

## Article

# Feeding Bakery Former Foodstuffs and Wheat Distiller's as Partial Replacement for Corn and Soybean Enhances the Environmental Sustainability and Circularity of Beef Cattle Farming

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**Abstract:** The effects of the partial substitution of corn and soybean meals with bakery former foodstuffs (BFF) and wheat wet distiller's grains (WDGs) on environmental sustainability, production performance, and health status were evaluated in beef cattle. Newly arrived Limousine beef heifers ( $n = 408$ ) housed an intensive farm in Campagnatico (Grosseto, Italy) were balanced for initial weight and body conformation and then randomly divided in two groups: (i) Traditional corn–soybean meal diet; (ii) Circular diet with average as-fed 1.5 kg BFF and 1.5 kg WDGs as substitute for 1.6 kg corn and 0.3 kg soybean meal. The environmental impact of the diet was analyzed considering greenhouse gases emissions (GHG, kg CO<sub>2</sub> eq), water (H<sub>2</sub>O, L), and land use (LU, m<sup>2</sup>) as well as consumption of human-edible feeds (HE, kg). The growth performance, feed intake (FI), feed conversion ratio (FCR), carcass characteristics, apparent total tract digestibility (aTTD), and health status of heifers were evaluated. The Circular diet led to a reduction per kg of cold carcass weight (CCW) of 1.00 kg CO<sub>2</sub> eq of GHG, 72.38 L of H<sub>2</sub>O, 1.20 m<sup>2</sup> of LU, and 0.95 kg of HE ( $p < 0.0001$ ). Growth performances, carcass characteristics, and health status were not affected ( $p > 0.05$ ). Sugar and pectin aTTD were significantly higher ( $p < 0.0001$ ) in the Circular group. Replacing traditional feed ingredients with BFF and WDGs reduced the environmental impact of the diet of fattening Limousine heifers and the food competition between humans and beef cattle in accordance with circular economy principles.

**Keywords:** beef cattle; environmental sustainability; circular economy; bakery former foodstuffs; wheat wet distiller's grains; resource efficiency; food competition

## 1. Introduction

The global population is expected to rise by two billion people in the next three decades with a parallel increase in the demand of animal-derived products, resulting in higher pressure on the food market to meet consumer needs [1–4].

Moreover, losses along the food chain remain another global dilemma with negative environmental, social, and economic consequences [5]. Globally, one-third of all edible food is lost across the supply chain as food losses or food waste, depending on the type of refusal and the point of production [6]. Minimizing these losses is an important avenue to improving global food security and management of land, water, and energy resources in food production systems, as stated in the United Nations (UN) 2030 goals, which include to “halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” [7]. In the past

60 years, this growth in demand for animal-derived foods has been met primarily by a steady rise in the number of animals reared and by improvement of genetics, performance as well as by an increase in the nutritional values of the feeds, often relying on higher levels of human-edible cereals and protein sources [8]. Those solutions are no longer feasible. In fact, zootechnical systems are facing many sustainability challenges, such as the emissions of human-induced greenhouse gases, deforestation, water and land uses, and pollution as well as human-edible resource consumption [9,10].

Of all the food-producing animals cattle are among the most criticized, especially due to their high contribution to total livestock farming greenhouse gases emissions (35% and 32% of the total for beef and dairy, respectively) and water footprint (33% and 19% of the total for beef and dairy, respectively) [11,12]. Although the majority of cattle environmental impacts are attributable to ruminal methane, feed production constitutes the second highest source of emissions, accounting for approximately 45% of the greenhouse gases emitted, and is especially impactful with respect to upstream resources such as feed production [13–15]. Among the feed types included in the diets of intensively reared cattle the production of soybean meal has the highest environmental impact due to the emissions related to both land use changes such as deforestation in South America and large transport distances [16,17]. Moreover, corn production accounts for 83–85% of greenhouse gases emissions for feed used in the finishing period of the fattening cycle [18].

In addition, about 70% of the global agricultural land and 30–40% of human-edible feed crops, mainly cereals such as corn, are currently used for cattle production [19,20]. Indeed, intensive beef cattle farming is often condemned for the high consumption of human-edible resources such as cereals and soybean to maintain high production efficiency. Compared with other livestock species, beef cattle need a higher quantity of human-competitive feed for the same food production per kg of protein [8,21]. Reducing dependency on corn and soybean meals can be an important means of improving the sustainability of the beef sector [22,23].

The use of alternative resources such as plant byproducts, coproducts, and foods leftovers that are food losses no longer suitable for human consumption instead of cereal grains and soybean in ruminants' diets can be an innovative way to valorize food losses, reduce food–feed competition, and mitigate the environmental impact of livestock [24–26]. Indeed, while food waste is not allowed under EU law as feed materials, food losses are allowed, and cattle can efficiently convert them into high-quality animal-derived foods [27].

Food leftovers such as bread, pasta, cereals, snacks, biscuits, and chocolate bars are known as bakery former foodstuffs (BFF). They are already used in livestock productions, mainly in monogastric animals (specifically, during the first life stages of pigs) thanks to their high energy content from fat and sugars and the high digestibility of cooked starch [22,28]. From a ruminant nutrition perspective, this might increase starch degradation in a way that could negatively affect feed intake as well as rumen health [29]. Furthermore, these feeds contain less fiber than native cereal grains [30]. Conversely, production performance, digestibility, and rumen health were enhanced in scientific studies carried out on dairy cows and sheep fed with BFF [26,31,32].

