Effect of limit feeding high- and low-concentrate diets with *Saccharomyces cerevisiae* on digestibility and on dairy heifer growth and first-lactation performance¹

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ABSTRACT

Growth and digestibility were examined for heifers limit fed high- (HC; 60%) and low-concentrate (LC; 20%) diets with or without yeast culture (YC) addition in 2 experiments. A third experiment was undertaken to monitor first-lactation production of heifers limit fed HC or LC diets. In experiment 1, 32 Holstein heifers were individually fed at controlled intakes for 133 d to maintain a targeted average daily gain of 0.80 kg/d for all 4 treatments [HC; LC with and without *Saccharomyces cerevisiae*; Yea-Sacc¹⁰²⁶ (Alltech Inc., Nicholasville, KY), 1 g/kg as fed]. Targeted average daily gain was achieved for all treatments during the individual feeding period (0.80 ± 0.01 kg/d). Average dry matter intake needed to maintain constant gain was slightly reduced for HC and YC treatments. Reduced dry matter intake and similar targeted average daily gain resulted in a tendency for improved feed efficiency of HC-fed heifers. Skeletal measurements and targeted average daily gain were not affected by concentrate level or YC. The objective of experiment 2 was to elucidate effects of concentrate level and YC on nutrient digestibility. Four young (284.35 ± 4.51 d) and 4 older (410.28 ± 2.14 d) heifers were allocated to the 4 treatments used in experiment 1. Heifers fed the HC diet had increased dry matter digestibility (75.67 vs. $72.96 \pm 0.72\%$), and YC addition increased dry matter digestibility (74.97 vs. $73.65 \pm 0.71\%$). Intake of N and apparent N digestibility were similar for all treatments. High-concentrate diets and YC addition decreased wet and dry matter output of feces. Urine excretion was not different; therefore, total manure output was lower for HC-fed heifers as compared with LC-fed heifers. Results suggest that HC diets can improve feed efficiency without affecting growth when limit fed to dairy heifers. Yeast culture increased dry matter digestibility in HC- and LC-fed

heifers; HC diets were more digestible and reduced fecal output, with YC enhancing this effect. In experiment 3, heifers from experiment 1 were group fed the same diets (HC or LC) without YC until parturition, and milk production was measured through 154 d of lactation. Group-fed average daily gain was not different between treatments (HC = 1.11 vs. LC = 1.04 kg/d, SE = ± 0.06 kg/d). Heifers fed the HC and LC diets calved at 23.50 and 23.79 ± 0.50 mo, respectively. Peak milk was lower and there was a tendency for reduced daily milk and protein yield for primiparous cows fed HC diets from 8 mo of age to the dry/prefresh period (long term), but predicted yields of milk and components were similar in the first 154 d of lactation.

Key words: growth, first lactation, digestibility, forage-to-concentrate ratio, yeast culture

INTRODUCTION

Finding strategies to raise dairy replacement heifers economically and efficiently is important in order to increase dairy industry profitability. Although heifers contribute no revenue until the onset of lactation, costs from birth to calving represent the second or third largest expense on a dairy farm (Heinrichs, 1993). Several cost-containment strategies have been explored (e.g., accelerated growth, reduced age at first calving, bST injections), but these have been inapplicable or have reduced milk production in first lactation (Van Amburgh et al., 1998; Lammers et al., 1999; Radcliff et al., 2000).

Dairy heifers are typically fed high-fiber diets, but there is inherent energy and protein inefficiency in these diets (Moody et al., 2007; Zanton and Heinrichs, 2007). This has attracted growing attention to the use of high-concentrate diets to improve feed utilization by ruminants. Reynolds et al. (1991a,b) observed that growing beef heifers retained more tissue energy when animals were fed a constant level of ME from high-concentrate (HC; 75% concentrate) versus low-concentrate (LC; 25% concentrate) diets, with the HC-fed heifers exhibiting less heat energy production. These findings appear to suggest that maintenance requirements for

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the purposes of digestion could be reduced, allowing a greater proportion of nutrients to be used for productive purposes (Zanton and Heinrichs, 2007). Thus, use of HC diets permits a reduction of the DMI needed to satisfy the nutrient requirement of the animal.

An important consideration when using this type of diet is to restrict intake to avoid problems related to increased ADG and reduction in first-lactation performance (Van Amburgh et al., 1998; Lammers et al., 1999). Research to date suggests that a prepubertal ADG of approximately 0.80 kg/d is appropriate for large-breed dairy heifers to maximize first-lactation milk yield (Sejrsen et al., 2000; Zanton and Heinrichs, 2005). Recently, the use of HC diets fed restrictively has reduced manure output (Moody et al., 2007), resulted in similar milk yields (Hoffman et al., 2007; Zanton and Heinrichs, 2007), and had no negative effects on rumen fermentation (Lascano and Heinrichs, 2009). However, there is a gap in the literature concerning the prolonged effect of HC or LC diets when fed from 8 mo of age to the dry/prefresh period (long term; **LT**) for a constant growth rate.

In addition, when limit feeding high-energy forages and diets, growth and performance of the growing dairy heifer might be challenged. Research shows that when yeast culture (**YC**) is added to ruminant diets, an increase in total number of rumen bacteria is often observed, including cellulolytic and lactate-using species. Although in many studies the increased number of bacteria did not reach statistical significance, most research demonstrated that feeding yeast stimulated total bacteria numbers (Lascano and Heinrichs, 2007). This stimulation of bacteria numbers can affect DM digestibility (**DMD**) because bacteria are required for rumen fiber degradation. Also, increased microbial protein flow to the small intestine and a lower risk of lactic acidosis (Erasmus et al., 1992; Martin and Nisbet, 1992; Wallace, 1994) could be beneficial for animal performance. It has been noted that when feeding traditional high-forage diets, the response of lactating cows and heifers to YC addition is variable and might have a more stable response when used in HC diets (Wallace, 1994).

