (dairy and beef) and technology used (*in vivo* derived – IVD or *in vitro* produced - IVP) is shown in Table 1. A decline in the number of embryos produced was observed relative to the previous year (375,894 in 2015 vs. 391,805 in 2014; -4.1%), similar to what has been observed since 2013, which was probably related to the Brazilian economic recession during this period. This retraction in the activity of the embryo industry ceased the trend of growth in Brazilian numbers observed during the last decade, determined mainly by a significant increase in the use of *in vitro* embryo production (IVEP) in dairy breeds (Fig. 1).

The increase in dairy IVEP was primarily supported by the commercial availability of sex-sorted semen (Pontes et al., 2010) and caused important changes in the features of the Brazilian embryo market. The most significant one was a shift towards the use of *B. taurus* breeds for IVEP (Fig. 2). In 2005, zebu beef breeds (mostly Nelore) accounted for 93.8% of all embryos produced, whereas dairy *B. taurus* breeds and crossbreds became the most important market for the embryo industry in 2015, corresponding to 51.8% of the total number of embryos. The majority of embryos are still transferred fresh, but the percentage of frozen-thawed embryos has grown in the past few years, reaching 22.8% in 2015, the highest in a decade, likely due to improvements in cryopreservation strategies, such as direct transfer (Sartori et al., 2016). Data from

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2005-2015 also demonstrates that there was no change in the use of in vitro fertilization/culture as the technique of choice for embryo production, both in dairy (97.2%) and beef (90.2%) breeds.

Table 1. Bovine embryo production in Brazil in 2015, according to genetic group (Bos taurus or Bos indicus), industry (dairy or beef), and technology used (in vivo derived - IVD or in vitro produced - IVP).

Group	IVD	IVP
B. indicus dairy	172	13,481
B. taurus dairy	5,759	188,853
Subtotal dairy	5,931	202,334
B. indicus beef	2,042	81,636
B. taurus beef	14,382	69,569
Subtotal beef	16,424	151,205
Total	22,355	353,539

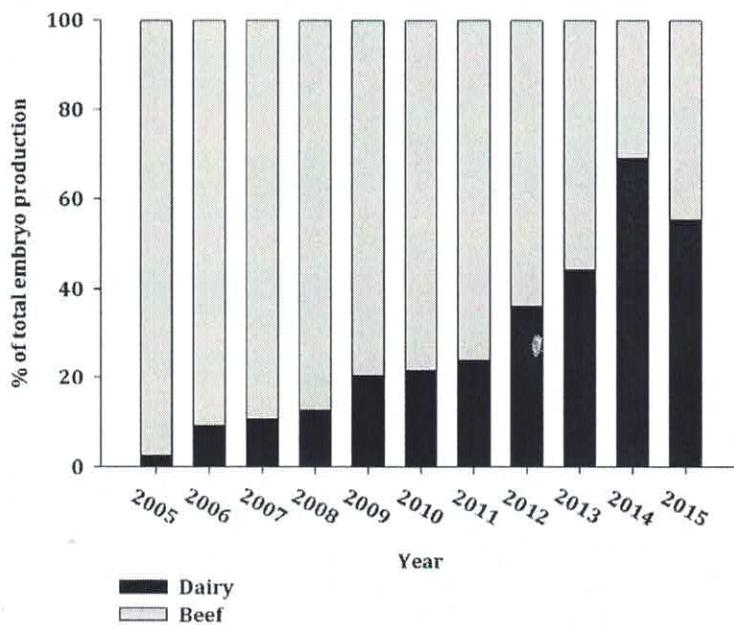


Figure 1. Percentage of Brazilian total embryo production from dairy and beef breeds, from 2005 to 2015.