The use of soybean meal as the main protein source can be reduced through the use of different alternatives such as wet distiller's grains (WDGs). Specifically, WDGs are a co-product of fermenting and distilling cereal grains to produce alcohol, and have a lower concentration of fermentable carbohydrates and higher concentrations of protein, oil, fiber, and ash than the original grains [33]. Wheat WDGs have been studied extensively in dairy and beef cattle diets, highlighting either no negative effect or an increase in production performance [34–37].

Both food leftovers such as BFF and co-products such as WDGs can be used as a substitute for the traditional corn and soybean meals as well as for other starch and protein sources, making the approach interesting worldwide for achieving better sustainability in zootechnical production and reducing the need for specifically dedicated agricultural land.

The aim of the present study was to evaluate the combined effect of partial substitution of corn and soybean meals with bakery former foodstuffs and wheat wet distiller's grains on environmental sustainability indicators, filling a gap present in the literature concerning the combined effect of these feed types on production performance, *in vivo* apparent total tract digestibility, and health status in beef cattle.

## 2. Materials and Methods

### 2.1. Animals, Groups, and Animal Care

The study was performed in an intensive beef fattening farm (coordinates 42.9197252, 11.2132199) located in Campagnatico, (Grosseto, Italy). The farm is located in the region of Tuscany, 40 km from the Tyrrhenian Sea, guaranteeing the typical temperate climate of central Italy. Alfalfa hay, rye grass hay, corn and wheat grain, and wheat straw are produced here.

A total of 408 Limousine heifers (average weight:  $338 \pm 24$  kg), imported from France, were enrolled. Three days after their arrival ( $d_0$ ), all the animals were individually weighed and evaluated for the body conformation as assessed on a 5-points scale [38]. Animals were balanced for conformation and body weight and randomly allotted into two study groups, Traditional (average weight:  $340 \pm 24$ ) or Circular (average weight:  $335 \pm 24$ ), with 204 heifers each.

The heifers were housed in twelve pens (six pens per group) with 34 animals each on concrete floor covered with straw, with a space allowance of  $4.5 \text{ m}^2/\text{head}$  in the rest zone and  $0.65 \text{ m}/\text{head}$  at the feed bunk.

The study covered the entire fattening period of 145 days.

### 2.2. Feeding Management: Experimental Diets

The two experimental groups received two isoenergetic and isoproteic diets (Table 1). The Traditional diet was based on corn and soybean meals as the main energy and protein sources and did not include BFF and WDGs. In the Circular diet, on average as fed, 1.6 kg of corn and 0.3 kg of soybean meals, respectively, was replaced with 1.5 kg (1.4 kg dry matter (DM)) of biscuit BFF (PRIMO—Dalma, Dalma Mangimi—Savigliano, CN—Italy) and 1.5 kg (0.5 kg DM) of wheat WDG (Distillers Dalma, Dalma Mangimi—Savigliano, CN—Italy), considering an average theoretical daily feed intake of 8.2 kg of DM. The diets were administered *ad libitum* in the form of total mixed ration (TMR) and delivered once a day in the morning by a feed mixer wagon equipped with an electronic scale to weigh the inclusion of each ingredient and the TMR unloaded in each pen. The TMR was formulated to meet the growth needs of the animals, as required by the National Research Council [39]. Water was available *ad libitum*.

**Table 1.** Composition (kg as fed) and nutritional characteristics (% DM) of the two experimental diets.

Feed	Traditional	Circular
Corn meal	4.5	2.9
Wheat bran	2.0	2.0
Hay, ryegrass	1.6	1.6
Soybean meal	0.9	0.6
Mineral and vitamin mix	0.13	0.13
Urea	0.02	0.02
BFF <sup>1</sup>	-	1.5
Wheat WDGs <sup>2</sup>	-	1.5
	Total kg	
As fed	9.15	10.25
DM <sup>3</sup>	8.24	8.22

Table 1. Cont.

Feed	Traditional	Circular
Nutritional characteristics		
Energy, Mcal/kg	1.85	1.86
Crude protein	15.33	15.30
RDP <sup>4</sup>	10.78	11.65
SCP <sup>5</sup>	4.31	5.94
SCP/RDP	0.40	0.51
Sugars	3.53	8.01
Starch	41.4	37.00
NDF	28.5	26.22
Crude fats	3.03	4.05
Ca tot	0.62	0.62
P tot	0.55	0.55

<sup>1</sup> BFF = bakery former foodstuff; <sup>2</sup> Wheat WDGs = wet distiller's grains from wheat; <sup>3</sup> DM = dry matter; <sup>4</sup> RDP = Rumen degradable protein; <sup>5</sup> SCP = Soluble crude protein.

### 2.3. Experimental Parameters

#### 2.3.1. Nutritional Evaluation of BFF and WDGs

Samples of the BFF and WDGs were analyzed for nutritional value. Samples were first analyzed for dry matter (method 934.01; AOAC [40]). Samples were further analyzed for crude protein (method 990.03; AOAC [40]), crude fats (method 920.39; AOAC I [40]), ash (method 942.05; AOAC [40]), starch (method 996.11; AOAC [40]), sugars (methods proposed by Vennard et al. [41]), neutral detergent fiber (Van Soest et al. [42]), acid detergent fiber (method 973.18; AOAC [40]), and acid detergent lignin (method 973.18; AOAC [40]).

