Running head: Pair housing at birth increases feed intake and weight gains

Interpretive summary

Early pair housing increases solid feed intake and weight gains in dairy calves

Costa et al. Page 000-000. Milk-fed calves are typically housed individually, but social housing may increase calf feed intake. The aim of this study was to assess the effects of early (6d of age) and late (43d of age) pairing on feeding behavior and weight gains in Holstein dairy calves. Calves paired soon after birth had the highest intake of solid feed and the highest body weight gains in comparison with late paired and individually housed calves. These results indicate that calves can benefit from early social housing.

EARLY PAIR HOUSING INCREASES SOLID FEED INTAKE AND WEIGHT GAINS IN DAIRY CALVES

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ABSTRACT

Dairy calves have traditionally been kept in individual pens throughout the milk-feeding period. Social rearing is associated with increased solid feed intake and hence higher weight gains before and after weaning. Little is known about the effect of the age at which social housing begins. The aim of this study was to assess the effects of early versus late pairing on feeding behavior and weight gain before and after weaning. Holstein bull calves were reared individually (n=8 calves), or paired with another calf at 6 ± 3 d (n=8 pairs) or 43 ± 3 d of age (n=8 pairs). All calves were fed 8 L of milk/d for 4 wk, 6 L/d from 4 to 7 wk and then milk was reduced by 20%/d until calves were completely weaned at 8 wk of age. Calves were provided *ad libitum* access to calf starter and a total mixed ration (TMR). Body weight and feed intake were measured weekly from 3 to 10 wk of age. Intake of calf starter was significantly higher for the early-paired calves than for individually-reared and late-paired calves throughout the experimental period. At 10 wk of age, starter dry matter intake (DMI) averaged 2.20 ± 0.22 kg/d, 1.09 ± 0.25 kg/d and 1.26 ± 0.33 kg/d for early pair, late pair and individually housed calves, respectively. Intake of TMR did not differ among treatments, TMR dry matter intake (averaged 3.27 ± 0.72 kg/d, 3.08 ± 0.46 kg/d, and 2.89 ± 0.54 kg/d for the same three treatments). Calves in the early pair treatment also showed significantly higher average daily gain (ADG) over the experimental period (0.89 ± 0.04 kg/d versus 0.76 ± 0.04 kg/d and 0.73 ± 0.04 kg/d for the early paired, individual and late-paired calves, respectively). These results indicate that social housing soon after birth can increase weight gains and intake of solid feed.

Key words: weaning; animal welfare; forage; social facilitation; social learning; Holstein

INTRODUCTION

Dairy farms often separate calves from their dams within 24 h after birth and then house calves individually (USDA, 2008; Vasseur et al., 2010; Hötzel et al., 2014). Housing milk-fed calves in pairs or groups is increasing in popularity, in part due to the potential of reducing labor requirements per head. Social housing can also provide animal welfare benefits as it allows calves to perform social behaviors and can provide calves more useable space (Jensen et al., 1997; Faerevik et al., 2006).

Calves that consume little solid feed before weaning are more likely to experience poor growth and prolonged hunger after weaning, until intake of solid feed meets their requirements for maintenance and growth (Jasper and Weary, 2002; de Passillé et al., 2011). Encouraging solid intakes early in life can help smooth the transition from milk to solid feed at weaning.

Social housing of dairy calves has been shown to reduce behavioral responses to weaning and improve performance when mixed with a larger group after weaning (de Paula Vieira et al., 2012). Housing dairy calves in a social group also reduces food neophobia (Costa et al., 2014). Group-housed calves have increased weaning weights compared with individually housed calves, likely due to increased DMI during the pre-weaning period (Chua et al., 2002; Xicatto et al., 2002; de Paula Vieira et al., 2010, Bernal-Rigoli et al., 2012). Increased DMI is often attributed to social learning and social facilitation during feeding (Launchbaugh and Howery, 2005).

On some farms calves are housed individually for the first weeks of life and then paired or moved to a group around the time of weaning (Staněk et al., 2014), but it is unknown when contact with peers is necessary to achieve the benefit of increased early intake of solids. The aim of this study was to assess the effects of early and late pairing on feeding behavior and weight gain before and after weaning. We predicted that calves paired early in life (at 6 d) would begin eating solids at a younger age, consume more solids throughout the pre-weaning period, and gain more BW in comparison with calves housed individually or calves paired later in life (6 weeks of age).

