Livestock Science 255 (2022) 104774

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Effects of wet distillers bran plus solubles and corn oil in diets containing flint corn grain and citrus pulp for finishing Nellore bulls

Arquimedes de S. Lima Junior [a], Murilo A.P. Meschiatti [a], Vinícius N. Gouvêa [b], James C. MacDonald [c], Galen E. Erickson [c], Victor G.V. Dantas [d], Flávio A.P. Santos [a,*]

[a] Department of Animal Science, "Luiz de Queiroz" College of Agriculture, University of São Paulo, 11 Padua Dias Avenue, Piracicaba, SP 13418-900, Brazil

[b] Department of Animal and Range Sciences, Clayton Livestock Research Center, New Mexico State University, Clayton, NM 88415, USA

[c] Department of Animal Science, University of Nebraska, 0908, Lincoln, NE 68583, USA

[d] Department of Animal Science, Federal University of Mato Grosso, Rondonópolis, MT 78735-901, Brazil

HIGHLIGHTS

- The inclusion of corn ethanol byproducts in feedlot diets is a common practice.
- Wet distillers brain plus solubles (WDBS) is a new corn ethanol byproduct.
- WDBS at 150 g/kg is a protein source alternative to soybean meal in feedlot diets.
- WDBS at 300 or 450 g/kg is a source of energy and protein for feedlot diets.
- Corn oil can increase the energy density of finishing diets containing WDBS.

ARTICLE INFO

Keywords:
Beef cattle
By-products
Corn
Feedlot
Fat
Starch

ABSTRACT

Objectives were to evaluate the effects of de-oiled wet distillers bran plus solubles (WDBS) as a protein source [when included at 150 g/kg of diet dry matter (DM)] to replace soybean meal (SBM); or as a protein and energy source (when included at 300 and 450 g/kg of diet DM) to replace a mix of soybean meal, ground flint corn, and citrus pulp, and to evaluate the effects of corn oil inclusion (0*vs* 30 g/kg of diet DM) in diets containing 0 to 450 g/kg of WDBS (DM basis). Two hundred and thirty-two Nellore bulls (BW = 425 ± 25 kg) were used in a randomized complete block design with a 2 × 4 factorial arrangement of treatments consisting of diets supplemented or not with 30 g/kg of corn oil (DM basis) each one combined with 4 inclusions of WDBS (0, 150, 300, and 450 g/kg; DM basis). Bulls were blocked by initial shrunk BW and allocated into 40 pens (5 pens/treatment; 5 or 6 bulls/pen). Effects of corn oil × WDBS interaction were not detected ($P \geq 0.29$) for feedlot growth performance, carcass traits, and dietary NE concentrations, except for dry matter intake (DMI; $P = 0.03$). Increasing inclusion of WDBS linearly decreased DMI ($P = 0.004$) of finishing bulls fed diets without corn oil supplementation, but quadratically decreased DMI ($P = 0.002$) in diets containing 30 g/kg of corn oil, resulting in the observed interaction ($P = 0.03$). Feeding WDBS did not affect average daily gain (ADG), hot carcass weight (HCW), and dressing percentage of finishing bulls regardless of corn oil supplementation ($P \geq 0.18$). Feed efficiency (G:F) tended (linear; $P = 0.09$) to increase due to WDBS inclusion. The inclusion of 30 g/kg corn oil (DM basis) in the diet tended ($P = 0.07$) to decrease DMI by 3% and increase G:F by 7.5% compared with diets not supplemented with corn oil. Including 30 g/kg of corn oil (DM basis) in the diet increased ($P = 0.05$) observed net energy of maintenance (NE_m) and net energy of gain (NE_g). Corn oil supplementation had no effect ($P \geq 0.19$) on final BW, ADG, HCW, and dressing percentage. In summary, WDBS is as a protein supplement alternative to

Abbreviations: ADG, average daily gain; aNDFom-NDF, NDF assayed with a heat stable amylase and expressed exclusive of residual ash; BW, Body weight; CP, crude protein; DBPS, dry bran plus solubles; DDG, dry distillers grains; DDGS, dry distillers grains plus solubles; DG, distillers grains; DM, Dry matter; DMI, Dry matter intake; G:F, feed efficiency; HCW, hot carcass weight; HPDG, high protein distillers grains; KPH, pelvic and heart fat; ME, metabolizable energy; NDF, neutral detergent fiber; NE, net energy; NEg, net energy of gain; NEm, net energy of maintenance; RUP, rumen undegradable protein; SBM, soybean meal; SCB, sugar cane bagasse; WDBS, wet distillers bran plus solubles; WDG, wet distillers grains; WDGS, wet distillers grains plus solubles.

* Corresponding author.
E-mail address: vgouvea@nmsu.edu (F.A.P. Santos).

https://doi.org/10.1016/j.livsci.2021.104774
Received 29 October 2020; Received in revised form 30 August 2021; Accepted 11 November 2021
Available online 14 November 2021
1871-1413/

SBM when fed at 150 g/kg of the diet DM. The supplementation with corn oil is an effective way to increase the energy density of finishing diets containing WDBS.

1. Introduction

The production of ethanol from corn grain results in several conventional by-products of interest for feeding ruminants, in particular distillers grains [DG; dried (DDG), wet (WDG), with or without solubles (DDGS or WDGS)]; (Di Constanzo et al., 2015). Distillers grains provide rumen undegradable protein (RUP), highly digestible fiber, fat, and may decrease ruminal acidosis (NASEM, 2016). Therefore, distillers grains have become a common dietary ingredient in beef cattle growing and finishing diets in the US (Klopfenstein et al., 2008) and more recently also are increasing in availability in South America (Bortoletto and Alcarde, 2015).

Bremer et al. (2011) summarized numerous experiments where increasing concentrations of WDGS, modified distillers grains plus solubles (MDGS), and DDGS were fed to replace dry-rolled corn, high moisture corn or a combination of both, plus urea in feedlot diets as the only protein supplement. Feeding WDGS and MDGS up to 400 g/kg [dry matter (DM) basis] caused a quadratic increase on DM intake (DMI), average daily gain (ADG) and feed-efficiency (G:F; gain to feed ratio), while feeding DDGS up to 400 g/kg of diet DM caused a quadratic increase on DMI, but a linear increase on ADG and G:F. Feeding values were always greater for the corn ethanol by-products when compared with corn regardless of the by-product source or inclusion level.

