

## **Nutritional Management Post-AI to Enhance Pregnancy Outcomes**

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### **Introduction**

Effective replacement heifer development is a critical segment of the integrated management program in an efficient beef cow production system. The most critical factor determining the success of any heifer development program is nutrition. Most efforts are concentrated in providing the right amount and quality of feed to achieve gains from 1.5 to 2.0 lb/day, so heifers can reach 65% of their mature BW by the day of breeding.

Approximately 80% of the U.S. cow-herds are spring calving, which means that producers utilizing estrous synchronization and AI are keeping their heifers in a feedlot environment until heifers are inseminated. Immediately following AI, heifers are typically moved to pasture. It is known that maternal recognition of pregnancy takes place around d 15 - 17 post-insemination and that transporting animals near this time compromises conception rates. However, moving heifers within the first 5 days post-insemination does not cause this reduction. Although, research suggests that conception rates are compromised when heifers are placed on early growth pasture forages. We hypothesized that feeding this high moisture pasture forage at turnout is limiting DMI which in turn causes a temporary energy deficiency that results in temporary heifer weight loss during the critical stages of early embryonic development and maternal recognition of pregnancy. Therefore, it is beneficial to ensure heifers maintain the same plane of nutrition after breeding, at least until day 25 when the embryo should be completely attached to the uterus. If this is true, maintaining a positive plane of nutrition on heifers after breeding will increase 1<sup>st</sup> service conception rates, improving herd fertility and longevity.

### **Direct relationships between post-insemination nutrition and fertility in cattle**

It is well established that general under-nutrition during the prepartum and postpartum period negatively impacts pregnancy success and reproductive efficiency in beef cattle (Diskin et al., 2003 review). Recently however, we have initiated a series of studies on a potential cattle management strategy that result in a period, albeit it brief, of nutritional insult immediately following insemination and investigated the potential impacts of this abbreviated period of negative energy balance on fertility. Many spring-born heifers are developed from weaning to breeding in a dry-lot scenario and fed a diet consisting of a combination of forage and concentrate needed to gain approximately 1.5 lb. per day, targeting a final weight of 65% of estimated mature body weight at the time of breeding. Often estrous is synchronized and AI is conducted while in the dry-lot to better facilitate protocol implementation. Immediately following AI, heifers are often moved to pastures to

expose them to clean-up bulls, take advantage of lush spring forage, and reduce the incidence of embryonic loss associated with handling and moving animals at later stages of early gestation (day 5 through implantation; Harrington et al., 1995). Such an immediate change in nutrition, due to shift in diet delivery method and/or quality and quantity of nutrients, may negatively impact metabolism, body weight gains, and ultimately reproductive efficiency in these beef heifers.

Recently, investigators at Purdue University and the University of Wyoming jointly examined the role of post-insemination nutrition on AI pregnancy rates in beef heifers (Arias et al., 2012). At two locations (Purdue; n = 53, Wyoming; n = 99) heifers were fed at 125% of NRC maintenance requirements (approximate ADG of 1.5 lbs/d) from weaning until estrous synchronization and AI. Immediately following estrous synchronization and AI, feed delivery to heifers was tightly controlled as heifers were specifically fed diets formulated to: 1) maintain pre-breeding plane of nutrition (125% of maintenance requirements; GAIN), 2) 100% of maintenance requirements (Maintain), or 3) 80% of maintenance requirements (LOSE). Heifers remained on these diets for 21 days following AI. Heifers that returned to estrus during the 21-day dietary treatment were inseminated and following the conclusion of the dietary treatment all heifers were comingled and placed with fertile bulls. Pregnancy diagnosis was conducted at 30 days post-AI to determine pregnancy success following the initial AI and 30 days after the breeding season to determine 2<sup>nd</sup> service AI pregnancy rates and overall breeding season pregnancy rates. Although limited numbers prevented detection of statistical differences between treatments within location, when locations were combined (Table 1) contrast analyses revealed that heifers that were fed to continue their pre-breeding plane of nutrition (GAIN treatment) for 21 days post-AI had greater ( $P = 0.04$ ) AI pregnancy rates compared to both groups of heifers that had a decrease in dietary plane of nutrition (Maintain and LOSE heifers). In addition, heifers in the maintain and lose treatments had decreased ( $P < 0.05$ ) 2<sup>nd</sup> service AI pregnancy rates and decreased ( $P < 0.05$ ) overall breeding season pregnancy rates. These results indicate that failing to maintain a pre-breeding plane of nutrition that results in heifer gain following insemination reduces the probability of AI pregnancy success. The results are in agreement with results reported by Perry et al. (2009). In a series of studies, these investigators demonstrated that developing heifers in a dry-lot scenario and then immediately moving heifers to pasture following AI can result in reduced pregnancy rates to AI, if heifers lose weight once placed on pasture. Moreover, if heifers transitioned to pasture immediately following AI are supplemented with a concentrated feedstuff such as distillers grains to prevent post-AI weight loss, pregnancy rates are not negatively impacted. Interestingly, Perry et al. (2009) reported that heifers transitioned from a feedlot to pasture can lose greater than 3 lbs per day in body weight in the first week after entry to the pasture. Hence, with such a dramatic nutritional insult, concomitant with the likely alterations in metabolic signaling occurring in response to this insult, it is not surprising the reproductive performance is negatively impacted.