Our project focused on reducing the costs to raise dairy heifers by feeding more concentrates relative to forages at a targeted ADG (**T-ADG**). In the United States, feed costs per unit of energy or protein are often cheaper for concentrates than for forages, and the use of YC in this type of diet could improve animal performance. Therefore, the objectives of these experiments were to evaluate 1) growth-feed efficiency (**FE**; kg of ADG/kg of DMI), 2) diet digestibility and N utilization of heifers limit fed HC or LC diets with or without supplemental YC, and 3) first-lactation milk produc-

tion for primiparous cows fed HC or LC diets **LT** for a constant ADG.

MATERIALS AND METHODS

Experiment Layout

Three experiments were conducted according to guidelines from The Pennsylvania State University Institutional Animal Care and Use Committee. Experiment 1 was a heifer growth trial that lasted for 133 d with 4 treatments using a completely randomized block design. Experiment 2 was a digestibility trial undertaken concurrently, utilizing the same diets and treatments as experiment 1. A split-plot, Latin square design with heifer age as the whole plot and treatment as subplot was used. Experiment 3 utilized heifers from experiment 1; heifers were group fed the same diets (HC or LC) without YC until parturition, and milk production was measured through 154 d of lactation.

Diets

Total mixed rations consisted of corn silage (sole forage source) with primary concentrate feeds (Table 1). Heifers were fed once a day at 0800 and 1000 h for experiments 1 and 2, respectively. Rations were mixed in a Calan Super Data Ranger (American Calan, Northwood, NH) for approximately 5 min, with refusal amounts recorded before feeding. Refusal amounts were negligible, and the amounts were recorded but not sampled. The forage-to-concentrate ratios (**F:C**) for HC and LC diets were 40:60 and 80:20, respectively. Forage and TMR samples were collected daily and composited every 15 d and monthly, respectively; concentrate samples were collected once per month. Immediately after collection, samples were dried in a forced-air oven (55°C) for 3 consecutive days and then stored for further analyses. Feedstuffs and TMR were ground through a 1-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA) and analyzed for DM, OM, ash (AOAC, 1990), and ADF and NDF (Van Soest et al., 1991) using an Ankom²⁰⁰ Fiber Analyzer (Ankom Technology Corporation, Fairport, NY) with heat-stable α -amylase and sodium sulfite for the NDF procedure. Crude protein was analyzed using the Kjeldahl method (AOAC, 1990). Rations were formulated and fed restrictively to provide 0.80 kg/d T-ADG and 0.22 Mcal of ME intake/kg of empty BW^{0.75}, with a fixed level of 13% CP. For experiment 3, heifers that finished experiment 1 were assigned to the same HC or LC diets but without YC addition. They were fed once daily at 0800 h, as in experiment 1, and then moved to dry-cow/prefreshening pens with uniform diets. After

Table 1. Ingredient and nutrient composition of high- (HC) or low-concentrate (LC) diets fed to Holstein dairy heifers

Item ¹	Experiment 1				Experiment 2			
	HC	SD	LC	SD	HC	SD	LC	SD
Ingredients, % DM								
Corn silage ²	40.00	—	80.00	—	40.00	—	80.00	—
Ground corn	47.70	—	5.67	—	47.70	—	5.67	—
Soybean meal (SBM)	9.00	—	9.47	—	9.00	—	9.47	—
Heat-treated SBM	0.00	—	1.60	—	0.00	—	1.60	—
Sodium bicarbonate	0.35	—	0.35	—	0.35	—	0.35	—
High mineral mix ³	2.95	—	0.00	—	2.95	—	0.00	—
Low mineral mix ⁴	0.00	—	2.45	—	0.00	—	2.45	—
Nutrients ⁵								
DM, %	55.67	1.61	44.31	4.54	60.45	0.74	43.73	1.10
CP, %	12.09	0.80	12.13	0.74	13.31	0.32	13.45	0.53
Soluble CP, % of CP	40.24	3.00	47.07	5.51	28.53	3.10	35.3	4.29
RDP, ⁶ % of CP	65.56	2.34	69.73	3.46	66.92	1.89	70.71	2.76
ADF, %	11.41	0.84	19.22	1.52	14.25	1.59	22.45	0.65
NDF, %	21.24	1.37	33.15	1.84	25.45	1.93	35.38	2.28
NFC, ⁷ %	53.68	1.12	44.21	1.59	53.88	2.08	43.97	3.46
TDN, ⁸ %	79.63	0.84	73.84	1.14	79.35	1.59	72.75	1.33
ME, ⁹ Mcal/kg of DM	2.88	0.03	2.67	0.04	2.87	0.06	2.63	0.05
Ca, %	0.3	0.09	0.37	0.06	0.35	0.57	0.3	0.60
P, %	0.29	0.01	0.27	0.01	0.22	0.06	0.28	0.06
Mg, %	0.22	0.01	0.21	0.01	0.22	0.01	0.28	0.01
K, %	0.88	0.10	1.23	0.09	0.98	0.02	1.12	0.01

¹All ingredients and nutrients are expressed on a DM basis unless otherwise specified.

²Contained 34.2% DM, 38.4% NDF, 22.9% ADF, 6.78% CP, and 36.32% starch on DM basis.

³Contained 7.8% vitamin E, 2.6% vitamin ADE, 28.6% distillers corn with soluble vitamin D, 14.6% plain salt, 36.5% limestone, 2.6% magnesium oxide, 5.7% trace mineral premix, and 1.6% selenium premix.

