Influence of free-choice vs mixed-ration diets on food intake and performance of fattening calves[1]

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ABSTRACT: Research findings and management recommendations typically emphasize responses of the "average" individual, yet more than half of the animals in a group may differ significantly from the mean regarding food preference and intake. The productivity of a herd may be adversely affected if animals differing from the mean are fed a uniform diet formulated to meet the needs of the "average" individual. We compared the intake and performance of beef calves offered a choice or no choice among foods. Diets consisted of ad libitum access to either a chopped, mixed ration of rolled barley (31.3%), rolled corn (31.3%), corn silage (15.5%), and alfalfa hay (18.9%) (n = 16 calves) or a choice among those foods offered individually (n = 15 calves). Averaged across the 63-d trial, the two groups did not differ in ratios of protein to energy ingested (43 vs 43 g CP/Mcal ME; $P = 0.50$), but preference for foods high in energy or protein varied markedly for animals fed free-choice: on d 21 they had protein:energy ratios higher than those of animals fed the mixed ration, on d 2 the ratios were equal, and on d 40 they had protein:energy ratios lower than those of animals fed the mixed ration. Throughout the trial, no two animals consistently chose the same ingredients, and none selected a diet similar to the nutritionally balanced mixed ration, yet each animal ate a diet adequate to meet its needs. Animals offered the mixed ration tended to eat more than animals offered a choice (109 vs 102 g/kg MBW/d; $P = 0.10$), but they did not gain at a faster rate (0.89 vs 0.92 kg/d; $P = 0.65$). Gain/unit of food consumed also was similar for both groups (0.09 vs 0.10 kg/kg; $P = 0.38$). However, food cost/day was higher for animals fed the mixed ration than for those offered a choice ($1.58 vs $1.36; $P = 0.03$). Consequently, cost/kilograms of gain was higher for the mixed ration than for the choice group ($1.84 vs $1.49/kg; $P = 0.045$). These findings suggest that 1) animals can more efficiently meet their *individual* needs for macronutrients when offered a choice among dietary ingredients than when constrained to a single diet, even if it is nutritionally balanced; 2) transient food aversions compound the inefficiency of a single mixed diet by depressing intake even among animals suited to that nutritional profile; and 3) alternative feeding practices may allow producers to efficiently capitalize on the agency of animals, thus reducing illness and improving performance.

Key Words: Food, Individuals, Intake, Variation, Varieties

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Introduction

Studies of nutrition and behavior typically emphasize responses of the "average" animal in a treatment, and management recommendations emanate from this practice. Unfortunately, this viewpoint neglects the importance of variation among individuals. As many as half of the animals within a group may differ significantly from the mean in food preferences and nutrient tolerances (Provenza et al., 1996; Villalba and Provenza, 1996; Scott and Provenza, 1999). Therefore, productivity of a herd may be adversely affected if animals differing from the mean are fed a uniform diet formulated to meet the needs of the "average" individual.

Free-ranging herbivores eat a diverse array of different foods. Choices are more limited in confinement, but animals can often select among plant parts (leaves and stems, cobs, kernels, and sheaths) and among different plant species. However, when rations are chopped and mixed, as in most intensive livestock operations, these components become increasingly difficult for animals to separate. Offering food free-choice partially mimics nature and facilitates selection based on nutrient re-

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Table 1. Total-mixed ration and ingredients fed individually and as part of the mixed ration (dry matter basis)[a]

Ration/ingredient	Mixed ration, %	Protein, %	Energy, ME Mcal/kg
Total-mixed ration	—	12.0	2.77
Alfalfa	18.9	18.0	2.17
Corn silage	15.5	8.1	2.53
Rolled barley	31.3	13.5	3.04
Rolled corn	31.3	10.1	3.24
Limestone	1.7	—	—
Vitamin premix[b]	0.6	—	—
Trace mineral salt[c]	0.5	—	—
Mineral premix[d]	0.3	—	—

[a]Values for crude protein were determined by the Kjeldahl procedure (AOAC, 1980). Values for energy for alfalfa were determined using the equation [(DE = 0.39 + 0.033CP −0.013ADF)(0.82)] of Fonnesbeck and Anderson (1981). Values for corn, barley, and corn silage were calculated using equations in Undersander et al. (1993; Table 2, p 130).