**Table 1.** Effect of post-AI nutrition on AI pregnancy rates in yearling heifers.

	<b>Ave. Daily Gain, lbs.</b>		<b>AI Pregnancy Rate<sup>1,2</sup>, % (n)</b>		
	<b>Wyoming</b>	<b>Purdue</b>	<b>Wyoming<sup>3</sup></b>	<b>Purdue<sup>4</sup></b>	<b>Combined<sup>5</sup></b>
Gain (NE <sub>m</sub> 125% NRC)	1.44	2.09	67.6 (23/34)	94.7 (18/19)	77.4 (41/53)
Maintain (NE <sub>m</sub> 100% NRC)	0.12	0.15	46.9 (15/32)	75.0 (12/16)	56.3 (27/48)
Lose (NE <sub>m</sub> 80% NRC)	-0.83	-0.75	51.5 (17/33)	77.8 (14/18)	60.8 (31/51)

<sup>1</sup> Location; P = 0.002<sup>2</sup> Location x Treatment; P = 0.73<sup>3</sup> Wyoming AI Pregnancy Rate; Contrast of Gain vs. Others; P = 0.09<sup>4</sup> Purdue AI Pregnancy Rate; Contrast of Gain vs. Others; P = 0.13<sup>5</sup> Combined AI Pregnancy Rate; Contrast of Gain vs. Others; P = 0.04

We recently conducted a study in beef heifers to further elucidate the direct effects of an immediate change in nutrition at AI on early embryonic development. The objective of our study was to determine if post-AI nutrient restriction directly impacted early embryo quality and the number of live/dead blastomeres. It was hypothesized that day 6 embryos collected from heifers that were fed restricted, sub-maintenance diets would have poor embryo quality (assessment of quality grade) with fewer total blastomeres and greater proportion of dead blastomeres than heifer fed diets that allow weight gain post-insemination. This study was conducted at two locations, University of Minnesota's North Central Research and Outreach Center (UMN) and South Dakota State University (SDSU). All heifers were on a common diet during development. Estrus was synchronized and timed-AI was conducted. On the day of AI, heifers were placed in one of two nutritional treatments. At UMN, half of the heifers continued on the pre-AI diet (approximately 120% NRC requirements), targeting an ADG of 1.5 lbs/hd/d (treatment designation = GAIN). The remaining heifers were fed at 80% NRC requirements (treatment designation = LOSE). At SDSU, half of the heifers continued on the pre-AI diet (approximately 125% NRC requirements). The remaining heifers were fed at 50% NRC requirements (treatment designation = LOSE). Dietary treatments were fed until embryo collection was done using non-surgical embryo flush techniques six days after AI. Recovered embryos were microscopically evaluated, classified by developmental stage (morula, blastocyst, expanded blastocyst) and graded on a 1 to 5 scale (1 = excellent, 2 = good, 3 = fair, 4 = poor, and 5 = degenerate) to evaluate embryo quality. Then embryos were transferred to the laboratory where number of dead blastomeres and total number of blastomeres was evaluated using epifluorescent staining. For purposes of this review, results across both locations were combined to illustrate the effects of nutrient restriction on early embryonic development. Nutrient restriction immediately following AI resulted (Table 2) in poorer quality embryos that were developmentally retarded as indicated by being at an earlier stage of development

and having fewer total blastomeres (Table 2). In addition, embryos from nutrient restricted heifers had a decreased ( $P = 0.01$ ) percentage of live blastomeres.