⁴Contained 7.4% vitamin E, 2.5% vitamin ADE, 28.6% distillers corn with soluble vitamin D, 13.9% plain salt, 34.8% limestone, 6.0% magnesium oxide, 5.5% trace mineral premix, and 1.5% selenium premix.

⁵n = 10 composite samples representing 42 samples per treatment taken daily throughout the collection period.

⁶Calculated from ingredients.

⁷Analyzed by Cumberland Valley Analytical Services Laboratory (Maugansville, MD).

⁸Total digestible nutrients (calculated from ingredients).

⁹Estimated: ME = TDN × 0.04409 × 0.82.

calving, all primiparous cows were fed the standard herd ration to meet NRC (2001) requirements. The lactating-cow TMR was offered daily at 0700 h, and animals had ad libitum access to feed and water.

Experiment 1: Growth

Thirty-two Holstein heifers at 246.53 ± 50.23 d of age and 227.94 ± 27.11 kg of BW were used to evaluate the effect of limit feeding HC and LC diets with or without YC addition (Yea-Sacc¹⁰²⁶, Alltech Inc., Nicholasville, KY). Heifers were randomly assigned to HC, HC with addition of YC, LC, or LC with addition of YC using a completely randomized block design in which heifers were blocked by weight and age. The addition of YC was at 1 g of YC/kg of feed on an as-fed basis in an attempt to maintain a similar quantity of YC in relation to the different rumen volumes of the 2 F:C treatments (Moody et al., 2007; Lascano and Heinrichs, 2009). A

40-d adaptation period was used: 30 d to train heifers to use the feeding system using the standard herd diet and 10 d for incremental adaptation to experimental diets.

Heifers were recruited in 2 batches of 20 and 12, respectively, as available from the university herd and were housed in 6 different pens equipped with individual Calan gates (American Calan). Pens housed 7, 5, or 4 heifers that were allocated to the 4 aforementioned treatments. Heifers in each pen received the same dietary treatment (either HC or LC) to avoid possible aggression between heifers because of the anticipated differences in time to complete a meal (Zanton and Heinrichs, 2007). Addition of YC was randomized by Calan gate within each pen. Heifers were housed in a naturally ventilated barn with free access to water and were bedded with sawdust that was changed twice a month with extra sawdust added weekly. Heifers were maintained in treatment groups for 133 d. Two heifers

were removed from the experiment (one HC and one LC) because of the presence of intense scours during the first weeks of the trial. Observation of heifer health and estrous was conducted daily at 0800 and 1900 h.

Skeletal growth (withers height, hip height, hip width, paunch girth, and body length) and BW measurements were recorded weekly approximately 1 h before feeding on 2 consecutive days, and the values were averaged to account for day-to-day variation. The ADG from the previous week was calculated, and DMI was adjusted accordingly to maintain the desired overall trial T-ADG of 0.80 kg/d.

Experiment 2: Digestibility

An experiment was conducted with 8 Holstein dairy heifers recruited from 2 different age groups (4 heifers per group), referred to as young (288.35 ± 4.51 d of age and BW of 234.76 ± 15.33 kg) and old (410.28 ± 2.24 d of age and BW of 409.34 ± 20.32 kg). Heifers were weighed weekly, with 2 measurements at 0800 and 1800 h (2 h before and 8 h after feeding), except the week immediately before intensive sampling. Changes in BW determined the quantity of treatment ration received for the following 7 d; however, DMI was not changed immediately before sampling because that could have artificially increased variation in results. Predicted DMI were determined using NRC (2001), and diets were formulated to restrict intake to maintain 0.22 Mcal of ME intake/kg of empty BW^{0.75}. Health checks were conducted twice daily at 0830 and 2030 h. Heifers were individually housed in tie stalls in an environmentally controlled barn. Heifers had free-choice access to water and were released 1 h postfeeding for approximately 1 h/d to a paved exercise lot, except on intensive sampling days. Lighting was automatically controlled to allow 13.5 h/d of light, except on intensive sampling days when light was provided approximately 18 h/d.

Heifers were allowed 30 d before starting the experiment to adapt to the tie stall facility and were randomly assigned to 1 of 4 treatment sequences (as described for experiment 1). A split-plot, Latin square design with heifer age as the whole plot and treatment as the sub-plot was administered over four 21-d periods. Periods consisted of 17 d of adaptation and 4 d of total fecal and urine collection.

Urine was collected using a noninvasive urinary device modified from Fellner et al. (1988). The urinary devices were held in place by an udder support (Nasco C17682N, Fort Atkinson, WI) adjusted to fit the vulva. Urine samples were collected into a carboy acidified with 12 N HCl to maintain pH below 3 and minimize NH₃ volatilization. Feces were collected hourly and stored in airtight containers. Every 24 h, total collected feces and

urine were weighed, recorded, mixed, and subsampled for chemical analysis. Fecal subsamples were dried in a 55°C forced-air oven for 4 d, DM determined (AOAC 1990), and ground through a 1-mm screen (Wiley mill, Arthur H. Thomas); 250 mL of urine subsample was frozen at -20°C for later analysis. Dried fecal samples were analyzed for CP using the Kjeldahl method (AOAC, 1990). Also, samples were analyzed for ADF and NDF using an Ankom²⁰⁰ Fiber Analyzer (Ankom Technology Corporation); NDF analysis included addition of heat-stable α -amylase and sodium sulfite. After thawing, urine samples were analyzed for CP (AOAC, 1990). Urine samples were diluted with distilled water (dilution factor 1:10), and NaOH was used as a solvent for creatinine (Cat No. 0400-100, Stanbio Laboratory, Boerne, TX), uric acid (Cat No. 1045-225, Stanbio Laboratory), and urea N (Cat No. 0580-250, Stanbio Laboratory).