[b]Vitamin A, 1,134,021 IU/kg; vitamin D, 113,402 IU/kg; vitamin E, 6,804 IU/kg.

[c]Zn, 3,500 mg/kg; Mn, 1,800 mg/kg; Cu, 350 mg/kg; I, 100 mg/kg; Se, 90 mg/kg; Co, 60 mg/kg.

[d]Zn, 6,000 mg/kg; Mn, 5,000 mg/kg; Cu, 2,000 mg/kg; I, 200 mg/kg; Se, 50 mg/kg; Co, 50 mg/kg.

quirements that fluctuate along with food quality and availability (Provenza, 1996).

Animals select a diet balanced for macronutrients in response to their changing needs (Kyriazakis and Oldham, 1993; Villalba and Provenza, 1999; Scott and Provenza, 2000). Thus, we hypothesized that animals offered a choice might eat more and gain more efficiently than animals restricted to a mixed diet, particularly if grain consumption restricted their intake. To test this hypothesis we measured the intake of dry matter, energy, and protein for calves fed the mixed ration or the ingredients offered individually. We also determined rate of gain, ratios of weight gain to food intake, cost/day to feed, and cost/kilogram of weight gain.

Materials and Methods

This experiment took place from December 1997 to March 1998 at the Utah State University South Farm near Wellsville, UT. For the study, 31 steers and heifers of known parentage and history were placed individually in adjacent pens. The pens were partially enclosed, which provided protection from weather and sheltered the feed bunks from rain and snow. Each pen had a feed bunk that enabled us to offer different foods in separate containers. Water was available continuously.

Animals were familiarized for 3 wk with a total-mixed finishing ration containing rolled barley (31.3%), rolled corn (31.3%), corn silage (15.5%), and alfalfa hay (18.9%) (Table 1; NRC, 1995). Food intake during the familiarization period was determined by recording the amount of food offered each day minus consumption the previous day. These data were used to assign animals to treatments, balanced for intake, sex, size, and sires. Ten of the animals, previously subject to an early-weaning program, were distributed equally between treatments. Components of the mixed ration were familiar to all calves because they were exposed to creep feed containing barley, corn, and oats beginning at 5 mo of age and to corn silage and alfalfa with their mothers in drylots.

During the study, calves in the two groups were offered either the mixed ration in a single feed bunk or offered the individual ingredients in four adjacent bunks. The location of the four foods remained the same throughout the study. The marked variation in intake of foods, from day to day and among individuals (see Results and Discussion), strongly suggests that animals offered a choice discriminated among the foods and changed preferences constantly throughout the study.

Throughout the trial, ad libitum intake of each ingredient was recorded at 0900. Bunks were checked periodically each day to ensure ad libitum access. One group (n = 16) received the total-mixed ration top-dressed with a vitamin-mineral mix. The other group (n = 15) received concurrent access to all four ingredients in separate bunks with the vitamin-mineral supplement top-dressed on the corn silage, the forage least likely to mix with the top-dress.

Measures of efficiency were calculated by determining the ADG for each animal, the dry matter intake of each food, and the cost of the various foods. Calves were weighed after the morning meal at the beginning (d 2) and end (d 66) of the study. To calculate measures of efficiency, we used data from 11 calves in each treatment; five calves from the mixed ration group and four calves from the free-choice group were not used because they were slaughtered well before the end of the experiment. Feed costs were determined by combining 10-yr (1988–1997) values for foods (Utah Agric. Statistics, 5% annual discount rate) and adding a \$14/ton barley and \$16/ton corn rolling charge (Trenton Feed Co., Logan, UT). No cost was assigned for feeding, mixing, or handling.