#### 2.3.2. Environmental Impact

Considering that the two diets differed only in the partial substitution of corn and soybean meals with BFF and WDGs, only the impacts of this substitution were evaluated. The indicators evaluated were the emission of greenhouse gases (GHG, kg CO<sub>2</sub> eq), water requirements (H<sub>2</sub>O, L), consumption of human-edible raw materials (i.e., corn and soybean meals) (HE, kg), and land use (LU, m<sup>2</sup>). The coefficients used for the calculation of the various environmental impact indicators were obtained from an LCA (Life Cycle Assessment) study carried out by Life Cycle Engineering S.p.a. (Via Livorno 60—Environment Park—Turin, Italy) following “from cradle to farm gate” LCA procedure that included only the production and transport phases, not their potential effect on ruminal methane production. The coefficients were as follows: for GHG (kg CO<sub>2</sub> eq/kg as fed), corn meal 0.7, soybean meal 3.9, BFF 0.1, and WDGs 0.1, and for H<sub>2</sub>O (L/kg as fed), corn meal 79.3, soybean meal 64.4, BFF 1.4, and WDGs 0.1. The LU was assessed considering a production of 9980 kg as-fed corn meal and 3810 kg as-fed soybean meal per 10,000 m<sup>2</sup> of arable land.

The land use for the production of BFF and WDGs was entirely covered by the main products for human consumption, and no human-edible feeds were used in the partial substitution of corn meal and soybean meal with BFF and WDGs. Consequently, the land use and the consumption of human-edible feed were, in the present conditions, null in the Circular group.

Daily, the effective intake of the feeds involved in the substitution was calculated considering the TMR intake and their proportional content. The daily environmental impacts of each group were then evaluated by multiplying those amounts by their related coefficients. Each daily impact was then summed together to obtain the effect of the substitution for the entire fattening period. Those total values were referred to 1 kg of cold carcass weight (CCW), dividing the total impacts of each pen to obtain the pen average CCW.

### 2.3.3. Growth and Slaughtering Performance and Health Status

Individual body weights were recorded through a digital scale before morning feeding at three time periods: on enrolment day ( $d_0$ ), at day 92 ( $d_{92}$ ), and on the day before slaughter ( $d_{145}$ ). The individual average daily gain (ADG) was then calculated from  $d_0$  to  $d_{92}$ , from  $d_{92}$  to  $d_{145}$ , and for the entire period from  $d_0$  to  $d_{145}$  using the following formula:

$$ADG = \frac{\text{Weight}_f - \text{Weight}_i}{\text{days } i - f} \quad (1)$$

where

ADG = average daily gain (kg/head/day);

Weight<sub>f</sub> = final weight of each period;

Weight<sub>i</sub> = initial weight of each period;

days  $i - f$  = days between the start and the end of each period.

Weekly, the daily dry matter feed intake (FI, kg/head/d DM) was evaluated by weighing the TMR administered and the residue in the feed bunk 24 h later, then correcting it for the dry matter contents of the two diets. Pen feed conversion rate (FCR) was calculated by comparing the dry matter feed intake with the average weight gain per pen and period.

At the slaughterhouse, animals were stunned by a captive bolt pistol and exsanguinated by a single cut to the jugular vein and carotid artery. Data related to cold carcass weight, carcass yield, conformation, and fattening status (SEUROP) were collected on all carcasses. The carcass evaluation was assessed by an expert judge according to EU legislation [43] by using the SEUROP classification method, including the rating scale for conformation, ranging from S to P (S—superior: all profiles extremely convex, exceptional muscle development, double-muscling conformation; E—excellent: all profiles convex to super-convex, exceptional muscle development; U—very good: profiles on the whole convex, very good muscle development; R—good: profiles on the whole straight, good muscle development; O—pretty good: profiles straight to concave, medium muscle development; P—poor: all profiles concave to very concave, poor muscle development) and the rating scale for fatness, ranging from 1 to 5 (1—low: none up to low fat cover; 2—slight: slight fat cover, flesh visible almost everywhere; 3—medium important: flesh, with the exception of the round and shoulder, almost everywhere covered by fat, slight fat deposits in the thoracic cavity; 4—high: flesh covered by fat, round and shoulder still partly visible, medium fat deposits in the thoracic cavity; 5—very high: carcass well covered by fat, heavy fat deposits in the thoracic cavity). The cold carcass weights were obtained after 48 h of chilling at a temperature of 0 to 4 °C.

The pH and colorimetric characteristics of the half carcasses at 24 h post mortem were evaluated in twenty animals per group in order to obtain a representative data on the batch. Measurements of pH were made using a portable pH meter (HI 98150, HANNA Instruments Inc., Woonsocket, RI, USA) equipped with a glass electrode (3 mm Ø conic tip) suitable for meat penetration. The values for each sample came from the average of three measurements. Color determination was performed using a CR310 Chromameter set on D65 illuminance, view angle 10° and calibrated on a CIE Lab colour space system using a white calibration plate (Calibration Plate CR-A43, Minolta Cameras); lightness ( $L^*$ ), redness ( $a^*$ ), and yellowness ( $b^*$ ) were calculated according to the CIE Lab system.