**Table 2.** Effect of post-AI nutrition on day 6 embryo development

TRT	n <sup>a</sup>	% Embryos Recovered	Embryo Stage <sup>b</sup>	Embryo Quality <sup>c</sup>	Dead Cells (n)	Total Cells (n)	% Live Cells
GAIN	46	70.8 (46/65)	4.6 ± 0.1	2.0 ± 0.2	7.8 ± 0.9	70.6 ± 5.6	83.3 ± 3.0
LOSE	42	62.1 (42/66)	3.8 ± 0.2	2.8 ± 0.2	9.7 ± 1.0	48.9 ± 3.9	71.1 ± 4.1
<i>P</i> -value	.	NS	< 0.01	0.02	0.42	0.03	0.01

<sup>a</sup> Defined as embryo number; not heifer with the exception of recovery rate

<sup>b</sup> Stage of development (1-9; 1 = UFO; 9 = expanded hatched blastocyst; per IETS Standards)

<sup>c</sup> Quality of embryo (1-5; 1 = excellent; 5 = degenerate; per IETS Standards)

These results suggest that the early embryo, oviduct, and uterus are sensitive to immediate changes in nutrition. It is proposed that the immediate retardation of embryonic development observed is likely responsible for reduced pregnancy rates due to an inability of the embryo to successfully signal maternal recognition of pregnancy at later stages of development. Currently, the mechanisms by which an abrupt change in nutritional inputs immediately following AI affects early embryonic development are not definitive and numerous physiological and endocrine processes may contribute. Further evaluation of circulating progesterone concentrations, IGF-1, and IGF-binding proteins in this study are currently being conducted. Given the importance of nutritional hormones (e.g. IGF-1, glucose, and insulin) on early embryonic development (Block et al., 2011), diet induced alterations in these factors could influence embryo health and ability to establish pregnancy. Lastly, the contribution of oviductal and uterine histotroph to embryo development is critical. It is unclear if an immediate change in nutritional status can impede histotroph secretion or if nutritional status can dictate composition of the histotroph. Further studies are warranted to investigate this potential phenomenon.

### Take Home Message

Without question, nutrition mediates reproductive function. It is well established that insufficient nutrition in cattle compromises general reproductive efficiency. Specifically in cattle, undernourishment can alter the secretion and circulating amount of various metabolic hormones including insulin, IGF-1 and IGFBP, GH, and leptin. Alterations in these hormones have direct effects on the ovarian follicles and the oocyte to compromise fertility. In addition, nutrient restriction following breeding appears to alter oviductal and uterine support for embryo growth and pregnancy maintenance. Therefore, to maximize fertility,

nutritional inputs to reproducing beef cows must be managed to allow for the animal to be in a positive energy balance. Caution is warranted however as over-nutrition may also compromise various reproductive parameters.

## References

Adamiak, S.J., K. Mackie, R.G. Watt, R. Webb, K.D. Sinclair. 2005. Impact of nutrition on oocyte quality: cumulative effects of body composition and diet leading to hyperinsulinemia in cattle. *Biol. Reprod.* 73: 918-926.

Amstalden, M., M.R. Garcia, S.W. Williams, R.L. Stanko, S.E. Nizielski, C.D. Morrison, D.H. Keisler, G.L. Williams. 2000. Leptin gene expression, circulating leptin, and luteinizing hormone pulsatility are acutely responsive to short-term fasting in pre-pubertal heifers: relationships to circulating insulin, and insulin-like growth factor I (Part I). *Biol. Reprod.* 63: 127-133.

Arias-Alvarez, M., P. Bermejo-Alvarez, A. Gutierrez-Adan, D. Rizos, P.L. Lorenzo, P. Lonergan. 2011. Effect of leptin supplementation during in vitro oocyte maturation and embryo culture on bovine embryo development and gene expression patterns. *Theriogenology* 75: 887-896.

Arias, R.P., P.J. Gunn, R.P. Lemenager, G.A. Bridges, and S.L. Lake. 2012. Effects of post-AI nutrition on reproductive and growth performance of yearling beef heifers. To be presented at the 2012 American Society of Animal Sciences Meeting, Phoenix, AZ. July 2012.

Armstrong, D.G., T.G. McEvoy, G. Baxter, J.J. Robinson, C.O. Hogg, K.J. Woad, R. Webb. 2001. Effect of dietary energy and protein on bovine follicular dynamics and embryo production in vitro: associations with the ovarian insulin-like growth factor system. *Biol. Reprod.* 64: 1624-1632.

Armstrong, D.G., J.G. Gong, J.O. Gardner, G. Baxter, C.O. Hogg, R. Webb. 2002. Steriodogenesis in bovine granulosa cells: the effect of short-term changes in dietary intake. *Reproduction.* 123: 371-378.

