

Evaluation of performance and carcass traits for a five-cohort All Heifer, No Cow beef production system demonstration herd

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ABSTRACT: The All Heifer, No Cow (AHNC) beef production system is an alternative to conventional cow/calf production that involves insemination of nulliparous heifers with sexed semen to produce female calves that are early weaned at 3 mo of age. Dams are finished on a high-concentrate diet and harvested before reaching 30 mo of age. Objectives of this research were to document reproductive, feedyard, calf, and carcass performance of an AHNC herd; evaluate effects of carcass maturity on carcass quality; and determine if performance of initial cohorts (i.e., cohorts 1 and 2) differed from sustaining cohorts (i.e., cohorts 3–5). A total of 272 heifers were enrolled in the AHNC system via five annual cohorts. The system was initiated with 51 yearling, Angus-based heifers, and a replicate set ($n = 56$) was started 12 mo after. Heifers in cohorts 3 ($n = 53$), 4 ($n = 56$), and 5 ($n = 56$) were primarily offspring of prior cohorts (i.e., cohort 3 heifers born to cohort 1 females), but some were purchased to maintain inventory. Angus replacement heifers were purchased in cohorts 3 ($n = 26$), 4 ($n = 26$), and 5 ($n = 28$). Mean (\pm standard deviation) pregnancy rate at 30 d after fixed-time artificial insemination (AI) with sexed semen was $50.8\% \pm 9.4\%$, and 140-d pregnancy rate was

$93.0\% \pm 1.5\%$. With AHNC, $61.0\% \pm 6.5\%$ of females replaced themselves with a heifer. During finishing, average daily gain (ADG) was $1.9 \pm 0.4 \text{ kg} \cdot \text{d}^{-1}$ and dry matter intake (DMI) was $14.9 \pm 1.9 \text{ kg} \cdot \text{d}^{-1}$. Hot carcass weight (HCW) was $367 \pm 35 \text{ kg}$. The USDA grading system classified 20.5% of all carcasses ($n = 220$) as C maturity ($A^{00} = 100$, $B^{00} = 200$, etc.), $62.4\% \pm 29.1\%$ of carcasses as USDA Choice. USDA yield grade (YG) was 2.6 ± 0.7 . Based on cohorts 1 and 2, there were no differences ($P = 0.96$) in Warner–Bratzler shear force values between A and B maturity vs. C maturity carcasses. Across all cohorts, there were no differences in USDA YG, marbling score (MA), and lean maturity between A and B maturity vs. C maturity carcasses; there were differences in age ($P < 0.001$), bone maturity ($P < 0.001$), and overall maturity ($P < 0.001$). A comparison of initial vs. sustaining cohorts showed that initial cohorts had lower ($P < 0.001$) DMI, heavier ($P < 0.001$) HCW, and more advanced ($P < 0.05$) bone maturity. However, there were no differences for 30- and 140-d pregnancy rates, ADG, USDA YG, and MA between initial and sustaining cohorts. The AHNC beef production system can effectively produce female calves and quality carcasses for harvest.

Key words: beef production system, biological efficiency, cattle, sex-selected semen, single-calf heifer

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INTRODUCTION

Conventional beef production in the United States is typically specialized, encompassing forage-based cow/calf production through intensively managed feedyards that finish cattle on grain and other concentrates. Often there is an intermediary, grass-based stocker segment between cow/calf and feedyard segments. In beef production, feed nutrients are partitioned to growth/development, lactation, reproduction, fat accretion, and maintenance (Ferrell and Jenkins, 1985). Collectively, considering cows' requirements combined with energy requirements of replacement heifers and bulls, about 70% of all nutrients consumed for beef production are expended by the cow/calf segment (Ferrell and Jenkins, 1985). The remaining 30% account for postweaning growth of calves during both stocker and feedyard segments. About 75% of all nutrients consumed by the cow/calf segment are for maintenance energy. Thus, integrated over the entire U.S. beef production system, nearly one-half of all nutrients consumed are utilized for cowherd maintenance energy (Ferrell and Jenkins, 1985).

Researchers analyzing beef production feed efficiency have reported that the greatest efficiency can be achieved by harvesting females shortly after the birth of their first calves (Taylor et al., 1985; Bourdon and Brinks, 1987). The All Heifer, No Cow (AHNC) beef production system produces beef without mature cows, inseminating nulliparous heifers with female sex-selected semen to produce primarily female calves that are early weaned 3 mo after parturition. After weaning, dams are finished on a high-concentrate ration and harvested before reaching 30 mo of age (Seidel and Whittier, 2015). Minimal performance data exist in the scientific literature that characterize this production system, thus limiting the ability of researchers to evaluate potential improved efficiencies that may result from this alternative beef production system.

Objectives of this study were to: 1) document reproductive, feedyard, calf, and carcass performance

of a five-cohort AHNC demonstration herd; 2) evaluate effects of carcass maturity on carcass quality variables; and 3) determine if performance of initial cohorts (i.e., cohorts 1 and 2) differed from sustaining cohorts (i.e., cohorts 3 through 5).

MATERIALS AND METHODS

Animals

All animals in this study were managed under the approval of the Colorado State University Institutional Animal Care and Use Committee guidelines. A total of 272 heifers were enrolled in the AHNC beef production system via five annual cohorts over a 6-yr period. The system was initiated in March 2013 (i.e., cohort 1) with the purchase of 51 yearling, Angus-based commercial heifers with an initial body weight (BW) = 354 ± 39 kg. A replicate set of similar heifers ($n = 56$; initial BW = 307 ± 30 kg) was purchased and enrolled the following year. With this system, annual income requires two herds, 12 mo apart in age from each other. One herd is being bred approximately the same time dams and calves from the other set enter the feedyard (Seidel and Whittier, 2015).

Exact ages of heifers in cohorts 1 and 2 were not known, but heifers were estimated to be 1 yr of age at purchase. Upon arrival, heifers were weighed, body condition scored, ear tagged, and rectally palpated to eliminate freemartins and reproductive tract abnormalities. Heifers enrolled in cohorts 3 ($n = 53$), 4 ($n = 56$), and 5 ($n = 56$) were primarily the offspring of prior cohorts (i.e., cohort 3 heifers were born to cohort 1 females). The numbers of replacements raised within the AHNC beef production system were 28, 32, and 28 for cohorts 3, 4, and 5, respectively. The remaining heifers were acquired in a similar manner as cohorts 1 and 2 to ensure the maintenance of annual herd inventory. Purchased replacement heifers for cohorts 3 through 5 were Angus heifers. Birthdates were known on all heifers for cohorts 3 through 5. Animals were maintained at East Rabbit Creek Ranch in Livermore, CO, and the feedyard at the Colorado State

University Agricultural Research, Development, and Education Center in Fort Collins, CO.

Ovulation Synchronization to Weaning

Ovulation was synchronized with a 14-d controlled internal drug releasing (CIDR) insert (Eazi-Breed; Zoetis, Parsippany, NJ). On day 17 after CIDR removal, estrus detection patches (Estroject; Rockway Inc., Spring Valley, WI) were placed in front of tail heads, and heifers received an intramuscular (i.m.) injection containing 25 mg of prostaglandin F₂ alpha (PGF_{2α}) (Lutalyse; Zoetis, Parsippany, NJ). Approximately 66 h after PGF_{2α} injection, patch status was assessed, and heifers with activated patches were inseminated with 0.25 cc of female sex-selected semen. Heifers with inactivated patches at 66 h after PGF_{2α} injection received an i.m. injection of 100 µg of gonadotropin releasing hormone (GnRH) (Factrel; Zoetis, Parsippany, NJ) and were inseminated 18 h later with 0.25 cc of female sex-selected semen. Cohorts 1 and 2 were inseminated with semen from polled Hereford bulls, so cohorts 3 and 4 were predominantly Angus × Hereford. Heifers in cohorts 3 and 4 were inseminated with semen from a polled, black Simmental bull with high breeding values for calving ease and carcass characteristics. Cohort 5 was inseminated with semen from a Hereford or Simmental sire that was used in a previous cohort or an Angus sire that was not previously used.