From arrival to day 145, general health evaluations were conducted twice a day, with direct examination of all animals by the farm veterinary and qualified animal health care staff. Any cases of disease, with a specific attention on ruminal acidosis, were recorded.

### 2.3.4. Characteristics of Diets, Feces, and Apparent Total Tract Digestibility

The characteristics of TMR and feces were monitored monthly through the use of a portable NIR instrument (Polispec, ITP Photonics, Via Astico, 39, Fara Vicentino—VI—Italy). The characteristics of the TMR were analyzed on the fresh feed, considering the entire feed bunk. Specifically, three measurements were made each time with the portable instrument

along the entire length of the feed bunk of each pen (beginning, middle, and end of the manger). The average of those three measurements represented the pen's chemical characteristics of the TMR.

The characteristics of the feces were analyzed for each group on a pool of fecal material collected the day after each TMR analysis. The pool of fecal material was collected directly by rectal grab on 20 heifers for each pen per group. Samples of feces of the same pen were then pooled together and mixed to create a pen's single sample. The pooled sample was analyzed with the portable NIR instrument. Specifically, three measurements were made in the same sample and the average values were used.

The portable NIR instrument directly analyzed TMR and feces for dry matter, crude protein, crude fats, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), starch, and ash.

Then, the content of hemicelluloses was obtained from the difference between NDF and ADF. The content of cellulose was obtained from the difference between ADF and ADL. Sugars and pectin were obtained by calculation:  $100 - (\text{ash} + \text{fats} + \text{proteins} + \text{NDF} + \text{starch})$ .

The ADL values were used as indigestible internal markers to evaluate feed digestibility [44].

The apparent total tract digestibility (aTTD) was evaluated through the following formula:

$$\text{aTTD \%} = \frac{\left(\frac{X_d}{\text{ADL}_d}\right) - \left(\frac{X_f}{\text{ADL}_f}\right)}{\left(\frac{X_d}{\text{ADL}_d}\right)} \times 100 \quad (2)$$

where

X = each analytical parameter considered (%);

ADL = acid detergent lignin (%);

d = diet;

f = feces.

#### 2.4. Statistical Analysis

Environmental parameters, expressed as daily averages in relation to daily feed intake, growth performance, and aTTD were analyzed, using the pen as experimental unit, through a mixed model (PROC MIXED) with a class statement which took into account the fixed effect of the treatment, the time of detection, and the random effect of the pen. Post hoc pairwise comparisons were performed for repeated measures using the Tukey–Kramer Test.

The environmental parameters were also referred to the CCW and statistically analyzed, using the pen as experimental unit, through a mixed model (PROC MIXED) with a class statement which took into account the fixed effect of the treatment and the random effect of the pen.

The single subject was instead used as experimental unit to evaluate carcass characteristics, using a mixed model (PROC MIXED) with a class statement which took into account the fixed effect of the treatment and random effect of the subject.

For non-continuous variables such as SEUROP classification, fattening, and health status, the difference in frequency distribution within classes was assessed by applying a chi-squared test (PROC FREQ). A difference was considered significant for  $p \leq 0.05$ . Data analysis was conducted using SAS statistical software (SAS 9.4, SAS, Cary, NC, USA).

### 3. Results and Discussion

#### 3.1. Nutritional Evaluation of BFF and WDGs

Data related to the nutritional evaluation of the BFF and WDGs are reported in Table 2.

**Table 2.** Nutritional evaluation of bakery former foodstuffs (BFF) and wheat wet distiller's grains (WDGs).

Feed	BFF <sup>1</sup>	Wheat WDGs <sup>2</sup>
Nutritional Characteristics		
Humidity, %	10.28	63.16
DM <sup>3</sup> , %	89.72	36.84
Crude protein, % DM	12.17	23.43
Crude fats, % DM	10.18	2.98
Ash, % DM	2.27	9.60
Starch, % DM	49.84	18.90
Sugars, % DM	21.28	27.84
NDF <sup>4</sup> , % DM	0.69	12.10
ADF <sup>5</sup> , % DM	0.21	2.10
ADL <sup>6</sup> , % DM	0.09	0.81

<sup>1</sup> BFF = bakery former foodstuffs; <sup>2</sup> Wheat WDGs = wet distiller's grains from wheat; <sup>3</sup> DM = dry matter; <sup>4</sup> NDF = neutral detergent fiber; <sup>5</sup> ADF = acid detergent fiber; <sup>6</sup> ADL = acid detergent fiber.

### 3.2. Environmental Impact

The effect of the partial substitution of traditional feeds (corn and soybean meals) with circular ones (BFF and WDGs) on environmental sustainability are reported in Tables 3 and 4.

**Table 3.** Average daily e greenhouse gas (GHG) emissions, water (H<sub>2</sub>O), and human-edible (HE) resource consumption and land use (LU) in Limousine heifers related to the partial substitution of traditional feeds (1.6 kg corn and 0.3 kg soybean meals) with circular ones (1.5 kg bakery former foodstuffs—BFF; and 1.5 kg wheat wet distiller's grains—WDGs).