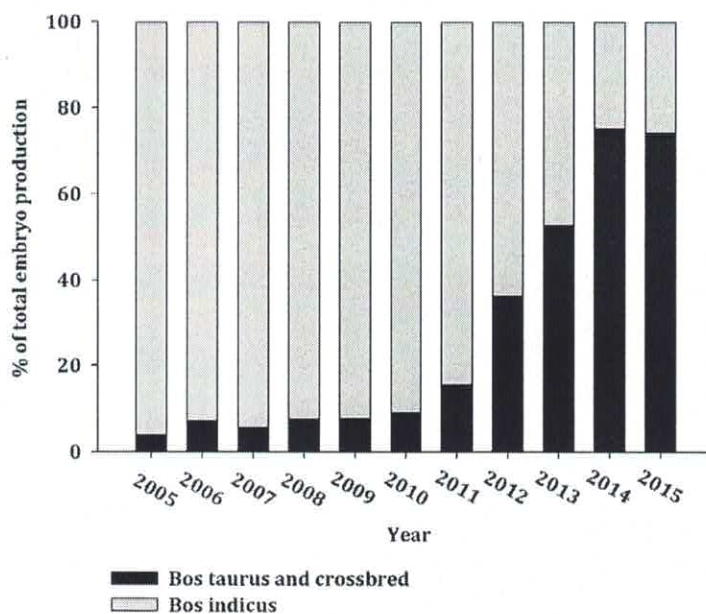


Figure 2. Percentage of Brazilian total embryo production from B. taurus and B. indicus breeds, from 2005 to 2015.



The relevance of embryo technologies

The success of commercial IVEP initiated an exponential growth in Brazilian embryo production and, since 2010, the country reports >300,000 embryos per year. Despite the scarce number of studies evaluating the economical aspects of IVEP in Brazil, the number of embryos produced undoubtedly illustrates the impact of the adoption of in vitro technologies for the embryo industry. Likewise, the growth of IVEP was associated with the parallel development of a chain of suppliers of veterinary services, hormones, media, disposables, equipments, recipients, among others.

Interestingly, if embryo production is analyzed in face of the Brazilian cattle herd size, an apparent

paradox is evident. Table 2 shows the evolution of cattle population in the period 1995-2015 and the estimated relative use of artificial insemination (AI) and embryo transfer (ET). These projections demonstrate that the use of embryo technologies increased by a remarkable rate of 726.5% in the past 20 years; yet, these technologies still reach only 0.33% of the cows and heifers suitable for reproduction, a very low proportion even considering the low use of other reproductive technologies such as AI (13.3%). In dairy breeds, the increase in the use of ET was even greater (2,261.7%), but the relative use is also very limited (0.48%). Therefore, we pose a question: how relevant were embryo technologies for the Brazilian livestock production?

Table 2. Estimated use of artificial insemination (AI) and embryo transfer (ET) as a percentage of the Brazilian cattle herd, 1995-2015.

	1995	2000	2005	2010	2015
Herd size ¹	161,227,938	169,875,524	207,156,696	209,541,109	215,199,488
Heifers and cows ²	42,886,632	45,186,889	55,103,681	55,810,800	57,243,064
Semen straws sales	4,180,971	5,769,348	7,028,308	9,637,337	13,700,000
Use of AI (%) ³	5.4	7.1	7.1	9.6	13.3
Embryos produced	34,076	72,050	259,252	303,237	375,894
Use of ET (%) ⁴	0.04	0.08	0.24	0.27	0.33

¹Total number of heads (Instituto Brasileiro de Geografia e Estatística - IBGE, 2016). ²Number of females at reproductive age, based on projections by the Brazilian Artificial Insemination Association (ASBIA). ³Proportion relative to the number of females at reproductive age. Estimated considering 1.8 straws per successful pregnancy.

⁴Proportion relative to the number of females at reproductive age. Estimated considering 2.0 ET per successful pregnancy in a given recipient.

To address this question, it is important to depict the use of embryo technologies amongst different livestock sectors and production strata. Since the early 2000's, when commercial IVEP began its rise in Brazil, until very recently, most embryos were produced from zebu breeds. As a consequence, these breeds represent the

most comprehensive database available. In Table 3, we estimate the percentage of calves born by ET (conceived by IVP or IVD embryos) relative to all birth records (RGN) reported by the Brazilian Association of Zebu Cattle Breeders (Associação Brasileira dos Criadores de Zebu - ABCZ, 2017) in the period 2005-2015.

Table 3. Estimated percentage of birth records (RGN) from embryo transfers based on records of the Brazilian Zebu Cattle Breeders Association, from 2005 to 2015*.