Cohorts 2 through 5 had ovulation resynchronized. Resynchronization of ovulation was initiated 12 d after timed AI with the insertion of an intrauterine CIDR. After 7.5 d, CIDR were removed, and estrus detection patches were applied. Heifers were observed for behavioral signs of estrus at least twice daily (i.e., am and pm). Heifers displaying standing

estrus in the pm were inseminated the following am. On average, heifers were inseminated approximately 3.5 d after CIDR removal. Generally, heifers that were inseminated a second time were bred to the same sire as their first insemination. Heifers that did not exhibit estrus were assumed to be pregnant to the first AI and were not inseminated a second time. Immediately following the second AI, heifers were placed with a natural service sire. For cohorts 1 and 2, a polled Hereford bull was used. In cohorts 3 and 4, a Gelbvieh × Angus bull was used. In cohort 5, a black Angus bull was used. Heifers remained with the bull uninterrupted for approximately 100 d. Since cohort 1 did not receive a second AI, the natural service sire was immediately placed with the heifers after the first AI.

Pregnancy rate to the first AI was diagnosed 33 to 36 d after the first AI via ultrasound (Aloka 500; Corometrics Medical Systems, Wellington, CT) fitted with a 5-MHz rectal probe. A second pregnancy diagnosis was performed by rectal palpation 140 d after the first-timed AI to determine season-long pregnancy rate. Following the second pregnancy diagnosis, nonpregnant heifers and heifers that conceived late in the breeding season (i.e., pregnancy determined to be less than 90 d) were sold. Heifers were maintained on native range May through November and were fed hay December through April. At parturition, date of birth, calving ease score, calf birth weight (BWT), and calf sex were recorded. After calving, dams were supplemented with 15% crude protein (CP) range cubes at an average level of 1.4 kg • dam⁻¹ • d⁻¹.

Management From Weaning to Harvest

Two weeks prior to early weaning, dams and calves were jointly shipped 45 km to the feedyard

Table 1. Description of variation in management across the five-cohort AHNC demonstration herd during feedyard phases

Management factor	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Time on grass hay, d	1	8	3	2	2
Time on receiving ration, d	6	–	22	12	9
Time on transitioning ration, d	11	21	16	21	15
Time on finishing ration, d	72	80	61	79	70
Total time in the feedyard, d	90	109	102	115	96
Time in the feed intake unit, d	42	48	–	–	–
Steam-flaked corn used in mixed ration in place of cracked corn	–	–	–	YES	–
Implanted ^a	YES	YES	–	YES	YES
Melengestrol acetate in finishing mixed ration	–	YES	YES	YES	YES
Calves fence-line weaned	–	YES	YES	YES	–
Lactation continued in some females prior to harvest	–	–	–	YES	–

^aRevalor-H (Intervet, Madison, NJ).

and placed into a single pen with a concrete bunk and ad libitum access to water. Dams and calves received ad libitum grass hay for at least 3 d (Table 1). For the next 2 to 3 weeks, dams and calves in cohorts 1 and 3 through 5 were fed a receiving ration. Cohort 2 was not fed the receiving ration but was transitioned directly from grass hay to a transitioning ration (Tables 1 and 2). Cohorts 1 and 3 through 5 were fed a moderate-energy, transitioning ration for approximately 3 wk (Tables 1 and 2). While the transitioning ration was fed, calves were early weaned at 105 ± 21 d. Cohorts 2 through 4 were weaned using fence-line weaning (Price et al., 2003). In cohorts 1 and 5, calves were weaned by placing them in a pen at the opposite end of the feedyard. Dams were implanted in the right ear with 200 mg of trenbolone acetate and 20 mg of β -estradiol (Revalor-H; Intervet, Madison, NJ). Cohorts 4 and 5 were implanted at weaning, cohorts 1 and 2 were implanted 6 wk after weaning, and cohort 3 was not implanted (Table 1). At-weaning calves were retagged and weighed.

After weaning, calves remained in the feedyard 50 ± 10 d on a moderate energy ration until returning to Rabbit Creek Ranch (Table 2). For the remaining time in the feedyard, dams were fed a high-energy, finishing ration (Tables 1–3). Finishing

ration for dams in cohorts 2 through 5 were formulated to provide 0.5 mg of melengestrol acetate per dam per day until harvest. Dams received the finishing ration for 72 ± 8 d until they reached a target harvest BW of 636 kg (Table 1). While calves and dams were in the feedyard, individual animal BW were collected at least every 3 wk in the morning prior to feeding.

In cohorts 1 and 2, individual daily feed intake data were collected by an automated feed intake monitoring system (GrowSafe, Calgary, Alberta, Canada) in the specialized feed intake unit (FIU). Dams were individually tagged with radio frequency identification tags (TFIW/GESMW, Allflex, Airport, TX) that were placed on the left ear and were sorted and placed in two 25-animal pens with free access to water and concrete bunks (Arce-Cordero, 2016). Dams remained in the FIU for 42 and 48 d in cohorts 1 and 2, respectively (Table 1). Dams in cohorts 1 and 2 were weighed upon entry to the FIU and again on days 14, 28, and 42. Cohort 2 remained in the FIU for an additional week and was weighed on day 48 when exiting the FIU. Individual simple linear regressions were performed using animal BW data, ADG was predicted, and individual dry matter intake (DMI) and gain:feed (G:F) values were

Table 2. Protein and energy content of rations fed to AHNC animals while in the feedyard by cohort^a

Nutrient composition (DM basis)		Receiving ration (low energy)	Transition ration (moderate energy)	Finishing ration (high energy)
Cohort 1 ^b	DM, %	–	63.91	67.48
	Net energy for gain, MCal • kg ⁻¹	–	0.48	0.64
	CP, %	–	16.48	12.58
	Acid detergent fiber, %	–	25.16	8.48
Cohort 2 ^c	DM, %	–	63.91	67.48
	Net energy for gain, MCal • kg ⁻¹	–	0.48	0.64
	CP, %	–	16.48	12.58
	Acid detergent fiber, %	–	25.16	8.48
Cohort 3 ^d	DM, %	70.20	71.24	–
	Net energy for gain, MCal • kg ⁻¹	0.36	0.58	–
	CP, %	14.74	14.43	–
	Acid detergent fiber, %	32.73	15.06	–
Cohort 4	DM, %	71.24	67.09	73.37
	Net energy for gain, MCal • kg ⁻¹	0.48	0.52	0.56
	CP, %	15.61	17.81	14.45
	Acid detergent fiber, %	18.31	14.09	8.90
Cohort 5	DM, %	80.00	69.46	77.52
	Net energy for gain, MCal • kg ⁻¹	0.53	0.46	0.57
	CP, %	16.52	15.50	12.15
	Acid detergent fiber, %	20.01	20.77	7.17

^aNutrient percentages were reported on a DM basis.

^bProximate analysis for the receiving ration from cohort 1 was unavailable.

^cCohort 2 was not fed the receiving ration.

^dProximate analysis for the finishing ration from cohort 3 was unavailable.

calculated. On days cattle were weighed, feed intake data were omitted from analyses to ensure that external factors did not influence feed intake. After the conclusion of feed intake measurements, dams remained in the feedyard on the finishing ration until harvest.

For cohorts 3 through 5, total BW of the pen was calculated using individual animal BW measurements. The proportion of each animal's individual BW to pen BW was calculated. Individual animal DMI was calculated by multiplying the proportion of individual animal BW to pen BW by the total amount of feed delivered to the pen daily. The proportion of individual animal BW to pen BW was recalculated when animal BW were updated every 3 wk. Gain:feed ratios were individually calculated using estimated DMI.

Cohorts 2 through 5, dams were individually mouth scored to quantify the number of permanent incisors 3 wk prior to harvest. A second mouth score was taken the day prior to harvest. In cohort 1, only a single mouth score was taken the day prior to harvest. Exit BW was individually calculated by averaging BW measured the final 2 d at the feedyard. Shrunken BW was calculated using 4% pencil shrink between the feedyard and packing plant.