	Groups		SEM	p-Value
	Circular	Traditional		
GHG <sup>1</sup> , CO <sub>2</sub> eq kg				
Average	0.30	2.27	0.01	<0.05
P(g) <sup>2</sup>		<0.05		
P(d)		<0.05		
P(g*d)		<0.05		
H <sub>2</sub> O <sup>3</sup> , L				
Average	2.23	144.85	0.32	<0.05
P(g)		<0.05		
P(d)		<0.05		
P(g*d)		<0.05		
HE <sup>4</sup> , kg				
Average	0.00	1.88	0.01	<0.05
P(g)		<0.05		
P(d)		<0.05		
P(g*d)		<0.05		
LU <sup>5</sup> , m <sup>2</sup>				
Average	0.00	2.37	0.01	<0.05
P(g)		<0.05		
P(d)		<0.05		
P(g*d)		<0.05		

Data are presented as least squared means ± standard error of the means (SEM). <sup>1</sup> GHG = greenhouse gas emissions deriving from the production of the feeds included in the substitution, expressed in CO<sub>2</sub> equivalents; <sup>2</sup> g = effect of the group, d = effect of the time (day), g\*d = effect of the relationship between group and time (group\*day); <sup>3</sup> H<sub>2</sub>O = litres of water consumed in the production the feeds included in the substitution; <sup>4</sup> HE = inclusion of human-edible feeds in the two groups, Intake = daily intake of dry matter kg/head/day, average per pen; <sup>5</sup> LU = land use square meters necessary for the production the feeds included in the substitution.

**Table 4.** Greenhouse gas (GHG) emissions, water (H<sub>2</sub>O), and human-edible (HE) resource consumption and land use (LU) per kg of cold carcass weight (CCW) in Limousine heifers related to the partial substitution of traditional feeds (1.6 kg corn and 0.3 kg soybean meals) with circular ones (1.5 kg bakery former foodstuffs—BFF; and 1.5 kg wheat wet distiller’s grains—WDGs).

Parameter	Groups		SEM	p-Value
	Circular	Traditional		
CCW <sup>1</sup> , kg	285	288	1.43	0.234
GHG <sup>2</sup> , kg CO <sub>2</sub> eq/kg CCW	0.15	1.15	0.01	<0.05
H <sub>2</sub> O <sup>3</sup> , L/kg CCW	1.14	73.52	0.23	<0.05
HE <sup>4</sup> , kg/kg CCW	0.00	0.95	0.01	<0.05
LU <sup>5</sup> , m <sup>2</sup> /kg CCW	0.00	1.20	0.01	<0.05

Data are presented as least squared means  $\pm$  standard error of the means (SEM). <sup>1</sup> CCW = cold carcass weight; <sup>2</sup> GHG = greenhouse gas emissions deriving from the production of the feeds included in the substitution, expressed in CO<sub>2</sub> equivalents; <sup>3</sup> H<sub>2</sub>O = litres of water consumed in the production the feeds included in the substitution; <sup>4</sup> HE = inclusion of human-edible feeds in the two groups, Intake = daily intake of dry matter kg/head/day, average per pen; <sup>5</sup> LU = land use square meters necessary for the production the feeds included in the substitution.

In terms of GHG emissions, the use of circular feeds led to an average daily reduction per head of 1.97 kg CO<sub>2</sub> eq (0.30 vs. 2.27 kg CO<sub>2</sub> eq in the Traditional group) ( $p < 0.0001$ ) (Table 3). Considering the entire fattening period of 145 days, the total reduction per head was equal to 287.87 kg CO<sub>2</sub> equivalent (43.40 vs. 331.26 kg CO<sub>2</sub> eq in the Traditional group). When expressed in terms of CCW, as shown in Table 4, the use of circular feeds led to an average reduction of 1 kg CO<sub>2</sub> eq per kg of CCW (0.15 vs. 1.15 kg CO<sub>2</sub> eq in the Traditional group) ( $p < 0.0001$ ).

In terms of H<sub>2</sub>O consumption, the use of circular feeds led to an average daily reduction per head of 142.62 L (2.23 vs. 144.84 L in the Traditional group) ( $p < 0.0001$ ) (Table 3). Considering the entire fattening period of 145 days, the total reduction per head was equal to 20822 L (325 vs. 21147 L in the Traditional group). When expressed in terms of CCW, as shown in Table 4, the use of circular feeds led to an average reduction of 72.38 L per kg of CCW (1.14 vs. 73.52 L in the Traditional group) ( $p < 0.0001$ ).

In addition, the LU and the consumption of HE resources were reduced by the inclusion of circular feeds in partial substitution of corn and soybean meals. On a daily basis, the reduction in LU was quantified in 2.37 m<sup>2</sup> per head (0.00 vs. 2.37 m<sup>2</sup> in the Traditional group) ( $p < 0.0001$ ) (Table 3). Considering the entire fattening period of 145 days, the total reduction per head was equal to 345.81 m<sup>2</sup> (0.00 vs. 345.81 m<sup>2</sup> in the Traditional group). When expressed in terms of CCW, the use of circular feeds, as shown in Table 4, led to an average reduction of 1.2 m<sup>2</sup> per kg of CCW (0.00 vs. 1.2 m<sup>2</sup> in the Traditional group) ( $p < 0.0001$ ).