Breed	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Mean
Gir	18.8	34.9	41.2	47.5	71.0	67.1	54.3	52.1	40.2	32.9	39.0	39.8
Guzerá	18.9	25.3	31.1	34.7	30.9	28.5	27.1	30.3	23.5	13.7	10.8	22.7
Indubrasil	21.8	22.8	7.8	0.5	6.8	51.1	29.0	17.8	24.0	2.3	27.8	16.3
Nelore	20.7	21.8	21.1	22.7	21.0	19.5	22.2	21.7	19.6	9.1	9.0	17.8
Sindi	0.0	0.1	13.2	19.6	29.4	26.8	21.6	28.6	21.5	25.4	28.8	16.5
Tababuã	4.5	6.5	7.8	6.9	6.0	8.3	7.3	6.9	3.0	2.8	5.4	5.5
Cangaian	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7
Brahman	63.6	78.0	73.9	55.6	46.4	48.3	50.1	40.5	29.8	9.4	8.7	45.5
Total	21.5	24.1	23.7	25.1	25.0	23.7	25.1	24.0	20.3	10.2	10.1	19.7

*Based on a projected 40% pregnancy rate relative to the total number of embryos transferred in the previous year.

The results of this projection suggest an entirely different scenario compared to the overall ET data, with ET accounting for an impressive 19.7% of all purebred calves registered by ABCZ. Because zebu

breeds are part of most Brazilian beef and dairy herds (either as purebred or crossbreds), any genetic progress in *B. indicus* profoundly affects national livestock productivity indexes. Such impact is likely to have been



boosted by the intensive use of embryo technologies in the past 10-15 years. Results from the Girolando (Gir x Holstein crosses) breeding program, for example, support this theory. Over 600 of the top 1,000 Girolando cows, ranked according to genetic merit for milk production (Silva et al., 2016), were generated by ET (IVP or IVD embryos).

In Table 3 we provide data to demonstrate that the use of ET was not uniform amongst zebu breeds. In absolute numbers, Nelore accounted for most embryos (76.8%) produced between 2005 and 2015. Nonetheless, the relative contribution of ET for Nelore calf production (17.8%) was lesser (although more stable) than for some other breeds. On average, ET was used more intensively in Brahman and Gir females (45.5 and 39.8%, respectively), but in both cases these numbers fluctuated, with peaks in 2006 for the former (78.0%) and 2009 for the latter (71.0%). In these particular two breeds, such oscillations were probably associated with the transitory use of ET to increase the number of animals rather than for genetic selection, due to the repressed demand for potential oocyte donors.

The Brazilian embryo industry in the world's context

The remarkable increase in embryo production caused by the use of in vitro technologies also changed Brazil's position in the world rank. In the late 1990's, the Brazilian embryo industry was already very active and the country ranked among the TOP 5 in bovine embryo production (Thibier, 2000). After the rise of commercial IVEP, the participation of Brazil in the world's total numbers increased two-fold (from 14.3% in 1999 to 33.9% in 2012) and the country became the largest producer of bovine IVP embryos (Table 4). Interestingly, in the early days of IVEP (up to 2005), the Brazilian embryo market diverged from the trends observed in other countries, particularly from those with relevant embryo production. Therefore, the commercial success of IVEP in Brazil seemed to be a result of particularities of the Brazilian internal market, such as the high economic values and a greater oocyte yield of zebu breeds.

Table 4. Brazilian share in the world's production of bovine embryos in vivo, in vitro, and total, from 2005 to 2015.

	In vivo			In vitro			Total		
	Brazil	World	%	Brazil	World	%	Brazil	World	%
2015	22,355	660,221	3.4	353,539	612,709	57.7	375,894	1,272,930	29.5
2014	43,337	614,464	7.1	348,468	590,359	59.0	391,805	1,204,823	32.5
2013	50,455	729,246	6.9	366,517	546,628	67.1	416,972	1,275,874	32.7
2012	52,719	699,585	7.5	334,913	443,533	75.5	387,632	1,143,118	33.9
2011	32,646	732,862	4.5	318,116	453,471	70.2	350,762	1,186,333	29.6
2010	38,974	732,227	5.3	264,263	450,549	58.7	303,237	1,182,776	25.6
2009	42,397	704,230	6.0	255,993	378,244	67.7	298,390	1,082,474	27.6
2008	69,527	746,250	9.3	220,425	330,953	66.6	289,952	1,077,203	26.9
2007	57,368	763,467	7.5	212,441	434,581	48.9	269,809	1,198,048	22.5
2006	83,741	777,747	10.8	204,402	441,364	46.3	288,143	1,219,111	23.6
2005	122,210	789,972	15.5	137,042	330,647	41.4	259,252	1,120,619	23.1

The recent trends in both Brazilian and international numbers, however, are changing this perception. The use of IVEP has increased consistently in the past 5 years in Europe and North America, considering either absolute numbers (+71.5 and +337.4%; Europe and North America, respectively) or the proportion of total embryo production (+41.3 and +214.5%; respectively), and may possibly replace MOET as the main source of embryos in a near future (Stroud, 2012; Perry, 2013, 2014, 2015, 2016).