Experiment 3: Rearing and Lactation

Thirty heifers finished the initial 133-d growth experiment and were transferred to 4 freestall pens. They were group fed (15/treatment) and assigned to the same HC or LC diets without YC addition for 126 d and then moved to a common diet that contained 70% grass silage and 20% corn silage before being transitioned to dry-cow/prefresh pens and fed a standard diet formulated to meet NRC (2001) requirements. The integrity of the HC and LC diets was maintained because one of the objectives of this experiment was to assess heifers' first-lactation performance when limit fed HC or LC diets LT. Logistics and small animal numbers made it impossible to maintain the 4 treatments from experiment 1. Heifers were housed in a naturally ventilated freestall barn with free access to water and were bedded with sand weekly. Body weight measurements were recorded every other week, and DMI was adjusted to restrict intake to maintain 0.22 Mcal of ME intake/kg of empty BW^{0.75}.

Once heifers calved, they were moved to a lactating-cow tie stall facility where a common transition diet was offered and postpartum problems were monitored. After calving, animals were followed until 154 d of lactation. Milking occurred twice daily at 0500 and 1700 h in a double-10 herringbone milking parlor equipped with the Afifarm system (S.A.E. Afikim, Kibbutz Afikim, Israel; US distributor: Germania Dairy Automation, Waunakee, WI). Milk yield for individual cows was recorded at each milking, and animals were weighed daily upon exiting the parlor. Milk samples were collected from 2 consecutive milkings each month and shipped to Dairy One (Ithaca, NY) for analyses of fat and protein concentrations. Mature-equivalent 305-d milk production was calculated based on the first 154 DIM.

Statistical Analysis

All 3 experiments were analyzed and are reported separately. All statistical analyses were conducted in SAS (SAS Institute, Cary, NC) using the MIXED procedure. Experiment 1 was a randomized complete block design with 4 treatments. Individual heifer was considered the experimental unit because heifers were individually fed and intake and ADG for each animal were known; complete randomization was penalized by retaining the blocking variable. To account for potential pen-to-pen effects because heifers were housed in the same pen as others receiving the same dietary treatment, a fixed covariate, pen nested within treatment, was included (Zanton and Heinrichs, 2007). Effects of dietary treatment, YC addition, pen grouping, heifer, and the interaction of dietary treatment and YC addition on growth and skeletal measurements were represented by the model

$$Y_{ijkh} = \mu + T_i + Y_g + P_j + G_{k(i)} + C_{h[k(i)]} + TY_{(ig)} + e_{ijkh},$$

where Y_{ijkh} is a continuous, dependent response variable; μ is the overall mean; T_i is the fixed effect of dietary treatment ($i = 1, 2$); Y_g is the fixed effect of YC ($g = 1, 2$); P_j is the fixed effect of block ($j = 1$ to 4); $G_{k(i)}$ is the fixed effect of pen grouping within treatment ($k = 1, 2, 3$); $C_{h[k(i)]}$ is the random effect of heifer within pen within treatment ($h = 15$); $TY_{(ig)}$ is the interaction of treatment and YC; and e_{ijkh} is the residual error.

For experiment 2, all dependent variables were analyzed as a split-plot, 4×4 Latin square design with age as the whole plot and diet treatment as the subplot. Sources of variation associated with fixed effects were period and YC addition. Repeated effects included F:C, YC, and their interaction with period, following the model used by Lascano et al. (2008). Heifer within age was included as a random effect. The first autoregressive covariance AR(1) model was utilized in analyzing repeated measurements of DMI, N intake, N excretion, and related calculations, total-tract apparent DM and N digestibility, urine volume, feces and manure output, urinary excretion of urea, and urinary creatinine. Residual variances were assumed to be normally distributed, and all data are presented as least squares means.

For experiment 3, measurements for the group-fed heifers were analyzed as a complete block design including the previous blocking variable and pen within treatment as a covariate. Measurements that were taken repeatedly during lactation were analyzed by the model mentioned earlier using a first-order autoregres-

sive covariance structure and included the fixed effect of week and treatment by week interaction (Zanton and Heinrichs, 2007). Treatment effects were considered significant when $P < 0.05$, and trends were declared at $P < 0.10$.

RESULTS AND DISCUSSION

Animal Numbers and Diet Composition

Thirty heifers finished the growth study of experiment 1; 2 were removed (1 HC and 1 LC) because of intense diarrhea, as mentioned earlier. Animals were healthy throughout this part of the trial, and no treatment effects on health were observed.

From the end of experiment 1 until moving to pre-freshening pens, 1 heifer (HC) died of an unknown reason. Therefore, there were 14 HC and 15 LC heifers that completed the group-fed part of experiment 3. For the subsequent lactation part of experiment 3, 4 heifers were removed ($n = 2/\text{treatment}$) because they were unable to become pregnant after 4 inseminations before first lactation, and 2 HC animals were diagnosed with chronic pneumonia and were sold. Thus, lactation results are presented for 23 animals (10 HC and 13 LC) that completed 154 d of their first lactation.

Ingredient and nutrient composition of rations for both experiments is shown in Table 1. Ingredient and chemical composition of the diets differed between treatments as planned, which allowed similar intakes of CP and ME. In both experiments, ME (Mcal/kg of DM) was greater for HC diets, which allowed a reduction in DMI. Intake for HC-fed heifers in experiment 1 had to be restricted more than originally planned to attain the T-ADG (Table 2). As a consequence of the DMI reduction, diets fed on a restricted basis throughout the experiment (1) ranged from 69 to 79% of that predicted by NRC (2001) for DMI of heifers of this age and BW gaining 0.80 kg/d.

