

The provision of solid feeds to veal calves: I. Growth performance, forestomach development, and carcass and meat quality^{1,2}

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ABSTRACT: Growth performance, forestomach development, and carcass and meat quality of veal calves fed a milk replacer diet (Control) were compared to those obtained from calves fed the same liquid diet plus 250 g·calf⁻¹·d⁻¹ of dried beet pulp or wheat straw. Three groups of 46 Polish Friesian calves, balanced according to initial BW, were assigned to the three dietary treatments in a fattening trial, which lasted 160 d. The provision of either solid feed did not affect the milk replacer intake. However, calves' ADG was increased ($P < 0.01$) only by feeding the beet pulp diet. The administration of both solid feeds improved calves' health status; calves fed solid feeds required fewer iron treatments for low hemoglobin and needed less medical treatments for respiratory or gastrointestinal diseases. In comparison to the Control calves, the provision of wheat straw and beet pulp increased iron intake throughout the fattening period by 41 and 130%, respectively. However, only calves fed beet pulp showed higher levels of hemoglobin and plasma iron concentrations ($P < 0.05$), whereas the same blood parameters were similar between Control calves and those fed

wheat straw. At slaughter, both solid feeds led to empty forestomach weights heavier than those of Controls without reducing dressing percentage. The reticulorumen was heaviest in calves fed beet pulp, whereas wheat straw promoted omasal development. The administration of beet pulp resulted in a better carcass conformation than did the Control diet or wheat straw, but it had a detrimental effect on carcass color, which was graded as the darkest ($P < 0.001$). Consistent with this result, meat color of calves fed beet pulp was darker than that of Control calves and those fed wheat straw, because of the higher hematin concentration measured at the muscle level. No differences in carcass and meat color were observed between Control calves and calves fed wheat straw.

The administration of solid feeds for welfare purposes does not always prevent the production of veal meat fulfilling the color standards required by the market. There is not a straight-forward relationship between a solid feed's iron content and the "redness" of veal meat, which should be related to the capability of the calves to use the iron provided by the roughage.

Key Words: Carcass Quality, Growth, Meat Quality, Roughage, Stomach, Veal

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Introduction

The traditional feeding system adopted by the veal calf industry is strongly criticized because of poor animal welfare (Broom, 1991). For the entire fattening period, which lasts about 6 mo, calves are fed a liquid diet based on milk replacer without any provision of solid feeds. Feeding milk replacer alone limits the physiological development of the forestomach and the display of oral activities such as chewing and rumination that are normally exhibited by young calves receiving solid feeds. Moreover, the rumen of veal calves fed only the liquid diet often contains hairballs, which, according to some authors, can reduce animal welfare by impairing digestion (Unshelm et al., 1982; Morisse et al., 1999, 2000). Digestive problems can also occur in

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response to hyperkeratosis of the rumen papillae, which has occasionally been observed in veal calves (Scientific Veterinary Committee, 1995). However, this type of feeding plan allows the production of carcasses and meat with pale color, which is one of the main criteria by which market experts and consumers judge veal quality (Miltenburg et al., 1992).

The 97/2/EC Directive by the Council of Europe (EU Council, 1997) set a minimum amount of fibrous feed to be provided to veal calves from 8 to 20 wk of age for welfare purposes. However, in the same directive no specific indication can be found about the type of fibrous feed to be fed to the calves. Therefore, research has been undertaken to identify specific feeds capable of improving calf welfare without detrimental effects on carcass and meat color.

The present study compared the provision of two different fibrous feeds, dried beet pulp and wheat straw, in addition to a liquid diet, and evaluated their effects on calves' growth performance, forestomach development and carcass and meat quality.

Materials and Methods

Treatments, Animals, and Management

This study compared the use of dried beet pulp and wheat straw as fibrous feeds for veal calves. The two solid feeds were chosen because of their different NDF content (NRC, 1989) and their roughage value, which, according to Mertens (1992), represents the capacity to stimulate chewing and rumination.

The study evaluated three different feeding plans for veal calves: a traditional liquid diet without any addition of solid feed (**Control**) and the same diet supplemented with 250 g·calf⁻¹·d⁻¹ of dried beet pulp or the same amount of wheat straw. The feeding treatments were evaluated in a 3 × 2 × 2 factorial arrangement that also considered the provision of drinking water in addition to the liquid diet (no water vs water) and the adoption of two housing systems (individual stall vs group pen).

We used 138 Polish Friesian male calves from two batches of 54 and 84 animals each. The two batches of calves were reared according to the same experimental protocol, the former in summer and fall 1997 and the latter in spring and summer 1998. On d 4 and 5 after the arrival at the farm, all the calves (10 to 12 d of age) were weighed, and based on their average initial BW they were assigned to the 12 factorial combinations of the study, as shown in Table 1.

All the housing structures used in the study were located in the same building. The 24 individual stalls (0.83 × 1.80 m) were wooden with slatted floors and lateral partitions provided with fences to allow social contact between neighboring calves. The calves housed in individual stalls were not tethered. The group pens were also wooden with slatted floors and they housed five calves each with a space allowance of 1.8 m²/calf.