Bazer, F.W., G. Wu, G.A. Johnson, J. Kim, and G. Song. 2011. Uterine histotroph and conceptus development: Select nutrients and secreted phosphoprotein 1 affect mechanistic target of rapamycin cell signaling in ewes. *Biol. Reprod.* 85:1094-1107.

Bazer, F.W., G. Song, J. Kim, D.W. Erikson, G.A. Johnson, R.C. Burghardt, H. Gao, M. C. Satterfield, T.E. Spencer, and G. Wu. 2012. Mechanistic mammalian target of rapamycin (MTOR) cell signaling: Effects of select nutrients and secreted phosphoprotein 1 on development of mammalian conceptuses. *Mol. Cell. Endocrin.* 354:22-33.

Benito, M., A.M. Valverde, M. Lorenzo. 1996. IGF-I: a mitogen also involved in differentiation processes in mammalian cells. *Int. J. Biochem. Cell Biol.* 28: 499-510.

Block, J., P.J. Hansen, B. Loureiro, and L. Bonilla. 2011. Improving post-transfer survival of bovine embryos produced *in vitro*: Actions of insulin-like growth factor-1, colony stimulating factor-2 and hyaluronan. *Theriogenology* 76:1602-1609.

Bridges, G.A., M.L. Mussard, C.R. Burke, and M.L. Day. 2010. Influence of length of proestrus on fertility and endocrine function in female cattle. *Anim. Reprod. Sci.* 117:208-215.

Bridges G.A., L.H. Cruppe, J.F. Currin, M.L. Day, P.J. Gunn, J.R. Jaeger, G.C. Lamb, A.E. Radunz, P. Repenning, J.S. Stevenson, J.C. Whittier, W.D. Whittier. 2012a. Determination of the appropriate delivery of PGF<sub>2α</sub> in the 5 day CO-Synch + CIDR protocol in lactating beef cows. *J. Anim. Sci.* In Press.

Bridges, G.A., Kruse, S.G., B. Funnell, S. Bird. Effect of change of body condition score of donor and recipient on ovarian function, endocrine status, and pregnancy success in beef cows. 2012b. Proceedings of the 45<sup>th</sup> Society for the Study of Reproduction Annual Meetings, State College, PA. August 2012.

Diskin, M.G., D.R. Mackey, J.F. Roche, and J.M. Sreenan. 2003. Effects of nutrition and metabolic status on circulating hormones and ovarian follicle development in cattle. *Anim. Reprod. Sci.* 78:345-370.

Ferrell, C.L. 1982. Effects of postweaning rate of gain on onset of puberty and productivity performance of heifers of different breeds. *J. Anim. Sci.* 55:1272.

Forde, N., M.E. Beltman, G.B. Duffy, P. Duffy, J.P. Mehta, P. O'Gaora, J.F. Roche, P. Lonergan, and M.A. Crowe. 2011. Changes in the endometrium transcriptome during the bovine estrous cycle: Effect of low circulating progesterone and consequences for conceptus elongation. *Biol Reprod.* 84:266-278.

Foster, D.L., S. Nagatani. 1999. Physiological perspectives on leptin as a regulator of reproduction: role in timing puberty. *Biol. Reprod.* 60: 205-215.

Gao, H., G. Wu, T.E. Spencer, G.A. Johnson, X. Li, and F.W. Bazer. 2009. Select nutrients in the ovine uterine lumen. I. Amino acids, glucose, and ions in uterine luminal flushings of cyclic and pregnant ewes. *Biol. Reprod.* 80:86-93.

Glister, C., D.S. Tannetta, N.P. Groome, P.G. Knight. 2001. Interactions between follicle-stimulating hormone and growth factors in modulating secretion of steroids and inhibin-related peptides by nonluteinized bovine granulosa cells. *Biol. Reprod.* 65: 1020-1028.

Gong, J.G., T.A. Bramley, R. Webb. 1991. The effect of recombinant bovine somatotropin on ovarian function in heifers: Follicular populations and peripheral hormones. *Biol. Reprod.* 45: 941-949.

Green, M. P., M. G. Hunter, and G. E. Mann. 2005. Relationships between maternal hormone secretion and embryo development on day 5 of pregnancy in dairy cows. *Anim. Reprod. Sci.* 88:179-189.

