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Effects of the physical form of starter feed on the intake, performance, and health of female Holstein calves

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ABSTRACT

Available literature on the effect of various physical forms of starter feed (**PFSF**) on calf performance is conflicting. Thus, this study aimed to investigate the effect of the PFSF on feed intake, growth performance, blood metabolites, and the health of dairy calves. Twenty-four female Holstein calves (5-d-old; 40.4 ± 3.86 kg BW; mean ± SD) were used in a completely randomized block design. Calves were individually housed and randomly assigned to the treatments (n = 12 calves/treatment): (1) textured starter feed (**TSF**, a mix of pelleted ingredients and whole-kernel corn) and (2) pelleted starter feed (**PSF**). Both starter feeds had the same ingredients, nutrient compositions and pellet die size. Calves were fed the same milk replacer and weaned in a step-down scheme at 67 d. Health was evaluated daily until weaning. Treatments did not affect starter feed intake, water intake, BW, ADG, withers height, or clinical signs of disease (loss of appetite, ear position, and cough incidence). Nonetheless, scores for abnormal attitude ($P = 0.01$), ocular discharge ($P < 0.01$), total respiratory disease ($P = 0.02$), and fecal consistency ($P = 0.04$) of PSF-fed calves were higher than those TSF-fed. Based on that, TSF-fed calves exhibited a higher non-disease probability compared to PSF over time. Calves TSF-fed sorted against small particles (0.425-mm sieve; $P = 0.01$). Coincidently, PSF-fed animals sorted for small particles in the same sieve sizes. No major changes in blood profile were found ($P > 0.05$). In conclusion, starter feeds containing whole-kernel corn as a texturizer did not improve the intake and performance of dairy calves compared with pelleted starter feed; however, improvements were observed in health scores and non-disease probability of calves fed textured starter feed.

Implications

Understanding the impact of starter feed type on calf development and health is essential for optimizing early-life nutrition strategies. This study compared textured starter feed and pelleted starter feed in dairy calves and found no differences in feed intake, growth performance, or most biochemical parameters. However, calves fed textured starter feed exhibited improved health outcomes, including fewer incidences of loose feces and better respiratory and digestive health scores. These findings suggest that textured starter feed may enhance calf welfare and gastrointestinal health. Further research is needed to investigate its effects on rumen development and long-term productivity in dairy systems.

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Introduction

Early weaning and restricted milk feeding programs are strategies that can be used to reduce the feeding cost of rearing calves and encourage starter feed consumption. Commercial starter feeds are available in multiple forms, such as textured or pelleted, and contain coarsely rolled or ground grains, whole grains, protein, mineral, and vitamin supplements in their composition (Jones and Heinrichs, 2022). Ideally, NDF levels should range between 15 and 25% (Davis and Drackley, 1998), and a good textured diet should have a minimum of 45% grains, whether whole, steam-flaked, dry-rolled, and contain more than 75% of particles > 1 190 μm in length (Khan et al., 2016; Ghaffari and Kertz, 2021). Failure to meet these targets may decrease solid feed intake and negatively impact calf ruminal health (Bateman et al., 2009). As shown by Rezapour et al. (2016), dry-rolling compared with

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grinding, regardless of the grain source, improved dairy calves' performance during the pre- and post-weaning periods.

Improvement in average daily gain (**ADG**), starter feed intake (**SFI**), digestibility, and earlier rumination were observed in neonatal calves fed a coarse meal versus a pelleted starter feed (Porter et al., 2007). These authors noticed that the physical form of starter feed (**PFSF**) and particle size distribution are more important than fiber concentration in improving rumen fermentation, digestibility, and initiating rumination. Recent studies have shown that feeding calves texturized starter feed compared to pelleted non-texturized starter feeds leads to several benefits. These include improved morphological development of the reticulorumen due to increased nutrient digestion (Quigley et al., 2018), higher rumen volatile fatty acids proportion and production (Diao et al., 2019), greater DM intake and ADG (Terré et al., 2016), and enhanced immune status (Jahani-Moghadam et al., 2015). Thus, it was hypothesized that feeding a textured pellet concentrate (a mix of a protein pellet with whole-kernel corn) during the preweaning period of female dairy calves would improve intake and growth compared to feeding only a pelleted starter, with no changes in their health status. Therefore, this study aimed to evaluate dairy calves' nutrient intake, performance, and health under different PFSF diets.

