



Characteristics of Wet and Dried Distillers Grains on *In vitro* Ruminal Fermentation and Effects of Dietary Wet Distillers Grains on Performance of Hanwoo Steers

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ABSTRACT: Two experiments were conducted to evaluate the nutrient composition, *in vitro* dry matter disappearance (IVDMD) and organic matter disappearance (IVOMD) of three kinds of distillers grains (DG); i) wet distillers grains (WDG, KRW 25/kg), ii) dried distillers grains (DDG, KRW 280/kg), iii) dried distillers grains with solubles (DDGS, KRW 270/kg) produced from tapioca 70% and rice 30%, and to evaluate dietary effects of WDG on the performance of Hanwoo steers. In Exp. 1, twelve-WDG, four-DDG and one-DDGS were collected from seven ethanol plants. Average crude protein, crude fiber, neutral detergent fiber, and acid detergent fiber of WDG, DDG, and DDGS were: 32.6%, 17.8%, 57.5%, and 30.2% for WDG, 36.7%, 13.9%, 51.4%, and 30.5% for DDG, and 31.0%, 11.9%, 40.3%, and 21.2% for DDGS (DM basis), respectively. The DDGS had a higher quantity of water-soluble fraction than WDG and DDG and showed the highest IVDMD ($p < 0.05$) in comparison to others during the whole experimental time. The IVDMD at 0 to 12 h incubation were higher ($p < 0.05$) in DDG than WDG, but did not show significant differences from 24 to 72 h. The same tendency was observed in IVOMD, showing that DG made from tapioca and rice (7:3) can be used as a feed ingredient for ruminants. Considering the price, WDG is a more useful feed ingredient than DDG and DDGS. In Exp. 2, 36 Hanwoo steers of 21 months (495.1 ± 91 kg) were randomly assigned to one of three dietary treatments for 85 days; i) Control (total mixed ration, TMR), ii) WDG 10% (TMR containing 10% of WDG, as fed basis), and iii) WDG 20% (TMR containing 20% of WDG, as fed basis). With respect to body weight and average daily gain, there were no differences between control and WDG treatments during the whole experimental period. Dry matter intake of control (9.34 kg), WDG 10% (9.21 kg) and 20% (8.86 kg) and feed conversion ratio of control (13.0), WDG 10% (13.2) and 20% (12.1) did not show differences between control and WDG treatments. Thus, the use of WDG up to 20% in TMR did not show any negative effect on the performance of Hanwoo steers. (**Key Words:** Hanwoo, Steers, Total Mixed Ration, Distillers By-products, Wet Distillers Grains)

INTRODUCTION

Wet distillers grains (WDG), dried distillers grains

(DDG) and dried distillers grains with solubles (DDGS) are by-products from ethanol production processing. Fiber, protein and fat are concentrated approximately 3-fold in distillers grains (DG) when starch is fermented to produce ethanol, thus DG can replace the protein source in diets of cattle (Klopfenstein et al., 2008). Because of the increasing production of DDGS, studies to evaluate DDGS as a protein source have been widely conducted. However, in United States, the source of these by-products was mostly DDGS from wheat and corn (Shurson et al., 2005), with limited data available about the usefulness of WDG and DDG as feed ingredients for ruminants.