Conversely, production of embryos from *B. taurus* and other dairy breeds is increasing in Brazil, as shown in Fig. 1 and 2. Altogether, the general trend is that features of the embryo industry will become more similar worldwide, in spite of regional differences (Table 5). This will probably contribute to an increase in the demand for international trade of embryos and also stimulates a greater participation of large animal breeding companies in the embryo industry, as we currently see for cattle semen.

Table 5. World production of bovine embryos in 2015, according to region, industry (dairy or beef), and technology used (in vivo derived - IVD or in vitro produced - IVP).

Region	IVD				IVP				Total
	Dairy	Beef	Subtotal	%	Dairy	Beef	Subtotal	%	
Africa	402	5,132	5,534	59.7	0	3,733	3,733	40.3	9,267
Asia	16,057	89,628	105,685	91.8	1,162	8,276	9,438	8.2	115,123
Europe	104,174	23,806	127,980	90.3	12,840	940	13,780	9.7	141,760
North America	127,613	232,407	360,020	62.9	105,198	106,848	212,046	37.1	572,066
Oceania	2,178	9,009	11,187	74.2	3,892	0	3,892	25.8	15,079
South America	8,636	41,179	49,815	11.9	208,752	161,068	369,820	88.1	419,635
Total	259,060	401,161	660,221	51.9	331,844	280,865	612,709	48.1	1,272,930

Adapted from Perry (2016).



The United States of America is currently the global leader in total embryo production (IVD plus IVP; Table 6) and may overtake Brazil's leadership in the production of embryos in vitro, as this technology replaces MOET, i.e., without any further increase in total embryo production. Taking into account the ratio between embryo production and cattle population, the Netherlands is the country that most intensively uses embryo technologies, followed by Canada. According

to this criteria, Brazil ranks only 11th. Nevertheless, considering that Brazil has the largest commercial cattle herd in the world, livestock production is of great importance for the country's economy, and that there is an ongoing pressure to increase cattle productivity, we believe that there is room for a sustainable increase in embryo production in the near future, which may eventually change positions on this ranking.

Table 6. Ranking of countries based on their proportion of embryos produced relative to size of the cattle herd, based on data from the year 2014.

Country	Embryos produced	Cattle population ¹	Intensity of use of ET (%)	Rank
The Netherlands	38,637	4,169,000	0.93	1st
Canada	87,113	12,220,000	0.71	2nd
Luxembourg	1,282	198,780	0.64	3rd
USA	506,626	88,526,000	0.57	4th
Finland	3,617	914,439	0.40	5th
Italy	19,355	5,756,072	0.34	6th
Denmark	4,428	1,563,535	0.28	7th
Switzerland	3,397	1,562,801	0.22	8th
Belgium	5,138	2,477,236	0.21	9th
France	38,422	19,095,797	0.20	10th
Brazil	391,805	212,366,132	0.18	11th
Panama	2,708	1,625,200	0.17	12th
Germany	20,913	12,742,190	0.16	13th
Hungary	675	782,000	0.09	14th
Spain	4,900	6,078,700	0.08	15th

¹Food Agriculture Organization (FAO; 2014).

Conclusions

Predicting the development of the embryo industry is always a complex task, due to the dynamic nature of livestock production and the continuous advance in the 'state of the art' of embryo technologies. Nonetheless, the numbers and trends observed in embryo production in the past decade points to some possible scenarios for the industry in the near future:

1. Despite the current retraction in activity, ET is still used in a low percentage of females and herds in Brazil and, therefore, there is a great potential to increase embryo production as more farms adopt these technologies to increase production and productivity, which was also predicted for AI (Baruselli et al., 2012). A new cycle of expansion in the use of ET, however, is more likely to occur associated to the supply of crossbred calves for dairy and beef farms, instead of animal breeding programs;
2. As first observed in Brazil, IVEP is likely to become the technique of choice for ET worldwide. This will reduce regional differences in embryo production systems, as well as reduce costs and increase the scale of embryo production, probably boosting national and international trading of embryos. Consequently, the international embryo market may become more similar to the semen market;
3. In both scenarios described above, the development of successful cryopreservation strategies is key to

further expand the embryo industry, as along with an agreement of sanitary protocols and regulations for the export/import of IVP embryos.

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