Table 1. Treatment allotments of the two batches of calves used in the study

Treatment allotment	Number of calves	
	Batch 1 (n = 54)	Batch 2 (n = 84)
Diet ^a		
Control	18	28
BP	18	28
WS	18	28
Drinking water		
No	27	42
Yes	27	42
Housing system		
Individual stall	24	24
Group pen	30	60

^aControl = milk replacer; BP = milk replacer + 250 g/d of dried beet pulp; WS = milk replacer + 250 g/d of wheat straw.

Environmental temperature in the building was controlled by an extractor fan system that automatically operated above 25°C. Regardless of the type of housing system, all the calves were bucket-fed the milk replacer diet. The buckets had a maximum capacity of 20 L and they were provided with a nipple 10 cm in length. The group pens had individual feeding gates to restrain the animals during the meal, allowing the individual recording of milk intake. The daily dose of milk was delivered in two equal meals at 0730 and 1930 and the daily amount of milk powder and its concentration in the liquid diet were increased throughout the fattening period from 400 to 3,000 g·calf⁻¹·d⁻¹ and from 7 to 18.8%, respectively.

A liquid milk replacer diet containing 50% skim milk (Starter) was fed in the first 30 d of the trial (Table 2). In the following part of the fattening period, calves received a liquid diet obtained by blending 36% Fast, a milk replacer containing 50% skim milk, with 64% Elat, a skim milk-free milk replacer. All milk replacers were provided by Realvit Italia S.p.A. (Ghedi, Italy).

The administration of solid feeds and drinking water started at the beginning of the 2nd wk of the study. Water and solid feeds were delivered after the evening meal and the amount of drinking water was progressively increased from 3 to 8 L·calf⁻¹·d⁻¹ throughout the fattening period. The calves housed in the stalls received the individual daily amount of drinking water and solid feed in two separate buckets. In the group pens, the solid feed was administered within a common trough (2.5 × 0.4 m) located in the side of the pen opposite the feeding gates and the water was delivered in the milk buckets with the feeding gates open.

Samples of milk replacers and solid feeds were collected monthly during the experimental period and analyzed for DM, CP, ether extract, and ash and iron content with AOAC methods (1990). Dried beet pulp and wheat straw samples were also analyzed for NDF and ADF content (Van Soest et al., 1991) and their nonfibrous carbohydrate content and roughage value were

Table 2. Feed and chemical composition of the milk replacers used in the study

Item	Starter	Fast	Elat
Feed composition (as-fed basis)			
Spray skim-milk powder, %	50	50	—
Whey powder, %	28	23	50
Whey albumin, %	—	—	25
Fat, %	15	19	17
Soy lecithin, %	1	1.5	1.5
Maize starch, %	3	3	3
Dextrose, %	1	1.5	1.5
Vitamin and mineral supplement, %	2	2	2
Chemical composition			
DM, %	94.8 ± 0.3	95.0 ± 0.4	94.7 ± 0.5
CP, % DM	21.5 ± 0.2	19.7 ± 0.3	21.6 ± 0.1
Ether extract, % DM	20.3 ± 0.5	22.8 ± 1.5	20.4 ± 0.5
Ash, % DM	7.1 ± 0.1	6.8 ± 0.1	8.2 ± 0.1
Iron, ppm	55.4 ± 2.0	14.6 ± 0.6	23.1 ± 0.4

calculated according to Mertens (1992). Chemical composition data of the two solid feeds are shown in Table 3.

Calves' Daily Gain, Feed Intake, Cleanliness, and Health Status

Calves' ADG was calculated by weighing the animals for two consecutive days at the beginning and at the end of the experimental period, which lasted 160 d. Individual intake of milk replacer, solid feed, and drinking water were recorded daily for the calves kept in stalls, and a daily average value was calculated for each group pen. Milk replacer and total DM efficiency were calculated as daily gain/intake.

A visual evaluation of calves' cleanliness and feces consistency and color was carried out at the 3rd, 14th, and 22nd wk of the fattening period. Individual calves' cleanliness was scored by looking at the dirty area of the ventral part of the body and of the hind legs using a 3-point scale: 1 (clean) = dirty area < 300 cm²; 2 (dirty) = 300 < dirty area < 600 cm²; and 3 (very dirty) = dirty area > 600 cm². The consistency of the feces within each crate and pen was recorded as 1 = firm/dry, 2 = creamy, and 3 = loose/wet, and their color was scored as 1 for white-yellow, 2 for light brown, and 3 for dark brown-grey.

The health status of the animals was monitored twice a day at the meals according to the following protocol: "feed refusal day" was used to record cases of a calf consuming less than one-half of the offered daily dose of milk; "medical treatment day" was used to record any individual treatment for respiratory or gastrointestinal diseases; and "iron treatment day" was used to record any individual intramuscular injection of iron dextrane (Imposil, IZO S.p.A., Brescia, Italy) to treat calves with a low hemoglobin level. The amount of iron dextrane to be injected was decided using 7 g/dL as the optimum hemoglobin level at the end of the fattening period. The iron treatment was then calculated based on the time distance to the end of the fattening period considering

a decrease of about 1 g/dL of hemoglobin per month of the growing cycle.