There were nine ethanol production companies in Korea

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in 2012, and WDG, DDG, and DDGS productions were 34,700, 13,880 and 7,000 t, respectively (Statistics Korea, 2014). The amount of WDG, DDG, and DDGS was equivalent to 6.6 billion Korean won (KRW) per year (2012). Unlike the case of the United States, almost all WDG, DDG, and DDGS produced in Korea are from tapioca and rice. Four out of nine ethanol plants had drying facilities for DG, thus the greatest amount of DG produced by ethanol plants in Korea within a year is WDG. The DDGS contribute the smallest amount of DG from ethanol plants because there was only one ethanol plant in Korea that produces DDGS. In addition, due to the absence of a drying process for WDG, the price of WDG (KRW 25/kg) is lower than DDG (KRW 280/kg) and DDGS (KRW 270/kg). The WDG have a nutritional and economic advantage over DDGS if managed correctly, and have greater energy concentrations, less heat damaged protein (because of the absence of drying process), and lower price per unit of dry matter (DM) compared with DDGS (Dooley et al., 2008). However, because of a higher water portion than DDG and DDGS, WDG have disadvantages such as greater transportation cost, difficult storage and handling, and a reduced shelf life (Lemenager et al., 2006). Thus, co-ensiling WDG with other feed sources such as a total mixed ration (TMR) can result in a safe way to store WDG for long periods of time (Buckmaster et al., 2008)

Waldo et al. (2009) reported that DDGS from wheat and corn was an excellent protein source for ruminants, but there was little or no data available concerning the characteristics and nutritional quality of WDG from tapioca 70% and rice 30%. In Korea, all of DG (WDG, DDG, and DDGS) are from tapioca and rice (most common ratio, 7:3), but to our knowledge, there are no published data on the use of these DG in the diets of beef cattle. Therefore, the purposes of this study were to i) investigate the nutritional value of WDG, DDG, and DDGS from tapioca 70% and rice 30%, and ii) evaluate the ability of WDG as a feed ingredient of TMR for Hanwoo steers in early to mid-fattening period.

MATERIALS AND METHODS

Exp. 1. Chemical analysis and *in vitro* dry matter and organic matter disappearances of WDG, DDG, and DDGS

WDG, DDG, and DDGS: The WDG, DDG, and DDGS were obtained from seven commercial ethanol plants (EP-1 to 7; located in Korea) producing alcoholic liquors and medical disinfectant. The samples collected in this study were eleven-WDG, four-DDG, and one-DDGS. The WDG samples from EP-1 (A and B) and 2 (A, B, C, and D) were collected from the same ethanol plant at different months (EP-1 A and B, during November and December; EP-7 A to

D, during March and December).

Chemical analysis: All WDG, DDG, and DDGS samples for chemical analysis were dried at 55°C (relatively low temperature to prevent browning reaction of protein) in a forced-air oven connected to a sucking fan for over 24 hours and ground through 1 mm screen using Wiley mill. Dry matter, crude protein (CP), ether extract (EE, crude fat), crude fiber (CF), and ash contents were analyzed by procedures of the AOAC (1999), whereas neutral detergent fiber (NDF) and acid detergent fiber contents were analyzed according to the procedure of Van Soest et al. (1991).

Amino acid analysis for glycine, alanine, cysteine, valine, methionine, isoleucine, leucine, histidine, lysine, and arginine of three-WDG and one-DDG were performed using an automatic amino acid analyzer (Amino acid analyzer S430, Sykam, Eresing, Germany) Calcium (Ca) and phosphorus (P) of three-WDG and one-DDG were analyzed by the procedure of the AOAC (1999), and alcohol residue was analyzed by automatic alcohol detector (Anton-Paar DMA 4500, Ashland, VA, USA).

***In vitro* dry matter and organic matter disappearances:** *In vitro* experiments were conducted to determine the *in vitro* dry matter disappearance (IVDMD) and *in vitro* organic matter disappearance (IVOMD) of WDG, DDG, and DDGS. The substrates used in this study (five-WDG, four-DDG, and one-DDGS) were ground through a Wiley mill to pass a 1 mm screen. A modified Tilley and Terry (1963) procedure was performed for the *in vitro* system. Ruminant fluid was obtained from a ruminally fistulated (120 mm) Hanwoo steer (568 kg) fed a 1:4 forage:concentrate diet. Ruminant fluid was strained through eight-layers of cheese cloth and flushed with CO₂-saturated gas for 5 min to maintain anaerobic condition. After CO₂ gas injection, ruminant fluid was transported immediately to the laboratory in a pre-warmed thermos maintained at 39°C. To measure IVDMD and IVOMD, approximately 0.5 g of substrate (WDG, DDG, and DDGS) was weighed and placed in triplicate 50 mL centrifuge tubes fitted with gas release hole (diameter, 0.5 mm).