Harvest

Across all five cohorts, a total of 222 AHNC females were harvested at a commercial packing plant located 48 km from the feedyard. In cohorts 1 and 5, one carcass was unavailable for measurements. Researchers from Colorado State University recorded the following carcass measurements: preliminary yield grade (YG); adjusted preliminary YG; HCW; ribeye area (REA); percentage of kidney, pelvic, and heart fat; marbling score (MA); lean maturity score (LM); and bone maturity score (BM). Yield grade and quality grade (QG) were calculated and USDA YG and QG assigned by USDA grading personnel were recorded. Yield and quality grades and overall maturity score (OM) were calculated using standards outlined in USDA Beef Quality and Yield Grades (Hale et al., 2013). Maturity scores of 100, 200, and 300 coincided with maturities of A⁰⁰, B⁰⁰, and C⁰⁰, respectively. Marbling score was assessed at the interface of the 12th and 13th rib and corresponded with the following marbling levels: practically devoid⁰⁰ = 100, traces⁰⁰ = 200, slight⁰⁰ = 300, small⁰⁰ = 400, modest⁰⁰ = 500, and moderate⁰⁰ = 600. Dressing percentage was calculated using shrunken BW and

HCW. For cohorts 3–5, age at harvest was calculated using available birthdates. Since no birthdates were available for cohorts 1 and 2, age at harvest was not known.

In cohorts 1 ($n = 42$) and 2 ($n = 43$) carcass meat tenderness was also evaluated. One 5-cm-thick longissimus muscle sample was removed from the loin portion of each carcass's left side at the interface of the 12th and 13th ribs. Longissimus muscle samples were used to evaluate slice shear force (SSF), Warner–Bratzler shear force (WBSF), and percentage of cooking loss. Longissimus muscle samples were packaged in vacuum-sealed bags and placed on ice for transport to the Colorado State University meat laboratory. Meat samples were repackaged in vacuum-sealed bags and wet aged at 2 °C until day 14 postmortem. After aging, samples were sliced into 2.54-cm-thick steaks and oven cooked to a peak temperature of 71 °C (Rational D88899, Landsberg am Lech, Germany). Precooking and postcooking weights were recorded, and cooking loss was calculated. After cooking, a 1-cm-thick, 5-cm-long slice was removed from each steak parallel to the muscle fibers. Samples were sheared perpendicular to the muscle fibers using a universal testing machine, (Instron Corp., Canton, MA) equipped with a flat, blunt-end blade to evaluate SSF. The same machine was fitted with a WBSF head, and two individual core samples were tested. The two peak force measurements from the core samples were averaged to calculate WBSF.

Weaning to Ovulation Synchronization

Recently weaned calves were transported from the feedyard to Rabbit Creek Ranch to graze fall pasture. Calves were supplemented daily with 15% CP range cubes at a level of 1.3 kg per animal. In all cohorts, steer calves were removed from the study and sold at a local auction market. Due to imperfections in the accuracy of sex-selected semen, reduced fertility of sex-selected semen, use of a natural service sire, and calf and dam death loss, the AHNC beef production system was unable to derive 100% of its replacements from within the system. Thus, replacement heifers were purchased annually for cohorts 3 through 5. A total of 80 Angus, replacement-quality heifers were purchased in cohorts 3 ($n = 26$; initial BW = 180 ± 6 kg), 4 ($n = 26$; initial BW = 222 ± 21 kg), and 5 ($n = 28$; initial BW = 228 ± 22 kg). In each cohort, the new set of heifers, including replacements, were transported to the feedyard in early winter. Heifers were

fed a moderate energy ration overwinter (99 ± 5 d; [Table 2](#)). Subsequently, heifers returned to the Rabbit Creek Ranch and were fed hay until May when the native range was available. Ovulation was synchronized as previously described.

Data Analyses

Data analyses were done using R (version 3.5.1). Descriptive statistics were used to calculate means (\pm SD) of key production parameters for reproducing females, calves, dams in the feed-yard, and carcasses. Pregnancy diagnoses, calving records, and production records from first and second inseminations were used to calculate percentages of heifers that conceived to first fixed-time AI and remained pregnant and percentages of heifers that conceived to the second fixed-time AI or natural service sires.

To evaluate differences in meat quality between youthful (i.e., A and B maturity) and mature (i.e., C maturity and greater) as classified by USDA grading personnel based on carcass maturity, a *t*-test was conducted. Carcasses were pooled across cohorts and sorted into two groups—youthful (i.e., OM <300) and mature (i.e., OM \geq 300) carcasses based on assigned USDA grades. The resultant means for HCW, REA, YG, MA, LM, BM, OM, and dressing percentage were compared. Slice shear force, WBSF, and cooking loss were compared on carcasses from cohorts 1 and 2.

Individual cohorts were not statistically compared to other cohorts since that was not an objective of this study. However comparisons were made between initial (i.e., cohorts 1 and 2) and sustaining (i.e., cohorts 3 through 5) cohorts since the background, genetics, and lifetime management differed. To test for performance differences between initial and sustaining cohorts, regression analyses were used. Group referred to whether an animal was from initial or sustaining cohorts. Logistic regression and contrasts were used for 30- and 140-d conception rates, and pregnancy was treated as the response variable. Prebreeding BW, body condition score (BCS), and group were considered as dependent variables. In the case of the 140-d regression, the categorical predictor repeat AI was also used (i.e., whether or not a heifer received a second AI). Age was not used as a predictor variable because ages were unknown for the initial cohorts.

Multiple linear regression models were fit to data to evaluate growth and carcass performance

between initial and sustaining cohorts. Response variables considered were ADG, DMI, HCW, dressing percentage, USDA YG, MA, LM, BM, and OM. Predictor variables included for consideration were BCS and BW at prebreeding, conception to first AI, second AI exposure, presence of a live calf at weaning, days on feed, ADG, G:F, HCW, MA, LM, BM, OM, USDA YG, and group. Measurements for SSF, WBSF, and cooking loss were not included because they were only performed on cohorts 1 and 2. Model selection was performed using backward selection. Data collected on animals that died were not used in analyses. Means were calculated using the emmeans package and reported as least squares means. Significance was declared at $P \leq 0.05$

RESULTS AND DISCUSSION

Reproductive Performance

At prebreeding, BW for the five cohorts was 346 ± 45 kg, and body condition score was 5.5 ± 0.6 ([Table 4](#)). Overall pregnancy rate at 30 d after fixed-time AI with sex-selected semen was $50.8\% \pm 9.4\%$; however, the final two cohorts had an average 30-d post-fixed-time AI pregnancy rate of 56.3%. Considering the reduced fertility of sex-selected semen due to decreased sperm numbers, these results were expected (Garner and [Seidel, 2008](#)). [Seidel et al. \(1999\)](#) evaluated the effects of breed, sperm concentration, and semen deposition site on conception rates for beef heifers inseminated with sex-selected semen and reported that pregnancy rates ranged from 26% to 86%. In a follow-up study, the average pregnancy rate for beef heifers inseminated with sex-selected semen 12–24 h after standing estrus was 55.9% (range: 47–80%), and sex-selected semen conception rates were typically 80% of conventional semen, but management played a key role in the success of breeding ([Seidel and Schenk, 2008](#)). In the current study, conception rates were within the reported range. However, conception rates improved in later cohorts; the unknown history of cohorts 1 and 2 may have negatively impacted breeding success, but improved conception rates were likely due to an improvement in semen sexing technology ([Seidel, 2014](#); [Vishwanath and Moreno, 2018](#)).

[Riggs \(2001\)](#) evaluated an integrated production system that included the use of early weaning, early breeding (i.e., 10 mo of age), and insemination with sex-selected semen. Conception rates to fixed-time AI with sex-selected semen were 19% and 8% in cohorts 1 and 2, respectively. However, at the

conclusion of the breeding season which included exposure to a natural service sire, conception rates were 58% and 16% for cohorts 1 and 2, respectively (Riggs, 2001). Riggs attributed low conception rates to only a small percentage of heifers cycling before the first AI. Results from the current study suggest that there are external management factors that also impact the success of insemination with

sex-selected semen. In cohort 1, there was a numerical reduction in 30-d post-fixed-time AI pregnancy rate (41.2%) compared to other cohorts (Table 4). The reduced conception rate for cohort 1 was attributed to the lack of fertility information on bulls used, incomplete history on purchased heifers (e.g., age or previous implant status), and other management factors.