MATERIALS AND METHODS

This experiment was carried out between April and December of 2013 at The University of British Columbia's (UBC) Dairy Education and Research Centre, located in Agassiz, British Colombia, Canada (49°N, 121°W). All procedures carried out in this study were approved by the UBC Animal Ethics Committee (AUP A12-0337). The animals were cared for according to the guidelines outlined by the Canadian Council of Animal Care (2009).

General Methodology and Treatments

Forty Holstein bull calves were enrolled at birth. Calves were separated from their dam and fed at least 4L of colostrum (with > 50 g/L of IgG) by bottle within 6 h of birth. Blood samples were collected from the jugular vein 24 h after the first feeding of colostrum and serum was analyzed using a Reichert AR 200 Digital Handheld Refractometer (Reichert, Depew, USA). Only calves with serum protein >5.5 g/dL were kept in the trial. After birth, calves were weighed (mean 43.5 ± 5.1 kg BW) and moved to individual pens with no visual contact with any other calf and were bottle-fed up to 8 L of whole milk daily.

At 6 ± 3 d of age calves were assigned to one of three treatments: individual (n=8), early pair (n=8 pairs) or late pair (n=8 pair). Assignment was random within blocks of 5 calves, within the constraint that calves closest in age were assigned to pair treatments. Individually-reared calves were kept in individual pens (1.2 m × 2 m) on sawdust bedding, with no visual contact with any other calf for the entire length of the experiment (70 d). For early-paired calves, 2 calves were paired at 6 ± 3 days of age by having the barrier to the neighboring pen removed to create a double pen. For late-paired calves, the individual housing continued until the age of 43 ± 3 d, 14 d before weaning. In both pair housing treatments, calves were provided twice the area (2.4 m × 2.0 m), milk bottle holders, water and solid feed buckets in the same pen system as the individually raised calves.

Milk delivery, solid feeding and weaning

All calves were bottle-fed pasteurized whole milk twice per day. From 0 d to 28 d of age calves in all treatments received 8 L/d of whole pasteurized milk, divided in 2 feedings, delivered at 0800h and 1630h. From d 29 to d 49 calves were fed 6 L/d, fed as described above. From d 50 to d 54 milk was reduced by 20%/d for 5 days until calves were completely weaned at d 55. Calves were enrolled in the experiment until d 70. All calves had ad libitum access to water, TMR (shown as % of DM, consisting of 26.1 % corn silage, 14.8 % grass silage, 10 % alfalfa hay and 49 % concentrated mix; which was on average 49.1 ± 1.5 % DM; chemical composition shown as % of DM, CP 17 %, NDF 32 %, ADF 20 %) and calf starter (Hi-Pro Medicated Calf Starter, Chilliwack, BC, Canada with an overall DM of 89.5%; chemical composition shown as % of DM, 90% DM; CP 21%, NDF 19%, ADF 11%; medicated with a coccidiostat [50 mg/kg of Lasalocid Sodium]) during the experimental period. Samples of the feed were taken prior to feeding bi-weekly and frozen, at the end of the experiment the samples were sent to A&L Canada Laboratories Inc. (London, ON). Samples for nutrient and DM analysis were oven dried at 55°C for 48 h. Dried samples were ground to pass though a 1-mm screen and for analysis of ADF (AOAC International, 2000: method 973.18), NDF with heat-stable α-amylase and sodium sulphite (Van Soest et al., 1991), and CP (N x 6.25; AOAC International 2000: method 990.03; Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI). Fresh feed and water were delivered daily at approximately 0830h, and feed refusals were removed before the new feed was delivered. Daily (24 h) calf starter and TMR intakes were determined each morning by disappearance.