The repeated measures analysis of variance had two treatments (total-mixed ration vs choice). Animals were nested within treatments. Day was the repeated measure. Separate analyses were conducted for intakes of

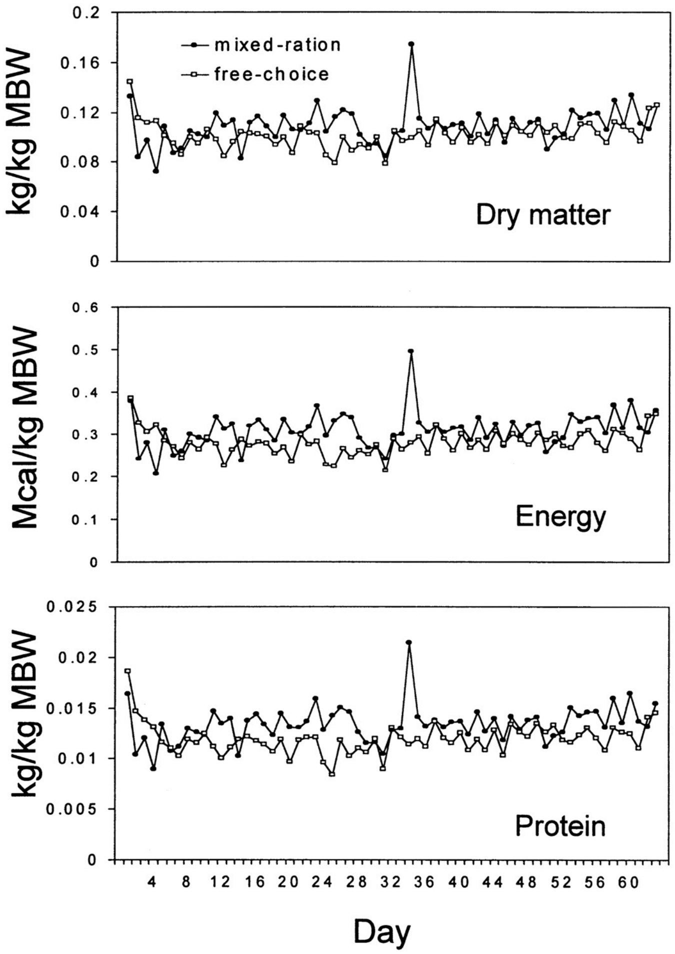

Figure 1. Intake of dry matter, energy, and protein by calves offered four ingredients (alfalfa, barley, corn silage, and corn grain) either as a total-mixed ration or free-choice. SEM for dry matter = 0.005, energy = 0.015, protein = 0.0001.

dry matter, energy, and protein, and for individual foods by the free-choice group. We also conducted analyses for rate of gain, food cost/day, cost/unit of energy, cost/unit of protein, gain/unit of food consumed, and cost/kilogram of gain. Finally, we did analyses for sex, sire, and weaning time.

Results

Dry Matter Intake

Animals offered the total-mixed ration tended to eat more than animals allowed to select among ingredients averaged throughout the trial (109 vs 102 g/kg metabolic body weight [**MBW**]; roughly 9.96 vs 9.32 kg DM/d; $P = 0.10$). Animals in the two treatments ate different amounts on different days, which resulted in a treatment × day interaction ($P = 0.0001$; Figure 1).