Material and methods

Calves and housing

The experiment was conducted at the Knot Dairy Farm, an experimental dairy station at Washington State University in Pullman, WA, USA. The trial was conducted between April and September of 2022. Meteorological data of the period is presented in Table 1. Twenty-four 5-d-old female Holstein dairy calves (40.4 ± 3.86 kg BW; mean ± SD) were used in the trial. A power analysis was conducted, and a difference from the control of 15% was expected in DM intake and starter intake within each timepoint, with a CV of 14.5%, a *P*-value of 0.05, and a Power (1 – Beta) of 90%. The calculation resulted in 12 calves per treatment for a total of 24 calves. Calves were treated according to the farm's protocol for the first five days of life (navel care, identification, and housing). All calves received 3.8 L of the first colostrum of cows within 3 h of life and another 3.8 L of the second milking of cows (second colostrum) 8 h after. The following meals consisted of 2.8 L of milk replacer (MR) twice a day at 0500 and 1330 h. Before entering the experiment, calves had their total circulatory protein level measured using a refractometer (HHTEC®, model RHB-32ATC, Heidelberg, Germany) to evaluate the success in the colostrum feeding, with 5.5 g/dL as the threshold (McGuirk and Collins, 2004). The colostrum fed was obtained from the farm's colostrum bank, and to ensure the transfer of passive immunity, with a quality rating of good or excellent was fed (> 50 mg/mL of Immunoglobulins; Puppel et al., 2019). Calves were blocked and assigned to one of the two treatments using a randomized complete block design based on their month of birth as blocking criteria, being block 1 April (n = 7); block 2 May (n = 10), and block 3 – June (n = 7). The calves were individually housed in a naturally ventilated calf barn. Each stall (3.05 × 1.12 m) had specific spots for feeders and freshwater buckets. During the experiment, calves had ad libitum access to water and were fed MR and starter feed. On a 2-d basis, manure removal and replacement of bedding with wheat straw were done to keep the stalls visibly dry and clean.

Table 1
The average monthly temperature, humidity, temperature, and humidity index (THI) during the experimental period with female Holstein calves.

Month	Weather data		
	Air Temperature (°C)	Relative Humidity (%)	THI[1]
April	4.7 ± 3.3	69 ± 9.8	43.4 ± 5.7
May	9.4 ± 2.8	71 ± 8.4	50.4 ± 4.2
June	14.9 ± 3.1	71 ± 11.1	58.7 ± 4.7
July	19.8 ± 2.8	62 ± 7.8	65.6 ± 3.6
August	21.6 ± 2.6	45 ± 7.3	66.9 ± 3.2

Source: AgWeatherNet, 2022.
[1] Calculated using the equation: $HI = 0.8 \times T + RH \times (T - 14.4) + 46.6$, where T is temperature in °C, and RH is relative humidity in decimal form (Epstein and Moran, 2006).

Experimental treatments and feeding schedule

Calves were randomly assigned to one of the following treatments fed as a starter feed mixture:

- Pelleted starter feed (**PSF**): 12 calves [fed exclusively a protein pellet containing ground corn (4 mm) in its composition, with the size of the die on the pelleting machine being 4.37 mm; California Pellet Mill, model 3000, Waterloo, IA, USA].
- Textured starter feed (**TSF**): 12 calves (fed a mix of a protein pellet with whole-kernel corn, 60:40% as fed matter). USDA #2 grade dent corn, the predominant type grown in the United States, was used. This corn has 84.5% DM and 71% starch (on a DM basis). It was sourced from a mixed collection of fields to ensure consistent quality and meet USDA grading standards and harvested at a stage of full physiological maturity (maximum dry weight).

Long forage was not offered, but alfalfa meal was included in the pellet composition independently of the treatment since both starter feeds had the same ingredients, chemical composition and pellet die size (Table 2).

Regarding the feeding scheme, MR (Calva®, Optimum, Acampo, CA, USA; Table 2) was mixed according to the manufacturer's guidelines and fed at 15% of their birth weight at a concentration of 140 g/L in a step-down scheme, in which calves received 6 L/d from d 5 to 30; then, it was fed 10% of their birth weight (4 L from d 31 to 60). Weaning started at d 61 of life by decreasing 1 L every other day until the calves were completely weaned at d 67. The MR was fed twice daily (0600 and 1400 h) until reaching 3 L of MR allowance during weaning (two meals of 1.5 L). When the feeding scheme reached the amount of only 2 L a day, it was fed in a single meal a day, in the afternoon (1400 h) up to total weaning. After weaning on d 67, the calves were moved into the farm's herd and grouped into pens of 5 calves each, fed the experimental diets and Timothy hay *ad libitum*, and provided free access to water. Calves were monitored daily to assess for any abnormalities until the last measurement of postweaning weight (at 157 d old) to evaluate any treatment carry-over effect.