Table 3. Ingredient composition of finishing rations fed to AHNC females by cohort^a

Item ^a	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Alfalfa hay, %	8.1	8.1	–	–	–
Wheat straw, %	–	–	–	–	4.6
Hay treat ^b , %	3.3	3.3	–	–	5.9
Corn silage, %	30.0	30.0	28.6	24.7	24.0
Cracked corn, %	35.0	35.0	–	56.2	58.0
Steam flaked corn, %	–	–	63.3	–	–
Dried distillers grains, %	7.8	7.8	–	11.3	6.5
Limestone, %	0.3	0.3	–	–	1.0
Salt, %	0.1	0.1	–	–	0.1
Ionophore ^c , g • ton ⁻¹	149	149	–	–	–
Melengestrol acetate, g • ton ⁻¹	1.0	1.0	1.0	1.0	1.0
Liquid supplement ^d , %	–	–	4.3	3.6	–
Mineral supplement ^e , %	–	–	3.8	4.2	–

^aAll ingredients reported on a DM basis.

^bHay treat was a molasses-based supplement that included glycerin, urea, condensed fermented corn extractives, ammonium polyphosphate, zinc sulfate, manganese sulfate, copper sulfate, xanthan gum, sodium selenite, vitamin E, vitamin A, vitamin D, cobalt sulfate, and ethylenediamine dihydroiodide.

^cRumensin (Elanco Animal Health, Indianapolis, IN).

^dLiquid supplement consisted of calcium carbonate, urea, condensed corn distillers solubles, molasses products, attapulgitic clays, water, salt, vitamin E, and vitamin A.

^eMineral supplement consisted of salt, zinc sulfate, iron carbonate, manganese sulfate, copper sulfate, and sodium selenite.

Table 4. Summary statistics (mean ± SD) for reproductive performance of AHNC females by cohort and overall

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Females exposed, <i>n</i>	51	56	54	56	56	273
BW at estrus synchronization, kg	354 ± 39	307 ± 30	390 ± 44	336 ± 32	348 ± 38	346 ± 45
Body condition score at estrus synchronization ^a	5.1 ± 0.8	5.1 ± 0.5	6.0 ± 0.3	5.7 ± 0.5	5.5 ± 0.5	5.5 ± 0.6
Pregnancy rate 30 d after fixed-time artificial insemination, %	41.2	48.2	51.9	46.4	66.1	50.8 ± 9.4
Pregnancy rate 140 d after fixed-time artificial insemination, %	94.1	92.9	90.7	92.9	94.6	93.0 ± 1.5
Heifers—failed to conceive ^b , %	5.9	3.5	7.4	7.1	3.6	5.5 ± 1.9
Heifers—artificial insemination and remained ^c , %	39.2	44.6	48.1	46.4	57.1	47.1 ± 6.5
Heifers—repeats ^d , %	–	35.7	33.3	35.7	19.6	31.1 ± 6.7
Heifers—bull ^e , %	54.9	32.1	33.3	32.1	30.4	36.6 ± 10.3
Heifers—late and sold ^f , %	7.8	10.7	0.0	7.1	8.9	6.9 ± 4.1
Calf crop ^g , %	94.1	85.7	74.1	81.8	92.9	85.7 ± 8.3
Calves born alive ^h , %	100.0	88.9	81.6	88.2	98.1	91.4 ± 7.6

^aBody condition scores were on a nine-point scale and included half scores (Herd and Sprott, 1996).

^bPercentage of heifers that were open at the 140-d pregnancy diagnosis.

^cPercentage of heifers that conceived to the first artificial insemination and remained pregnant.

^dPercentage of heifers that received a repeat artificial insemination; only a single artificial insemination was performed on cohort 1.

^ePercentage of heifers that conceived via natural service.

^fPercentage of heifers that conceived late (i.e., pregnancy less than 90 d at the 140-d pregnancy diagnosis) and were sold.

^g(N° weaned calves/ N° exposed females) × 100; heifers sold pregnant were assumed to wean a live calf.

^h(N° weaned calves/ N° pregnant females) × 100; heifers sold pregnant were assumed to wean a live calf.

At the conclusion of breeding seasons, $93.0\% \pm 1.5\%$ of heifers were pregnant. A small number of heifers failed to conceive ($19/272 = 7.0\%$) and were sold from the system (Table 4). The percentage of heifers that conceived to first AI and remained pregnant ($47.1\% \pm 6.5\%$), the percentage of heifers that received a repeat AI ($31.1\% \pm 6.7\%$), and the percentage of heifers that likely conceived to natural service ($36.6\% \pm 10.3\%$) were calculated (Table 4). The numerical reduction between pregnancy rate at 30 d after AI (50.8%) and heifers pregnant to first AI and remained pregnant (47.1% ; Table 4) was due to early embryonic death.

The hastened system timeline (Fig. 1) in the current study required a timely conception. Overall, $6.9\% \pm 4.1\%$ of exposed heifers achieved pregnancy but were sold because the projected calving date was outside the desired calving season (i.e., 50-d breeding season; Table 4). Heifers that calve late in the calving season will have difficulty achieving target harvest weight prior to reaching 30 mo of age. Furthermore, calves born later in the calving season would be younger and lighter at weaning and, thus, may struggle to achieve puberty in sufficient time for conception to the first AI. Although these pregnant heifers are not suitable for this system, selling them as pregnant females is a viable strategy for offsetting the lengthy time to income associated with the AHNC beef production system.

As shown in Table 4, the percentage of calf crop was $85.7\% \pm 8.3\%$. The 2007–2008 National Animal Health Survey for the cow/calf segment conducted by the USDA (2010) reported an average percentage of calf crop of 83.2% for primiparous females and 91.5% for all females. An evaluation

conducted by Laster and Gregory (1973) evaluated parturition and calf death loss in a variety of cattle breeds and concluded that calf losses were greater in primiparous females than cows due to a greater number of assisted births with primiparous females. Similar results were reported by Patterson et al. (1987) who documented the greatest calf mortality rates in primiparous females. Results showed that AHNC heifers were able to perform reproductively and achieved reproductive rates similar to those of conventional cow/calf production.

Calf Performance

Over the five-cohort study, a total of 213 calves were weaned. Combined across sexes and cohorts, calf BWT was 33 ± 5 kg (Table 5). There was a difference ($P < 0.001$) in BWT between male ($n = 51$; 35 ± 10 kg) and female ($n = 173$; 32 ± 9 kg) calves. These results were consistent with Tubman et al. (2004) who concluded that heifer calves weighed an average of 1.9 kg less than their male contemporaries. The difference between male and female BWT was also partly due to sire differences. Most female calves were conceived via AI sires with accurate expected progeny difference (EPD) for calving ease, and most male calves were sired by natural service sires with less accurate EPD for calving ease. The reduction in the number of calves born ($n = 224$) and calves weaned ($n = 213$) was due to calf death loss prior to weaning.

Calves were early weaned at 105 ± 21 d with an average weaning weight (WWT) of 125 ± 28 kg (Table 5). Calves from cohorts 1 and 2 were heavier ($P < 0.001$) at weaning than calves in cohorts 3

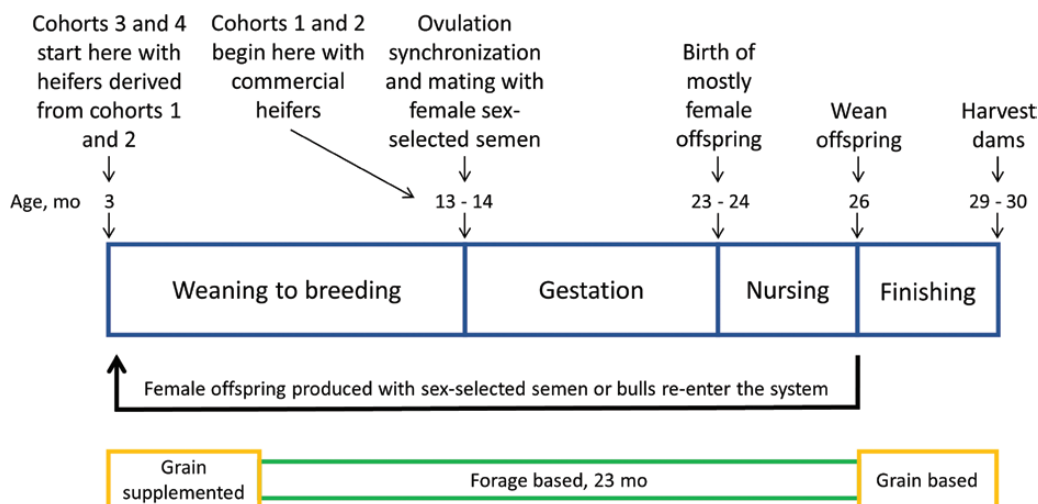


Figure 1. General timeline for five cohorts of the AHNC beef production system. Annual income requires a second set of heifers (i.e., cohort 2) started 12 mo after the first. During subsequent years, a few additional commercial heifers enter the system prior to breeding to maintain system inventory.