Considering the consumption of HE resources, the use of circular feeds led to an average daily reduction per head of 1.88 kg (0.00 vs. 1.88 kg in the Traditional group) ( $p < 0.0001$ ) (Table 3). In the entire fattening period, the total reduction per head was equal to 274.83 kg (0.00 vs. 274.83 kg in the Traditional group). When expressed in terms of CCW, the reduction, as shown in Table 4, is equal to 0.95 kg per kg of CCW (0.00 vs. 0.96 kg in the Traditional group) ( $p < 0.0001$ ).

To our knowledge, there are few studies on the assessment of the sustainability indicators associated with the use of former foodstuffs such as BFF and other co-products such as wheat WDGs for livestock purposes, especially in beef cattle farming. However, BFF and co-products can be considered as the future of animal feeding in line with perspectives on world population growth and food supply requirements [45]. Vandermeersch et al. [46], for example, compared the environmental footprint of “bread food losses” used to produce former foodstuffs or conversely processed for biogas production, pointing out that the conversion into animal feed was the most sustainable option.

Several life cycle analysis (LCA) studies have considered food waste for livestock feeding, which differs from former foodstuffs due to the treatments needed prior to use as ani-

mal feed and the costs and risk for the environment related to these treatments [25,27,47,48]. Moreover, food wastes are not allowed as feed materials in the EU. Only Mackenzie et al. [49] have evaluated the potential effects of using BFF and dried distiller's grains (DDG) in pig diets on environmental sustainability, which they carried out through a "from cradle to farm-gate" LCA, finding a significant reduction in the environmental load using BFF and a reduction in the acidification potential with DDG. Furthermore, Leinonen et al. [50], in a comprehensive LCA study that evaluated the potential re-use of distillery co-products including WDGs, found that the substitution of soybean meal with these co-products led to a significant reduction in GHG emissions when considering the entire system from the production of the raw materials to their use as animal feeds, especially when including the effect of the reduced deforestation induced by lower use of soybean meal.

The results of the present study in terms of environmental indicators comes from the reduction in the use of soybean and corn meals, which, in addition to being in competition with human nutrition, are correlated with high environmental impact in terms of energy, water, and land use for their production.

Moreover, the reuse of WDGs, a coproduct of the production of ethanol which is thus reconverted into a nutrient-rich feed for food-producing animals rather than simply being eliminated, increases the value of ethanol production while reducing its entire GHG emissions by 50–70% [51,52].

It is important to underline that the present study did not consider the potential effect of both these feeds on ruminal fermentation dynamics. Indeed, the evaluation of ruminal methane production is excluded from this paper. However, dietary inclusion of distiller's grains has led to a reduction in methane emissions in different *in vivo* trials in growing [53] and finishing beef cattle [54] compared to barley-based control diets. Moreover, Humer et al. 2018 found that ruminal methane production was reduced *in vitro* using BFF as a replacement for corn meal [30].

### 3.3. Growth, Slaughtering Performance, and Health Status

The growth performance and incidence of acidosis were recorded during the trial and are summarized in Table 5. The heifers considered in this trial were distributed evenly over the two different treatments, and all of them showed a good health status. All the performance parameters as well as the overall health status were not affected by the dietary treatment ( $p > 0.05$ ), underlining that the partial substitution of corn and soybean meals with BFF and WDGs did not have detrimental effects on productivity or welfare. Moreover, there was no effect ( $p > 0.05$ ) of the BFF and WDGs inclusion on feed intake, indicating that the palatability of the diet was not influenced by the treatment.

These results partially agree with the findings of Guiroy et al. [54], which did not report any effect on average daily weight gain in beef cattle steers fed with BFF instead of corn meal. In addition, other studies carried out in sheep [32] and monogastric animals [54] did not reveal any significant effect of the inclusion of BFF food leftovers on the main growth indicators. However, other studies showed a significant improvement in the feed conversion rate, with a lower feed intake combined with the same average daily weight gain in steers fed with BFF [53]. Conversely, Kaltenecker et al. [26] reported higher feed intake and daily milk production in dairy cows fed with BFF in partial substitution of corn meal.

The results of the present trial agree with the findings of Schingoethe et al. [34] and Gaillard et al. [36], where the inclusion of either DDGs or WDGs in partial substitution of the soybean meal did not alter the production performance of dairy cows. Conversely, Ferreira et al. [37] found a significant improvement in terms of average daily gain in beef cattle feed with WDGs instead of soybean meal.

**Table 5.** Growth parameters and production performance of Limousine heifers associated with the partial substitution of traditional feeds (1.6 kg corn and 0.3 kg soybean meals) with circular ones (1.5 kg bakery former foodstuffs—BFF; and 1.5 kg wheat wet distiller’s grains—WDGs).