The inoculum was prepared by diluting the rumen fluid with McDougall's buffer in a 1:4 (vol/vol) ratio. After adding inoculum (40 mL) to the centrifuge tube, CO₂-saturated gas was injected for five seconds to maintain anaerobic condition in the tube. Two blanks (only inoculum without substrate) were included in each incubation time. The tubes incubated in a shaking water bath with constant oscillation (80 rpm) at 39°C for 0, 4, 8, 12, 24, 48, and 72 h incubation times. After each incubation time, distilled water and filter paper (No. 417, VWR, Radnor, PA, USA) was used for rinsing the incubation tube and washing the residue. The residue on the filter paper was dried in a forced-air oven at 105°C for over 24 hours and weighed to determine the dry matter disappearance, and burned in a furnace

(550°C, over 5 hours; Muffle furnace, Daisan General Firm, Seoul, Korea) and weighed to determine the organic matter disappearance.

Calculations and statistical analysis: The IVDMD (%) was calculated as $100 \times ([\text{dry weight of initial sample} - \text{residue} - \text{blank}] / \text{dry weight of initial sample})$ and IVOMD (%) was calculated as $100 \times ([\text{weight of organic matter of initial sample} - \text{residue} - \text{blank}] / \text{weight of organic matter of initial sample})$. Data obtained from *in vitro* experiments (IVDMD and IVOMD) were subjected to statistical analysis using the GLM procedure of SAS (SAS Institute, 2002; version 9.01). Data were analyzed by analysis of variance and Duncan's multiple range tests were used to determine significant differences ($p < 0.05$) among the treatments within each classification.

Exp. 2. Effects of dietary WDG on performance of Hanwoo steers

Experimental design: Thirty six Hanwoo steers of 21 months age (body weight [BW], 495.1 ± 91 kg) were randomly divided into three groups of 12 each and assigned to one of the three dietary treatments for 85 days (initial to mid-fattening period); i) Control (TMR), ii) WDG 10% (TMR containing 10% of WDG, as fed basis), and iii) WDG 20% (TMR containing 20% of WDG, as fed basis). The formulation and chemical composition of experimental diets for each treatment are shown in Table 1. The steers were housed in sawdust bedding-surfaced pens (4 steers/pen; 8.0 m wide \times 8.0 m length = 64 m²/pen; 16 m²/steer; 8.0 m wide linear bunk space) and were marked with a numbered tag in their ear. Feeds were offered equally at 06:00, 12:00, and 18:00 h on daily basis. They were allowed to access fresh water and mineral block without any restriction during the whole experimental period. Steers were weighed at initial, mid and final days before morning feeding of the whole experimental period. Dry matter intake (DMI) was measured every week for calculating feed conversion ratio (FCR).

Calculations and statistical analysis: Nitrogen-free extract (NFE), total digestible nutrients (TDN) and FCR value of experimental feeds were calculated as follows: i) $\text{NFE} = \% \text{DM} - (\% \text{EE} + \% \text{CP} + \% \text{ash} + \% \text{CF})$. ii) $\text{TDN} = 0.93 \times \text{CP} + 0.92 \times (1 + \text{EE} - \text{ash} - \text{CP} - \text{NDF}) + 0.75 \times (\text{NDF} - \text{acid detergent lignin [ADL]}) \times (1 - \text{ADL}^{2/3} / (\text{NDF})^{2/3})$ (Conrad et al., 1984). iii) $\text{FCR} = \text{dry matter intake (kg)} / \text{gain (kg)}$.