Performance and health

Calves were weighed and health scored weekly. Individual BW of each calf was recorded and ADG was calculated for the pre-weaning period (3 to 6 wk), the weaning period (6 to 10 wk) and over the whole experimental period (3 to 10 wk). Health checks were performed following de Paula Vieira et al. (2010), which consisted of diarrhea scoring, where 1 = normal feces; 2 = plaques but not watery; 3 = watery and body temperature < 39.5°C; 4 = watery and body temperature ≥ 39.5°C. Calves with a score = 4 were treated with electrolytic solutions (Hydrafeed, EXL Laboratories, Minneapolis, MN, USA), and calves failing to respond to treatment within 2-d were administered a NSAID (Metacam 20 mg/mL, Boehringer Ingelheim, Burlington, Ont., Canada), according to our farm's standard procedure. During the experimental period 3 calves from the early-paired, 3 calves from the late-paired and 1 calf from the individually-reared treatment were treated with NSAID. Clinical examination of respiratory health was also performed. Calves showing nasal discharge and pathological sounds of pulmonary infection during auscultation were classified as ill, and treated with antibiotic drugs (Resflor GOLD®, Intervet Inc. Roseland, NJ, USA) according to the farm's standard operating procedure. During the experimental period 2 calves from each treatment were treated with antibiotic drugs.

Statistical Analysis

All analyses were performed with SAS (version 9.3; SAS Inst. Inc., Cary, NC) using the pen (i.e. calf or pair) as the experimental unit. Intake of TMR and calf starter were measured daily but averaged to form weekly values for intake per calf per day. Intake of TMR and calf starter are expressed on a DM basis. DMI of TMR and calf starter, total DMI (i.e. TMR + calf starter), ADG and birth BW were considered as dependent variables. Prior to analysis, data were checked for normality using the UNIVARIATE procedure in SAS and probability distribution plots. The effect of treatment on each variable was tested using the MIXED procedure in SAS.

For the variables intakes of TMR, calf starter and total DMI the model included treatment, week and the interaction of the week and the treatments. Week was specified as a repeated measure and calf or pair specified as subject, using an autoregressive covariance structure. ADG over each period (pre-weaning, weaning and over the whole experimental period) was calculated and tested in a model that included treatment and calf or pair as a random effect. The PDIFF statement was used to compare the least square means of each combination of treatments, and the p-values were corrected using the Bonferroni correction.

RESULTS

Intake of TMR was similar across the 3 treatments ($F_{2, 22} = 0.46$; $P = 0.63$; Fig. 1a), but early-paired calves ate more calf starter ($F_{2, 22} = 3.46$; $P = 0.03$; Fig. 1b) and consequently showed higher total DMI ($F_{2, 22} = 10.61$; $P < 0.001$; Fig. 1c) relative to the individual and late pair treatments. Solid feed intake was minimal until calves were 3 wk old. At 6 wk, intake of TMR was not different between treatments ($F_{2, 22} = 1.40$; $P = 0.27$) and averaged 0.17 ± 0.07 kg/d, 0.31 ± 0.07 kg/d, 0.18 ± 0.06 kg/d, for individually, early pair and late pair housed calves, respectively. Starter intake was similar for the individually-reared and late-paired calves (0.07 ± 0.03 kg/d and 0.05 ± 0.03 kg/d) but higher for the early-paired calves (0.18 ± 0.03 kg/d; $F_{2, 22} = 5.00$; $P = 0.02$). Consumption increased after weaning in all treatments, but this increase was greatest for the early-paired calves. At 10 wk of age, intake of calf starter was higher than the other two treatments ($F_{2, 22} = 4.11$; $P = 0.03$). Calf starter intake averaged 2.20 ± 0.22 kg/d, 1.09 ± 0.25 kg/d and 1.26 ± 0.33 kg/d for early pair, late pair and individually housed calves, respectively. Intake of TMR did not differ among treatments ($F_{2, 22} = 1.18$; $P = 0.33$), TMR intake averaged 3.27 ± 0.72 kg/d, 3.08 ± 0.46 kg/d, and 2.89 ± 0.54 kg/d for the same three treatments.

Calves in the early pair treatment gained more weight than did the calves in the other 2 treatments during the entire experimental period (0.89 ± 0.04 kg/d versus 0.76 ± 0.04 kg/d and 0.73 ± 0.04 kg/d for the early-paired, individual and late-paired calves, respectively; $F_{2, 22} = 4.87$; $P < 0.01$). ADG was not different between treatments during the pre-weaning period (3 to 6 wk) ($F_{2, 22} = 0.98$; $P = 0.39$; Fig 2a) but early-paired calves had higher ADG ($F_{2, 22} = 4.13$; $P = 0.03$; Fig. 2b) during the weaning period (6 to 10 wk) relative to the individual and late pair treatments.