- Harrington, T.E., M.E. King, H.I. Mihura, D.G. LeFever, R. Hill, and K.G. Odde. 1995. Effect of transportation time on pregnancy rates of synchronized yearling beef heifers. Colorado State University Beef Program Report. Colorado State University, Fort Collins.
- Harrison, L.M., R.D. Randel. 1986. Influence of insulin and energy intake on ovulation rate, luteinizing hormone and progesterone in beef heifers. *J. Anim. Sci.* 63: 1228-1235.
- Hill, J.R., Jr., D.R. Lamond, D.M. Henricks, J.F. Dickey, and G.D. Niswender. 1970. The effects of undernutrition on ovarian function and fertility in beef heifers. *Biol. Reprod.* 2:78-84.
- Jimenez-Krassel, F., J.J. Ireland. 2002. Development and validation of a short-term, serum-free culture system for bovine granulosa cells: Evaluation of the effects of somatotropin and growth hormone-releasing factor as estradiol production. *J. Dairy Sci.* 85: 68-78.
- Kerbler, T. L., M. M. Buhr, L. T. Jordan, K. E. Leslie, and J. S. Walton. 1997. Relationship between maternal plasma progesterone concentration and interferon-tau synthesis by the conceptus in cattle. *Theriogenology* 47:703-714.
- Kim, J. G. Song, H. Gao, J.L. Farmer, M.C. Satterfield, R.C. Burghardt, G. Wu, G.A. Johnson, T.E. Spencer, and F.W. Bazer. 2008. Insulin-like growth factor II activates phosphatidylinositol 3-kinase-protooncogenic protein kinase 1 and mitogen-activated protein kinase cell signaling pathways, and stimulates migration of ovine trophectoderm cells. *Endocrinology* 149:3085-3094.
- Kim, J., D.W. Erikson, R.C. Burghardt, T.E. Spencer, G. Wu, K.J. Bayless, G.A. Johnson, and F.W. Bazer. 2010. Secreted phosphoprotein 1 binds integrins to initiate multiple cell signaling pathways, including FRAP1/nTOR, to support attachment and force-generated migration of trophectoderm cells. *Matrix Biol.* 29:369-382.
- Kruse, S.G., B. Funnell, S. Bird, and G.A. Bridges. Effects of change of body condition score on embryo quality and yield in postpartum beef cows. 2012a. Proceedings of the 45<sup>th</sup> Society for the Study of Reproduction Annual Meetings, State College, PA. August 2012.
- Leroy, J.L., A. Van Soom, G. Opsomer, I.G. Goovaerts, and P.E. Bols. 2008. Reduced fertility in high-yielding dairy cows: are the oocytes and embryos in danger? Part II. Mechanisms linking nutrition and reduced oocyte and embryo quality in high-yielding dairy cows. *Dom. Anim. Reprod.* 43:623.
- Lucy, M.C., C.R. Bilby, C.J. Kirby, W. Yuan, C.K. Boyd. 1999. Role of growth hormone in the maintenance of follicles and corpora lutea. *J. Reprod. Fertil.* 54:49-59.
- Mackey, D.R., J.M. Sreenan, J.F. Roche, and M.G. Diskin. Effect of acute nutritional restriction on incidence of anovulation and periovulatory estradiol and gonadotropin concentrations in beef heifers. *Biol. Reprod.* 61:1601-1607.
- Morimoto, S., C. Fernandez-Mejia, G. Romerri-Navarro, N. Morales-Peza, V. Diaz-Sanchez. 2001. Testosterone effect on insulin content, messenger ribonucleic acid levels, promoter activity and secretion in rats. *Endocrinology.* 142: 1442-1447.

Mulliniks, J.T., M.E. Kemp, S.H. Cox, D.E. Hawkins, A.F. Cibils, D.M. Vanleeuwen, M.K. Petersen. 2011. The effect of increasing amount of glucogenic precursors on reproductive performance in young postpartum range cows. *J. Anim. Sci.* 89: 2932-2943.

Perry, G.A., J. Walker, C. Wright, and K. Olson. 2009. Impact of method of heifer development and post-AI management on reproductive efficiency. Proceedings, The Range Beef Cow Symposium XXI, Casper WY.

Randel, R.D. 1990. Nutrition and postpartum rebreeding in cattle. *J. Anim. Sci.* 68:853.

Rhodes, F.M., L.A. Fitzpatrick, K.W. Entwistle, and G. De'ath. 1995. Sequential changes in ovarian follicular dynamics in *Bos indicus* heifers before and after nutritional anoestrus. *J. Reprod. Fertil.* 104:41-49.