Sampling procedures

Intake, feed and fecal composition

Starter feed, water offered, and refusals were weighed daily at 1400 h. Water intake was corrected for evaporative loss using the Penman-Monteith equation (Penman, 1948). Starter feed was offered at a rate that allowed about 10% refusals. Calf starters and orts were sampled every other week and analyzed as follows. All samples were predried at 60 °C in a forced-air oven until constant weight, ground, and sifted through a 1-mm screen in a Wiley mill (Thomas Wiley®, Model 4, Philadelphia, PA, USA) and analyzed for DM [method 934.01; Association of Official Analytical Chemists (**AOAC**) 2006], OM (method 942.05; AOAC, 2006), CP (method 990.03; AOAC, 2006), ether extract (EE; method 2003.05; AOAC, 2006), NDF (Van Soest et al., 1991) method using ANKOM® system

Table 2
Ingredients, chemical composition (% of DM unless otherwise noted), and particle size distribution in the basal starter feed diet fed to dairy young calves (Measured data).

Ingredient composition	Starter feed		MR[1]
Alfalfa meal	15.1		–
Corn grain	56.7		–
Soybean meal	23.3		–
Molasses	2.5		–
Limestone	0.8		–
Mineral mixture[2]	0.5		–
Dicalcium phosphate	0.3		–
Salt	0.2		–
Magnesium oxide	0.2		–
Chemical composition	TSF[3]	PSF[3]	
DM	93.5	93.8	95.6
OM	93.5	93.6	90.1
CP	18.8	18.6	26.8
NDF	15.2	15.4	–
EE[4]	2.9	3.1	20.9*
Ash	6.5	6.4	8.90
Starch	35.2	36.7	–
NFC[5]	21.4	21.6	–
Particle size distribution (% of DM retained on sieves)			
4.00 mm	93.93	84.71	–
2.00 mm	3.07	3.44	–
1.18 mm	0.66	2.63	–
0.71 mm	0.87	3.86	–
0.425 mm	0.39	2.14	–
0.3 mm	0.29	1.32	–
Pan	0.80	1.89	–

Abbreviations: OM = Organic matter; EE = Ether extract; NFC = Non-fibre carbohydrate.
[1] Milk replacer; Mineral composition: 1.3 g of Ca, 0.8 g of P, 0.1 g of Mg, 1.7 g of K, 0.4 g of S, 64.4 parts per million (PPM) of Fe, 59 PPM of Zn, 11.4 PPM of Cu, 34.4 PPM of Mn, 0.9 PPM of Mo, 0.69% of Na. Soluble Protein % CP = 97.4 (%DM), Net energy for lactation = 2.89 Mcal/Kg. * Crude fat. Pool from 5 samples. Data from Dairy One Laboratory Analyses (n = 5).
[2] Contained per kilogram of the supplement: 975 000 IU of vitamin A, 750 000 IU of vitamin D, 1 800 IU of vitamin E, 143 g of Zn, 76 g of Mn, 48.6 g of Cu, 19.5 g of Se, 18.4 g of Fe, 8 g of Ca, and 1.3 g of Co + 0.02 g of Vitamin A and 0.40 g of Vitamin E.
[3] TSF = Textured feed and PSF = Pelleted starter feed (n = 7).
[4] Means obtained from analysis at Washington State University Feed Mill Facility.
[5] NFC = 100 – (starter CP + NDF + EE + Ash; NRC, 2001).

with the addition of heat-stable α-amylase (Mertens, 2002), and starch (method 996.11; AOAC, 2006). Once a week, after the 4th week within the experiment, a spot sample of feces was collected from each calf, frozen immediately after sampling to stop fermentation, and stored at −20 °C until further analysis. Fecal samples were chemically analyzed for DM, NDF, CP, and starch. All analyses were performed in the Department of Animal Sciences at Washington State University.

Performance

Body measurements were conducted weekly, before the afternoon feeding, for 9 consecutive weeks. The BW was measured with an electronic scale (Metter Toledo®, model IND236, Columbus, OH, USA), whilst withers height was measured using a graduated ruler. Calves were weighed and measured at 30 and 90 d after weaning to determine the postweaning performance. Preweaning, postweaning, and overall means of ADG were calculated as the difference between BW taken in a 7-d interval divided by 7. The result was considered as the ADG (g of BW/d; Khan et al., 2007).