DISCUSSION

This study is the first to explore the effects on feed intake of late pairing of calves, in comparison to early pair housing and individual housing. Early pair housing increased calf feed intake and BW. Calves paired soon after birth began to consume solid feed earlier than late-paired and individually housed calves likely contributing to the increased weight gains.

The findings of the current study, showing increased intake by socially housed calves, are consistent with earlier work on social versus individual housing (Chua et al., 2002; Xicatto et al., 2002; de Paula Vieira et al., 2010, Bernal-Rigoli et al., 2012). The results of the current study indicate that grouping must occur before 6 wk to provide this benefit. Tapki (2007) compared calves grouped at birth versus at 3 wk of age and found no difference in solid feed intake.

The results of the current study are also consistent with previous work showing that early grouping can have an important influence on the development of dairy calves. For example, social housing is associated with cognitive benefits including improved performance in reversal learning and improved object recognition (Gaillard et al., 2014). Duve and Jensen (2012) found that when calves were housed individually for 3 wk and then paired, they performed more social behaviors than calves housed individually with limited social contact throughout the pre-weaning period. Only minor differences were found between calves housed together from birth compared with those paired at 3 wk of life. In combination, these results indicate that the critical phase for grouping occurs sometime between 3 and 6 wk of age, as calves paired at 3wk did not differ from calves paired at birth. Based upon these results our conservative recommendation is to group calves within the first 3 wk of life.

The early-paired calves in the current study gained weight at a faster rate than did the individually-reared and late-paired calves. This increased ADG can be explained by the greater solid feed intake. Solid feed intakes are likely to be an important determinant of gains, especially when calves are fed limited quantities of milk (see review by Khan et al., 2011). Solid intakes likely became more important to growth in the current study after 4 wk of age, when the milk ration was reduced from 8 L to 6 L. An additional benefit of establishing high solid intakes before weaning is that calves should then transition more smoothly to exclusively solid feed when milk is fully withdrawn at weaning. Although all treatment groups exhibited a growth check during weaning at wk 7, this check was more pronounced in individually raised calves than in late and early paired calves, indicating an advantage to being paired during the weaning phase. A reduced growth check at weaning for group housed calves has also been reported in earlier studies (Chua et al., 2002; de Paula Vieira et al., 2010). In addition to potential animal welfare benefits from the higher gains this early advantage in BW is likely to benefit farm profitability; recent research has shown the advantages of higher weight gains in calves on the onset of puberty and first lactation, as well as overall milk production (Moallem et al., 2010; Soberon et al., 2012).

A recent paper found that social contact was associated with increased solid feed intake when calves were fed a high intake of milk, but not when calves were fed low milk volumes (Jensen et al., 2015). Feeding low volumes of milk increases calf hunger (de Paula Vieira et al., 2008), increasing motivation to eat solid feed. Thus the effects of social housing on solid intakes are expected to be greatest for calves with higher milk intakes, as in the current study.

In the current study TMR intake did not differ among treatments. This result contrasts with that of Phillips (2004) in which calves reared in groups showed increased intakes of grass (but not starter) relative to calves housed individually. The difference between these two studies may be due to different types of solid feed intake motivation. In the current study, calves were fed 8 L/d and in the study by Phillips (2004) calves received 4L/d. Increased milk allowance is thought to increase motivation to consume forages (as reviewed by Khan et al., 2011), and all calves in this study consumed high quantities of TMR. Intakes were more variable for calf starter, likely making it easier to detect the beneficial effects of social rearing on calf starter intake. In contrast, Phillips (2004) fed calves just 4 L of milk /d, likely leaving animals highly motivated to eat concentrate. In this context, intakes of concentrates were likely consistently high, such that treatment differences were more likely to be observed for forage intake.

The increased intake of solids may be due to social facilitation, social learning or some combination. Social facilitation can be defined as "the initiation of a particular response while observing others engaged in that behavior" (Galef, 1988); in this way the stimulus of an animal eating or approaching the feed would increase the likelihood of the other calf in the same pen performing the same behaviors. Social learning can be defined as learning that is influenced by observation of, or interaction with, another individual (Keeling and Hurnik, 1996). In the previous literature on the development of feeding behavior in farmed species some authors have implicated social facilitation (e.g. Ralphs et al., 1994) and other social learning (e.g. Launchbaugh and Howery, 2005), but in our view distinguishing between these mechanisms is not possible based on the current data and should be explored in future work. Also, if socially reared calves eat more solids simply because their attention is drawn to the feed by their social partner, other methods that draw attention to the feed may also be effective at increasing early intakes. For example, mechanically shaking or changing the feed might also increase attention and ultimately increase intakes. In piglets, it has been shown that a ‘play feeder’ (an open trough with 3 protrusions to stimulate exploration) can increase creep feed intake (Kuller et al., 2010). To our knowledge this approach has never been applied to dairy calves.