At the 3rd, 13th, 18th, and 23rd wk of the experimental period, blood samples were taken from all the calves by jugular vein puncture before the morning meal using heparinized vacutainer tubes (Becton Dickinson Inson, Meylan Cedex, France). Plasma hemoglobin and iron concentration were then measured according to the procedures of Sigma (1984) and Siedel et al. (1984), respectively.

Slaughter Measurements and Meat Quality Evaluation

At the slaughterhouse, carcasses were weighed to calculate individual dressing percentage and then they were graded for conformation and fatness according to the European grading scheme (OFIVAL, 1984). A 15-point scale was adopted by dividing into three subclasses each of the five main classes of conformation from 1 = Poor- to 15 = Excellent+ and fatness from 1 = Minimum to 15 = Maximum. An evaluation of carcass color was made by visual observation of the visible external muscular tissue using the following 4-point scale: 1 = white, 2 = pale pink, 3 = pink, and 4 = dark pink.

Empty forestomachs and abomasums were weighed to assess their development, and the number of calves

Table 3. Chemical composition of the solid feeds

Chemical composition	Dried beet pulp	Wheat straw
DM, %	91.2 ± 0.8	93.0 ± 0.3
CP, % DM	9.3 ± 0.8	2.3 ± 0.3
Ether extract, % DM	0.8 ± 0.1	1.7 ± 0.1
Ash, % DM	4.5 ± 0.5	5.7 ± 0.4
NDF, % DM	47.0 ± 2.2	85.5 ± 0.7
ADF, % DM	25.4 ± 1.3	51.7 ± 1.6
NFC, % DM ^a	38.4 ± 1.4	4.8 ± 0.5
Roughage value, % NDF	18.8 ± 0.9	85.5 ± 0.7
Iron, ppm	217 ± 5.6	79 ± 14.5

^aNonfibrous carbohydrate content calculated as: 100 - (NDF + CP + ether extract + ash).

with hairballs in the rumen was counted. The rumens of the 54 calves of the first batch were inspected and the consistency of the ruminal content was evaluated using the following categories: 1 = liquid, 2 = pasty and frothy, and 3 = thick and firm. A visual evaluation of the color of the ruminal mucosa was carried out, scoring 1 for white-yellow, 2 for light brown, and 3 for dark brown-grey.

A tissue sample from the dorsal sac of each rumen was excised and fixed in 10% neutral buffered formalin for subsequent microscopic examination. The histological examination of the samples was carried out after hematoxylin eosin staining. For each case, the length of three randomly selected papillae was measured with light microscopy with the aid of a micrometer, and the mean was calculated. Similarly, the thickness of the mucosal epithelium and the thickness of the keratinized epithelium were measured in three randomly chosen microscopic fields and the means were calculated. Histological sections were examined in a blinded fashion.

A joint sample of the longissimus muscle from the fifth to the ninth rib was taken from the right half-carcass of each calf at 24 h after slaughter. The sample was vacuum-packaged and stored at 2 to 4°C in a chilling room for 6 d. After this aging period, the meat samples were frozen and kept until analysis at -20°C. Meat chemical analysis considered pH, moisture, and intramuscular fat content measured as ether extract (AOAC, 1990). Total pigment content was measured as hematin on fresh meat samples as proposed by Hornsey (1956).

Meat color was measured with a CR 100 Chromometer (Minolta Camera, Osaka, Japan) equipped with C illuminant on samples exposed for 1 h to air at 2°C (Boccard et al., 1981). Color data were expressed according to the Hunter-Lab system. Weight cooking losses were determined on 2.5-cm-thick steaks heated in a water bath at 75°C for 50 min and cooled in running tap water for at least 40 min (Boccard et al., 1981). The instrumental measurement of veal meat tenderness was carried out using a Warner-Bratzler shear force meter (Instron Ltd., High Wycombe, U.K.) on cylindrical core samples of cooked meat 1.25 cm in diameter (Joseph, 1979).

Sensory assessment of meat quality was carried out by a taste panel according to the guidelines of the AMSA (1978). A 1.9-cm-thick steak was cooked in an electrical oven at 165°C until the meat core reached the temperature of 70°C and then cut into 1.3- × 1.3-cm square pieces, which were immediately offered to the panelists. Sensory evaluation of meat tenderness, juiciness, and flavor was scored adopting for each parameter a 5-point scale (1 = undesirable; 5 = extremely desirable).