Saha, S., M. Shimizu, M. Geshi, Y. Izaike. 2000. In vitro culture of bovine preantral follicles. *Anim. Reprod. Sci.* 63: 27-39.

Sakagami, N., H. Umeki, O. Nishino, H. Uchiyama, K. Ichikawa, K. Takeshita, E. Kaneko, K. Akiyama, S. Kobayashi, H. Tamada. 2012. Normal calves produced after transfer of embryos cultured in a chemically defined medium supplemented with epidermal growth factor and insulin-like growth factor I following ovum pick up and in vitro fertilization in Japanese black cows. *J. Reprod. Dev.* 58: 140-146.

Satterfield, M.C., H. Gau, X. Li, G.A. Johnson, T.E. Spencer, and F.W. Bazer. 2010. Select nutrients and their associated transporters are increased in the ovine uterus following early progesterone administration. *Biol. Reprod.* 82:224-231.

Schallenberger, E., D. Schams, B. Bullermann, and D.L. Walters. 1984. Pulsatile secretion of gonadotropins, ovarian steroids and ovarian oxytocin during prostaglandin-induced regression of the corpus luteum in the cow. *J. Reprod. Fert.* 71:493.

Siddiqui, M.A., E.L. Gastal, M.O. Gastal, M. Almamun, M.A. Beg, O.J. Ginther. 2009. Relationship of vascular perfusion of the wall of the preovulatory follicle to in vitro fertilization and embryo development in heifers. *Reproduction* 137: 689-697.

Simpson, R.B., C.C. Chase, Jr., L.J. Spicer, R.K. Vernan, A.L. Hamond, D.O. Rae. 1994. Effects of exogenous insulin on plasma and follicular insulin like growth factor I, insulin like growth factor binding activity, follicular oestradiol and progesterone and follicular growth in superovulated Angus and Brahman cows. *J. Reprod. Fertil.* 120: 483-492.

Sosa, C., J.A. Abecia, M. Carriquiry, M.I. Vazquez, A. Fernandez-Foren, M. Talmon, F. Forcada, and A. Meikle. 2009. Effect of undernutrition on the uterine environment during maternal recognition of pregnancy in sheep. *Reprod. Fertil. Devel.* 21:869-881.

Spitzer, J.C., G.D. Niswender, G.E. Seidel, and J.N. Wiltbank. 1978. Fertilization and blood levels of progesterone and LH in beef heifers on a restricted energy diet. *J. Anim. Sci.* 46:1071-1077.



Wasielak, M., M. Bogacki. 2007. Apoptosis inhibition by insulin-like growth factor (IGF)-I during in vitro maturation of bovine oocytes. *J. Reprod. Dev.* 53: 419-426.

Wathes, D.C., T.S. Reynolds, R.S. Robinson, and K.R. Stevenson. 1998. Role of the insulin-like growth factor system in uterine function and placental development in ruminants. *J. Dairy Sci.* 81:1778-1789.

Webb, R., R.G. Gosden, E.E. Telfer, R.M. Moor. 1999. Factors affecting folliculogenesis in ruminants. *J. Anim. Sci.* 68: 257-284.

Webb, R. P.C. Garnsworthy, J.G. Gong, D.G. Armstrong. 2004. Control of follicular growth: Local interactions and nutritional influences. *J. Anim. Sci.* 82(E Suppl.): E63-E74.

Velazquez, M.A., J. Zaraza, A. Oropeza, R. Webb, H. Niemann. 2009. The role of IGF1 in the vivo production of bovine embryos from superovulated donors. *Reproduction.* 137: 161-180.

Velazquez, M.A., D. Hermann, W.A. Kues, H. Niemann. 2011. Increased apoptosis in bovine blastocysts exposed to high levels of IGF1 is not associated with downregulation of the IGF1 receptor. *Reproduction.* 141: 91-103.

Velazquez, M.A., K. G. Haderl, D. Herrmann, W.A. Kues, B. Remy, J.F. Beckers, H. Niemann. 2012. In vivo oocyte IGF-1 priming increases inner cell mass proliferation of in vitro-formed bovine blastocysts. *Theriogenology* 78: 517-527

Yelich, J.V., R.P. Wettemann, H.G. Dolezal, K.S. Lusby, D.K. Bishop, and L.J. Spicer. 1995. Effects of growth rate on carcass composition and lipid partitioning at puberty and growth hormone, insulin-like growth factor I, insulin, and metabolites before puberty in beef heifers. *J. Anim. Sci.* 73:2390.