A new technology has been adopted to remove the fiber portion of the ground and cooked corn before fermentation. The solubles stream can then be added to the fiber stream and two different products can be produced, the dry (DDBS) or the wet (WDBS) distillers bran plus solubles containing more than 300 g/kg (DM basis) of crude protein (CP) marketed to ruminants. The solid material obtained post fermentation results in a third byproduct, high protein distillers grains (HPDG), containing more than 400 g/kg (DM basis) of CP, marketed for both ruminants and non-ruminant species (Garland et al., 2019a, 2019b, 2019c). Compared with a standard corn control diet, HPDG and the DDBS improved feed efficiency respectively by 9.20 and 10.9% suggesting 23 and 27% greater feeding values than corn (Garland et al. 2019a). Some large corn ethanol companies are using this new technology in South America; however, limited data are available in the literature about animal response to these new by-products, particularly from Zebu cattle fed flint instead of dent corn (Gouvêa et al., 2016; Marques et al., 2016).

Supplementing fat sources is a very effective strategy to increase energy density of finishing diets (NASEM, 2016). The most consistent effect of fat supplementation for feedlot cattle is a decrease in DMI and an increase in feed efficiency (Barducci et al., 2015; Brandt and Anderson, 1990; Choi et al., 2013; Krehbiel et al., 2006; Putrino, 2006; Ramirez and Zinn, 2000; Rosa et al., 2013; Zinn, 1989; Zinn and Plascencia, 1996). However, some authors have reported increased ADG (Fiorentini et al., 2014; Silva et al., 2007; Rosa et al., 2013; Barducci et al., 2015) for fat-supplemented cattle.

On the other hand, there is limited information about fat supplementation for cattle fed diets containing distillers grains. Burhoop et al. (2017) reported that corn oil decreased DMI by 7.6% and improved G:F by 4.9% for de-oiled MDGS fed cattle, with no effect on carcass traits. Winders et al. (2019) reported 4.3% lower DMI and 7.0% better feed efficiency for feedlot cattle fed diets containing 150 g/kg (DM basis) of WDGS supplemented with 30 g/kg (DM basis) of corn oil compared with cattle fed diets not supplemented with fat. Carcass traits were not affected by corn oil supplementation.

We hypothesized that: (a) WDBS (150 g/kg of diet DM) can replace SBM as a protein source with no differences in cattle performance; (b) WDBS fed at 300 or 450 g/kg of diet DM would increase cattle ADG and G:F compared to the control diet, containing flint corn plus citrus pulp; and (c) corn oil supplementation would increase feed efficiency of cattle regardless of WDBS inclusion. Therefore, the objectives of this study were to evaluate the cattle response when de-oiled WDBS was included at 150 g/kg of diet DM to replaced soybean meal (SBM; protein source) and at greater dietary concentration, at witch de-oiled WDBS was included at 300 and 450 g/kg of diet DM to replace both SBM, ground flint corn, and citrus pulp (protein and energy source). The third objective was to evaluate the effects of corn oil inclusion (0 *vs* 30 g/kg of diet DM) in diets containing 0 to 450 g/kg of WDBS (DM basis).

2. Materials and methods

This study was conducted at the experimental feedlot cattle facilities of the Animal Science Department of the "Luiz de Queiroz" College of Agriculture (ESALQ), University of São Paulo (USP), in Piracicaba, State of São Paulo, Brazil. All procedures using animals were approved and followed guidelines recommended by the Animal Care and Use Committee of the ESALQ/USP, protocol # 2018–11.

2.1. Animals, housing, and feeding

Two hundred and thirty-two commercial Nellore bulls from grazing systems with unknown previous nutritional and management history were used in this trial. Bulls were received at the University feedlot research facility and adapted to high energy diets through a 21 days step-up protocol as follow (DM basis): 250 g/kg of sugarcane bagasse (SCB) diet for 5 days, 200 g/kg of sugarcane bagasse diets for 5 days, 150 g/kg of sugarcane bagasse for 5 days and 100 g/kg of sugarcane bagasse diet for 6 days. At the beginning of the experiment, after the adaptation period, bulls were individually weighted after a 16-h period of feed and water withdrawal [initial body weight (BW) = 425 ± 25 kg], identified with ear tags, vaccinated against clostridia (2 ml s.c.; Sintoxan Polivalent T, Merial Saúde Animal Ltda, Paulínia, Brazil), and dewormed using Albendazole sulfoxite (20 ml s.c.; Ricobendazole 10, Ouro Fino Saúde Animal Ltda, Cravinhos, Brazil), and Ivermectin 3.5 g/100 ml (8 ml s.c.; Ivomec Gold, Merial Saúde Animal Ltda). Bulls also received a subcutaneous dose of vitamins A, D, and E (8 ml s.c.; ADE Vallée, MSD Saúde Animal, São Paulo, Brazil). A randomized complete block design was used with a 2 × 4 factorial arrangement of treatments consisting of diets supplemented or not with 30 g/kg of corn oil (DM basis) each one combined with one of 4 inclusions of WDBS (0, 150, 300 and 450 g/kg; DM basis).

Bulls were blocked by initial shrunk BW (day 0; 5 BW blocks) and allocated into 1 of 40 partially covered feedlot pens with concrete floors [32 pens with 6 bulls/pen (5.3 m^2/bull) and 8 pens with 5 bulls/pen (6.4 m^2/bull)]. Treatments were randomly assigned to pens within each weight block (5 pens/treatment).

All diets were formulated to meet or exceed requirements of finishing Nellore bulls for 1.5 kg ADG as specified by NASEM (2016; Tables 1 and 2). The WDBS and the corn oil (978 g/kg of lipid; DM basis) used in the experiment were produced by Cargill Alimentos, Quirinópolis, Brazil, and shipped to the feedlot research facility before the beginning of the experiment. The WDBS was stored in a single bunker silo and the corn oil was stored in 1000 L plastic containers. The flint corn was processed through a hammer mill (DPM-4; Nogueira S/A Máquinas Agrícolas, São João da Boa Vista, Brazil) for a theoretical mean particle size of 1.3 mm (Gouvêa et al., 2016). Bulls were fed fresh mixed diets once daily at 0700 h throughout the experiment (76 days) and had free-choice access to feed and fresh water. Feed ingredients were weighed into the feed-mixer wagon, except for the soybean meal, urea and mineral

Table 1
Chemical composition (g/kg DM basis) of ground corn (GC), wet distillers bran plus solubles (WDBS), citrus pulp (CP), soybean meal (SBM) and sugar cane bagasse (SCB) used in experimental diets.