Experiment 1: Growth

Heifers assigned to the 4 different treatments grew at a similar rate throughout the 133-d study (Table 2; 0.80 ± 0.01 kg/d ADG). Thus, BW at the end of this part of the experiment was not different among treatments. This result demonstrates that maintaining similar daily gains of the heifers was achieved by restricting and controlling feed intakes. To maintain this constant level of growth, DMI had to be reduced for HC diets ($P < 0.09$). This resulted in a tendency for improvement ($P < 0.09$) of FE (kg of ADG/kg of DMI) for the HC-fed heifers in the current experiment (Table 2). In the same way, Zanton and Heinrichs (2007) reduced

Table 2. Growth characteristics, feed efficiency, and ADG of heifers fed high- (HC) or low-concentrate (LC) diets with or without supplemental yeast culture (YC) for 133 d in experiment 1

Item	Diet				SE	P-value ¹		
	HC	HC+YC	LC	LC+YC		F:C	YC	Interaction
Initial BW, kg	227.3	207.1	228.7	208.3	27.1	0.92	0.15	1.00
Final BW, kg	335.0	312.9	336.4	314.3	28.2	0.92	0.13	0.99
ADG, g/d	0.80	0.80	0.80	0.80	0.01	0.95	0.75	0.65
Feed efficiency ²	0.15	0.17	0.15	0.15	0.01	0.09	0.47	0.41
DMI, kg	5.34	4.59	5.52	5.33	0.46	0.09	0.10	0.32
DMI, % of BW	1.93	1.81	2.01	2.11	0.22	0.07	0.80	0.37
Total gain, kg	107.6	105.9	107.6	106.1	3.7	0.98	0.40	0.95
Structural measurements ³								
Withers height, cm	13.6	13.8	12.4	12.9	1.9	0.30	0.72	0.91
Hip height, cm	12.3	12.6	11.9	11.8	2.1	0.59	0.90	0.86
Body length, cm	17.9	18.8	17.6	15.0	4.1	0.06	0.56	0.80
Heart girth, cm	24.5	27.6	26.2	23.7	3.3	0.52	0.83	0.10
Paunch girth, cm	24.5	28.4	26.5	25.7	5.9	0.64	0.87	0.27
Hip width, cm	12.3	12.6	11.9	11.8	2.2	0.60	0.90	0.86

¹Effect of forage-to-concentrate ratio (F:C), YC addition, and their interaction.²kg of ADG/kg of DMI.³Change in structural measurements during the 133-d growth trial.

DMI offered to prepubertal dairy heifers fed HC (75% concentrate) compared with LC (25% concentrate) diets to attain similar T-ADG (around 0.80 kg/d) and observed increased FE for heifers limit fed HC versus LC. Furthermore, Hoffman et al. (2007) observed no appreciable differences in ADG of gravid heifers, but found improvements of 23.7 and 28.9% in FE when diets fed to dairy heifers were restricted to 80 or 90% of NRC (2001) recommendations, respectively. All of these results can be explained by previous studies that have shown HC-fed heifers have higher energy retention ability in comparison to those fed diets with higher inclusion of forage (Reynolds et al., 1991a). In a limit-fed heifer experiment, NE_M and NE_G were similar, but ME required to attain similar ADG increased as the level of concentrate decreased (Hoffman et al., 2007), indicating that there is a higher loss of energy in metabolic heat for LC diets.

Inclusion of YC in heifer diets tended ($P \leq 0.10$) to require less DMI to maintain T-ADG as compared with nonsupplemented heifers (Table 2); FE was similar between heifers supplemented or not with YC (Table 2; $P = 0.47$). Several studies have reported a positive influence of YC on intake in growing animals given feed ad libitum (Lascano and Heinrichs, 2007), but in the current study, methods included DMI restriction to attain a T-ADG. In addition, ability of YC to stabilize the rumen environment (lower lactic acid and NH_3 -N concentrations, increased DMD, and greater microbial synthesis) has been shown when YC is added to HC diets (Erasmus et al., 1992; Mutsvangwa et al., 1992). Lascano and Heinrichs (2009) observed increased total VFA concentrations with YC addition when diets with

increasing proportions of concentrate (20, 40, and 60%) were fed to dairy heifers, with no effect on rumen pH and a smaller concentration of ruminal ammonia, which was interpreted as an increase in rumen microbial activity. This enhanced output of fermentation products at the rumen level, and improved total-tract digestibility might be responsible for an increase in intake reported in other studies in which animals were given ad libitum access to feed. Only numerical improvements of FE with YC addition were observed by El Hassan et al. (1996) when bulls were given ad libitum access to feed. In that study, failure to reach statistical difference was attributed to the increase in DMI induced by YC. Wiedmeier et al. (1987) suggested that YC provides stimulatory factors, amino acids, and peptides that increase the number of cellulolytic bacteria and could lessen the negative effects associated with HC diets by increasing the population of lactic acid-using bacteria such as *Selenomonas ruminantium* and *Megasphaera elsdenii*.