Statistical Analysis

The normal distribution of all the variables included in the dataset was tested with the PROC UNIVARIATE

of SAS (SAS Inst. Inc., Cary, NC) using the Shapiro-Wilk test. The tested variables that showed values of $W > 0.80$ were considered normal and therefore were then submitted to a weighted ANOVA within PROC GLM (SAS Inst. Inc.). The calf was the unit for the animals housed in the individual stalls, whereas the group mean was the unit for group-housed calves. Because the variance of a mean of n observations is σ^2/n , we used the number of observations per mean (five for group-housed calves and one for individually housed calves) as a weighting in the analysis, thus correcting the imbalance of the design. The model used for data processing of these variables was $Y_{ijmlk} = \mu + B_i + S_j + H_m + W_1 + (SH)_{jm} + (SW)_{jl} + (HW)_{ml} + (SHW)_{jml} + e_{ijmlk}$, where Y_{ijmlk} = observation, μ = overall mean, B_i = effect of batch (block), S_j = effect of diet, H_m = effect of type of housing, W_1 = effect of water provision, $(SH)_{jm}$ = interaction of diet and type of housing, $(SW)_{jl}$ = interaction of diet and water provision, $(HW)_{ml}$ = interaction of type of housing and water provision, $(SHW)_{jml}$ = interaction of diet, type of housing, and water provision, and e_{ijmlk} = random residual error. Differences were considered significant at $P < 0.05$ and the PDIFF statement of the PROC GLM (SAS Inst. Inc.) was used to perform multiple comparisons among least squares means.

Kruskal-Wallis and Mann-Whitney tests with the PROC NPARIWAY (SAS Inst. Inc.) were performed for variables that did not show a Gaussian distribution, whereas the proportions data recorded to describe the number of calves with hairballs in the rumen were compared by χ^2 calculations (SAS Inst. Inc.).

Results

The statistical analysis did not show any significant interaction among the three main factors (diet, type of housing, and water provision), allowing a separate discussion of the results obtained feeding the calves different solid feeds. The results regarding the effects of the other two main factors will be presented in following separate articles.

Growth Performance and Health Status

Four calves of the second batch (two Controls and two fed the wheat straw diet) showed severe respiratory disorders from the beginning to the end of the fattening period, likely because they had been sick since their arrival at the fattening unit. Although these animals completed the trial, they required continuous medical treatment and their growth performances were severely impaired by the disease, which was diagnosed as chronic pneumonia by veterinary inspection at the slaughterhouse. The BW of these calves at the end of the fattening period were below the lower 95% confidence limit of the mean and therefore they were considered outliers and all the data for these calves were discarded from the processed data set.

The administration of beet pulp significantly increased the calves' ADG compared to that of Controls

Table 4. Growth performance and intake of veal calves receiving different diets

Item	Diet ^a			SEM	F
	Control	BP	WS		
Live weight					
Initial, kg	60.4	60.5	60.6	3.9	0.04
Final, kg	229.2 ^y	245.1 ^x	233.0 ^y	23.3	5.3 ^{**}
Average daily gain, g	1,078 ^y	1,178 ^x	1,100 ^y	145	5.5 ^{**}
Feed consumption					
Milk replacer, g DM/d	1,878	1,891	1,878	34	2.1
Solid feed, g DM/d	—	210 ^x	200 ^y	13	5.7 [*]
Total DM, g DM/d	1,878 ^z	2,101 ^x	2,078 ^y	37	441.6 ^{**}
Feed efficiency	0.57 ^x	0.56 ^x	0.53 ^y	0.07	4.45 [*]
Water intake, L/d	2.72	2.87	2.86	0.63	0.70
Iron intake ^b					
From milk replacer, g	6.34	6.38	6.34	0.10	1.81
From solid feeds, g	—	8.18 ^x	2.57 ^y	0.44	1,460.20 ^{***}
Total, g	6.34 ^z	14.56 ^x	8.91 ^y	0.53	2,580.51 ^{***}

^aControl = milk replacer; BP = milk replacer + 250 g/d of dried beet pulp; WS = milk replacer + 250 g/d of wheat straw.

^bTotal intake throughout the fattening period.

^{x,y,z}Least squares means in a row with different superscript letters are significantly different ($P < 0.05$).

^{*} $P < 0.05$.

^{**} $P < 0.01$.

^{***} $P < 0.001$.

and calves fed wheat straw, which were similar (Table 4). Milk replacer and water intake were not affected by the consumption of either solid feed. However, the daily intake of beet pulp was higher than that of wheat straw. Feed efficiency was decreased by feeding wheat straw, whereas it was similar in Controls and calves fed beet pulp.

Comparison to the Controls, calves receiving the wheat straw and the dried beet pulp had increased iron intake throughout the fattening period by 41% and 130%, respectively ($P < 0.001$, Table 4). However, in the blood samples taken at wk 13, 18, and 23 of the fattening period, only calves fed beet pulp showed hemoglobin and plasma iron concentrations higher than those of Control calves (Figure 1).

Regardless of the feeding treatment, the health status of the calves was considered satisfactory, as shown by the low incidence of feed refusal days (Table 5) and the total absence of bloating. Despite the low number

of iron and medical treatments, differences among diets were observed (Table 5). Calves receiving beet pulp did not require any iron treatment, and they had the lowest number of medical treatment days. In comparison to the Control treatment, the administration of wheat straw did not affect the iron treatments but it significantly decreased the medical treatments.

The consistency of the feces was increased only by the provision of wheat straw; no differences among diets were observed in the evaluation of fecal color (Figure 2). The cleanliness of calves' bodies was improved only by the administration of wheat straw (Figure 3).