Item	GC[1]	WDBS[2]	CP[3]	SBM	SCB[4]
Dry matter	882	338	875	899	438
Crude protein	80.0	339.0	71.9	507	16
Ether extract	41.8	67.9	23.6	28.0	7.0
Neutral detergent fiber	115	525	260	150	856

[1] All corn grain used was flint corn as is regularly used in Brazil and was processed through a hammer mill (DPM-4; Nogueira S/A Máquinas Agrícolas, São João da Boa Vista, Brazil) for a theoretical mean particle size of 1.3 mm.
[2] Supplied by Cargill Alimentos, Quirinópolis, Goiás, Brazil.
[3] Pelletized dry citrus pulp from commercial orange juice industry.
[4] A byproduct from the ethanol industry; it is the fibrous portion remaining after sugarcane stalks are crushed and juices extracted.

premix that were individually weighed using a fixed scale (Weightech WT1000, Weightech Equipamentos de Pesagem, Florianópolis, SC, Brazil). Total mixed ration was prepared using a feed-mix wagon (Totalmix 25, Casale Equipamantos, São Carlos, Brazil) and mixing time was set according to manufacturer's recommendation of 5 min. The amount of fresh feed offered to each pen was adjusted daily based on the DMI of the previous day, and the amount of orts should not exceed 30 g/kg. Orts were collected 3 times a week, weighed (Weightech WT1000), sampled (100 g/kg as fed basis), and dried in a forced-air oven at 105 °C for 12 h to estimate DMI for each pen.

2.2. Sample collection and analyses

Individual shrunk BW was recorded on day 0 (after the 21 days adaptation period) and at the end of the experimental period (day 76) after 16-h period of feed and water withdrawal. These data were used to calculate ADG and G:F, which was calculated by dividing pen ADG by pen DMI.

Samples of SCB and WDBS were collected every 3 days and dried at 105 °C for 12 h for diet adjustments and diet DM determination. Samples of SCB, corn, citrus pulp, soybean meal, and WDBS were collected weekly and stored at −20 °C. At the end of the experiment, feed samples were thawed, composited by feed ingredient, dried in a forced-air oven at 55 °C for 72 h, and ground using a Wiley-type mill (MA-680 Marconi Ltda, Piracicaba, SP, Brazil) through a 1-mm screen. All samples were analyzed for DM at 105 °C (method 930.15; AOAC, 1990), aNDFom-NDF (nonsequential and ash-free; Van Soest et al., 1991, modified for Ankom 200 fiber analyzer, Ankom Technology Corp.) using sodium sulfite and heat-stable α-amylase for all the samples, ether extract (EE; method 920.29; AOAC, 1990), and crude protein (CP; using a Leco FP-528, Leco Corp., St. Joseph, MI).

The equations proposed by Zinn and Shen (1998) were used to calculate observed net energy of maintenance (NE_m) and gain (NE_g) of each dietary treatment, taking into account average values for pen DMI, ADG, and BW. These observed NE concentrations were compared to the expected values. The expected dietary NE values were calculated based on the sum of NASEM (2016) tabular values for each feed ingredient, with addition of monensin [2.3% increase in diet metabolizable energy (ME) content].

At the end of the experimental period, bulls were shipped 10.3 km (approximately 20 min) using commercial beef trucks to a commercial packing plant, where they were slaughtered on the following day. The hot carcass weight (HCW) was obtained at the time of slaughter after evisceration and removal of kidney, pelvic and heart fat (KPH). Dressing percentage was calculated as the ratio of HCW to final shrunk BW. Average dressing percent (55.3%) was also used to estimate carcass-adjusted final BW from HCW (HWC/0.553 = carcass-adjusted final BW) and so, carcass-adjusted ADG and G:F were calculated using the carcass-adjusted final BW, but since no statistical differences were observed using these adjusted-carcass data, the discussion was based on live performance.

2.3. Statistical analysis

The data were analyzed using the MIXED procedure of SAS (SAS

Table 2
Ingredients and chemical composition of experimental diets (DM basis).

	No corn oil				Corn oil at 30 g/kg			
	Wet distillers bran plus solubles, g/kg							
Item	0	150	300	450	0	150	300	450
Ingredient, g/kg								
Sugarcane bagasse[1]	85	85	85	85	85	85	85	85
Coarse ground corn[2]	403	367.5	294.5	223.5	387.5	352	279.5	208.5
Citrus pulp	403	367.5	294.5	223.5	387.5	352	279.5	208.5
WDBS[3]	–	150	300	450	–	150	300	450
Soybean meal	80	–	–	–	80	–	–	–
Corn oil	–	–	–	–	30	30	30	30
Urea	11	12	8	–	12	13	8	–
Sodium Chloride	3	3	3	3	3	3	3	3
Mineral supplement[4]	15	15	15	15	15	15	15	15
Analyzed composition, g/kg[5]								
Crude protein	139	138	161	189	137	136	159	187
Neutral detergent fiber	223	275	329	384	218	270	324	378
Ether Extract	32.8	34.2	39.9	45.5	61.9	63.2	68.9	74.6
NE_m,[6] MJ/kg	7.78	8.08	8.41	8.74	8.20	8.49	8.83	9.16
NE_g,[6] MJ/kg	5.15	5.36	5.65	5.94	5.44	5.69	5.98	6.23

[1] A byproduct from the ethanol industry; it is the fibrous portion remaining after sugarcane stalks are crushed and juices extracted.
[2] Ground corn was processed through a hammer mill (DPM-4; Nogueira S/A Máquinas Agrícolas, São João da Boa Vista, Brazil) for a theoretical mean particle size of 1.3 mm.
[3] Wet distillers bran plus solubles was from Cargill Alimentos, Quirinópolis, Brazil.
[4] Custom blend manufactured by Agroceres Multimix, Piracicaba, Brazil, containing (DM basis) 275 g/kg Ca, 10 g/kg Mg, 10 g/kg Mg, 56 g/kg S, 2240 mg/kg of Mn, 3360 mg/kg of Zn, 1120 mg/kg of Cu, 16.46 mg/kg of Co, 56 mg/kg of I, 11.2 mg/kg of Se, and 2000 mg/kg of monensin.
[5] Based on chemical analysis of a composited sample of each ingredient collected weekly throughout the experiment (n = 12 samples/ingredient).
[6] The dietary expected net energy for maintenance (NE_m) and gain (NE_g) were estimated according to the equations proposed by NASEM (2016; solution type = empirical level) with the addition of monensin as feed additive, and based on the sum of total digestible nutrient tabular values from each ingredient. The NASEM (2016) tabular total digestible nutrients values of wet distillers bran plus solubles (WDBS) was used for the experimental WDBS.