Data obtained from the *in vivo* trial (BW, average daily gain [ADG], DMI, and FCR) were subjected to statistical analysis using the general linear model (GLM) procedure of SAS (SAS Institute, 2002; version 9.01). Data were analyzed by analysis of variance and Duncan's multiple range tests were used to determine significant differences ($p < 0.05$) among treatments.

Table 1. Ingredients and chemical composition of TMR

Items (%)	Control	WDG 10%	WDG 20%
Concentrates ¹	40.00	40.00	38.50
WDG	0.00	10.00	20.00
Starch pulp	25.00	20.00	7.00
Corn gluten feed	9.76	5.53	5.81
Corn flake	5.87	7.89	8.99
Alfalfa hay	1.50	1.50	1.50
Tall fescue	2.00	2.00	2.00
Rye grass	7.04	7.48	7.05
Oat hay	2.00	2.00	2.00
Water	5.40	2.10	5.60
Fermentation starter ²	0.60	0.60	0.60
Limestone	0.83	0.90	0.95
Total	100	100	100
Chemical composition (DM basis, %)			
DM	68.2	67.6	65.9
CP	15.7	15.3	15.4
EE	4.7	4.7	4.6
Ash	11.5	11.5	13.0
CF	10.5	10.0	10.8
Ca	1.77	1.54	1.74
P	0.52	0.47	0.46
NDF	44.2	43.5	44.3
ADF	18.8	20.2	20.5
TDN	65.8	65.2	63.6

TMR, total mixed rations (as fed basis); WDG, wet distillers grains; DM, dry matter; CP, crude protein; EE, ether extract; CF, crude fiber; NDF, neutral detergent fiber; ADF, acid detergent fiber; TDN, total digestible nutrients.

¹ Corn (23.7%), Corn gluten feed (18.52%), Ground wheat (10%), Copra meal (10%), Corn starch (9%), Palm kernel cake (8.66%), Rice bran (6%), Soybean hull (3.4%), Molasses (5%), Salt (0.32%), Limestone (1.95%), Porphyry (1.6%), CMS (1.5%), Vitamin premix (0.2%), Mineral premix (0.15%)

² Complex of lactic acid bacteria.

RESULTS AND DISCUSSIONS

Exp. 1. Chemical analysis and *in vitro* dry matter and organic matter disappearances of WDG, DDG, and DDGS

The average nutrient composition and concentration of amino acids of WDG, DDG, and DDGS in this study are shown in Table 2 and 3, respectively. All WDG, DDG, and DDGS were produced from a blend of approximately 70% of tapioca and 30% of rice (7:3) in this study. Average DM of WDG, DDG, and DDGS were 23.1%, 93.2%, and 86.9%, respectively. Average CP concentrations of WDG, DDG, and DDGS were 32.6%, 36.7%, and 31.0% (DM basis), respectively. Waldo et al. (2009) reported that DDGS from wheat or corn (wheat 100%, corn 100% or blended [wheat 70% and corn 30%]) are a good protein source (CP, 32% to 39%, DM basis) for growing and finishing cattle. In our

Table 2. Chemical composition of WDG, DDG, and DDGS from different ethanol plants