Particle size and sorting behavior evaluation

The particle size distribution and the geometric distribution of particles were determined by a particle analyzer, according to the American Society of Agricultural and Biological Engineers (ASABE, 2006). A representative sample (∼100 g) was sieved for 10 min through a series of six screen sieves with nominal aperture sizes of 4, 2, 1.18, 0.71, 0.425, and 0.3 mm using a coarse sieve shaker (W.S. Tyler®, RX-812 model, Mentor, OH, USA). A bottom pan was included as a 7th screen to retain particles smaller than 0.125 mm. Each sieve was individually weighed before and after each sieve to obtain the weight of the samples on each sieve, thus determining particle size distribution and the geometric mean particle size. One run per sample was done, and sieves were cleaned thoroughly with an air compressor prior to each run.

The sorting index was computed as the ratio of actual intake to expected intake for particles retained on each sieve (Leonardi and Armentano, 2003). The intake of an individual fraction was computed as the product of the DM intake of the total diet multiplied by the DM percentage of that fraction in the fed TMR. Values equal to 1.0 indicate no sorting, < 1.0 indicate selective refusals (sorting against), and > 1.0 indicate preferential consumption (sorting for). One sorting value was generated per calf every 14 d until the end of the experimental period.

Health evaluation

A daily health evaluation of the calves was conducted during the MR-feeding period (d-5 to 67) using the Calf Health Score App® (McGuirk and Peek, 2014). A trained handler evaluated all enrolled calves in a blinded way to the treatment groups. Calves were also examined daily for respiratory disease incidence during the experimental period. Calves were categorized based on the clinical signs of disease exhibited, with a scoring system ranging from 0- normal, 1- variation of or slightly abnormal, 2- abnormal, to 3- severely abnormal for nasal discharge, cough, appetite, attitude, ocular discharge, and ear position. The ocular and ear scores were used to obtain a sum of the clinical scores. Calves with a sum score of ≥4 or with two or more clinical parameters that were scored as 2 or 3 were classified as having respiratory disease, and the remaining calves (those with sum of scores < 3) were considered healthy.

Fecal score

A daily fecal score assessment was conducted using the Calf Health Score App®. The fecal consistency scores ranged from 0 to 3 (0 – normal; 1 – semi-formed, pasty feces; 2 – loose feces, but feces stayed on the top of the bedding; 3 – meant watery feces sifted through the bedding). Five calves under 1 month of age identified with a score of 3 were treated according to the farm's protocol for scours. The treatment was initiated if a calf was identified as depressed, with eyes slightly sunken, did not finish a bottle or refused to drink the liquid diet, had signs of liquid manure, wet tail, or presence of fever. If the calf refused to drink milk, 1.9 L of electrolytes were offered instead. If skipping a meal, an esophageal feeder ensured the calf could get at least 1.9 L of milk or electrolytes daily. For the severe cases (3 in total), calves under antibiotic treatment received Polyflex® (1 mL/45.4 kg of BW intra-muscular once a day for 4–5 d) and Banamine (1 mL/45.4 kg of BW intra-venous once a day for 1–3 d). A reassessment was performed on d 4. If the scouring was severe, a 3-d treatment with Albon bolus® was added (Sulfadimethoxine – Zoetis Inc., Kalamazoo, MI, U.S.A.), as per label instructions.

Survival analysis

Non-disease probability curves were built according to the Kaplan-Meier estimator function method to better illustrate the health results by describing the probability (with a 95% confidence interval; Kaplan and Meier, 1958) of survival for the calves during the days of the experiment receiving the different types of starter feed. The survival was modeled as a function of calf age, with d 5 as the date of the calf's entrance in the trial up to weaning.

Blood sampling

Two blood samples (per calf) were collected by venipuncture of the jugular vein into vacutainer tubes, one at d 31 and another at d 61. Samples were centrifuged at 1 500 × *g* for 15 min (Geyer®, Premiere model XC-2415, Cincinnati, OH, USA), and serum was aliquoted and stored at −80°C until used. Samples were submitted to Catalytic One Chemistry Analyzer (IDEXX®, Westbrook, ME, U.S.A.) using its specific kits (Chem-15 CLIP), and the following parameters were analyzed according to the manufacturer's instructions: glucose, creatinine, blood urea nitrogen (**BUN**), phosphorus, calcium, total protein, albumin, globulin, alanine aminotransferase (ALT), alkaline phosphatase (**ALP**), gamma-glutamyl transferase (**GGT**), bilirubin, and cholesterol.