Skeletal measurements were not different, and heifers in the 4 treatment groups grew in a normal manner (Hoffman, 1997), which indicates that there was no effect of using different F:C or YC addition on growth parameters of dairy heifers (Table 2). Zanton and Heinrichs (2007) did not observe any differences in most skeletal growth measurements, but detected an increase in paunch girth daily gain for HC-fed heifers, even when initial paunch girth was greater for LC-fed heifers. The authors attributed this response to changes in gut fill. There were no differences in the current experiment related to paunch girth overall gain, possibly because of the older age of the animals used compared with those

Table 3. Nutrient intake, apparent total-tract digestibilities, and N dynamics of growing heifers fed either high- (HC) or low-concentrate (LC) diets with (YC) or without (CC) yeast culture supplementation in experiment 2

Item	Age ¹		F:C		YC		SE ²	P-value ³		
	Young	Old	HC	LC	CC	YC		Age	F:C	YC
DMI, kg/d	5.08	7.53	6.12	6.49	6.30	6.31	0.10	<0.01	<0.01	0.93
N intake, g/d	108.74	160.98	133.94	135.79	134.77	134.95	3.11	<0.01	0.13	0.88
ME intake ⁴	13.97	20.68	17.57	17.07	17.32	17.33	0.47	<0.01	0.26	0.96
CP:ME ⁵	48.65	48.65	47.64	49.72	48.63	48.67	0.53	0.35	<0.01	0.44
Apparent digestibility, %										
DM	75.05	73.57	75.67	72.96	73.65	74.97	0.77	0.34	<0.01	0.03
OM	75.71	74.67	76.44	73.94	74.51	75.87	0.75	0.47	<0.01	0.03
N	67.55	66.66	66.63	67.59	66.60	67.61	1.45	0.52	0.30	0.28
NDF	54.14	52.53	53.10	53.57	51.90	54.77	1.67	0.59	0.64	<0.01
ADF	49.98	45.89	47.34	48.52	47.05	48.81	3.71	0.33	0.57	0.40
Fecal N, g/d	49.58	69.81	58.94	60.97	59.01	58.71	2.11	<0.01	0.48	0.11
Urinary N, g/d	27.60	44.54	35.75	36.76	35.55	35.64	3.78	<0.01	0.12	0.87
Total N excreted, g/d	77.19	114.36	94.71	97.73	94.57	94.35	4.60	<0.01	0.24	0.42
Retained N, g/d	31.42	43.10	37.58	37.25	36.78	36.68	3.17	<0.01	0.81	0.38
% of N intake	29.13	26.16	27.60	27.80	27.09	27.30	2.44	0.07	0.32	0.51
% of N digested	53.32	48.09	51.29	50.31	50.10	49.65	2.47	0.07	0.51	0.31
Wet feces, kg/d	6.82	10.94	7.28	10.48	9.21	8.55	0.56	<0.01	<0.01	0.02
Dry feces, kg/d	1.27	1.99	1.49	1.77	1.67	1.58	0.09	<0.01	<0.01	0.03
Urine, kg/d	6.86	8.45	7.76	7.55	7.71	7.60	0.91	0.19	0.61	0.78
Total manure, kg/d	13.67	19.40	15.05	18.02	16.91	16.16	1.12	<0.01	<0.01	0.11
Urinary urea N, mg/dL	172.37	280.43	233.80	221.27	231.76	215.09	33.10	<0.01	0.54	0.50
Urinary urea N, g/d	12.00	20.85	17.18	15.85	17.39	15.05	2.84	<0.01	0.47	0.26
Urine creatinine, g/d	3.18	6.28	4.47	4.99	4.49	4.97	0.83	0.02	0.19	0.22

¹Young and old heifer groups were 284.0 ± 3.6 and 405.8 ± 1.5 d of age and 234 ± 15 and 409 ± 20 kg of BW, respectively, at the start of the experiment.

²Mean standard error for the main effect of age, forage-to-concentrate ratio (F:C), and YC additions.

³Main effects of age, F:C, and YC addition; no interactions were detected.

⁴Estimated: ME = TDN $\times$ 0.04409 $\times$ 0.82. TDN = total digestible nutrients.

⁵g of CP/Mcal of ME.

of Zanton and Heinrichs (2007). The lack of response might be the result of the lack of significant differences in DMI or the more highly digestible forage component of LC diets in the current study. Heifers fed the HC diet tended ($P = 0.06$) to have a greater change in body length. Body length and paunch girth are parameters that relate to rumen capacity or volume. Daccarett et al. (1993) observed similar results with heifers from 9 to 15 mo of age when fed enhanced diets (115% of NRC recommendation) and concluded that higher intakes result in greater skeletal development. In the current experiment, intake was restricted and was lower than NRC recommendations.

Experiment 2: Digestibility

Dry matter intake was restricted by 20.65 and 15.97% (HC and LC, respectively) for the younger heifers and 23.05 and 19.27% (HC and LC, respectively) for the older heifers compared with NRC (2001) estimates (Table 3). Because there were no significant ($P > 0.05$) interactions between F:C, YC, and age, only the main effects of age, F:C, and YC are reported. Differences between the 2 age groups were primarily observed in

nutrient intake or were caused by differences in nutrient intake in this experiment. The estimated dietary requirement for 250- and 450-kg Holstein heifers with a target gain of 0.80 kg/d is 129.95 and 174.08 g of N/d, respectively (NRC, 2001). The N intake used in the current study has been shown to maximize gross N efficiency (1.84 g/kg of BW^{0.75}; Zanton and Heinrichs, 2008) through higher N retention in the growing dairy heifer.

All diets had high apparent DMD ($>72.5\%$), with HC-fed heifers having a greater DMD than LC-fed heifers ($P < 0.01$). Apparent OM digestibility was increased for HC-fed heifers ($P < 0.01$) in a manner consistent with increases in DMD. Yeast culture addition increased DMD (Table 3; $P < 0.05$). Yoon and Stern (1996) attributed increased digestibility to decreased ruminal dilution rate or increased OM digestion in the rumen with YC. Increased disappearance or digestibility of DM, ruminal NDF, total-tract hemicellulose, and apparent crude fiber has been reported with supplemental YC (Robinson, 2002).

Apparent N digestibility was not affected by F:C, YC addition, or heifer age. Nitrogen intake was similar between treatments, and because younger heifers

consumed fewer grams of N per day, an age effect was detected ($P < 0.01$). Young heifers, as a consequence of less intake, had less N excretion in feces, urine, and total manure and retained fewer grams of N ($P < 0.01$).