Intake of Protein and Energy

Animals fed the total-mixed ration ingested more energy (0.31 vs 0.28 Mcal ME·kg MBW^{-1}·d^{-1}; $P = 0.015$)

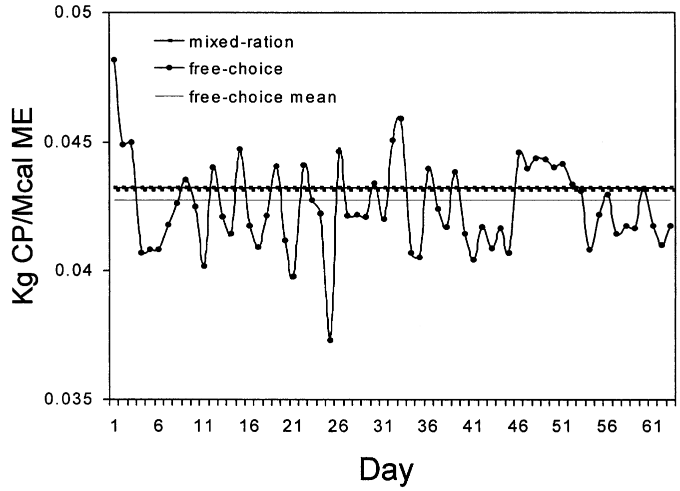

Figure 2. Ratio of protein to energy selected by calves offered four ingredients (alfalfa, barley, corn silage, and corn grain) as a total-mixed ration or free-choice. SEM for free choice = 0.0012.

and protein (130 vs 120 g CP·kg MBW^{-1}·d^{-1}; $P = 0.007$) than animals allowed to select among ingredients. Animals in the two treatments ate different amounts of macronutrients on different days, which resulted in a treatment × day interaction ($P = 0.0001$; Figure 1).

Calves restricted to the total-mixed ration ate a constant ratio of protein to energy, whereas animals offered a choice fluctuated throughout the trial ($P < 0.0001$; Figures 2 and 3). Averaged across the 63-d trial, means for the two groups did not differ (43 vs 43 g CP/Mcal ME; $P = 0.50$), but individuals offered a choice varied considerably in their preferred ratio of protein to energy.

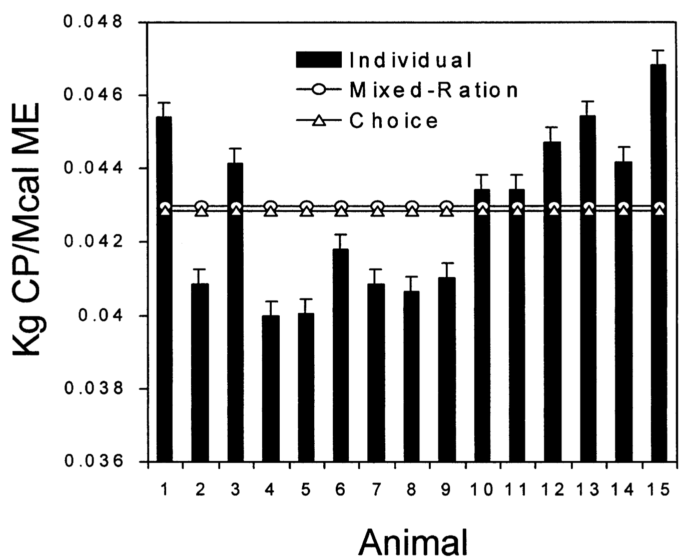

Figure 3. Ratio of protein to energy selected by individual calves compared with the total-mixed ration and free-choice means. Vertical bars represent SEM.