Statistical analysis

Data analysis was done using the GLIMMIX procedure of SAS (Statistical Analysis System, version 9.4). All variables measured over time were analyzed as a randomized block design, and the week was included as a repeated measure in the model:

$$Y_{ijkl} = \mu + T_i + \delta_{ij} + P_k + (TxP)_{ik} + B_l + iBW_{ijkl} + \varepsilon_{ijkl}$$

where μ = general mean; T_i = fixed effect of the treatment I; δ_{ij} =-random error with a mean of zero and variance of σ^2, the variance among calves within treatment, equal to the covariance among repeated measures within calves; P_k = fixed effect of the period; $(T \times P)_{ik}$ = fixed effect of the interaction between treatment I and period e; B_l = random effect of the block (entry date); iBW_{ijkl} = initial BW as a covariate and ε_{ijkl} = random error with a mean of zero and variance of σ^2, the variance among measures between calves. It was excluded from the model whenever the covariate did not demonstrate statistical significance. All variance–covariance structures available in the GLIMMIX procedure were tested, and the one that provided the best fit based on the Akaike information criterion was used.

Since health scores typically do not conform to a normal distribution, weekly averages for the daily scores were calculated. However, it is worth noting that the residual scores did follow a normal distribution (with a *P*-value > 0.05), and the Gaussian distribution exhibited the lowest AIC for all the scores. Cox proportional hazard models (PROC PHREG, SAS 9.4) were also created to evaluate the proportional association between treatment and health scores over time. Then, non-disease probability curves were estimated by the Kaplan-Meier function method (PROC LIFETEST, SAS 9.4) for all significant health scores.

Results

There were no interactions between time and treatment (*P* > 0.05; Table 3). No significant differences were detected in SFI (*P* > 0.05) and water intake (*P* > 0.05). Body weight, ADG, and withers height (*P* > 0.05) were not affected by treatment. Orts from TSF-fed calves were lower in non-fibre carbohydrate content (*P* = 0.001; Table 4) than those from the PSF-fed calves. Calves fed TSF highly sorted against small particle sizes in the sieve of 0.425 mm (*P* = 0.011; Table 5), and a trend with the same pattern was also found in the sieve of 0.3 mm (*P* = 0.060; Table 5); however, no sorting behavior was observed in the sieves of 4, 3, 1.18, 0.71, and 0.125 (pan) mm (*P* > 0.05). Conversely, calves receiving the PSF diet sorted for these particle sizes in the same sieves.

Clinical signs of disease based on health scores, such as loss of appetite, ear position, and cough incidence, were not affected by treatments (*P* > 0.05; Table 6), whereas calves fed PSF presented higher/worse scores in abnormal attitude (*P* = 0.010), presence of ocular discharge (*P* = 0.004), total respiratory score (*P* = 0.019), and fecal score (*P* = 0.040) than those fed the TSF. Non-respiratory scores had a similar pattern (trend, *P* = 0.087). Both treatment groups exhibited similar health performance trends during the early stages of the trial (Fig. 1). However, a noticeable divergence emerged between the two groups around the very 1st week of evaluation. The TSF treatment group showed a distinct improvement in health performance compared to the PSF group, which became more pronounced as the trial progressed.

The PFSF did not affect glucose, BUN, BUN:creatinine ratio, phosphorus, calcium, albumin, ALT, ALP, GGT, bilirubin, and cholesterol (*P* > 0.05, Table 7). A trend was found in creatinine (*P* = 0.061), total protein (*P* = 0.058), globulin (*P* = 0.067) with higher means for TSF-fed calves, and albumin:globulin ratio (*P* = 0.093), higher in the PSF-fed calves. The age at sampling affected the levels of creatinine (*P* = 0.003), GGT (*P* = 0.001), and bilirubin (*P* = 0.022), all were higher in the calves with 30 d of age, while calcium (*P* = 0.015) had a higher mean at 60 d of age. Conversely, there was no age-related effect on the variables glucose, BUN:Creatinine ratio, phosphorus, total protein, albumin, Globulin, Albumin:Globulin ratio, ALT, ALP, and cholesterol (*P* > 0.05).

Discussion

Feed intake was not affected by diet, contradicting the expectation of a higher intake of starter feed with TSF-fed calves. Pelleting may reduce the particle size of starter feeds and might, consequently, negatively influence rumen fermentation and feed intake, accompanied either with or without impacts on growth perfor-

Table 3
Nutrient intake and performance of young calves influenced by feeding textured starter feed (TSF) or pelleted starter feed (PSF; n = 24; 12 per treatment).