Contents	Ethanol plant		Chemical composition (%)								
			DM	CP	EE	CF	Ash	NDF	ADF	NFE	TDN
WDG	EP ¹ -1	A	23.0	34.0	8.9	16.8	6.5	57.7	28.7	33.7	41.1
		B	25.5	37.0	9.4	11.1	5.7	59.6	31.0	36.8	41.3
	EP-2		21.0	32.6	3.2	17.6	6.4	42.9	28.8	40.1	42.0
	EP-3		25.9	32.3	3.6	20.1	13.0	52.3	31.8	31.6	39.3
	EP-4		28.0	32.5	6.1	20.2	6.8	58.0	30.7	31.4	41.7
	EP-5		25.8	27.6	4.5	11.5	6.7	60.7	33.4	33.4	41.4
	EP-6		25.5	36.4	5.0	22.6	3.9	61.7	26.0	26.0	42.8
	EP-7	A	19.8	29.3	4.2	19.7	10.2	59.6	29.7	36.6	36.9
		B	18.1	40.4	9.1	17.8	7.8	59.4	29.7	24.9	37.0
		C	19.9	26.5	3.5	17.3	4.9	59.5	30.7	47.8	38.8
D		21.2	30.2	2.4	20.9	8.2	61.2	31.9	38.3	37.8	
	Mean		23.1	32.6	5.4	17.8	7.3	57.5	30.2	34.6	40.0
DDG	EP-1	A	92.7	33.6	7.4	12.4	8.8	43.3	25.2	37.8	37.0
		B	94.5	35.9	5.4	13.3	7.3	56.2	33.0	38.1	37.8
	EP-2		93.5	37.7	2.1	13.1	3.6	47.3	28.1	43.5	39.5
	EP-3		92.0	39.6	3.5	16.6	11.9	58.9	35.8	28.4	36.3
	Mean		93.2	36.7	4.6	13.9	7.9	51.4	30.5	37.0	37.7
DDGS	EP-4		86.9	31.0	3.7	11.9	10.7	40.3	21.2	42.7	36.8

WDG, wet distillers grains; DDG, dried distillers grains; DDGS, dried distillers grains with solubles; DM, dry matter; CP, crude protein; EE, ether extract; CF, crude fiber; NDF, neutral detergent fiber; ADF, acid detergent fiber; NFE, nitrogen-free extract; TDN, total digestible nutrients.

¹ Types of ethanol plant, 1 to 7; A to D, replication with different sampling dates.

study, CP concentrations of WDG, DDG, and DDGS from tapioca 70% and rice 30% ranged from 27% to 40%, thus showed similar protein concentrations to DDGS from wheat or corn. Likewise, Quinn et al. (2011) found the average CP concentration of WDG from 70% corn and 30% sorghum was 30.0% (DM basis). According to May et al. (2010), WDG showed greater CP concentration (33.4%) from a blend of corn 90% and sorghum 10% grains than WDG

from corn 70% and sorghum 30% (CP, 30.0%).

According to the NRC (2000), methionine and lysine concentrations of corn are 0.24 and 0.21 mg/kg, respectively. In our study, concentrations of WDG were 0.47 (EP-7 A) to 1.04 (EP-1) for methionine, and 0.18 (EP-7 A) to 1.07 (EP-7 B) for lysine. Thus, WDG from tapioca and rice showed higher methionine and lysine concentrations than corn. There was no alcohol detected from WDG and DDG in this study. Itabashi et al. (1991) reported that alcohol concentration over 5% in the diet reduced ruminal fermentation of beef cattle.

The IVDMD and IVOMD of WDG, DDG, and DDGS are shown in Table 4 and 5, respectively. The DDGS had a higher quantity of water-soluble fraction than WDG and DDG, thus showed higher IVDMD (37.3%) than WDG (12.8%) and DDG (20.3%) at early incubation time (4 h; $p < 0.05$), and showed the highest IVDMD throughout the whole incubation time (0 to 72 h, $p < 0.05$). The WDG showed lower IVDMD than DDG at 0 to 12 hours of incubation ($p < 0.05$), but WDG and DDG did not show significant differences from 24 to 72 hours of incubation. The same tendency was observed in IVOMD. Likewise, Smith et al. (2013) reported that IVDMD of WDG from a blend of approximately 70% corn and 30% sorghum did not show statistical differences between control and WDG treatments (12.5%, 25.0%, and 37.5%, DM basis). These results showed that WDG, DDG, and DDGS from tapioca and rice (7:3) can be used as a feed ingredient for protein source in ruminants. In addition, considering its low price,