Table 5. Summary statistics (mean \pm SD) for performance of early weaned calves managed in the AHNC system by cohort and overall

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Birth weight, kg	33 \pm 3	34 \pm 4	33 \pm 4	32 \pm 6	35 \pm 6	33 \pm 5
Age at weaning, d	108 \pm 20	120 \pm 21	101 \pm 21	97 \pm 18	100 \pm 19	105 \pm 21
Preweaning ADG, kg \cdot d ⁻¹	0.48 \pm 0.06	0.38 \pm 0.04	0.36 \pm 0.08	0.40 \pm 0.06	0.36 \pm 0.09	0.40 \pm 0.08
Weaning weight, kg	147 \pm 24	133 \pm 25	111 \pm 26	118 \pm 22	115 \pm 28	125 \pm 28
Postweaning ADG ^a , kg \cdot d ⁻¹	0.8 \pm 0.2	1.0 \pm 0.3	0.9 \pm 0.3	1.1 \pm 0.2	1.2 \pm 0.4	0.9 \pm 0.3
Postweaning dry lot period, d	43	40	55	61	58	51 \pm 9
Female calves weaned, %	58.8	57.1	53.7	67.9	67.9	61.1 \pm 6.5

^aDry lot phase.

through 5. The increased WWT for cohorts 1 and 2 was attributed to the increased ($P < 0.001$) age of cohort 1 and 2 calves at weaning but also to the unknown genetic history and age of dams in the initial cohorts. Calves gained 0.40 ± 0.08 kg \cdot d⁻¹ preweaning and 0.9 ± 0.3 kg \cdot d⁻¹ during the postweaning dry lot phase (Table 5). Reiling et al. (1995) reported an average WWT of 159 kg and preweaning ADG of 1.1 kg \cdot d⁻¹ for calves produced by once-calved females (OCF) that were early weaned at 117 d of age. Similarly, Peterson et al. (1987) reported an average WWT and preweaning ADG for early weaned, crossbred calves of 109 and 0.76 kg \cdot d⁻¹, respectively.

An important measure for the AHNC beef production system is the percentage of females weaned. This will influence the number of replacements that must be purchased annually to maintain consistent herd inventory. Overall, $61.1\% \pm 6.5\%$ of females replaced themselves with a heifer, although the final two cohorts averaged a replacement rate of 67.9% (Table 5). This number was slightly below initial expectations; the goal was to achieve a replacement rate of 75%. Reduced accuracy and reduced fertility of sex-selected semen, calf and dam death loss, and the use of natural service sires reduced the percentage of female calves weaned. The AHNC beef production system would function with conventional semen, in which about 40% of females would replace themselves with a heifer but require purchasing more replacement heifers; however, management burdens and insemination costs would be reduced.

Feedyard performance

Upon entering the feedyard, initial BW was 464 ± 54 kg (Table 6). Dams in cohort 1 were heavier upon entry to the feedyard (518 ± 49 kg), but dams in this cohort were assumed to have been slightly older than those in other cohorts since birthdates were unknown. This theory was supported by the

greater percentage of C maturity carcasses based on carcass maturity in cohort 1. Overall, dams remained in the feedyard 102 ± 10 d prior to harvest and, majority of the time (72 ± 8 d), dams were fed a high-energy finishing ration (Tables 1 and 3). The length of the feeding period in the current study was consistent with previously reported feeding periods for primiparous and multiparous females. Schnell et al. (1997) concluded that feeding a grain-based diet for 56 d was a sufficient amount of time to convert yellow fat to white fat. A longer feeding period of 105 d was reported by Pritchard and Berg (1993) for cull cows ranging 4 to 10 yr of age.

While on the finishing ration, overall ADG for dams was 1.9 ± 0.4 kg \cdot d⁻¹ (Table 6). The ADG observed in the current study was greater than ADG previously reported for OCF. Field et al. (1996) fed a grain-based diet to crossbred OCF (entry BW = 525 kg) for 100 d after early weaning of calves. Dams gained 1.3 kg \cdot d⁻¹ (Field et al., 1996). A similar study by Waggoner et al. (1990) evaluated Simmental \times Hereford OCF that calved at 24 mo of age, were implanted, and fed a grain-based diet for 137 d prior to harvest, and ADG was 1.0 kg \cdot d⁻¹ (Waggoner et al., 1990). The ADG achieved by dams in the current study exceeded ADG values reported for conventionally raised and finished heifers (1.5 kg \cdot d⁻¹) and steers (1.7 kg \cdot d⁻¹; Kansas State Research and Extension, 2017). The increased rate of gain for dams in the current study compared to previously reported ADG was likely due to dams being lighter at the start of the finishing period. Furthermore, dams experienced compensatory gain upon entering the feedyard. After calving in late winter, the combination of lactation and growth/development facilitated a negative energy balance. Thus, the increased plane of nutrition and early weaning of calves resulted in a faster than normal rate of gain.

Overall dams consumed 14.9 ± 1.9 kg \cdot d⁻¹ of dry matter (DM), and G:F was 0.120 ± 0.023 , but

Table 6. Summary statistics (mean \pm SD) for finishing performance of AHNC primiparous females by cohort and overall

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4 ^a	Cohort 5	Overall
Entry BW, kg	518 \pm 49	453 \pm 41	481 \pm 45	421 \pm 40	451 \pm 50	464 \pm 54
Exit BW, kg	664 \pm 55	620 \pm 64	626 \pm 50	645 \pm 55	631 \pm 52	637 \pm 57
ADG ^b , kg \cdot d ⁻¹	1.6 \pm 0.3	1.8 \pm 0.4	1.9 \pm 0.3	1.9 \pm 0.3	2.0 \pm 0.4	1.9 \pm 0.4
DMI ^b , kg \cdot d ⁻¹	14.3 \pm 1.3	14.6 \pm 1.7	14.1 \pm 1.2	17.5 \pm 1.4	14.0 \pm 1.0	14.9 \pm 1.9
Gain:feed ^b	0.112 \pm 0.022	0.123 \pm 0.023	0.133 \pm 0.019	0.109 \pm 0.016	0.123 \pm 0.025	0.120 \pm 0.023

^aWeaning time was unintentionally delayed in over half of the dams in this cohort.

^bADG, daily DMI, and gain:feed were calculated for time on the finishing ration.

G:F continued to improve in later cohorts (Table 6). Although dams in the current study were able to gain weight rapidly, their conversion of feed to BW was poor. There was a numerical reduction in G:F for cohort 4 when compared to other cohorts, especially other sustaining cohorts (e.g., cohorts 3 and 5; Table 6). In cohort 4, fence-line weaning was unsuccessful, and half of the dams were still lactating up to a few weeks prior to harvest. Increased energy requirements of lactation likely contributed to the decreased feed efficiency in cohort 4 (Ferrell and Jenkins, 1985; Nkrumah et al., 2006).

Kansas State Research and Extension (2017) reported average G:F of 0.159 for conventionally raised and finished heifers. Wertz et al. (2002) analyzed the feed efficiency of conventionally raised and finished 2 yr-old Angus heifers and determined a G:F of 0.132. The G:F of AHNC females was reduced when compared to their nulliparous contemporaries. It was assumed that the reduced efficiency was due to recent parturition and lactation (e.g., presence of mammary tissue). Additionally, reduced feed efficiency is often associated with heavy animals at the start of the finishing period (Nkrumah et al., 2006). Although the feed efficiency of AHNC dams was poorer than conventionally raised and finished heifers, AHNC dams received the finishing ration a fewer number of days than animals in conventional finishing systems. Additionally, the elimination of the highly inefficient mature cowherd may offset decreased feed efficiency during the short finishing phase.