Items	Treatment (T)		SEM	*P*-value		
	TSF	PSF		T	Week (W)	T × W
Intake						
Starter, g/d	611	581	41.6	0.564	0.001	0.921
Water, g/d	1 859	1 973	353.7	0.595	0.001	0.729
Performance						
ADG, kg/d	0.76	0.78	0.029	0.664	0.001	0.252
Initial BW, kg	39.7	41.2	1.11	0.363	–	–
BW[1], kg	77.1	79.6	1.34	0.109	0.001	0.706
Final BW, kg	191.2	196.0	8.09	0.520	–	–
Withers height[1], cm	85	84	0.67	0.257	0.001	0.853

Abbreviation: ADG = Average daily gain.
[1] Average over the experiment.

Table 4
Orts and fecal chemical composition of young calves influenced by feeding textured starter feed (TSF) or pelleted starter feed (PSF; Measured data; n = 24; 12 per treatment).

Items, % of DM	Treatment (T)		SEM	*P*-value		
	TSF	PSF		T	Week (W)	T × W
Orts						
DM	93.4	93.7	0.06	0.001	0.294	0.431
OM	93.5	93.5	0.06	0.719	0.663	0.901
CP	18.6	18.4	0.13	0.319	0.088	0.727
NFC	55.7	58.0	0.36	0.001	0.511	0.883
NDF	16.3	15.8	0.25	0.152	0.590	0.814
Starch	15.2	14.3	0.37	0.122	0.531	0.688
Fecal						
NDF	39.6	38.3	13.93	0.987	0.589	0.090
Starch	2.84	2.67	0.400	0.768	0.005	0.277
Protein	22.5	22.9	0.49	0.567	0.004	0.069

Abbreviations: OM = Organic matter; NFC = Non-fibre carbohydrates.

Table 5
The sorting index of the diet (DM-based) fed to dairy young calves influenced by feeding textured starter feed (TSF) or pelleted starter feed (PSF) by particle size distribution (n = 24; 12 per treatment).

Particle size distribution, mm*	Treatment (T)		SEM	*P*-value		
	TSF	PSF		T	Week (W)	T × W
4.00	0.982	0.971	0.2674	0.456	0.473	0.464
2.00	1.100	1.085	0.0410	0.831	0.471	0.687
1.18	1.001	0.911	0.4961	0.701	0.603	0.461
0.71	1.167	1.129	0.2011	0.897	0.008	0.436
0.425	0.688	1.183	0.1332	0.011	0.927	0.402
0.3	0.753	1.228	0.1596	0.060	0.482	0.383
Pan	1.245	1.447	0.6677	0.511	0.028	0.564

* Values equal to 1.0 indicate no sorting, < 1.0 indicate selective refusals (sorting against), and >1.0 indicate preferential consumption (sorting for).

Table 6
Health scores of young calves influenced by feeding textured starter feed (TSF) or pelleted starter feed (PSF; n = 24; 12 per treatment).

Items	Treatment (T)		SEM	*P*-value		
	TSF	PSF		T	Week (W)	T × W
Attitude	0.005	0.028	0.0007	0.010	0.001	0.114
Appetite	0.007	0.024	0.0085	0.122	0.001	0.786
Ear	0.002	0.005	0.0020	0.103	0.603	0.603
Cough	0.053	0.044	0.0263	0.672	0.001	0.577
Ocular	0.070	0.160	0.0219	0.004	0.438	0.998
Fecal	0.151	0.237	0.0325	0.040	0.001	0.279
TRS	0.121	0.206	0.0430	0.019	0.068	0.967
NRS	0.071	0.126	0.0278	0.087	0.001	0.143

Abbreviations: TRS = Total respiratory score; NRS = Non-respiratory score.

mance (Bach et al., 2007; Porter et al., 2007). Calves usually avoid finely ground feeds (e.g., meal), frequently associated with reduced palatability and DM intake (Bateman et al., 2009). Further, PFSF can affect rumen development by increasing rumen pH and decreasing ammonia nitrogen levels with larger particle sizes. Coarser feeds slow fermentation, leading to higher pH and lower ammonia, while finer feeds lower pH and increase ammonia levels (Pazoki et al., 2017), which is also linked to DM intake. However, similar to studies of Mirzaei et al. (2016) and Omidi-Mirzaei et al. (2018), there was no difference between the PFSF diets concerning SFI (textured vs. pelleted forms). Visually, no corn kernels were observed in the calves' feces during the samplings, suggesting a better digestion of the starter feed, likely due to the coarser nature of the TSF. Strappini et al. (2021), evaluating calves' behavior and oral interactions, observed that the calves spent more time manipulating objects with their mouth than doing other activities, which might be expressed by chewing the whole-kernel corn of the TSF in the present study. Nevertheless, researchers such as Peng et al. (2023) may perceive the observed phenomenon as indicative of rumination, as it typically begins at 1–2 weeks of age and stabilizes around 4–6 weeks.