Inst., Inc., Cary, NC) as a randomized complete block design with a 2 × 4 factorial arrangement of treatments [2 corn oil inclusions (0 and 30 g/kg, DM basis) and 4 inclusions of WDBS (0, 150, 300, and 450 g/kg; DM basis)]. Pen was the experimental unit. The model included the fixed effects of corn oil supplementation, WDBS inclusion, and the corn oil × WDBS interaction. BW block was used as random variable and Satterthwaite approximation method was used to determine denominator degrees of freedom for testing fixed effects. When significant interactions ($P \leq 0.05$) were observed for a trait, orthogonal polynomial contrasts were used to detect linear and quadratic effects of WDBS inclusion within each level of oil supplementation. When no significant interactions ($P > 0.05$) were detected, differences between corn oil supplementation were tested by an ANOVA *F*-test and WDBS inclusion effects across oil supplementation were tested using orthogonal contrasts to detect linear and quadratic responses. All results are reported as LS means. Differences were declared significant when $P \leq 0.05$, whereas trends were discussed when $0.05 < P \leq 0.10$.

3. Results

Effects of corn oil × WDBS interaction were not detected ($P \geq 0.29$) for feedlot growth performance, carcass traits (Table 3), and dietary NE concentrations (Table 4), except for DMI ($P = 0.03$; Table 3).

3.1. Effects of corn oil × WDBS inclusion

Increasing inclusion of WDBS linearly decreased DMI ($P = 0.004$) of finishing bulls fed diets without corn oil supplementation, but quadratically decreased DMI ($P = 0.002$) in diets containing 30 g/kg of corn oil (DM basis; Fig. 1), resulting in the observed interaction ($P = 0.03$; Table 3).

3.2. Effects of WDBS inclusion

Feeding WDBS did not affect ADG, final BW, HCW, and dressing percentage of finishing bulls regardless of corn oil supplementation ($P \geq 0.18$; Table 4). The G:F tended (linear; $P = 0.09$) to increase because of the decrease in DMI due to WDBS inclusion. As WDBS increased from 0 to 450 g/kg of dietary DM, the NE_m tended (linear; $P = 0.07$) to increase (Table 4).

3.3. Effects of corn oil supplementation

The inclusion of 30 g/kg corn oil (DM basis) in the diet tended ($P = 0.07$) to decrease DMI by 3% and increase G:F by 7.53% compared with diets not supplemented with corn oil (Table 3). Also, including 30 g/kg of corn oil (DM basis) in the diet increased ($P = 0.05$) NE_m by 5.28% and NE_g by 6.56% (Table 4). Corn oil supplementation had no effect ($P \geq 0.19$) on final BW, ADG, HCW, and dressing percentage (Table 3).

4. Discussion

4.1. Effects of WDBS inclusion

Published research examining corn distillers grains for *Bos taurus* cattle fed high-concentrate diets is abundant (Klopfenstein et al., 2008; Bremer et al., 2011; DiConstanzo et al., 2015; NASEM, 2016). In almost all the studies reviewed by these authors the control diets contained high amounts of corn, exclusively dent corn, and the ethanol by-products tested were full fat or de-oiled distillers grains. Less is known, however, about feedlot cattle response to new corn ethanol by-products such as bran plus solubles (Garland et al.2019a, b, c), about cattle response to these new by-products inclusion in feedlot diets containing medium levels of flint corn combined with by-products such as citrus pulp as used in South America, especially southeast Brazil, and about *Bos indicus* (Zebu) cattle response to corn ethanol by-products.

The linear decrease in DMI when bulls were fed WDBS without corn oil supplementation is not consistent with previous data summarized by Klopfenstein et al. (2008), Bremer et al. (2011), and by NASEM (2016), who reported a quadratic response to both WDGS and DDGS compared with corn control diets. When DBPS was fed up to 400 g/kg of diet DM, Garland et al. (2019a) reported no effect on finishing cattle DMI while Garland et al. (2019b) reported a quadratic effect on DMI compared with a high dent corn control diet, and similar NE values for WDGS and DBPS. According to NASEM (2016), WDGS have greater NE values than citrus pulp and dry processed dent corn and this difference, presumably, is even greater when compared with the flint corn fed in the present study. Starch availability is less for Brazilian flint corn than for US dent corn because of its greater proportion of vitreous endosperm (Correa et al., 2002). So, the linear decrease in DMI when WDBS was fed may be related to the physiological mechanism regulating DMI of cattle fed high-energy density diets (Allen, 2014), as WDBS tended to linearly

Table 3
Effects of corn oil (CO; 0 *vs* 30 g/kg DM basis) and inclusions of wet distillers bran plus solubles (WDBS; 0, 150, 300, and 450 g/kg DM basis) on growth performance and carcass traits of finishing Nellore bulls.