Table 3. Concentrations of amino acids and major minerals in WDG and DDG

Items (mg/kg)	WDG			DDG
	EP ¹ -1	EP-7		EP-1
		A	B	
Glycine	0.44	0.25	1.19	0.45
Alanine	0.50	0.25	1.31	0.49
Cysteine	0.84	0.50	0.62	0.81
Valine	0.53	0.27	1.50	0.52
Methionine	1.04	0.47	0.76	0.99
Isoleucine	0.36	0.21	1.06	0.37
Leucine	0.61	0.33	1.82	0.61
Histidine	0.27	0.23	0.65	0.23
Lysine	0.25	0.18	1.07	0.20
Arginine	0.20	0.00	1.85	0.31
Calcium (%)	0.16	0.35	0.42	0.16
Phosphorus (%)	0.26	0.40	0.43	0.40

WDG, wet distillers grains; DDG, dried distillers grains

¹ Types of ethanol plant, 1 and 7; A and B, replication with different sampling date.

Table 4. Effects of dietary WDG, DDG, and DDGS on *in vitro* DMD (%) from different ethanol plants and sampling dates

Contents	Ethanol plant		<i>In vitro</i> DMD (%)						
			0 h	4 h	8 h	12 h	24 h	48 h	72 h
WDG	EP ¹ -1	A	11.15 ^f	13.81 ^c	19.19 ^c	21.37 ^e	27.51 ^{de}	38.72 ^f	39.40 ^e
		B	12.99 ^e	15.05 ^c	13.77 ^d	25.20 ^d	26.54 ^e	39.00 ^{ef}	39.83 ^e
	EP-2		7.07 ^g	14.54 ^c	18.40 ^{cd}	23.99 ^d	43.37 ^a	48.34 ^{bc}	56.22 ^a
	EP-3		5.07 ⁱ	10.94 ^d	15.23 ^{cd}	20.68 ^e	32.08 ^{bc}	45.03 ^{cd}	52.18 ^b
	EP-4		7.59 ^g	9.58 ^d	16.49 ^{cd}	18.47 ^f	30.42 ^{cd}	47.24 ^{bcd}	47.75 ^c
		Mean	8.77 ^C	12.78 ^C	16.62 ^C	21.94 ^C	31.98 ^B	43.67 ^B	47.08 ^B
DDG	EP-1	A	23.36 ^b	21.31 ^b	30.28 ^b	35.96 ^b	35.51 ^b	42.98 ^{de}	43.80 ^d
		B	17.54 ^c	22.29 ^b	19.97 ^c	25.49 ^d	31.15 ^{cd}	35.12 ^f	39.35 ^e
	EP-2		15.68 ^d	22.93 ^b	25.91 ^b	30.86 ^c	44.47 ^a	50.06 ^b	56.13 ^a
	EP-3		6.13 ^h	14.79 ^c	19.05 ^c	18.57 ^f	25.08 ^e	35.35 ^f	40.65 ^{de}
		Mean	15.68 ^B	20.33 ^B	23.80 ^B	27.72 ^B	34.05 ^B	40.88 ^B	44.98 ^B
DDGS	EP-4		35.88 ^a	37.26 ^a	43.57 ^a	44.97 ^a	46.73 ^a	57.13 ^a	58.66 ^a
		Mean	35.88 ^A	37.26 ^A	43.57 ^A	44.97 ^A	46.73 ^A	57.13 ^A	58.66 ^A
SEM			0.23	1.35	6.18	1.00	4.09	5.10	4.83

WDG, wet distillers grains; DDG, dried distillers grains; DDGS, dried distillers grains with solubles; DMD, dry matter disappearance; SEM, standard error of means.

¹ Types of ethanol plant, 1 to 4; A and B, replication with different sampling date.

^{A-C} Means within a column without a common superscript capital letter differ ($p < 0.05$).

^{a-i} Means within a column without a common superscript letter differ ($p < 0.05$).

WDG may be a more useful feed ingredient than DDG and DDGS. The price of WDG (KRW 25/kg) is much cheaper than DDG (KRW 280/kg) and DDGS (KRW 270/kg) due to the absence of drying process.