Miller-Cushon and DeVries (2017) suggested that feed sorting behavior in calves is most likely to initiate when they are: 1) first given a diet that they are physically able to sort (e.g., a diet comprising of a mixture of components that can be sorted) and 2) driven to sort (e.g., a diet that diverges in chemical composition from the ratio of constituents they would sort themselves). Despite anticipating different sorting behaviors based on feeding preferences due to visual differences in the PFSP, it was insufficient to stimulate the sorting among all 7 sieves evaluated; noticeable effects were only observed in the smallest sieves (0.425 and 0.3 mm). The present study findings for the PSF treatment were contrary to Costa et al. (2016), in which calves could not sort for specific components within the calf starter feed.

Although, to the best of the authors' knowledge, there has been no research specifically investigating this matter, PSF, in contrast to texturized varieties, has been suggested to reduce sorting behavior (Moran, 2012; Costa et al., 2016). In the present study,

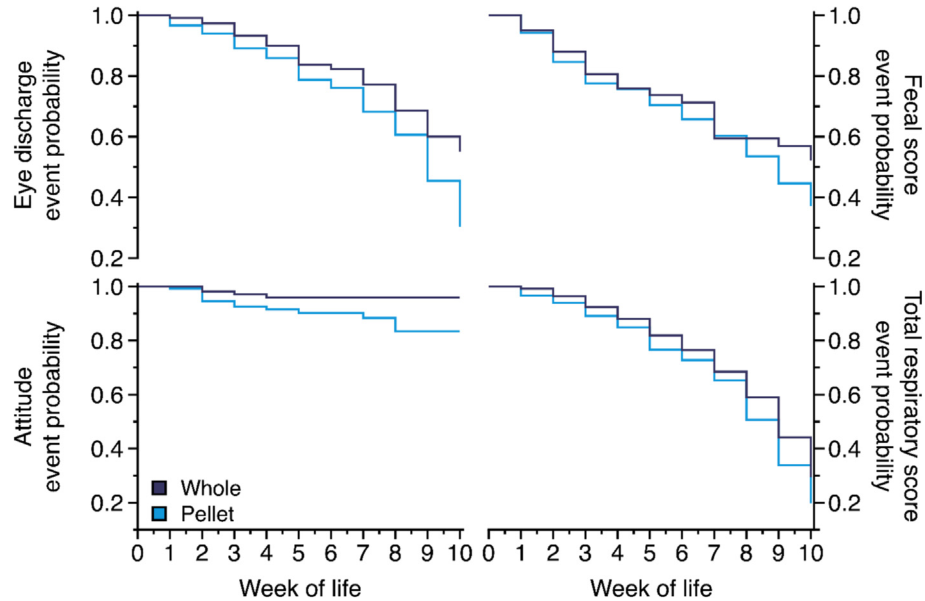

Fig. 1. Kaplan-Meier survival curves for female Holstein calves based on the physical form of the starter feed provided.

Table 7
Blood metabolites (in mg/dL, unless otherwise stated) of young calves influenced by feeding textured starter feed (TSF) or pelleted starter feed (PSF; n = 24; 12 per treatment).