Slaughter Performance and Meat Quality Evaluation

Consistent with final BW, the beet pulp diet produced heavier carcasses than Control or wheat straw diets (Table 6); however, dressing percentage was not affected by the administration of solid feeds. The provi-

Table 5. Health status of veal calves receiving different diets

Item	Diet ^a			SEM	F
	Control	BP	WS		
Feed refusal ^b	0.49	0.60	0.53	1.73	0.04
Iron treatment ^c	0.58 ^x	0.02 ^y	0.19 ^y	0.76	6.01 ^{**}
Medical treatment ^c	2.42 ^x	1.02 ^y	1.37 ^y	0.84	2.68 [*]

^aControl = milk replacer; BP = milk replacer + 250 g/d of dried beet pulp; WS = milk replacer + 250 g/d of wheat straw.

^bNumber of days on which milk replacer was refused.

^cNumber of days of treatment.

^{x,y}Means in a row with different superscript letters are significantly different ($P < 0.05$).

^{*} $P < 0.05$.

^{**} $P < 0.01$.

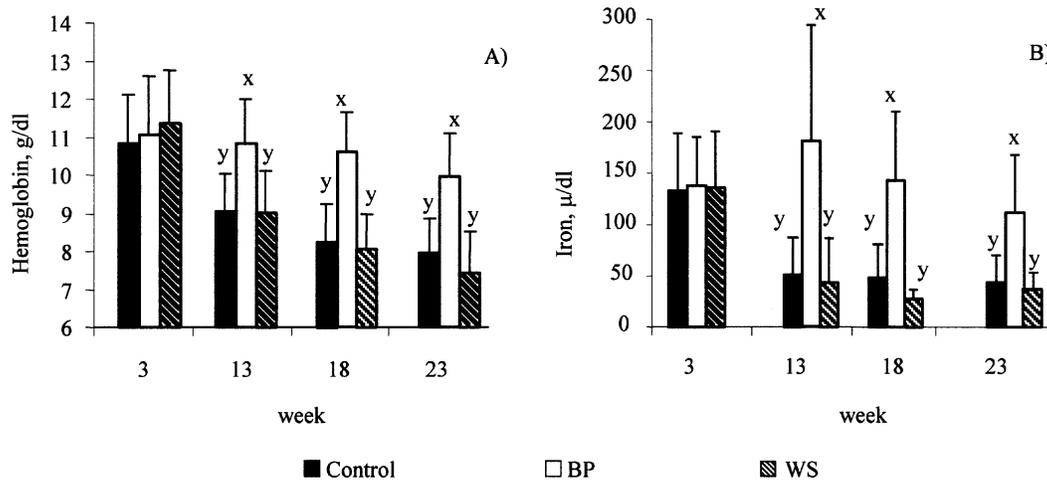


Figure 1. Hemoglobin (A) and plasma iron (B) concentration (least squares means + SD) in veal calves fed only milk replacer (Control), milk replacer + 250 g/d of dried beet pulp (BP), or milk replacer + 250 g/d of wheat straw (WS), at the 3rd, 13th, 18th, and 23rd wk of the fattening period. Different letters (x, y) indicate significant differences ($P < 0.05$) at a given sampling time.

sion of dried beet pulp improved carcass conformation but it had a detrimental effect on carcass color score, which was graded darker than that of Control calves and calves fed wheat straw.

Feeding the solid feeds significantly increased the weight of the empty forestomachs but it did not affect the weight of the abomasum, which was similar among treatments (Table 7). The reticulorumen was particularly developed by the consumption of beet pulp, and the heaviest omasums were measured in calves fed wheat straw. In comparison to the Control diet, both diets containing solid feeds significantly reduced the number of calves with hairballs in their rumens. The ruminal content was always liquid in calves fed only the milk replacer diet, whereas the provision of the

solid feeds increased its consistency, which was more pasty and frothy.

The visual evaluation of ruminal mucosa pigmentation yielded similar scores for Control calves and calves fed wheat straw, ranging between yellow and light brown (Table 7). The beet pulp diet led to a darker pigmentation close, on average, to medium brown.

The histological examination of the ruminal mucosa showed a similar length of the papillae for all the dietary treatments (Table 7). Compared with the Control diet, the thickness of the mucosal epithelium was reduced only by the wheat straw diet. No case of severe hyperkeratosis was observed, although the keratinized epithelium was significantly thicker in Control calves.