Exp. 2. Effects of dietary WDG on the performance of Hanwoo steers

The BW, ADG, DMI, and FCR of control and WDG treatments are presented in Table 6. In the middle of the

experimental period (42 days), BW of control, WDG 10% and 20% were 527.8, 518.2, and 529.9 kg, respectively. Final BW (85 days) of WDG 10% (549.7 kg) was numerically lower than that of control (562.0 kg) and WDG 20% (561.8 kg), but there were no significant differences among treatments. Thus, BW of control and WDG treatments did not show any statistical difference during the whole experimental period.

The ADG of control, WDG 10% and 20% in phase 1

Table 5. Effects of dietary WDG, DDG, and DDGS on *in vitro* OMD (%) from different ethanol plants and sampling dates

Contents	Ethanol plant		<i>In vitro</i> OMD (%)						
			0 h	4 h	8 h	12 h	24 h	48 h	72 h
WDG	EP ¹ -1	A	12.02 ^e	14.82 ^{de}	20.45 ^c	22.86 ^f	30.76 ^{de}	42.78 ^{de}	42.98 ^e
		B	15.01 ^c	16.22 ^d	14.73 ^d	26.83 ^{de}	29.28 ^{de}	43.69 ^{cd}	43.83 ^e
	EP-2		7.55 ^f	15.59 ^d	19.70 ^{cd}	25.51 ^e	46.89 ^a	54.27 ^a	61.33 ^b
	EP-3		5.32 ^f	12.62 ^{ef}	16.70 ^{cd}	22.90 ^f	37.00 ^{bc}	51.41 ^b	59.68 ^b
	EP-4		8.00 ^f	10.59 ^f	17.62 ^{cd}	20.04 ^g	32.53 ^{cd}	51.91 ^b	52.68 ^c
		Mean	9.98 ^C	14.81 ^C	17.90 ^C	24.52 ^C	35.98 ^C	48.04 ^B	51.96 ^B
DDG	EP-1	A	25.58 ^b	21.33 ^c	31.97 ^b	38.09 ^b	38.20 ^b	47.06 ^c	47.58 ^d
		B	19.06 ^c	24.51 ^b	21.54 ^c	27.54 ^d	33.58 ^{bc}	38.96 ^c	42.71 ^e
	EP-2		16.40 ^{cd}	24.03 ^b	27.77 ^b	32.32 ^c	48.16 ^a	53.78 ^a	61.32 ^b
	EP-3		6.58 ^f	17.32 ^d	21.00 ^c	19.81 ^g	27.96 ^e	40.45 ^{de}	45.70 ^{de}
		Mean	16.78 ^B	21.80 ^B	25.57 ^B	29.44 ^B	36.97 ^B	45.06 ^B	49.33 ^B
DDGS	EP-4		37.80 ^a	40.79 ^a	46.70 ^a	47.93 ^a	49.02 ^a	63.03 ^a	65.15 ^a
		Mean	37.80 ^A	40.79 ^A	46.70 ^A	47.93 ^A	49.02 ^A	63.03 ^A	62.15 ^A
SEM			2.42	1.60	4.92	2.85	3.96	4.97	3.29

WDG, wet distillers grains; DDG, dried distillers grains; DDGS, dried distillers grains with solubles; OMD, organic matter disappearance; SEM, standard error of means.

¹ Types of ethanol plant, 1 to 4; A and B, replication with different sampling date.

^{A-C} Means within a column without a common superscript capital letter differ ($p < 0.05$).

^{a-i} Means within a column without a common superscript letter differ ($p < 0.05$).