Items	Treatment (T)		Age, in days		SEM	*P*-value		
	TSF	PSF	30	60		T	Age (A)	T × A
Glucose	96.9	94.6	98.3	93.1	2.45	0.564	0.166	0.899
Creatinine	0.9	0.8	0.9	0.8	0.03	0.061	0.003	0.827
BUN	7.5	7.2	7.9	6.8	0.43	0.592	0.071	0.423
BUN:Creatinine	9.2	9.4	9.3	9.3	0.46	0.705	0.899	0.264
Phosphorus	7.8	7.5	7.5	7.8	0.26	0.382	0.336	0.667
Calcium	7.9	7.9	7.0	8.8	0.49	0.933	0.015	0.783
Total protein, g/dL	5.8	5.4	5.5	5.7	0.14	0.058	0.318	0.967
Albumin, g/dL	2.4	2.3	2.3	2.4	0.05	0.235	0.157	0.999
Globulin, g/dL	3.4	3.1	3.2	3.3	0.10	0.067	0.318	0.910
Alb:Glob	0.7	0.8	0.7	0.7	0.02	0.093	0.563	0.999
ALT, U/L	31.5	29.1	31.3	29.3	1.01	0.118	0.177	0.818
ALP, U/L	259	235	244	250	17.4	0.331	0.804	0.602
GGT, U/L	33.1	33.0	42.0	24.1	2.35	0.981	0.001	0.797
Bilirubin	0.2	0.2	0.3	0.1	0.03	0.350	0.022	0.850
Cholesterol	98.8	102	104	96.3	5.65	0.719	0.324	0.518

Abbreviations: BUN = Blood Urea Nitrogen; BUN:Creatinine = ratio of BUN to Creatinine; Alb:Glob = ratio albumin to globulin; ALT = Alanine Aminotransferase; ALP = Alkaline Phosphatase; GGT = Gamma-Glutamyl Transferase.

the pellets had the same size, but the handling during feeding and throughout the day as the calves were eating may have caused the pellets to break down and crumble, eventually turning into powder. This degradation can lead to the formation of smaller particles, potentially resulting in variability in nutrient intake.

According to Bateman et al. (2009), calves tend to eat less starter feeds that are finely ground compared to those with larger particles. Thus, consistent with this finding, calves in the PSF group preferred coarser particles, while calves in the TSF group sorted the starter feed against the smaller particles. Similarly, Webb et al. (2014) evaluated that 2–to 5-month-old calves fed MR and concentrate that were trained to work for roughage rewards from two simultaneously available starter feed options. The authors noticed that the calves already choose to consume longer/bigger particles at this age. Furthermore, the present study supports their finding that ruminants can make choices based on rumen function/health and possibly also based on their motivation to chew and ruminate.

While existing studies suggest a link between sorting and rumen metabolism and development and health, the literature contains conflicting data (Pezhveh et al., 2014; Mirzaei et al., 2016; Pazoki et al., 2017). The sorting preference observed in the present study indicated it could affect rumen development. Previous studies showed that grain fineness might impact papillae development and overall health (Yavuz et al., 2015), and the reduction in episodes of loose feces for TSF compared with PSF may have contributed to a lower likelihood of diseases in this study. No direct measurements of gastrointestinal tract development and function were performed in the current study, but daily monitoring of fecal scores permitted a good determination of the digestive health status of each calf individually. Calves fed PSF had a higher incidence of loosened feces throughout the experiment when compared to the TSF-fed calves, which might indicate better digestive and intestinal health of the TSF-fed calves. Moreover, existing literature provides evidence that when calves are fed diets rich in easily digestible corn (processed corn such as ground corn, steam-flaked corn, etc.), their fecal consistency is affected, resulting in looser and softer stools in comparison to calves that consume coarser corn-based diets (Casper et al., 2017). Nevertheless, despite the similar environmental challenges faced by young calves, TSF-fed calves could express higher health scores when compared to the PSF-fed group. Overall, treatments did not impact the metabolic status of the calves or influence the blood concentrations of key enzyme markers. This suggests that regardless of the treatment, there was no impairment in the healthy functioning of the liver, consequently posing no threat to the overall health status of the calves.

The findings reported in this study warrant further investigation through slaughter analysis that is scarce in the literature, focusing on specific aspects of structural development like papillae development, variations in volatile fatty acids production, and changes in the microbial population in calves receiving different types of PFSF. Expanding this research in this direction could unveil the underlying mechanisms and provide valuable insights for optimizing calf nutrition, health, and overall performance.

Conclusions

Contrary to the initial hypothesis, incorporating whole-kernel corn as a texturizer in calf starter feed did not improve starter feed intake and performance in young dairy calves when compared to pelleted starter feed. However, the results pointed to an improvement in calf health considering the enhancements in scores of general attitude, reduced ocular discharge, better fecal score, and lower total respiratory disease. These findings imply a potential association between the use of textured starter feed and improved gastrointestinal development, suggesting a positive impact on calf health when fed with coarser starter feed diets since early life.

Ethics approval

The Institutional Animal Care and Use Committee of Washington State approved the study under protocol #7069.

Data and model availability statement

None of the data were deposited in an official repository. The authors' data supporting the study findings are available upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

The authors have no conflicts of interest to report.

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