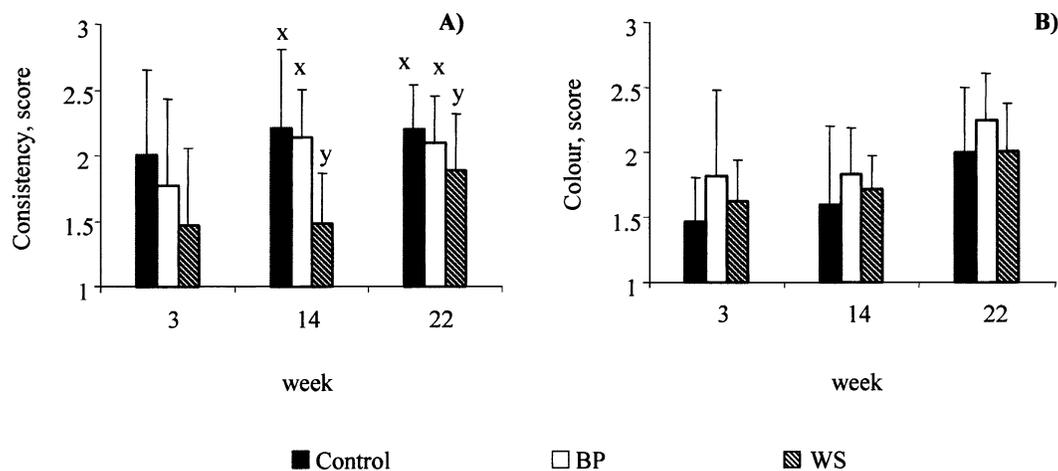


Figure 2. Evaluation (mean + SD) of (A) feces consistency (1 = firm/dry, 2 = creamy, 3 = loose/wet) and (B) feces color (1 = white-yellow, 2 = light brown, 3 = dark brown-gray) in veal calves fed only milk replacer (Control), milk replacer + 250 g/d of dried beet pulp (BP), or milk replacer + 250 g/d of wheat straw (WS) at the 3rd, 14th, and 22nd wk of the fattening period. Different letters (x, y) indicate significant differences ($P < 0.05$) at a given evaluation time.

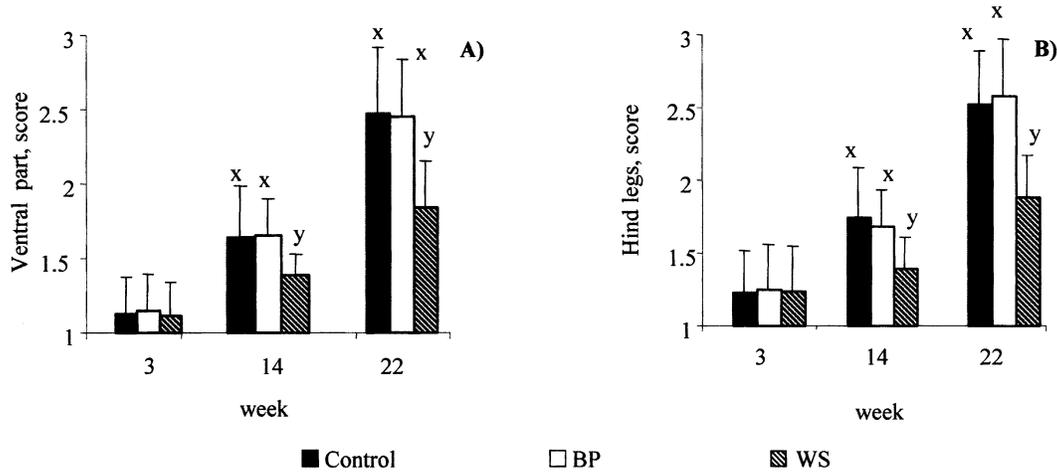


Figure 3. Cleanliness evaluation (means + SD) of (A) ventral part and (B) hind legs of veal calves fed only milk replacer (Control), milk replacer + 250 g/d of dried beet pulp (BP), or milk replacer + 250 g/d of wheat straw (WS) at the 3rd, 14th, and 22nd wk of the fattening period. Evaluation scale: 1 = clean, 2 = dirty, 3 = very dirty. Different letters (x, y) indicate significant differences ($P < 0.05$) at a given evaluation time.

The chemical composition analysis of meat samples did not show significant differences among diets regardless of the hematin content, which was significantly increased in calves fed beet pulp (Table 8). Consistent with this result and with the visual evaluation of carcass color, the instrumental measurement of meat color showed lowest lightness and highest redness values for calves fed beet pulp.

Other meat quality traits such as shear force and weight cooking losses were not affected by the provision of the solid feeds. Moreover, no differences among diets were recorded in the sensory evaluation of veal meat tenderness, juiciness, and flavor carried out by a taste panel (Table 8).

Discussion

One of the main concerns about the use of solid feeds in veal calf feeding is the potential decrease of the intake of milk replacer and the consequent negative effect on growth performance. In the present study, the intake of milk replacer was not affected by the provision of solid feeds (Table 4) and the occurrence of feed refusals was similar among diets (Table 5). Moreover, none of the calves used in the study had bloating problems, and a lower percentage of medical treatment days was recorded for calves receiving the solid feeds.

Table 6. Slaughter performance and carcass evaluation of veal calves receiving different diets

Item	Diet ^a			SEM	F/Z^b
	Control	BP	WS		
Carcass weight, kg	136.7 ^y	147.2 ^x	138.5 ^y	15.0	5.8**
Dressing percentage, % BW	59.6	60.1	59.4	1.8	1.5
Carcass evaluation					
EUROP score ^c	7.09 ^y ± 1.81	7.98 ^x ± 1.83	7.19 ^y ± 1.17		7.11**
Fatness score ^d	6.80 ± 1.11	7.33 ± 1.00	7.24 ± 1.16		2.28
Color score ^e	1.98 ^y ± 0.61	2.56 ^x ± 0.70	1.99 ^y ± 0.77		20.09***

^aControl = milk replacer; BP = milk replacer + 250 g/d of dried beet pulp; WS = milk replacer + 250 g/d of wheat straw.