	Corn oil, g/kg DM		Wet distillers bran plus solubles, g/kg DM					*P*-value		
Item	0	30	0	150	300	450	SEM	CO	WDBS	CO × WDBS
Initial BW,[1] kg	425	425	425	425	425	425	25.1	–	–	–
Final BW,[1] kg	529	532	532	534	528	530	18.4	0.44	0.60	0.29
Adj. final BW,[2] kg	532	533	531	538	526	534	21.9	0.36	0.83	0.68
DMI,[3,8] kg	9.66	9.37	9.90	9.89	9.54	8.72	0.277	0.07	0.001	0.03
ADG,[4] kg	1.38	1.44	1.42	1.49	1.33	1.39	0.057	0.20	0.18	0.64
Adj. ADG,[2] kg	1.40	1.42	1.39	1.49	1.33	1.44	0.084	0.33	0.76	0.70
ADG:DMI[5,8]	0.143	0.154	0.145	0.152	0.139	0.160	0.006	0.07	0.09	0.58
Adj. ADG:DMI[2,8]	0.146	0.153	0.142	0.152	0.139	0.165	0.007	0.07	0.08	0.44
HCW,[6] kg	294	295	294	298	292	296	12.4	0.83	0.36	0.68
Dressing,[7]%	55.5	55.2	55.1	55.5	55.2	55.6	0.43	0.19	0.32	0.29

[1] Initial and final individual body weight (BW) measured live and after 16 h of feed and water restriction.
[2] Carcass-adjusted values. Adjusted (Adj.) final BW was estimated by dividing hot carcass weight by the overall average dressing percentage obtained for treatments (55.3%) and so, adjusted ADG and feed efficiency were calculated.
[3] Dry mater intake (DMI) was recorded from each pen (5 pens/treatment: 32 pens with 6 bulls + 8 pens with 5 bulls) and divided by the number of animals within each pen, and expressed as kg animal/d.
[4] Average daily gain (ADG) was calculated using initial and final BW (after 16 h of feed and water restriction).
[5] Feed efficiency was calculated as the ratio ADG to DMI.
[6] Hot carcass weight (HCW) was obtained at the time of slaughter after evisceration and removal of kidney, pelvic and heart fat.
[7] Calculated as the ratio of HCW to final shrunk BW.
[8] Orthogonal contrast: linear effect of WDBS inclusion (main effect; $P \leq 0.05$).

Table 4
Effects of corn oil (CO; 0 *vs* 30 g/kg DM basis) and inclusions of wet distillers bran plus solubles (WDBS; 0, 150, 300, and 450 g/kg DM basis) on observed dietary net energy of maintenance (NE_m) and gain (NE_g) concentrations (MJ/kg DM basis).

	Corn oil, g/kg DM		Wet distillers bran plus solubles, g/kg DM					*P*-value		
Item	0	30	0	150	300	450	SEM	CO	WDBS	CO × WDBS
Observed NE_m[1,3]	8.12	8.41	8.12	8.41	7.99	8.91	0.44	0.05	0.07	0.44
Observed NE_g[1]	5.40	5.73	5.31	5.65	5.31	6.07	0.39	0.05	0.12	0.61
Observed:expected NE_m[2,3]	0.98	0.99	1.01	1.01	0.93	0.99	0.054	0.06	0.01	0.43
Observed:expected NE_g[2,3]	0.98	0.98	1.00	1.02	0.91	1.00	0.073	0.14	0.02	0.64

[1] Calculated using cattle growth performance data based on the equation proposed by Zinn and Shen (1998).
[2] Expected NE values were estimated with the equations proposed by NASEM (2016; solution type = empirical level) with addition of monensin as feed additive and using the NASEM (2016) tabular total digestible nutrient values.
[3] Orthogonal contrast: linear effect of WDBS inclusion (main effect; $P \leq 0.05$).

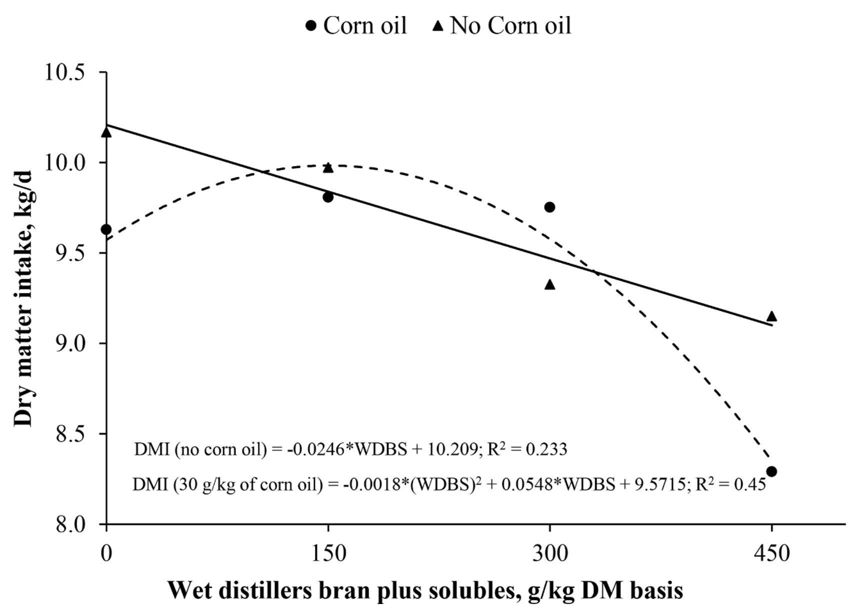

Fig. 1. Effects of inclusion of wet distillers bran plus solubles (WDBS) on dry matter intake (DMI) of finishing Nellore bulls fed diets with (●) or without (▲) corn oil supplementation at 30 g/kg DM basis. A linear effect ($P = 0.004$; SEM = 0.233) of WDBS was detected in diets without corn oil supplementation and a quadratic effect ($P = 0.002$; SEM = 0.445) of WDBS was detected in diets containing 30 g/kg of corn oil (DM basis).

increase observed NE density of the diets. Whereas, when 30 g/kg of corn oil was included in the diets (DM basis), the quadratic response on DMI to WDBS inclusion was consistent with data summarized by Klopfenstein et al. (2008), Bremer et al. (2011), and by NASEM (2016), except for the dramatic drop when 450 g/kg of WDBS was fed (DM basis). Feeding 450 g/kg of WDBS (DM basis) reduced DMI by 10% without corn oil (10.17 × 9.15 kg) and 13.9% with corn oil supplementation (9.63 × 8.29 kg) compared with diets without WDBS.