While in the FIU, dams in cohorts 1 and 2 consumed 15.6 \pm 1.6 and 13.9 \pm 1.9 kg \cdot d⁻¹ of DM, respectively. The five-cohort DMI average was within the range of the two DMI measurements obtained from robust feed intake measurements. The ADG for the period was 1.9 \pm 0.5 and 1.7 \pm 0.5 kg \cdot d⁻¹ for cohorts 1 and 2, respectively. These values were similar to the five-cohort ADG (Table 6), indicating that ADG remained relatively consistent across all five cohorts. Gain:feed calculated for time in the

FIU was 0.112 \pm 0.294 and 0.116 \pm 0.357 for cohorts 1 and 2, respectively. The increased DMI and less desirable G:F for cohort 1 was likely due to a heavier BW at the beginning of the feeding period than dams in cohort 2. Dams in the current study gained rapidly in the feedyard but were slightly less efficient than conventionally raised and finished heifers (Kansas State Research and Extension, 2017).

Carcass Performance

Table 7 includes carcass characteristics of the 222 AHNC females that were harvested. For cohorts 3–5, age at harvest was 904 \pm 20 d (i.e., under 30 mo of age based on documented chronological age). The packing plant did not use birthdates to determine chronological age but used dentition as a surrogate criterion to determine chronological age. Dams with three or more permanent incisors were declared over 30 mo of age. Dentition classified 68.3% of carcasses as over 30 mo of age. This is an important consideration for an AHNC producer, as carcasses declared over 30 mo of age will receive a sizeable discount (e.g., \$100 per carcass in the current study) *in addition* to any discounts for advanced ossification that is assessed by the USDA grader. In the current study, only 29.5% of carcasses exceeded 30 mo of age based on documented birthdates for cohorts 3–5, indicating that dentition was a crude measure of chronological age (Shorthose et al., 1990; Schönfeldt and Strydom, 2011). However, recent changes to the USDA grading system allows producers to provide third-party age and source verification of cattle, which overrides dentition scores and would help mitigate discounts for carcasses declared over 30 mo of age based on dentition.

Overall, the five cohorts had an HCW of 367 \pm 35 kg and dressing percentage of 59.8% \pm 1.9% (Table 7). Finding an industry average for the dressing percentage of similar cattle was difficult,

Table 7. Summary statistics (mean \pm SD) for general characteristics of AHNC primiparous females and carcasses at harvest by cohort and overall

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Females harvested, <i>n</i>	43	43	46	44	46	222
Age at harvest ^a , d	–	–	898 \pm 14	919 \pm 16	895 \pm 20	904 \pm 20
Shrunk BW ^b , kg	638 \pm 53	596 \pm 62	602 \pm 48	620 \pm 53	607 \pm 50	613 \pm 55
HCW, kg	389 \pm 33	366 \pm 36.3	351 \pm 28.1	372 \pm 31.7	358 \pm 32.1	367 \pm 35
Dressing percentage, %	61.0 \pm 1.5	61.0 \pm 2.0	58.3 \pm 1.6	59.8 \pm 1.2	59.0 \pm 1.6	59.8 \pm 1.9
Carcasses classified over 30 mo of age ^{c,d} , %	71.4	69.8	63.0	75.0	63.0	68.3 \pm 5.3

^aUnable to calculate for cohorts 1 and 2 since birthdates were unknown.

^bLive shrunk BW using 4% pencil shrink.

^cAssessed via dentition by the packer; carcasses with three or more permanent incisors were declared over 30 mo of age.

^dBased on documented birthdates for cohorts 3 through 5, only 29.5% of carcasses were over 30 mo of age at harvest.

Table 8. Summary statistics (mean \pm SD) for YG-related attributes of carcasses from AHNC primiparous females and percentages of carcasses in each USDA YG category by cohort and overall

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Ribeye area, sq. cm.	89.8 \pm 11.7	86.9 \pm 9.6	80.5 \pm 6.7	90.3 \pm 11.9	91.9 \pm 4.7	88.2 \pm 11.0
Calculated YG	2.9 \pm 0.7	2.9 \pm 0.8	3.2 \pm 0.5	2.8 \pm 0.7	2.5 \pm 0.7	2.9 \pm 0.7
Kidney pelvic heart fat, %	1.62 \pm 0.29	2.00 \pm 0.45	2.12 \pm 0.26	1.85 \pm 0.29	2.20 \pm 0.27	1.96 \pm 0.38
Back fat thickness ^a , cm	1.30 \pm 0.25	1.21 \pm 0.42	1.26 \pm 0.30	1.29 \pm 0.39	0.97 \pm 0.36	1.20 \pm 0.37
USDA YG	2.3 \pm 0.8	2.6 \pm 0.8	2.5 \pm 0.6	2.9 \pm 0.6	2.6 \pm 0.7	2.6 \pm 0.7
USDA YG 1, %	16.7	4.7	2.2	0.0	2.2	5.2 \pm 6.7
USDA YG 2, %	33.3	39.5	47.8	22.7	44.4	37.5 \pm 9.9
USDA YG 3, %	50.0	48.8	50.0	68.2	44.4	52.3 \pm 9.2
USDA YG 4, %	0.0	4.7	0.0	4.5	8.9	3.6 \pm 3.7
USDA YG 5, %	0.0	2.3	0.0	2.3	0.0	0.9 \pm 1.3

^aMeasured at a point three-fourths of the distance of the outer length of the ribeye (USDA, 2018).

but generally 62% is used as an industry benchmark for dressing percentage, considering both conventionally raised and finished steers and heifers (Nold, 2013; Content, 2018). Decreased dressing percentages observed in the current study were likely due to increased reproductive and mammary tissue associated with calving and lactation and an increased age at harvest (Waggoner et al., 1990; Pritchard and Berg, 1993; Nkrumah et al., 2006; Nogalski et al., 2016). Dressing percentages of females in the current study exceeded dressing percentages reported for OCF in the literature. Nogalski et al. (2016) harvested maiden heifers at 18 mo after being conventionally raised and finished and OCF that were subsequently finished and harvested at 28 mo of age. The OCF had heavier live BW at harvest (570 \pm 17 kg) but decreased dressing percentage (54.5% \pm 0.4%) when compared to the maiden heifers (BW = 482 \pm 13 kg; dressing percent = 57.1% \pm 0.3%; Nogalski et al., 2016). Additional comparisons of OCF carcasses to conventionally raised and finished carcasses have also reported decreased yields for OCF (Joseph and Crowley, 1971; Boucqué et al., 1980). Hot carcass weights of AHNC dams in the current study were

only slightly lower than HCW of conventionally raised and finished steers and heifers (394 kg) reported in the 2016 National Fed Beef Quality Audit (NCBA, 2017).

In the current study, all carcasses were sold on a value-based grid, in which YG and QG were important attributes. Yield grade-related attributes are included in Table 8. Across the five cohorts, USDA YG was 2.6 \pm 0.7 and calculated YG was 2.9 \pm 0.7. A comparison of USDA YG and calculated YG showed that mean USDA YG was less ($P = 0.001$) than calculated YG. This difference was expected considering USDA yield grading does not use standard rounding rules (i.e., YG 2.6 is classified as a YG 2, not a YG 3). Overall, REA measured 88.2 \pm 11.0 cm², back fat thickness measured 1.20 \pm 0.37 cm, and KPH was 1.96% \pm 0.38% (Table 8). Based on results from the 2016 National Fed Beef Quality Audit, mean REA was 83.2 cm² and mean back fat thickness was 1.42 cm (NCBA, 2017). Carcasses in the current study were leaner than conventionally raised and finished steers and heifers based on the objective measures of REA and back fat thickness. Performance of these

carcasses resembled carcass performance from females managed in an integrated system where heifers were bred young, calves were early weaned, and dams were finished and slaughtered at 24 mo of age (Riggs, 2001). Integrated system females ($n = 22$) had similar HCW (361 ± 28 kg), dressing percentage ($60.0\% \pm 2.2\%$), and USDA YG (3.1 ± 0.7) to females in the current study (Riggs, 2001).

The distribution of USDA YG assigned to AHNC carcasses closely resembled the YG distribution for conventionally raised and finished beef cattle (NCBA, 2017). The authors reported 9.5%, 36.5%, 39.4%, 12.1%, and 2.5% of carcasses graded YG 1, YG 2, YG 3, YG 4, and YG 5, respectively (NCBA, 2017). Table 7 shows percentages of AHNC carcasses that were represented in the five YG categories. In the current study, the predominant USDA YG was 3 and included $52.3\% \pm 9.2\%$ of all graded carcasses. In the current study, YG 4 and 5 only represented $3.6\% \pm 3.7\%$ and $0.9\% \pm 1.3\%$ of total harvested carcasses, respectively (Table 8).