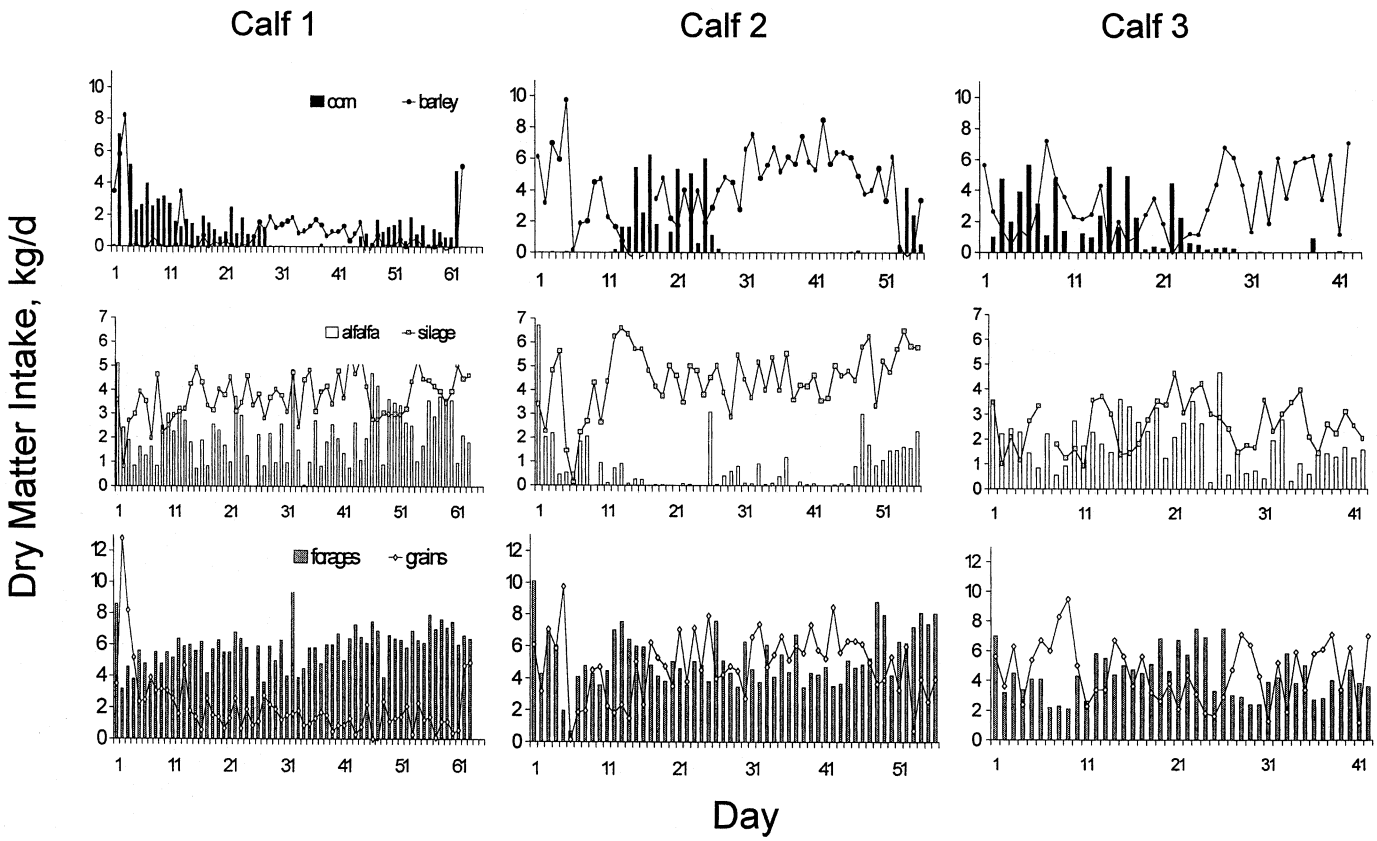

Figure 4. Variation among individual calves for intake of concentrates (corn and barley) and roughages (alfalfa and silage).

Intake of Foods Offered Free-Choice

Animals offered a choice ate more barley and corn silage (3.6 vs 3.4 kg/d) than alfalfa and rolled corn (1.3 vs 1.1 kg/d) averaged throughout the study ($P = 0.0001$). However, individuals ate markedly different amounts of the four foods on different days (food × day interaction, P = 0.0001) and strikingly different amounts of the each of the four foods from day to day (Figure 4).