No effect on apparent total-tract NDF or ADF digestibility was detected between HC- and LC-fed heifers; similar results were reported by Zanton and Heinrichs (2006). Although DMD and OM digestibility were greater for HC-fed heifers, digestibility of the fiber fraction (NDF and ADF) was numerically higher for LC diets. This is probably because of a greater fibrolytic bacteria population associated with this type of diet. The YC addition in the current study increased NDF apparent digestibility ($P < 0.01$). In part, these results could be explained by the digestion and utilization of starch and simple sugars and the removal of easily fermentable substrates that improve fiber digestion (Carro et al., 1992). However, ADF apparent digestibility was not affected by F:C or by the addition of YC in this experiment. In the same manner, Wiedmeier et al. (1987) found improved digestion of hemicellulose that was concurrent with the increased number and proportion of cellulolytic bacteria, but not ADF digestibility, when YC was added to the ration.

Retained N as a percentage of daily intake and as a percentage of N digested tended to be greater for the younger heifers ($P = 0.07$), which is likely because of the tendency of younger animals to be more efficient at converting protein into muscle (Gerrard and Grant, 2006). No F:C or YC effect was observed for retained N as a percentage of daily intake nor as a percentage of N digested. Whereas Moody et al. (2007) reported an increase in retained N as a percentage of daily intake when HC diets were fed at higher amounts of N per day than LC diets, no differences in retained N were observed when heifers were fed equal quantities of N in the current experiment. The current study possibly overestimated N retention as a result of the use of dried fecal samples to estimate N. Nitrogen retention is potentially greater when using digestibility experimental data because of failure to account for possible N losses in scurf, evaporation, and volatile N compounds in a drying oven (Blome et al., 2003). Reynolds et al. (1991a) observed that retained N was greater for HC-fed beef heifers; this group also excreted less fecal DM, N, and energy and more urinary N. Yeast culture did not affect any N dynamics parameters measured in this experiment.

In the current study, manure output decreased in HC-fed heifers in comparison with LC-fed heifers. Wet and dry fecal output was lower for the HC-fed heifers ($P < 0.01$), in agreement with results reported in previous studies (Moody et al., 2007). On the other hand, manure output was reduced but failed to reach

significance with the addition of YC ($P = 0.11$), even though YC had a significant effect on wet and dry fecal output (Table 3; $P < 0.05$).

Urine excretion was not different; therefore, total manure output was lower for HC-fed heifers ($P < 0.01$). Urine output is mostly dependent on individual animal variation, body storage, internal metabolism, and other factors such as mineral intake, especially potassium (Bannink et al., 1999). Heifers in the current study excreted 37, 20, and 21% less wet feces, dry feces, and total manure, respectively, when HC diets with added YC were implemented in comparison with LC and no YC supplementation. A recent study with gravid Holstein heifers fed 40% concentrate diets restricted to get 90 or 80% of the normal-fed heifers also observed reduced manure output (12.9 and 34.6% less manure excreted; Hoffman et al., 2007).

Urinary urea N and urinary creatinine results are presented in Table 3. Mean values of these parameters were different between old and young heifers in direct response to N intake of the 2 different ages. Urea is produced in the liver when microbial degradation of dietary CP in the rumen is not incorporated into microbial protein, but absorbed, causing an elevation of BUN (James et al., 1999). In a companion study, the NH_3 concentrations in the rumen of heifers fed the same diets as in this study decreased with YC supplementation, suggesting increased microbial activity (Lascano and Heinrichs, 2009) and NH_3 uptake by bacteria (Chaucheyras-Durand and Fonty, 2001). Urinary urea N excretion in the current study was not different between treatments. Likewise, NH_3 emissions, a direct response of urea excreted in urine being hydrolyzed by urease in feces, were not different between HC- or LC-fed heifers (Lascano et al., 2008).

Experiment 3: Rearing and Lactation Period

Effects of limit feeding HC or LC to heifers LT on lactation responses are presented in Tables 4 and 5. Average daily gain between the end of the 133-d growth trial and before the prefreshening period ($P = 0.32$) and from the beginning of the 133-d growth trial through parturition ($P = 0.85$) was not different between both F:C treatments. In the current experiment, there was a similar increase in ADG after puberty for both F:C treatments (1.11 and 1.04 ± 0.06 kg/d; HC and LC, respectively) when DMI was adjusted to restrict intake to attempt to maintain 0.22 Mcal of ME intake/kg of empty $\text{BW}^{0.75}$. It has been shown that increases in ADG after puberty do not affect mammary gland development or milk production (Grummer et al., 1995; Carson et al., 2000).

Body weight at calving was slightly greater for HC-fed heifers (525 vs. 517 ± 17 kg; Table 4), even when no

Table 4. Production parameters through 154 DIM for Holstein heifers fed a high- (HC) or low-concentrate (LC) diet in experiment 1

Item ¹	HC	LC	SE	P-value ²
ADG before prefresh, ³ kg/d	1.11	1.04	0.06	0.32
ADG before calving, ⁴ kg/d	0.81	0.79	0.085	0.85
Age at first calving, mo	23.50	23.79	0.50	0.79
BW at calving, ⁵ kg	525	517	17	0.73
BW at 154 d, ⁶ kg	541	556	26	0.58
Milk production, kg/d	33.11	35.22	0.09	0.07
Fat, kg/d	1.41	1.46	0.04	0.34
Protein, kg/d	0.99	1.07	0.03	0.08
Peak milk, kg/d	40	44	1.10	0.02

¹Production values for animals that finished 150 d of lactation (n = 10 HC and 13 LC heifers).

²Treatment effect.

³Average daily gain from the end of the growth experiment until animals were moved to prefreshening group.