Based on carcass maturity, the USDA grader classified $20.5\% \pm 18.7\%$ of carcasses as mature and the remaining were classified as youthful (Table 9). Mean LM for AHNC carcasses was 166 ± 26 and BM was 236 ± 81 for youthful and mature carcasses combined (Table 8). It is important to note in cohort 3 that there were no C maturity carcasses. Females in cohort 3 did not receive an estrogenic implant during the feedyard phase, likely contributing to the absence of mature carcasses as it has been demonstrated that estrogenic implants increase the rate of

skeletal ossification in beef carcasses (Grumbach and Auchus, 1999; Tatum, 2011). When calculating OM, BM is more influential than LM. Overall maturity score was 213 ± 54 , which coincides with B maturity (Table 9). The young age of these females coupled with accelerated levels of ossification supported the theory that hormones associated with pregnancy, calving, and lactation cause accelerated bone ossification (Waggoner et al., 1990; Kreikemeier and Unruh, 1993; Field et al., 1996). Waggoner et al. (1990) reported similar mean (\pm SD) maturity scores for OCF: LM = 180 ± 3 , BM = 216 ± 4 , and OM = 205 ± 3 .

Mean (\pm SD) MA of AHNC carcasses was 457 ± 87 and corresponded with a marbling level of small⁵⁷ (Table 9). The 2016 National Fed Beef Quality Audit reported an average MA of small⁷⁰ for conventionally raised and finished steers and heifers (NCBA, 2017). Reiling et al. (1995) and Shackelford et al. (1995) reported MA of small⁷⁵ and small²⁷ for conventionally raised and finished heifers and OCF, respectively. Marbling scores of AHNC carcasses in the current study were within the range of MA previously reported for beef produced by OCF and only slightly less than scores reported for conventionally raised and finished steers and heifers (Reiling et al., 1995; Shackelford et al., 1995; Nogalski et al., 2016; NCBA, 2017). Carcasses produced by AHNC females were able to sufficiently marble, but advanced carcass maturity is penalized carcasses when QG was assigned.

Overall, $62.4\% \pm 29.1\%$ of carcasses were classified as USDA Choice by USDA grading

Table 9. Summary statistics (mean \pm SD) for QG-related attributes of carcasses from AHNC primiparous females and percentages of carcasses in each USDA QG category by cohort and overall

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
MA ^a	475 \pm 75.7	430 \pm 85.8	490 \pm 89.4	428 \pm 95.3	460 \pm 71.8	457 \pm 87.1
Lean maturity score ^b	170 \pm 14.1	161 \pm 37.1	173 \pm 13.0	155 \pm 20.7	170 \pm 32.1	166 \pm 26.0
Bone maturity score ^b	281 \pm 55.5	229 \pm 101.7	215 \pm 31.3	245 \pm 110.8	213 \pm 60.7	236 \pm 80.7
Overall maturity score ^b	249 \pm 40.8	213 \pm 75.8	201 \pm 22.4	205 \pm 56.2	202 \pm 47.5	213 \pm 53.9
C maturity carcasses ^c , %	47.6	27.9	0.0	20.5	6.7	20.5 \pm 18.7
Calculated C maturity carcasses ^d , %	35.7	32.6	0	13.6	13.3	19.0 \pm 14.9
USDA Choice and greater, %	42.9	25.6	97.8	63.6	82.2	62.4 \pm 29.1
USDA Prime, %	0.0	0.0	6.5	4.6	13.3	4.9 \pm 5.5
USDA Certified Angus Beef, %	0.0	2.3	6.5	4.6	22.2	7.1 \pm 8.8
USDA Choice, %	42.9	23.3	84.8	54.6	46.7	50.5 \pm 22.4
USDA Select, %	9.5	32.6	2.2	15.9	11.1	14.3 \pm 11.4
Other ^e , %	47.6	41.9	0.0	20.5	6.7	23.3 \pm 21.0

^aMA (slight⁰⁰ = 300, small⁰⁰ = 400, modest⁰⁰ = 500, etc.).

^bMaturity score (A⁰⁰ = 100, B⁰⁰ = 200, C⁰⁰ = 300, etc.).

^cCarcasses classified as C maturity by the USDA grader.

^dCarcasses classified as C maturity based on overall maturity calculated by Colorado State University.

^eOther included: Standard, Commercial, Utility, dark cutter, blood splash, and advanced bone maturity.

personnel (Table 9). This was only slightly less than the percentage of USDA Choice carcasses (68.8%) reported in the 2016 National Fed Beef Quality Audit (NCBA, 2017). The large amount of variation in the percentage of USDA Choice carcasses was due to the advanced maturity of some carcasses, which caused carcasses to not be graded and receive carcass discounts. There were especially large numbers of ungraded carcasses in cohorts 1 and 2 due to their unknown age (Table 9). In cohorts 3 through 5, QG greatly improved with 110/136 grading USDA Choice or better. The integrated system studied by Riggs (2001) resulted in 68.2% of carcasses grading USDA Choice. In the current study, $4.9 \pm 5.5\%$ of all carcasses were USDA Prime (Table 8). On average, only 4.6% of conventionally raised and finished carcasses graded USDA Prime (NCBA, 2017). However, the percentages of ungraded carcasses in the current study ($23.3\% \pm 21.0\%$) greatly exceeded that of conventionally raised and finished carcasses (3.6%; NCBA, 2017). Carcasses that were ungraded in the current study were mostly ineligible for grading due to advanced bone ossification. However, recent changes to the USDA grading rules require that if the carcass is declared under 30 mo of age on the harvest floor by either dentition or third-party age and source verification, the USDA must use that as the maturity determinant in the QG instead of physiological carcass maturity. Thus, with third-party age and source verification and harvesting females at less than 30 mo of age, discounts for carcasses over 30 mo of age and advanced physiological maturity could be avoided and overall profitability could be increased.

Table 10 presents mean (\pm SD) tenderness and cooking measurements for cohorts 1 and 2. Slice shear force values were 25.2 ± 6.2 and 27.0 ± 10.7 kg, WBSF values were 4.9 ± 0.9 and 5.0 ± 1.2 kg, and CL estimates were 25.8 ± 3.7 and 26.5 ± 4.3 for cohorts 1 and 2, respectively. Huffman et al. (1996) noted that a WBSF value of 4.1 kg would result in a 98% consumer acceptability rating. Furthermore, a wide range of WBSF values has been reported for beef produced by primiparous females, with values ranging from 3.6 to 9.8 (Waggoner et al., 1990; Shackelford et al., 1995; Field et al., 1996, 1997). Field and colleagues (1997) examined differences between A and C maturity carcasses produced by finished beef females of similar chronological age (i.e., both groups consisted of heifers 31 to 35 mo of age) and determined that there were no differences between mature collagen crosslinks or steak tenderness. The authors concluded that collagen

Table 10. Comparison (mean \pm SD) of key carcass attributes between A and B maturity carcasses vs. C maturity carcasses produced from AHNC primiparous females across five cohorts

Parameter	Overall maturity		<i>P</i> > t
	A and B maturity	C maturity ^a	
Carcasses, <i>n</i>	177	43	–
HCW, kg	363 \pm 32	383 \pm 39	<0.01
Dressing percentage, %	58.4 \pm 2.9	60.6 \pm 2.2	<0.001
Ribeye area, cm ²	87.74 \pm 10.3	90.1 \pm 13.2	0.13
USDA YG	2.6 \pm 0.7	2.5 \pm 0.8	0.67
MA ^b	459 \pm 89	450 \pm 76	0.25
Lean maturity score ^c	166 \pm 26	166 \pm 25	0.99
Bone maturity score ^c	213 \pm 68	330 \pm 62	<0.001
Overall maturity score ^{c,d}	197 \pm 43	283 \pm 39 ^d	<0.001
Age at harvest ^e , d	902 \pm 20	919 \pm 11	<0.001
Slice shear force ^f , kg	25.4 \pm 8.6	27.6 \pm 9.1	0.29
WBSF ^f , kg	4.9 \pm 1.2	5.0 \pm 0.8	0.96
Cooking loss ^f , %	25.4 \pm 4.1	26.1 \pm 4.2	0.47

^aC maturity carcasses classified by USDA grader.