Measures of Efficiency

Rate of gain did not differ for animals fed the mixed ration and those allowed to select a diet (0.89 vs 0.92 kg/d; P = 0.65). Gain/unit of food consumed also was similar for both groups (0.09 vs 0.10 kg/kg; P = 0.38). However, cost/day was higher for animals fed the mixed ration than for those offered a choice per unit of dry matter ($1.58 vs $1.36; P = 0.03), energy ($0.0580 vs $0.0544/Mcal ME, P = 0.0001), and protein ($1.33 vs $1.28/kg CP; P = 0.05). Consequently, cost/kilogram of gain was higher for the mixed ration than for the choice group ($1.84 vs $1.49/kg; P = 0.045).

Dry matter intakes were lower at the beginning than at the end of the study for cattle fed the mixed ration (Figure 1); and as a result, differences in gut fill could have influenced weights and calculated measures of efficiency. Averaged over the first and last weeks of the study, calves fed the mixed ration consumed 8.8 and 10.6 kg/d, whereas calves offered a choice consumed 10.1 and 9.9 kg/d. Thus, dry matter intakes were 1.8 kg higher at the end than at the beginning of the study for cattle fed the mixed ration (Figure 1). Body weights for the mixed ration and choice groups were 366 vs 362 kg at the beginning of the trial and 423 vs 422 kg at the end of the trial. Two points are obvious: 1) daily dry matter intake was a small percentage (about 3%) of the change in weight from the beginning to the end of the trial and 2) if dry matter intake affected body weight, cattle fed the mixed ration would erroneously seem to have gained more weight than cattle fed free-choice, which would decrease their gain/unit of food consumed and further increase their cost/kilogram of gain.

Sex, Sire, and Weaning

There were no main effects on dry matter intake due to sex (P = 0.75), nor did sex interact with day (P = 0.26), treatment (P = 0.56), or treatment × day (P = 0.34). No effect was observed among animals offered choice for sex (heifers = 2.24, steers = 2.39; P = 0.31), sex × day (P = 0.90), food (P = 0.40), or food × sex × day (P = 0.30). Daily gain (0.95 vs 0.88 kg/d; P = 0.31) and cost/unit of gain (1.63 vs 1.69 $/kg; P = 0.73) did not differ between heifers and steers.

Three sires were analyzed for their progeny's intake, growth rate, and cost of gain. Calves sired by the three bulls (nine by one Angus bull, five by another Angus bull, and six by a Simmental bull) did not differ in intake (9.3, 9.9, and 9.3 kg DM/d; $P = 0.55$), rate of gain (0.86, 0.92, and 0.92 kg/d; $P = 0.74$), or cost of gain (1.68, 1.54, and 1.77 \$/kg; $P = 0.69$).

Early- and late-weaned calves did not differ for growth rate (0.88 vs 0.92 kg/d; $P = 0.64$) or cost of gain (1.84 vs 1.60 \$/kg; $P = 0.23$).

Discussion

We hypothesized there might be biological and economic benefits if animals are allowed to select among alternative foods, rather than be restricted to a total-mixed ration. We speculated that animals offered a choice might gain more efficiently than those restricted to a total-mixed ration because the former might better met their *individual* needs.

During the 1st wk of the trial, cattle that selected their own diets ate more than animals fed the total-mixed ration (Figures 1 and 2), apparently because they could choose from a variety of foods with different flavors and nutrient contents (Atwood et al., 2001). However, for the remainder of the trial, animals offered a choice tended to eat less than animals offered a total-mixed ration (9.32 vs 9.96 kg DM/d; $P = 0.10$). Rate of gain did not differ for animals fed the mixed ration and those allowed to select a diet (0.89 vs 0.92 kg/d; $P = 0.65$). The animals offered a choice also cost less per day to feed because they ate less food and they ate less expensive food, so the cost per kilogram of gain was lower for the free-choice than for the mixed ration group. Because cost/gain was lower, it may be preferable to allow animals to select their own diets 1) to enable each individual to meet its needs, 2) to minimize food aversions, and 3) to maximize energy intake.