In conclusion, dairy calves benefit from early social housing in terms of increased solid intakes and increased gains. To achieve these benefits calves should be grouped within 3 weeks of life.

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REFERENCES

AOAC International. 2000. AOAC International Official Methods of Analysis (17th ed.), Vol. 1 AOAC Int., Arlington, Virginia.

Bernal-Rigoli, J. C., J. D. Allen, J. A. Marchello, S. P. Cuneo, S. R. Garcia, G. Xie, L. W. Hall, C. D. Burrows, and G. C. Duff. 2012. Effects of housing and feeding systems on performance of neonatal Holstein bull calves. J. Anim Sci. 90: 2818-2825.

Chua, B., E. Coenen, J. Van Delen, and D. M. Weary. 2002. Effects of pair versus individual housing on the behavior and performance of dairy calves. J. Dairy Sci. 85: 360-364.

Costa, J. H. C., R. R. Daros, M. A. G. von Keyserlingk, and D. M. Weary. 2014. Complex social housing reduces food neophobia in dairy calves. J. Dairy Sci. 97: 7804-7810.

de Passilé, A. M., T. F. Borderas, and J. Rushen. 2011. Weaning age of calves fed a high milk allowance by automated feeders: Effects on feed, water, and energy intake, behavioral signs of hunger, and weight gains. J. Dairy Sci. 94: 1401–1408.

de Paula Vieira, A., M. A. G. von Keyserlingk, and D. M. Weary. 2010. Effects of pair versus single housing on performance and behavior of dairy calves before and after weaning from milk. J. Dairy Sci. 93: 3079-3085.

de Paula Vieira, A., M. A. G. von Keyserlingk, and D. M. Weary. 2012. Presence of an older weaned companion influences feeding behavior and improves performance of dairy calves before and after weaning from milk. J. Dairy Sci. 95: 3218-3224.

de Paula Vieira, A., V. Guesdon, A. M. de Passillé, M. A. G. von Keyserlingk, and D. M. Weary. 2008. Behavioural indicators of hunger in dairy calves. Appl. Anim. Behav. Sci. 109: 180-189.

Duve, L. R., and M. B. Jensen. 2012. Social behavior of young dairy calves housed with limited or full social contact with a peer. J. Dairy Sci. 95: 5936-5945.

Færevik, G., M. B. Jensen, and K. E. Bøe. 2006. Dairy calves social preferences and the significance of a companion animal during separation from the group. Appl. Anim. Behav. Sci. 99: 205-221.

Gaillard, C., R. K. Meagher, M. A. G. von Keyserlingk, and D. M. Weary. 2014. Social housing improves dairy calves' performance in two cognitive tests. PLoS ONE 9.2: e90205.

Galef, B. J. 1988. Communication of information concerning distant diets in a social, central-place foraging species: Rattus norvegicus. 119- 139. In T. R. Zentall and B. G. Galef, Jr. (Eds.), Social learning: Psychological and biological perspectives. Hillsdale, NJ: Erlbaum.

Hötzel, M. J., C. Longo, L. F. Balcão, C. S. Cardoso, and J. H. C. Costa. 2014. A Survey of Management Practices That Influence Performance and Welfare of Dairy Calves Reared in Southern Brazil. PLoS ONE. 9(12): e114995.

Jasper, J., and D. M. Weary. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85: 3054-3058.

Jensen, M. B., K. S. Vestergaard, C. C. Krohn, and L. Munksgaard. 1997. Effect of single versus group housing and space allowance on responses of calves during open-field tests. Appl. Anim. Behav. Sci. 54: 109–121.

Jensen, M. B., L. R. Duve, and D.M. Weary. 2015. Pair housing and enhanced milk allowance increase play behavior and improve performance in dairy calves. J dairy Sci. doi: 10.3168/jds.2014-8272.

Keeling, L. J., and J. F. Hurnik. 1996. Social facilitation and synchronization of eating between familiar and unfamiliar newly weaned piglets. Acta Agric. Scand. Section A: Anim. Sci., 46: 54–60.