	Group		SEM	p-Value
	Circular	Traditional		
Weight, kg				
Body Weigh d <sub>0</sub>	335	340	2.12	0.166
Body Weight d <sub>92</sub>	427	429	2.12	0.571
Body Weight d <sub>145</sub>	481	482	2.12	0.851
P(g) <sup>1</sup>	0.408			
P(d)	<0.05			
P(g*d)	0.381			
ADG <sup>2</sup> , kg/head/d				
ADG <sub>0–145</sub>	1.022	0.995	0.02	0.254
ADG <sub>0–92</sub>	0.996	0.968	0.02	0.245
ADG <sub>92–145</sub>	1.048	1.02	0.02	0.272
P(g)	0.254			
P(d)	<0.05			
P(g*d)	0.825			
Feed intake kg DM <sup>3</sup> /d				
Intake <sub>0–145</sub>	8.22	8.23	0.02	0.730
Intake <sub>0–92</sub>	7.93	7.93	0.02	0.929
Intake <sub>92–145</sub>	8.51	8.53	0.02	0.626
P(g)	0.730			
P(d)	<0.05			
P(g*d)	0.725			
FCR <sup>4</sup>				
FCR <sub>0–145</sub>	8.04	8.27	0.13	0.257
FCR <sub>0–92</sub>	7.96	8.20	0.14	0.251
FCR <sub>92–145</sub>	8.13	8.35	0.14	0.277
P(g)	0.257			
P(d)	0.001			
P(g*d)	0.862			
Acidosis, % (n)				
Acidosis, % (n)	0.74 (3)	0.49 (2)	-	0.648

Data are presented as least squared means ± standard error of the means (SEM). <sup>1</sup> g = effect of the group, d = effect of the time (day), g\*d = combined effect of group and time (day); <sup>2</sup> ADG = average daily gain; <sup>3</sup> DM = dry matter; <sup>4</sup> FCR = feed conversion rate.

The results related to the carcass characteristics are summarized in Table 6. The carcass characteristics were not affected significantly by the dietary treatment. Our results agree with the findings of Guiroy et al. [54], which did not report any effect of the inclusion of food leftovers on steer carcass characteristics. On the other hand, Ferreira et al. [37] reported a higher cold carcass weight and ribeye area of *Longissimus* muscle in steers fed with WDGs instead of soybean meal. Neither Guiroy et al. [54] or Ferreira et al. [37] found any effect on carcass pH or meat color, in agreement with the present study.

**Table 6.** Carcass characteristics of Limousine heifers that differed due to the partial substitution of traditional feeds (1.6 kg corn and 0.3 kg soybean meals) with circular ones (1.5 kg bakery former foodstuffs—BFF; and 1.5 kg wheat wet distiller’s grains—WDGs).

	Groups		SEM	p-Value
	Circular	Traditional		
CCW <sup>1</sup> , kg	285.25	287.66	1.43	0.234
Yield, %	59.37	59.69	0.06	0.100
SEUROP Classification				
% carcass conformation U (3)	96.06	93.14	-	0.192
% carcass conformation E (2)	3.94	6.86	-	0.192
% carcass fatness score 2	88.18	83.33	-	0.162
% carcass fatness score 3	11.82	16.67	-	0.162
pH 24 h	5.71	5.72	0.01	0.423
Colour				
L <sup>2</sup>	41.59	41.97	0.35	0.443
a <sup>2</sup>	17.37	16.90	0.25	0.191
b <sup>2</sup>	12.99	12.40	0.22	0.063
h <sup>2</sup>	0.64	0.63	0.01	0.475
C <sup>2</sup>	21.71	20.98	0.29	0.077

Data are presented as least squared means  $\pm$  standard error of the means (SEM). <sup>1</sup> CCW = cold carcass weight, kg; <sup>2</sup> L = Luminosity; a = red index; b = yellow index; h = hue angle; C = Chroma.

### 3.4. Characteristics of the Diets, Feces, and Apparent Total Tract Digestibility

The average values of the chemical characteristics of the diets are shown in Supplementary Tables S1 and S2. The data highlight good correspondence between the projection of the rationing software and the analytical results. Supplementary Tables S3 and S4 summarize the chemical characteristics of the feces of both experimental groups.

Table 7 shows the aTTD values of the different nutrients in both experimental groups in the different months of the survey.

The aTTD results show that the partial substitution of corn and soybean meals with BFF and WDGs significantly enhanced sugar and pectin aTTD ( $p < 0.0001$ ), while the aTTD of the other nutrients remained equal ( $p > 0.05$ ).

These results partially agree with previous findings in studies that separately evaluated the effects of BFF and distiller’s grains, either WDGs and DDGs, on both in vitro and in vivo nutrient digestibility [30,55–58]. Vastolo et al. [59] reported that former foodstuffs have higher in vivo digestibility and degradability compared to conventional feed sources. In feedlot cattle diets, the inclusion up to 45% of the total dry matter of DDGs in partial substitution of corn and soybean meal did not affect total tract dry matter digestibility [57,58].

Regarding former foodstuffs, BFF showed higher (>80%) in vitro organic matter digestibility values compared to cereals [24,56]. Furthermore, in another in vitro study that mimicked ruminal digestion, the inclusion of BFF significantly increased the *Megasphaera* bacteria genus and sugar digestibility due to a high content of rapidly digestible carbohydrates [30]. This finding can explain the significantly higher sugar aTTD highlighted in the present research. Moreover, Humer et al. [30] reported that an inclusion of BFF lower than 30% of the DM, as in the present study, did not affect fiber degradability, while a higher inclusion level (45%) could impair it through a reduction in the biodiversity of microbiota and in the number of cellulolytic bacteria.