In all the studies summarized by Klopfenstein et al. (2008) and Bremer et al. (2011) with WDGS and DDGS as well as in the studies conducted by Garland et al. (2019a, b) with DDBS, the by-products were compared with high corn control diets, either dry rolled corn, high moisture corn or combinations of both, while in the present study the diets without WDBS contained only 404 g/kg of corn and 404 g/kg citrus pulp (DM basis). Replacing part of the dietary starch with pectin may improve the rumen environment and lower the risk of acidotic conditions (NASEM, 2016). Gouvêa et al. (2016) reported a quadratic effect on feedlot cattle DMI when citrus pulp replaced 0, 25, 50, and 75% of ground flint corn in the diets. The greatest DMI was reported when citrus pulp replaced 50% of the corn, resulting in diets containing 402 g/kg of corn and 402 g/kg of citrus pulp (DM basis), the same contents of the diets containing no WDBS in the present study. The lower starch content of the experimental diets and the positive associative effect of combining dry ground corn and citrus pulp on DMI may explain the differences in cattle DMI responses to WDBS compared with the data reported by Klopfenstein et al. (2008), Bremer et al. (2011), and by Garland et al. (2019a, b).

The consistent positive effect of feeding WDGS and DDGS (Klopfenstein et al., 2008; Bremer et al., 2011; Di Constanzo et al., 2015; NASEM, 2016) and DDBS (Garland et al., 2019a,b) on cattle ADG was not observed in the present study when WDBS was fed up to 450 g/kg of diet DM, primarily because of its negative effect on DMI. Despite the greater energy density of the DBPS compared with dent corn (Garland et al. 2019a,b) and the linear increase in observed NE density of the diets, cattle NE intake was not increased. The positive effects of WDGS, DDGS, and DDBS on cattle ADG reported by the authors above were relative to high-dent corn diets, while in the present study, flint corn was blended (50:50) with citrus pulp. Gouvêa et al. (2016) reported a quadratic increase in finishing cattle ADG when citrus pulp replaced 0, 25, 50, and 75% of ground flint corn in the diets with the greatest ADG observed for the 50:50 blend (402 g/kg of corn and 402 g/kg of citrus pulp; DM basis). The positive effects of replacing 50% of ground flint corn with citrus pulp on cattle DMI and ADG may explain the different responses in ADG of cattle fed WDBS in the present study, compared with the data reported by Klopfenstein et al. (2008), Bremer et al. (2011), and by Garland et al. (2019a,b).

Despite the differences in DMI and ADG responses, the linear increase in G:F when WDBS was fed is consistent with the data reported by the authors cited above and confirm the higher energy content of this by-product compared with the blends of ground flint corn, citrus pulp and soybean meal it replaced in the experimental diets. Feeding WDBS (150 and 450 g/kg of diet DM) increased mean G:F (0.145, 0.152, 0,130, and 0.160) by +5.2% and +10.4% compared with the diets with no WDBS. Garland et al. (2019a) reported similar DMI, 9.3% greater ADG, and 9.3% improved G:F when DDBS (400 g/kg of diet DM) replaced a blend (50:50) of dry rolled and high moisture corn. In a second study Garland et al. (2019b), feeding 0, 200, and 400 g/kg of DDBS (DM basis) in the diets resulted in a quadratic response for DMI and ADG and a linear increase in G:F of 4.72% for both inclusions compared with a control diet containing a blend (50:50) of dry rolled and high moisture corn. Both Klopfenstein et al. (2008) and Bremer et al. (2011) reported in their reviews a quadratic effect of WDGS on cattle G:F compared with corn. Bremer et al. (2011) reported 11.61% greater G:F when WDGS was fed at 400 g/kg (DM basis) compared with corn, close to the 10.4% increase reported in the present study for the treatments containing 450 g/kg of WDBS (DM basis).

In the present study, the WDBS included at 150 and 450 g/kg of diet DM, had feeding values (percentage of corn feeding values were calculated from WDGS inclusion G:F relative to 0 WDGS G:F, divided by WDGS inclusion) of 134.6 and 133%, respectively, compared with the replaced blends of ground flint corn, citrus pulp, soybean meal, and urea. These values are in close agreement with the ones reported by Bremer et al. (2011) for WDGS of 150, 143, 136, and 130% relative to dent corn, when included at 100, 200, 300 and 400 g/kg of died DM, respectively.

Based on cattle growth performance data (mean BW, ADG, and DMI) the observed NE values of the diets increased linearly as WDBS was included in the diet, indicating a greater NE_m value for WDBS compared with the replaced blends of ground flint corn, citrus pulp, soybean meal, and urea. On average, diets with 450 g/kg of WDBS (DM basis) contained 9.85% greater NE_m and 14.17% numerically greater NE_g than diets with no WDBS. Assuming the improvements are attributable solely to WDBS that constitutes 45% of the diet (DM basis), WDBS contains 21.9% more NE_m and 32.7% more NE_g than the replaced blend of ground flint corn, citrus pulp, soybean meal, and urea. According to NASEM (2016) tabular values, WDGS contains 32.9% and 32.7% greater NE_m and NE_g values, respectively, than the replaced blend of ground flint corn, citrus pulp, soybean meal, and urea.

3.2. Effects of corn oil supplementation

Supplementing fat sources is an effective strategy to increase energy density of finishing diets (NASEM, 2016) witch explains the consistent decrease in DMI (Krehbiel et al., 1995; Zinn and Plascencia, 1996; Zinn and Shen, 1996; Bindel et al., 2000; Ramirez and Zinn, 2000; Zinn and Plascencia, 2002; Krehbiel et al., 2006; Choi et al., 2013) such as observed in the present study where the inclusion of 30 g/kg of corn oil to the diets (DM basis) tended ($P = 0.07$) to decrease DMI by 3%. The effect of fat on DMI is related to the physiological mechanism regulating DMI for cattle fed high-energy density diets (Allen, 2014) and the process may be associated with the secretagogue action of unsaturated FA on the release of cholecystokinin and glucagon-like peptide-1, which acts by inhibiting gastric emptying, or associated with the increase in plasma NEFA concentration, increasing hepatic uptake and oxidation of NEFA (Allen, 2000).

The effects of fat supplementation on ADG of finishing cattle are inconsistent. As in the present study, Sutter et al. (2000) did not report any effect of fat supplementation on cattle ADG. On the other hand, some have reported positive (Silva et al., 2007; Fiorentini et al., 2014; Rosa et al., 2013; Barducci et al., 2015) or negative (Gibb et al., 2004; Pavan et al., 2007) effects of fat supplementation on ADG. Once ADG was not affected in the present study, final BW, HCW, and dressing percentage were not expected to change with corn oil supplementation.