^bQuantitative data were analyzed by ANOVA when Gaussian distribution and homogeneous variances were found. Scores were compared by Kruskal-Wallis and Mann-Whitney test.

^c1 = Poor- to 15 = Excellent+.

^d1 = Minimum to 15 = maximum.

^e1 = white to 4 = dark pink.

^{x,y,z}Least squares means or means in a row with different superscript letters are significantly different ($P < 0.05$).

** $P < 0.01$.

*** $P < 0.001$.

Table 7. Empty forestomach and abomasum weights and rumen measurements of veal calves receiving different diets

Item	Diet ^a			SEM	F/ χ^2 /Z ^b
	Control	BP	WS		
Empty reticulorumen weight, g	1,669 ^z	2,372 ^x	2,062 ^y	304	54.1***
Empty omasum weight, g	403 ^z	467 ^y	596 ^x	96	41.8***
Empty abomasum weight, g	939	989	917	154	2.4
Rumen measurements					
Calves with hairballs, no.	36 ^x	5 ^y	8 ^y		55.5***
Consistency of ruminal content score ^{cd}	1.00 ^y ± 0.01	1.72 ^x ± 0.55	1.94 ^x ± 0.51		25.07***
Pigmentation of ruminal mucosa score ^{ce}	1.68 ^y ± 0.61	2.65 ^x ± 0.55	1.86 ^y ± 0.38		20.01***
Length of papillae, mm ^c	0.79	0.90	0.86	0.07	1.03
Thickness of mucosal epithelium μm^c	74.4 ^x	73.0 ^x	61.7 ^y	3.4	2.1*
Thickness of keratinized epithelium, μm^c	19.5 ^x	12.9 ^y	13.8 ^y	1.0	5.1***

^aControl = milk replacer; BP = milk replacer + 250 g/d of dried beet pulp; WS = milk replacer + 250 g/d of wheat straw.

^bQuantitative data were analyzed by ANOVA when Gaussian distribution and homogeneous variances were found. Proportions were compared with χ^2 calculations. Scores were compared by Kruskal-Wallis and Mann-Whitney test.

^cNumber of animals: 54 (first batch).

^d1 = liquid, 2 = pasty and frothy, 3 = thick and firm.

^e1 = white-yellow, 2 = light brown, 3 = dark brown-gray.

^{x,y,z}Least squares means or means in a row with different superscript letters are significantly different ($P < 0.05$).

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

According to Morisse et al. (1999), the additional iron intake from solid feeds should result in an increased hemoglobin concentration. In the present study, only the beet pulp diet resulted in a higher hemoglobin concentration than the Control diet (Figure 1). Calves fed dried beet pulp received 8.18 g of iron from the solid feed in addition to the amount given

by the milk replacer (Table 4) and they did not require any iron treatment during the entire fattening period (Table 5). The animals fed wheat straw had 2.57 g of iron provided by the solid feed but their hemoglobin and blood iron concentrations were similar to those of Control calves (Figure 1). Therefore, calves did not use the iron provided by wheat straw, and this limited

Table 8. Meat quality traits of veal calves receiving different diets

Item	Diet ^a			SEM	F/Z ^b
	Control	BP	WS		
Chemical composition					
DM, %	24.4	24.9	24.6	1.1	2.0
Ether extract, % DM	5.3	5.6	5.3	1.9	0.4
Ash, % DM	4.7	4.6	4.6	0.6	0.2
pH	5.61	5.60	5.58	0.15	0.43
Hematin, $\mu\text{g/g DM}$	23.3 ^y	28.5 ^x	21.4 ^y	5.2	20.4***
Meat color					
Lightness (L)	53.2 ^x	50.7 ^y	54.0 ^x	3.5	10.2***
Redness (a)	12.6 ^y	14.8 ^x	12.3 ^y	2.2	16.6***
Yellowness (b)	8.5 ^y	9.4 ^x	8.8 ^{xy}	1.5	3.4*
Shear force, kg/cm^2	2.44	2.64	2.51	0.78	0.69
Cooking weight losses, %	28.6	28.4	29.1	4.1	0.3
Sensorial evaluation					
Tenderness score ^c	3.35 ± 0.46	3.46 ± 0.35	3.30 ± 0.39		1.67
Flavor score ^c	2.99 ± 0.34	2.98 ± 0.33	2.97 ± 0.28		1.01
Juiciness score ^c	3.07 ± 0.41	3.15 ± 0.35	3.04 ± 0.43		3.29

^aControl = milk replacer; BP = milk replacer + 250 g/d of dried beet pulp; WS = milk replacer + 250 g/d of wheat straw.

^bQuantitative data were analyzed by ANOVA when Gaussian distribution and homogeneous variances were found. Scores were compared by Kruskal-Wallis and Mann-Whitney test.

^c1 = Extremely undesirable to 5 = extremely desirable.

^{x,y,z}Least squares means or means in a row with different superscript letters are significantly different ($P < 0.05$).

* $P < 0.05$.