Khan, M. A., D. M. Weary, and M. A. G. von Keyserlingk. 2011. Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. J. Dairy Sci. 94 :1071-1081.

Kuller, W. I., T. J. Tobias, and A. van Nes. 2010. Creep feed intake in unweaned piglets is increased by exploration stimulating feeder. Livest. Prod. Sci. 129: 228-231.

Launchbaugh, K. L., and L. D. Howery. 2005. Understanding landscape use patterns of livestock as a consequence of foraging behavior. Rangeland Ecology & Management. 58: 99-108.

Moallem, U., D. Werner, H. Lehrer, M. Zachut, L. Livshitz, S. Yakoby, and A. Shamay. 2010. Long-term effects of ad libitum whole milk prior to weaning and prepubertal protein supplementation on skeletal growth rate and first-lactation milk production. J. Dairy Sci. 93: 2639-2650.

Phillips, C. J. C. 2004. The effects of forage provision and group size on the behavior of calves. J. Dairy Sci. 87: 1380-1388.

Ralphs, M. H., D. Graham, and L. F. James. 1994. Social facilitation influences cattle to graze locoweed. J. Range Manage. 1994: 123-126.

Soberon, F., E. Raffrenato, R. W. Everett, and M. E. Van Amburgh. 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. J. Dairy Sci. 95: 783-793.

Staněk, S., V. Zink, O. Doležal, and L. Štolc. 2014. Survey of preweaning dairy calf-rearing practices in Czech dairy herds. J. Dairy Sci. 97: 3973-3981.

Tapki, İ. 2007. Effects of individual or combined housing systems on behavioural and growth responses of dairy calves. Acta Agric. Scand. Section A. 57: 55-60.

USDA. 2008. Dairy 2007, Part III: Reference of Dairy Cattle Health and Management Practices in the United States. 2007. USDA, National Animal Health Monitoring System, Fort Collins, CO.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fibre, neutral detergent fibre and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583-3597.

Vasseur, E., F. Borderas, R. I Cue, D. Lefebvre, D. Pellerin, J. Rushen, K. M. Wade, and A. M. dePassillé. 2010. A survey of dairy calf management practices in Canada that affect animal welfare. J. Dairy Sci. 93: 1307-1316.

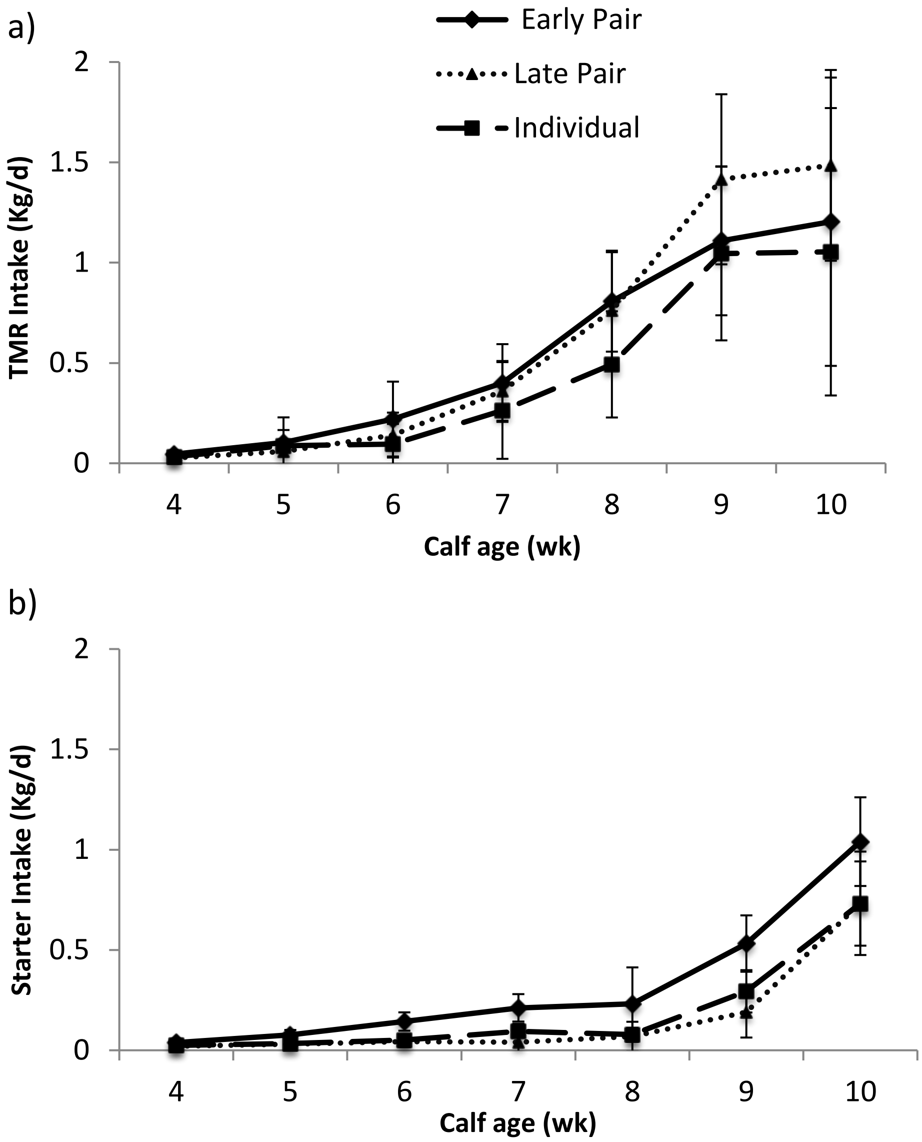
Xiccato, G., A. Trocino, P. I. Queaque, A. Sartori, and A. Carazzolo. 2002. Rearing veal calves with respect to animal welfare: effects of group housing and solid feed supplementation on growth performance and meat quality. Livest. Prod. Sci. 75: 269-280.