The tendency for 7.53% greater G:F of cattle supplemented with corn oil is corroborated by several studies with various fat sources (Zinn, 1989; Brandt and Anderson, 1990; Zinn and Placencia, 1996; Zinn and Shen, 1998; Ramirez and Zinn, 2000; Krehbiel et al., 2006; Putrino , 2006; Rosa et al., 2013; Barducci et al., 2015; Ramirez and Zinn, 2000) and it is a consequence of the 5.28% greater NE_m and 6.56% greater NE_g of the diets containing 30 g/kg of corn oil (DM basis).

On the other hand, there is limited information about fat supplementation for cattle fed diets containing distillers grains. Burhoop et al. (2018) compared a high corn diet with 3 diets containing (DM basis): (a) 400 g/kg de-oiled MDGS; (b) 380 g/kg de-oiled MDGS plus 20 g/kg corn oil or c) 400 g/kg full fat MDGS. Corn oil decreased DMI by 7.6% and improved feed conversion by 4.9% for de-oiled MDGS fed cattle, with no effect on carcass traits. Winders et al. (2019) reported 4.3% lower DMI and 7.0% better feed conversion for feedlot cattle fed diets containing 150 g/kg of WDGS supplemented with 30 g/kg of corn oil compared with cattle fed diets not supplemented with fat. Carcass traits were not affected by corn oil supplementation. These data corroborate the results of the present study.

In summary, WDBS tested in this experiment is as a protein supplement alternative to soybean meal when fed at 150 g/kg of the diet DM and it contains greater energy density than the replaced blend of ground flint corn, citrus pulp, soybean meal, and urea regardless of WDBS inclusion. The supplementation with corn oil is an effective way to increase the energy density of finishing diets containing WDBS.

CRediT authorship contribution statement

Arquimedes de S. Lima Junior: Investigation, Data curation, Project administration. **Murilo A.P. Meschiatti:** Investigation, Methodology, Project administration. **Vinícius N. Gouvêa:** Data curation, Formal analysis, Writing – review & editing, Visualization. **James C. MacDonald:** Conceptualization, Writing – review & editing. **Galen E. Erickson:** Conceptualization, Writing – review & editing. **Victor G.V. Dantas:** Investigation. **Flávio A.P. Santos:** Conceptualization, Methodology, Resources, Writing – review & editing, Visualization, Project administration.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

References

Allen, M.S., 2014. Drives and limits to feed intake in ruminants. Anim. Prod. Sci. 54, 1513–1524. https://doi.org/10.1071/AN14478.

Allen, M.S., 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83, 1598–1624. https://doi.org/10.3168/jds.S0022-0302(00)75030-2.

AOAC, 1990. Official Methods of Analysis of the Association of Official Analytical Chemists, 15th ed. Association of Official Analytical Chemists Inc., Arlington, Virginia, USA.

Barducci, R.S., Sarti, L.M.N., Millen, D.D., Putarov, T.C., Ribeiro, F.A., da Silva Franzói, M.C., da Costa, C.F., Martins, C.L., De Beni Arrigoni, M.M., 2015. Ácidos graxos no desempenho e nas respostas imunológicas de bovinos Nelore confinados. Pesqui. Agropecu. Bras. 50, 499–509. https://doi.org/10.1590/S0100-204X2015000600009.

Bindel, D.J., Drouillard, J.S., Titgemeyer, E.C., Wessels, R.H., Löest, C.A., 2000. Effects of ruminally protected choline and dietary fat on performance and blood metabolites of finishing heifers. J. Anim. Sci. 78, 2497–2503. https://doi.org/10.2527/2000.78102497x.

Bortoletto, A.M., Alcarde, A.R., 2015. Dominante nos EUA, etanol de milho é opção, no Brasil, para safra excedente. Rev. visão agrícola 135–137.

Brandt, R.T., Anderson, S.J., 1990. Supplemental fat source affects feedlot performance and carcass traits of finishing yearling steers and estimated diet net energy value. J. Anim. Sci. 68, 2208–2216. https://doi.org/10.2527/1990.6882208x.

Bremer, V.R., Watson, A.K., Liska, A.J., Erickson, G.E., Cassman, K.G., Hanford, K.J., Klopfenstein, T.J., 2011. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. Prof. Anim. Sci. 27, 449–455. https://doi.org/10.15232/S1080-7446(15)30517-9.

Burhoop, J.E., Bittner, C.J., Hilscher, F.H., Luebbe, M.K., MacDonald, J.C., Erickson, G. E., 2018. Impact of corn oil removal from modified distiller's grains plus solubles and supplemental corn oil on finishing cattle performance. Nebraska Beef Cattle Rep. 993, 102–104. http://digitalcommons.unl.edu/animalscinbcr/993. In press.

Burhoop, J.E., Bittner, C.J., Hilscher, F.H., Luebbe, M.K., MacDonald, J.C., Erickson, G. E., 2017. 344 Impact of corn oil removal from modified distiller's grains plus solubles and supplemental corn oil on finishing cattle performance. J. Anim. Sci. 95 https://doi.org/10.2527/asasmw.2017.344, 167–167.

Choi, S.H., Gang, G.O., Sawyer, J.E., Johnson, B.J., Kim, K.H., Choi, C.W., Smith, S.B., 2013. Fatty acid biosynthesis and lipogenic enzyme activities in subcutaneous adipose tissue of feedlot steers fed supplementary palm oil or soybean oil. J. Anim. Sci. 91, 2091–2098. https://doi.org/10.2527/jas.2012-5801.

Correa, C.E.S., Shaver, R.D., Pereira, M.N., Lauer, J.G., Kohn, K., 2002. Relationship between corn vitreousness and ruminal *in situ* starch degradability. J. Dairy Sci. 85, 3008–3012. https://doi.org/10.3168/jds.S0022-0302(02)74386-5.

DiConstanzo, A., Hohertz, A., Owens, F., 2015. Ethanol co-products: changes in the last 15 years, changes to come. In: Proceedings of the 2015 Plains Nutrition Council Spring Conference, pp. 39–53.