Contrary to the results of this study, diets that include BFF showed better in vitro rumen degradation of starch, mainly due to heat treatment and increased abundance of the *Prevotella* genus in the rumen [25,30]. Moreover, the partial substitution of corn meal with BFF linearly enhanced the aTTD of all the main nutrients in lactating Simmental cows [31], whereas no effects were found in sheep [32].

In vivo studies in monogastric animals such as pigs have shown that organic matter digestibility can be improved in comparison with conventional diets using BFF (30% of inclusion) [55].

**Table 7.** Apparent total tract digestion (aTTD) in Limousine heifers that differed with the partial substitution of traditional feeds (1.6 kg corn and 0.3 kg soybean meals) with circular ones (1.5 kg bakery former foodstuffs—BFF; and 1.5 kg wheat wet distiller’s grains—WDGs).

Month	November	December	January	February	March	Average	P(g) <sup>1</sup>	P(m) <sup>1</sup>	P(g*m) <sup>1</sup>
Group	Ash, %								
Circular	69.95	67.95	70.67	70.65	71.36	69.92	0.966	0.857	0.415
Traditional	70.21	70.28	70.19	69.90	68.82	69.88			
SEM	1.33	1.33	1.33	1.33	1.33	0.59			
p-Value	0.506	0.222	0.797	0.694	0.184	0.966			
Crude Protein, %									
Circular	83.54	82.77	83.25	83.16	82.41	83.02	0.852	0.849	0.796
Traditional	82.80	82.78	82.71	83.46	83.01	82.95			
SEM	0.62	0.62	0.62	0.62	0.62	0.30			
p-Value	0.400	0.989	0.540	0.733	0.493	0.852			
Fats, %									
Circular	69.20	65.82	70.80	67.44	69.98	68.65	0.391	0.115	0.176
Traditional	70.70	68.43	68.75	69.76	68.81	69.29			
SEM	1.16	1.16	1.16	1.16	1.16	0.52			
p-Value	0.369	0.120	0.218	0.166	0.481	0.391			
Cellulose, %									
Circular	44.25	44.23	45.32	44.45	41.79	44.01	0.122	0.041	0.446
Traditional	47.05	42.98	45.78	47.94	43.12	45.37			
SEM	1.37	1.37	1.37	1.37	1.37	0.61			
p-Value	0.156	0.523	0.817	0.078	0.498	0.122			
Hemicellulose, %									
Circular	70.61	68.62	68.00	68.18	68.93	69.45	0.081	0.142	0.376
Traditional	70.19	68.37	69.25	70.88	71.10	69.96			
SEM	0.92	0.92	0.92	0.92	0.92	0.40			
p-Value	0.747	0.852	0.338	0.041	0.160	0.081			
Starch, %									
Circular	94.99	94.12	93.85	94.10	94.50	94.31	0.206	0.474	0.818
Traditional	94.80	94.68	94.51	94.60	94.61	94.64			
SEM	0.40	0.40	0.40	0.40	0.40	0.18			
p-Value	0.744	0.332	0.255	0.389	0.846	0.206			
Sugars + Pectins, %									
Circular	97.38	97.13	97.20	97.01	97.10	97.17	<0.05	0.3512	0.728
Traditional	95.74	95.68	95.22	95.44	95.44	95.50			
SEM	0.20	0.20	0.20	0.20	0.20	0.10			
p-Value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05			

Data are presented as least squared means  $\pm$  standard error of the means (SEM). <sup>1</sup> g = effect of the group; m = effect of the time (month); g\*m = combined effect of the group and time (group\*month).

#### 4. Conclusions

The present study showed that the environmental sustainability of beef cattle diets can be improved through the inclusion of bakery former foodstuffs and wheat wet distiller’s grains in partial substitution of corn and soybean meals, reducing greenhouse gases emission, water consumption, and land use related to feeds production. Furthermore, replacing traditional feeds with bakery former foodstuffs and wheat wet distiller’s grains, which are human co-products, can lead to reduced competition between humans and food-producing animals for raw materials as well as to better recycling of human food losses, in accordance to the circular economy principles. The substitution of corn and soybean meals with bakery former foodstuffs and wheat wet distiller’s grains did not negatively affect the growth performance, health status, or carcass characteristics of fattening beef cattle.

From a zootechnical point of view, this study contributes to improving knowledge about the use of bakery former foodstuffs and other co-products such as wheat wet distiller's grains in ruminant nutrition as well as their combined effects on a variety of beef cattle performance indicators.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/article/10.3390/su14094908/s1>, Table S1: Chemical composition of the Traditional diet in the different months, acquired with the portable NIR instrument Polisppec; Table S2: Chemical composition of the Circular diet in the different months, acquired with the portable NIR instrument Polisppec; Table S3: Chemical composition of the faeces in the Traditional group in the different months, acquired with the portable NIR instrument Polisppec; Table S4: Chemical composition of the faeces in the Circular group in the different months, acquired with the portable NIR instrument Polisppec.

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**Institutional Review Board Statement:** The trial was a field and practical study, not an experimental one, and did not need approval. For the trial, we used only data usually recorded by the farmer (growth performance, feed intake, FCR, health status etc.), without adding any additional or “experimental” practices that will or can harm the animals or put their welfare at risk. The products used are already registered and used in beef cattle feed.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest.

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