Variation Among Individuals

Averaged across the 63-d trial, the two groups of calves did not differ in ratios of protein to energy ingested (43 vs 43 g CP/Mcal ME; Figure 1), but preference for foods high in energy or protein varied markedly for animals fed free-choice: on d 21 they had protein:energy ratios higher than those of animals fed the mixed ration, on d 2 the ratios were equal, and on d 40 they had protein:energy ratios lower than those of animals fed the mixed ration. Throughout the trial, no two animals consistently chose the same ingredients, no individual routinely selected the same foods (Figure 4), and none consumed a diet similar to the nutritionally balanced mixed ration (Figure 3), yet each animal seemed to be able to select a diet that met its needs as seen in other studies (Kyriazakis and Oldham, 1993; Kyriazakis et al., 1994; Villalba and Provenza, 1999).

Food intake and preference depend in part on differences in how animals are built morphologically and how they function physiologically. Marked variation is common even among closely related animals. Differences in morphology and physiology influence intake of foods that differ in nutrients (Thiessen et al., 1985; Hotovy et al., 1991; Scott and Provenza, 1999). Striking variation also occurs as an animal's nutritional needs change due to growth (Kyriazakis and Oldham, 1993) and ongoing demands (Kyriazakis et al., 1994). Rations with higher proportions of grain can result in higher rates of gain, but animals differ greatly in their ability to process concentrates (Villalba and Provenza, 1996; Wang and Provenza, 1996; Scott and Provenza, 1999). When forced to eat rations that exceed tolerance for grain, animals reduce intake rather than suffer consequences such as acidosis from exceeding thresholds (Phy and Provenza, 1998). Conversely, animals offered a choice can mix concentrates with roughages to avoid overconsumption of grain (Wang and Provenza, 1996; Tolkamp and Kyriazakis, 1997; Scott and Provenza, 1999).

Transient Food Aversions

The food preferences of calves varied within meals and from day to day (Figure 3). Some believe animals eat a variety of foods to meet nutritional needs (Westoby, 1978). Others contend that animals eat a variety of foods to reduce the likelihood of overingesting toxins (Freeland and Janzen, 1974). We hypothesize that animals eat varied diets due to transient food aversions mediated by the flavor-feedback interactions that influence palatability (Provenza, 1995, 1996). Flavor integrates odor, taste, and texture with the postingestive effects of nutrients and toxins. The senses help animals discriminate among foods, and postingestive feedback relates sensory experiences with a food's utility. Cyclic patterns of intake of different foods reflect seemingly chaotic interactions among flavors, nutrients, and toxins (Pfister et al., 1997; Provenza et al., 1998; Atwood et al., 2001).

Palatability is linked to preference for a variety of foods by the satiety hypothesis. The satiety hypothesis attributes changes in palatability to transient food aversions due to eating a food too often or in too large an amount (Provenza, 1995, 1996). These aversions may become more pronounced when foods contain toxins or excessive levels of nutrients or nutrient imbalances. Taste aversions also result when foods are deficient in nutrients. Aversions can occur even when the diet is nutritionally adequate because satiety (adequate) and surfeit (excess) are on a continuum. Thus, transient aversions are likely any time a food is consumed too frequently or in excess.

The existence of aversions does not imply that animals lack food preferences. Their strong preferences are due to past experiences and current nutritional needs. Rather, a temporary decrease in the palatability of foods, even those that are nutritious, encourages animals to eat a variety of foods (Parsons et al., 1994; Early and Provenza, 1998; Atwood et al., 2001) and to forage in a variety of locations (Scott and Provenza, 1998, 2000). Thus, offering a variety of foods that differ in flavors and nutrient contents encourages animals to maintain high levels of intake.