Fiorentini, G., Carvalho, I.P.C., Messana, J.D., Canesin, R.C., Castagnino, P.S., Lage, J.F., Arcuri, P.B., Berchielli, T.T., 2014. Effect of lipid sources with different fatty acid profiles on intake, nutrient digestion and ruminal fermentation of feedlot Nellore steers. J. Anim. Sci. 92, 1613–1620. https://doi.org/10.5713/ajas.15.0130.

Garland, S.A., Boyd, B.M., Erickson, G.E., Macdonald, J.C., 2019a. Evaluation of fractionated distillers grains (high protein and bran plus solubles) on performance and carcass characteristics in finishing diets. Nebraska Beef Cattle Rep. 1021, 88–90. https://digitalcommons.unl.edu/animalscinbcr/1021.

Garland, S.A., Boyd, B.M., Erickson, G.E., Macdonald, J.C., 2019b. Ealuation of corn bran plus solubles on performance and carcass characteristics in finishing diets. Nebraska Beef Cattle Rep. 1020, 91–93. https://digitalcommons.unl.edu/animalscinbcr/1020.

Garland, S.A., Jolly-breithaupt, M.L., Hamilton, H.C.H., Erickson, G.E., Macdonald, J.C., 2019c. Evaluation of the energy value and nutrient digestibility of distillers grains that have undergone a fiber separation process in finishing diets. Nebraska Beef Cattle Rep. 1019, 94–96. https://digitalcommons.unl.edu/animalscinbcr/1019.

Gibb, D.J., Owens, F.N., Mir, P.S., Mir, Z., Ivan, M., McAllister, T.A., 2004. Value of sunflower seed in finishing diets of feedlot cattle. J. Anim. Sci. 82, 2679–2692.

Gouvêa, V.N., Batistel, F., Souza, J., Chagas, L.J., Sitta, C., Campanili, P.R.B., Galvani, D. B., Pires, A.V., Owens, F.N., Santos, F.A.P., 2016. Flint corn grain processing and citrus pulp level in finishing diets for feedlot cattle. J. Anim. Sci. 94, 665–677. https://doi.org/10.2527/jas.2015-9459.

Klopfenstein, T.J., Erickson, G.E., Bremer, V.R., 2008. Board-invited review: use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86, 1223–1231. https://doi.org/10.2527/jas.2007-0550.

Krehbiel, C.R., Cranston, J.J., McCurdy, M.P., 2006. An upper limit for caloric density of finishing diets. J. Anim. Sci. 84, 34–49. https://doi.org/10.2527/2006.8413_supplE34x. Suppl.

Krehbiel, C.R., McCoy, R.A., Stock, R.A., Klopfenstein, T.J., Shain, D.H., Huffman, R.P., 1995. Influence of grain type, tallow level, and tallow feeding system on feedlot cattle performance. J. Anim. Sci. 73, 2916–2921. https://doi.org/10.2527/1995.73102916x.

Marques, R.S., Chagas, L.J., Owens, F.N., Santos, F.A.P., 2016. Effects of various roughage levels with whole flint corn grain on performance of finishing cattle. J. Anim. Sci. 94, 339–348. https://doi.org/10.2527/jas.2015-9758.

NASEM, 2016. Nutrient requirements of Beef Cattle, 8th ed. National Academies of Sciences, Engineering, and Medicine, Washington, DC. https://doi.org/10.17226/19014.

Pavan, E., Duckett, S.K., Andrae, J.G., 2007. Corn oil supplementation to steers grazing endophyte-free tall fescue. I. Effects on *in vivo* digestibility, performance, and carcass traits. J. Anim. Sci. 85, 1330–1339. https://doi.org/10.2527/jas.2006-623.

Putrino, S.M., 2006. Composição corporal, exigências de energia e proteína para ganho e composição da carne de novilhos Nelore alimentados com dietas com milho grão seco ou úmido contendo gordura não degradável no rúmen. Fac. Zootec. e Eng. Aliment. Doutorado 100.

Ramirez, J.E., Zinn, R.A., 2000. Interaction of dietary magnesium level on the feeding value of supplemental fat in finishing diets for feedlot steers. J. Anim. Sci. 78, 2072–2080. https://doi.org/10.2527/2000.7882072x.

Rosa, B.L., Sampaio, A.A.M., Henrique, W., de Oliveira, E.A., Pivaro, T.M., de Andrade, A.T., Fernandes, A.R.M., 2013. Performance and carcass characteristics of Nellore young bulls fed different sources of oils, protected or not from rumen degradation. Rev. Bras. Zootec. 42, 109–116. https://doi.org/10.1590/S1516-35982013000200005.

Silva, S.da L.e, Leme, P.R., Putrino, S.M., Valinote, A.C., Nogueira Filho, J.C.M., Lanna, D.P.D., 2007. Milho grão seco ou úmido com sais de cálcio de ácidos graxos para novilhos Nelore em confinamento. Rev. Bras. Zootec. 36, 1426–1434. https://doi.org/10.1590/s1516-35982007000600028.

Sutter, F., Casutt, M.M., Ossowski, D.A., Scheeder, M.R., Kreuzer, M., 2000. Comparative evaluation of rumen-protected fat, coconut oil and various oilseeds supplemented to fattening bulls. 1. Effects on growth, carcass and meat quality. Arch. Anim. Nutr. 53, 1–23. https://doi.org/10.1080/17450390009381935.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2.

Winders, T.M., Boyd, B.M., Hilscher, H.F., Fernando, S.C., Stowell, R.R., Winders, T.M., Boyd, B.M., Hilscher, H.F., Fernando, S.C., Stowell, R.R., Erickson, G.E., 2019. Corn oil supplementation on performance and methane production in finishing steers. Nebraska Beef Cattle Rep. 1030, 60–62. http://digitalcommons.unl.edu/animalscinbcr/1030.

Zinn, R.A., 1989. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for feedlot steers: metabolism. J. Anim. Sci. 67, 1038–1049.

Zinn, R.A., Plascencia, A., 1996. Effects of forage level on the comparative feeding value of supplemental fat in growing-finishing diets for feedlot cattle. J. Anim. Sci. 74, 1194–1201. https://doi.org/10.2527/1996.7461194x.

Zinn, R.A., Shen, Y., 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. J. Anim. Sci. 76, 1280–1289.