Figure legends

Figure 1. Least square mean (± SE) of weekly a), total mixed ration (TMR; kg of DM) b) calf starter (kg of DM) and c) solid feed dry matter intake (DMI; kg of DM) for early-paired (paired at 6 ± 3 d old; n=8 pairs), late-paired calves (paired at 43 ± 3 d old; n=8 pairs) and individually (n=8 calves) from 3 to 10 wk old.

Figure 2. Least square mean (± SE) of average daily gain (ADG) (kg/d) for early-paired (paired at 6 ± 3 d old; n=8 pairs), late-paired calves (paired at 43 ± 3 d old; n=8 pairs) and individually (n=8 calves) during the a) whole experimental time (wk 3 to wk 10) b) pre-weaning (wk 3 to wk 6) and c) weaning (wk 6 to wk 10) periods.

Figure 1.



a)
Early Pair
Late Pair
Individual
TMR Intake (Kg/d)
0
0.5
1
1.5
2
4
5
6
7
8
9
10
Calf age (wk)
b)
Starter Intake (Kg/d)
0
0.5
1
1.5
2
4
5
6
7
8
9
10
Calf age (wk)

c)

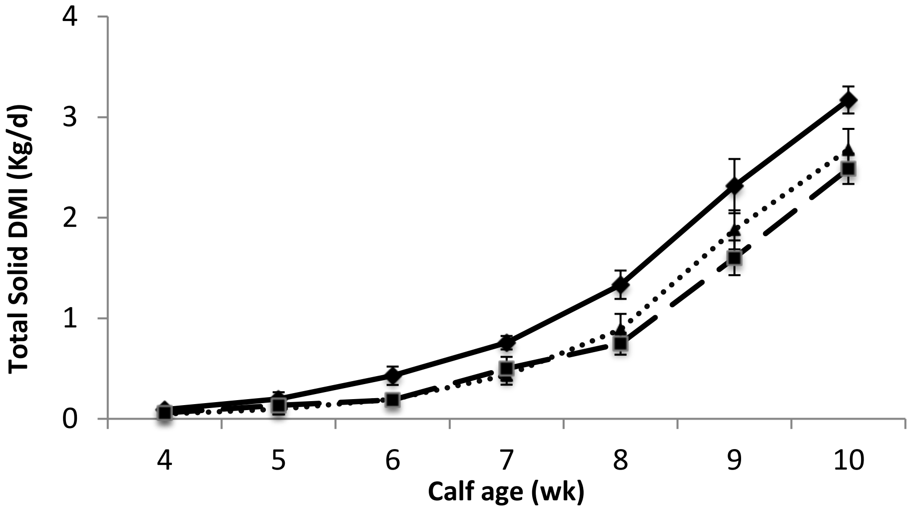
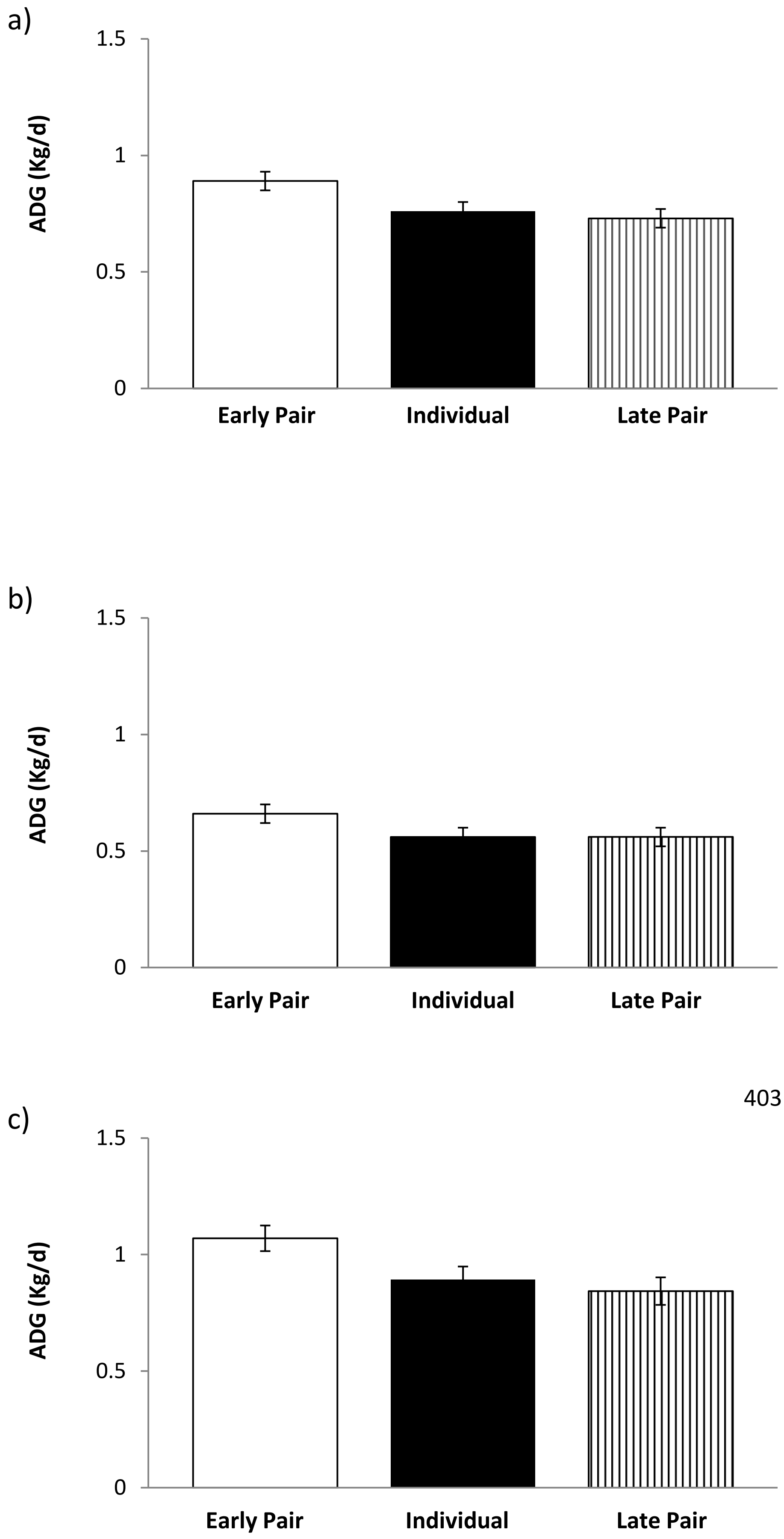


Figure 2.


a)
1.5
1
0.5
0
ADG (Kg/d)
Early Pair
Individual
Late Pair
b)
1.5
1
0.5
0
ADG (Kg/d)
Early Pair
Individual
Late Pair
c)
1.5
1
0.5
0
ADG (Kg/d)
Early Pair
Individual
Late Pair