*** $P < 0.001$.

bioavailability may arise mainly from the binding of the mineral to lowly digestible compounds of the roughage such as the NDF fraction. Studies carried out in human nutrition (Reinhold, 1982; Leigh et al., 1983); have shown that the mobilization of ferric iron from vegetable sources may be impeded by NDF and the ability of cell walls to bind the mineral can reduce its absorption.

Calves' ADG was significantly improved by the provision of the beet pulp diet (Table 4). This better growth performance seems to be related primarily to the higher net energy for growth given by this type of roughage and not to the higher hemoglobin levels promoted by its iron content. Wilson et al. (1995) found no relationship between hemoglobin levels and veal calves' growth performance traits. Previously, Webster et al. (1975), measuring the energy balance of Friesian veal calves, found increased losses of metabolizable energy only when the dietary iron concentration was below 15 ppm, and they reported a reduction of appetite as the principal effect of iron deficiency anemia. In the present study, the average dietary iron concentration was above the 15 ppm threshold (21, 43, and 27 ppm for Control, beet pulp, and wheat straw diets, respectively). Also in this study, no calf was anemic, which could explain the very low number of feed refusal days recorded for all the treatments (Table 5).

The provision of wheat straw, a solid feed rich in NDF (Table 3), decreased feed efficiency but it resulted in improved calf cleanliness (Figure 3), likely because of the production of more dry and firm feces (Figure 2) that adhered less to the slatted floor and to the calves' bodies while laying.

At the slaughterhouse, carcass weights and EUROP scores were higher for calves fed the beet pulp diet (Table 6), confirming the increased energy available for muscular growth. However, the administration of the beet pulp diet had a detrimental effect on carcass and meat color (Tables 6 and 8), which were darker than those of Control calves and calves fed wheat straw because of the increased hematin concentration at the muscle level promoted by the higher intake of bioavailable iron. According to Bremner et al. (1976), calf hematin concentration increases significantly with the production of undesirable, darkly colored meat when dietary iron content is above 40 ppm. In our study this value was exceeded only by feeding the beet pulp diet.

A clear progression in forestomach development was observed by providing the calves with solid feeds (Table 7). However, the development of the different compartments was affected by the type of roughage. The reticulorumen was heaviest in calves fed beet pulp, whereas wheat straw particularly promoted omasum growth. Consistent with the present results, the reticulorumen weight of weaned calves slaughtered at 20 wk of age was shown to be heavier when a concentrate diet rather than a more fibrous one was fed (Nocek et al., 1984). An adequate rumen development requires

the supply of fiber, to support the increase in capacity, and of readily fermentable carbohydrates, whose end products of fermentation promote papillary growth (Morrill, 1992).

The increased fermentation activity in the rumen of the calves fed beet pulp was confirmed also by the darkest pigmentation of the mucosa which, according to Morisse et al. (1992), is induced by VFA production resulting from the fermentation of digestible carbohydrates.

The administration of both solid feeds increased the consistency of the ruminal content and led to a marked reduction of the number of calves showing hairballs (Table 7). The influence of feeding fibrous feeds on the reduction of hairballs has been reported in recent French studies (Morisse et al., 1999, 2000), and it was related to a continuous elimination of ingested hair induced by ruminal motility. Moreover, roughage is thought to remove food particles and hairs that tend to accumulate among the matted papillae of the hyperkeratotic mucosa and to penetrate the lamina propria. These foreign bodies may be a vehicle for bacteria that induce an inflammatory process characterized by leukocytic infiltration and often microabscesses (Jones et al., 1997). This situation may be further exacerbated by metastatic lesions that can develop in the liver through the portal route, possibly leading to a severe pathological state. In Control calves, the lack of any abrasive effect of roughage, which can prevent the excessive accumulation of keratin on the ruminal surface (Barker et al., 1993; Jones et al., 1997), could explain the thicker layer of keratinized epithelium (Table 7).

In the meat quality evaluation carried out on the longissimus muscle, the administration of solid feeds was shown to affect only the color measurements and the hematin content, which varied according to the bioavailable iron provided by the roughage (Table 8). Color is the crucial trait for marketability of veal meat; in the present study, the Controls and calves fed wheat straw were considered satisfactory from this point of view, whereas feeding beet pulp led to a severe depreciation of the meat's selling price. Based on the results obtained from the meat quality evaluation (Table 8), consumers may detect a difference only in color but not in the remaining quality traits when comparing veal meat produced by calves fed only a milk replacer diet with that produced by calves fed solid feeds.

Implications

The administration of solid feeds to veal calves for welfare purposes had no detrimental effects on growth performance and promoted forestomach development. Both beet pulp and wheat straw improved calves' health status, and fewer iron treatments for anemia and medical treatments for respiratory or gastrointestinal diseases were needed. Farmers refrain from feeding solid feeds to veal calves mainly because they can lead to the production of darker meat. The present

study showed that there is not a straight-forward relationship between roughage iron content and meat color. The final "redness" of veal meat does not depend on the amount of iron provided by a roughage source. In a solid feed rich in NDF such as wheat straw, the iron, likely entrapped by the cell wall constituents, was not available for metabolism. Therefore veal calves receiving wheat straw produce carcasses and meat with a color similar to that of calves fed only milk replacer.

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