Alternative Feeding Practices to Maximize Energy Intake

Dairy cows, beef cattle, and sheep maximize energy intakes when the diet consists of a mixture of concentrates and roughages, especially when the concentrate portion of the ration greatly exceeds needs. The amount of roughage needed to maximize energy intake depends on the individual, as well as the species, age, and level of production (reviewed by Grovum, 1988). Lactating cows consume less energy from an extremely high-energy diet containing mainly grain than they do when the mixture of grain and roughage is such that rumen function is within physiological limits. Cattle in feedlots seem to maximize energy intake with diets containing a mixture of concentrates and roughages, although the amount of roughage required to maximize intake seems to be less than that required in dairy cows. In beef cattle, dry matter intakes decline with increasing energy concentrations between 2.5 and 2.8 Mcal ME/kg. Lambs seem to maximize energy intake with rations containing 2.5 Mcal DE/kg. Sheep consume less DE when high-concentrate, as opposed to low- to moderate-concentrate, diets are fed. In every case, energy intake is higher when animals are offered a variety of concentrates and roughages. Consequently, feeding practices that enable animals to choose among appropriate ingredients may present opportunities to enhance production at less cost.

In our study, calves given a choice consumed less energy than calves fed the mixed ration, apparently because the energy concentration of the mixed ration (2.77 Mcal/kg ME, Table 1) was near a threshold for energy intake (2.5 to 2.8 Mcal/kg ME; Grovum, 1988). If the energy density of the mixed ration had been increased, the differences in energy intake likely would have been reversed as animals fed the mixed ration decreased intake due to the aversive effects of excessive grain consumption. At that point, cyclic patterns of food consumption, typical of food aversions, would cause energy intake of calves fed the mixed ration to vacillate widely (Provenza, 1996). Conversely, if we offered more synchronous sources of protein to match the high rates of fermentation of energy available from the barley and corn, calves in both groups may have consumed more grain. Rates of fermentation of protein relative to energy markedly influence diet selection and intake (Kyriazakis and Oldham, 1997; Villalba and Provenza, 1997; Early and Provenza, 1998).

Livestock producers typically believe that animals will overingest grain offered free-choice and become ill. Thus, production losses are cited as one reason to feed mixed rations. Our study shows that cattle accustomed to grains regulated their intake and consumed a ratio of protein:energy that was consistent with a scientifically balanced ration. Calves fed free-choice will vary in their ability to consume grain. Before the study, our calves had continuous access to creep feed in addition to either a drylot forage mix or pasture. Average consumption of creep feed at that time was approximately 6.8 kg per animal per day (Wiedmeier, unpublished data). Prior experience with creep feed enabled the calves to regulate intake of concentrates and roughages to match individual needs and to avoid stress from illness, nutrient deprivation, and monotony. During the 63-d trial, no animal became clinically ill, even though half of the animals had unlimited access to highly fermentable concentrates. However, if access to concentrates is suddenly increased without appropriate adaptation, animals that never had the opportunity to learn about the delayed adverse consequences of eating too much grain may gorge themselves and become ill (Ortega-Reyes et al., 1992). Conversely, calves prepared to consume grain can be started on an energy-dense ration sooner than calves without experience of grain, and in cases in which rapid gains are required, offering multiple high-energy foods along with roughages may promote higher levels of intake.

Implications

Cattle given a choice among ingredients in a total-mixed ration selected a diet comparable nutritionally to the scientifically balanced mixed ration. During the 1st wk of the 63-d trial, cattle that selected their own diets ate more than animals fed the total-mixed ration, seemingly because they could choose from a variety of foods with different flavors and nutrient contents. However, for the remainder of the trial, animals offered a choice tended to eat less than animals offered a total-mixed ration. Rate of gain did not differ for animals fed the mixed ration and those allowed to select a diet. Animals offered a choice cost less per day to feed, so the cost per kilogram gain was lower for the free-choice than for the mixed ration group. Because cost/gain was lower, it may be preferable to allow animals to select their own diets 1) to enable each individual to meet its needs, 2) to minimize food aversions, and 3) to maximize energy intake.

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