^bMA (slight⁰⁰ = 300, small⁰⁰ = 400, modest⁰⁰ = 500, etc.).

^cMaturity score (A⁰⁰ = 100, B⁰⁰ = 200, C⁰⁰ = 300, etc.).

^dAverage overall maturity score for the C maturity group was not over 300 because the number over C maturity was classified by the USDA grader, but Colorado State University took the bone measurements and determined some of the carcasses classified as C maturity were B maturity.

^eAge at harvest was only evaluated for cohorts 3 through 5 since birth dates were unknown for cohorts 1 and 2.

^fComparisons were only made on cohorts 1 and 2: youthful carcasses (*n* = 28) and mature carcasses (*n* = 57).

maturation was independent of skeletal maturation (Field et al., 1997). Current research has not yet demonstrated a significant correlation between meat tenderness and carcass maturity (Tatum, 2011; Acheson et al., 2014; Semler et al., 2016).

In this study, even though birthdates were unknown for cohorts 1 and 2, it was very unlikely that any harvested females exceeded 42 mo of age at harvest (i.e., OM = C or greater). Overall, 177 carcasses were classified as youthful and 43 were classified as mature based on carcass maturity that was assessed by USDA grading personnel. There were no differences between maturity groups for REA (*P* = 0.13), USDA YG (*P* = 0.67), MA (*P* = 0.26), or LM (*P* = 1.00). Mature carcasses had greater BM (*P* < 0.001) and OM (*P* < 0.001) when compared to youthful carcasses (Table 10). These results were expected since BM is the major determinant of OM (Hale et al., 2013). The mature group had greater (*P* < 0.01) HCW and greater (*P* < 0.001) dressing percentages. Increased HCW for the mature group was likely due to increased age at harvest. The reduced dressing percentage for

youthful carcasses was surprising because, generally, older animals have decreased dressing percentages (Content, 2018). However, decreased dressing percentages in the youthful group were likely due to a small number of animals not reaching target harvest BW. For cohorts 3 through 5, mature carcasses ($n = 12$; 919 ± 11 d) were older ($P = 0.001$) than youthful carcasses ($n = 120$; 903 ± 20 d) at harvest (Table 10). Differences in meat tenderness between youthful ($n = 28$) and mature ($n = 57$) carcasses were compared using data collected on cohorts 1 and 2. There were no differences ($P = 0.29$; $P = 0.96$; $P = 0.47$) between youthful and mature carcasses for SSF, WBSF, and CL, respectively (Table 10). Based on the objective value of meat tenderness, there were no differences between youthful and advanced carcass maturities.

Field et al. (1997) compared A and C maturity carcasses produced by grain-finished OCF that were harvested at 32.5 mo of age and found no differences in comparisons of LM, MA, WBSF, and muscle collagen concentration between maturity groups. However, there were differences in BM across maturity groups (Field et al., 1997). A comparison of maiden yearling, 2-yr-old, and once-calved females showed that OCF had greater BM than maiden heifers, but MA was the same across all groups (Waggoner et al., 1990). Sensory panelists and WBSF values indicated that beef produced by OCF was similar in tenderness to beef produced by maiden 2-yr-old heifers but tougher than beef produced by maiden yearling heifers (Waggoner et al., 1990). Joseph and Crowley (1971) compared beef from 12 maiden and 24 Hereford OCF that were harvested at 27 to 30 mo of age in a taste panel and found no differences between the two groups (Joseph and Crowley, 1971).

These results indicated that the AHNC beef production system is a viable system for producing beef. Carcasses produced by AHNC females are of similar quality to carcasses produced by conventionally raised and finished steers and heifers. With exceptions of BM and OM, beef produced by youthful AHNC carcasses was the same quality as beef produced by mature carcasses based on carcass maturity.

Comparison of Cohorts

Seidel and Whittier (2015) hypothesized that the AHNC beef production system would not reach equilibrium until later cohorts due to the influence of purchased heifers with little background

information decreasing the performance of initial cohorts. Thus, it was anticipated that the performance of sustaining cohorts would exceed the performance of initial cohorts. However, results of regression analyses yielded conflicting results. As shown in Table 12, mean 30-d pregnancy rates were 47.1% and 55.6% for initial and sustaining cohorts, respectively. At the 140-d pregnancy diagnosis, 94.1% and 92.6% of heifers were pregnant in initial and sustaining cohorts, respectively. There were no differences in 30-d ($P = 0.17$) and 140-d ($P = 0.48$) pregnancy rates between initial and sustaining cohorts (Table 11).

Table 12 summarizes differences in carcass and growth performance for initial and sustaining cohorts. Analyses showed that ADG ($P = 0.88$), YG ($P = 0.25$), and MA ($P = 0.44$) did not differ between cohorts. However, females in sustaining cohorts consumed more ($P < 0.001$) feed than females in initial cohorts, but carcasses in initial cohorts had heavier ($P < 0.001$) HCW and improved ($P < 0.001$) dressing percentages when compared to carcasses in the sustaining cohorts. These results were somewhat surprising; however, increased DMI for sustaining cohorts was likely due to females in cohort 4 lactating longer than females in other cohorts. Carcasses produced by the initial cohorts had more advanced BM ($P < 0.01$) and OM ($P < 0.05$), indicating, based on estimates of carcass maturity, that females in cohorts 1 and 2 were older at harvest (Table 12). Performance of initial cohorts was only slightly decreased, suggesting that producers could easily enter and exit the AHNC beef production system without compromised performance.

Over 30 yr ago, several studies evaluated single-calf heifer beef production. At the time, the consensus based on theoretical simulations was that the system was the most efficient means of producing

Table 11. Comparison of reproductive performance between initial and sustaining cohorts of the AHNC beef production system^a

Parameter	Initial cohorts ^b	Sustaining cohorts ^c	SE	$P > t $
Females, n	102	162	—	—
Pregnant 30 d after fixed time artificial insemination, %	47.1	55.6	26.2	0.17
Pregnant 140 d after fixed time artificial insemination, %	94.1	92.6	52.5	0.48

^aAnimals with missing data were omitted from analyses.

^bCohorts 1 and 2.

^cCohorts 3 through 5.

Table 12. Comparison of growth and carcass performance between initial and sustaining cohorts of the AHNC beef production system^{a,b}

Parameter	Initial cohorts ^c	Sustaining cohorts ^d	SE	<i>P</i> > t
Carcasses, <i>n</i>	85	135	–	–
ADG, kg · d ⁻¹	1.83	1.83	0.03	0.88
Daily DMI, kg · d ⁻¹	14.6	15.1	0.33	<0.001
HCW, kg	385	355	8.41	<0.001
Dressing percentage, %	62.3	58.3	0.31	<0.001
USDA YG	2.5	2.6	0.09	0.25
MA ^e	451	460	12.60	0.44
Lean maturity score ^f	159	164	3.07	<0.01
Bone maturity score ^f	230	239	3.35	<0.01
Overall maturity score ^f	218	213	2.42	<0.05

^aAnimals with missing data were omitted from analyses.

^bLeast squares means are reported.

^cCohorts 1 and 2.

^dCohorts 3 through 5.

^eMA (slight⁰⁰ = 300, small⁰⁰ = 400, modest⁰⁰ = 500, etc.).

^fMaturity score (A⁰⁰ = 100, B⁰⁰ = 200, C⁰⁰ = 300, etc.) assessed by carcass maturity.

beef (Taylor et al., 1985; Sell et al., 1988). The current study indicated that the AHNC beef production system can effectively produce female calves for replacements and high-quality carcasses at harvest. The AHNC beef production system offers flexibility. The AHNC beef production system could be started with calves, yearling heifers, bred heifers, or pairs and, similarly, producers could exit the system by selling yearling heifers, bred heifers, pairs, or cows after calving depending on market conditions and goals of the producer.

Further research should be conducted to compare the biological and economic efficiency of AHNC beef production to conventional cow-/calf-based beef production. Furthermore, due to age-related and carcass maturity discounts, the AHNC beef production system warrants evaluation in a grass-based finishing system since grass-finished animals are typically older at harvest and not assigned USDA QG. Another aspect that merits further evaluation is the potential to accelerate the rates of genetic improvement due to the very short generation interval of heifers that replace themselves with a heifer. Additionally, this program would be well suited to a branded beef program where carcass discounts could be avoided and system efficiency could be highlighted.

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