⁴Overall ADG from the beginning of the growth experiment until calving.

⁵Body weight at 7 d postpartum.

⁶Body weight after 154 DIM.

significant differences were observed ($P = 0.73$). Similarly, Zanton and Heinrichs (2007) observed a numerical difference in live BW at calving between HC and LC diets and attributed this effect to a greater empty BW (not considering digesta) during the experimental period for HC-fed heifers; it was stated that if the quantity of digesta becomes proportional between the HC- and LC-fed heifers when offered similar diets and intakes, then this difference in live BW is mainly due to a greater empty BW during the experimental period. This could explain, in part, the numerical differences in BW at calving observed in the current experiment. Age at first calving did not differ between treatments and averaged 23.65 ± 0.50 mo (Table 4). Average BW (through 154 DIM) was not different between treatments. Daily milk and protein yields tended to be less ($P = 0.07$ and 0.08 , respectively) and peak milk yield was less ($P = 0.02$) for primiparous cows fed HC diets as heifers (Table 4). These results are opposite from findings of previous studies (Hoffman et al., 2007; Zan-

ton and Heinrichs, 2007) in which numerical increases in daily milk yield and components were reported for primiparous cows fed HC diets as heifers.

Literature assessing lactation performance of dairy heifers restrictively fed HC or LC diets is limited. Among the few studies comparing controlled feeding of HC or LC diets, there have not been differences in milk yields when limit feeding has been used as a strategy to compare different rates of growth in the rearing period (Sejrsen and Foldager, 1992; Carson et al., 2000). Recently, Zanton and Heinrichs (2007) compared controlled feeding of HC or LC diets (75 or 25% concentrate, respectively) to prepubertal heifers and observed no differences in milk production. Likewise, in another recent study, Hoffman et al. (2007) limit fed postpubertal, gravid Holstein dairy heifers (100, 90, and 80% of NRC requirements) and reported no differences in milk production. Zanton and Heinrichs (2007) fed higher proportions of concentrate to heifers than Hoffman et al. (2007) to accomplish the restriction, but diet energy (Mcal/d) was the same between treatments within each of the cited experiments. In fact, in both studies, there was a numerically greater milk yield for the higher concentrate treatments (Hoffman et al., 2007; Zanton and Heinrichs, 2007). These studies were designed to study the effects of this type of feeding system during the prepubertal allometric growth phase (125 to 325 kg; Zanton and Heinrichs, 2007) and in the postpubertal rearing period (465 to 555 kg; Hoffman et al., 2007). An important distinction is that the current experiment followed heifers that later became primiparous cows from 227 kg (LT) to the onset of lactation. Puberty was not detected, but according to results of previous research (Lammers et al., 1999; Zanton and Heinrichs, 2007), heifers in this study started the experiment before reaching puberty.

Results for predicted first-lactation milk production and component parameters (154 DIM) are presented in Table 5. Predicted 305-d mature-equivalent milk production and 4% FCM yields were not different. However, a greater numerical production was observed for LC-fed heifers as a result of the tendency of this treatment toward greater daily milk yield. These results agree, in part, with results reported by other research groups (Sejrsen and Foldager, 1992; Carson et al., 2000; Hoffman et al., 2007), whereas a numerical increase for primiparous cows limit fed HC as heifers was reported by Zanton and Heinrichs (2007). Studies that have presented differences in milk production have used differential planes of nutrition associated with HC or LC diets (Lammers et al., 1999; Radcliff et al., 2000). For example, Radcliff et al. (2000) used a high-energy diet to support an ADG of 1.20 kg/d; meanwhile, the standard (LC) diet was formulated to provide 0.80 kg/d.

Table 5. Projected 305-d mature equivalent production parameters¹ for Holstein heifers fed a high- (HC) or low-concentrate (LC) diet in experiment 1

Item	HC	LC	SE	P-value ²
Milk, kg	9,092	9,754	291	0.12
4% FCM, kg	9,433	10,018	301	0.19
Fat, kg	381	402	13	0.25
Protein, kg	274	296	12	0.08
Fat, %	4.18	4.12	0.16	0.81
Protein, %	3.01	3.03	0.05	0.77

¹Projected at a mean of 154 DIM; DHIA test-day values measured at 2 consecutive milkings monthly. n = 10 HC and 13 LC heifers.

²Treatment effect.

In the current experiment, no statistical differences were observed for predicted first-lactation performance when heifers were limit fed LT either HC or LC diets, but further experiments are needed to elucidate the observed numerical differences and physiological changes in mammary gland development throughout this entire period when diet composition differs but growth rates are equal.

CONCLUSIONS

Based on results from these experiments, it is concluded that when heifers are limit fed HC or LC diets with or without YC, they achieve similar ADG, skeletal growth, total gain, and FE. Dry matter intake needed to achieve the T-ADG for HC tended to be lower than for LC, and YC tended to allow for a decreased DMI in both F:C treatments. Feed efficiency in the HC-fed heifers tended to increase because of changes in DMI. Results observed in experiment 1 related to FE were corroborated with increased DM, OM, and NDF digestibility in experiment 2. A significant reduction in total feces and manure output was observed for HC-fed heifers compared with LC-fed heifers. Addition of YC enabled a further reduction in these responses. Apparent N digestibility was not different between treatments or age groups, and a greater percentage of N was retained in young heifers. No differences in N retention were found with different F:C fed to similar N intakes. Furthermore, when ADG was controlled during the rearing period (LT), feeding either HC or LC did not affect predicted or corrected 4% FCM production during first lactation, even when HC diets tended to reduce daily milk and protein yield along with peak milk yield. Consideration should be taken for numerical differences related to milk production observed in this experiment, and further research with a larger number of animals should be undertaken.

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