Table 6. Effects of dietary WDG for TMR ingredients on BW, ADG, DMI, and FCR of Hanwoo steers

Items	Control	WDG 10%	WDG 20%	SEM
BW (kg)				
0 d	497.6	488.2	499.4	14.03
42 d	527.8	518.2	529.9	14.53
85 d	562.0	549.7	561.8	14.68
ADG (kg/d)				
1 to 42 d	0.71	0.72	0.73	0.04
43 to 85 d	0.82	0.75	0.76	0.04
1 to 85 d	0.77	0.73	0.74	0.03
DMI (kg/d)				
1 to 42 d	9.12	8.95	8.61	0.15
43 to 85 d	9.55	9.46	9.10	0.07
1 to 85 d	9.34	9.21	8.86	0.09
FCR				
1 to 42 d	13.0	12.9	12.0	0.91
43 to 85 d	12.9	13.4	12.1	1.02
1 to 85 d	13.0	13.2	12.1	0.87

WDG, wet distillers grains; TMR, total mixed rations; BW, body weight; ADG, average daily gain; DMI, dry matter intake; FCR, feed conversion ratio (Feed intake/kg gain); SEM, standard error of means.

(0.71, 0.72, and 0.73 kg, respectively; 1 to 42 days) and 2 (0.82, 0.75, and 0.76 kg, respectively; 43 to 85 days) did not show any statistical differences. Thus, ADG of control and WDG treatments did not show any difference during the whole experimental period (WDG, 0.77 kg/d; DDG, 0.73 kg/d; DDGS, 0.74 kg/d). Likewise, Larson et al. (1993) reported that WDG making up to 40% of the diets (DM basis, corn silage and alfalfa hay) did not affect ADG of finishing steers. Uwituzze et al. (2010) also reported that there were no differences as a result of roughage source (alfalfa hay and corn silage) in BW and ADG with finishing diets containing 25% corn and sorghum-based DDG (DM basis). Similarly, when May (2008) fed 25% corn and sorghum-based DDGS (DM basis) in steam-flaked corn diets, DMI was not affected by the level of DDGS. Maximum inclusion level of WDG as calculated by the feed formulation program (NIAS, Korean feeding standard program for Hanwoo, 2012a) in this study was 28% (as fed basis) because to meet the requirement of finishing Hanwoo cattle (NIAS, Korean feeding standard for Hanwoo, 2012b) the relatively high concentrations of CP and low TDN of WDG limit a higher inclusion level.

Average DMI of control and WDG treatments were 9.1 kg/d during the whole experimental period, and did not show any statistical difference between control and WDG treatments. In contrast to our results, Larson et al. (1993) reported a linear decrease in DMI when corn-based WDG increased from 0% to 40% (DM basis) in the diets, but did not affect ADG. In the whole experimental period (1 to 85 days), FCR of control, WDG 10% and 20% were 13.0, 13.2,

and 12.1 feed/gain/kg, respectively. Relatively higher FCR values along with low ADG were observed in our study, probably due to the relatively lower TDN and slightly higher CP concentrations of TMR. According to NIAS (Korean feeding standard for Hanwoo, 2012a), recommended levels of CP and TDN in feeds of Hanwoo steers at early fattening period are 13% to 14% and 69% to 70%, respectively. In this study, average concentrations of TDN and CP were 64.9% and 15.5%, respectively. Probably, an unbalanced energy:protein ratio of feeds may lead to high FCR due to the wasted N metabolism.

In summary of the fattening period trial, BW, ADG, DMI, and FCR of control and WDG treatments during the whole experimental period (1 to 85 days) did not show any statistical difference. Thus, the use of WDG up to 20% (as fed basis) in TMR did not show any negative effect on the performance of Hanwoo steers in early to mid-fattening period.

CONCLUSION

Considering CP concentrations, IVDMD and low price, WDG from tapioca and rice (7:3) can be a more useful feed ingredient for ruminants than either DDG or DDGS. The use of WDG from tapioca and rice up to 20% (as fed basis) in TMR did not show any negative effect on the performance of Hanwoo steers (in BW, ADG, DMI, and FCR) in the initial to mid-fattening period. Therefore, WDG (up to 20% in TMR, as fed basis) from tapioca and rice (7:3) can be safely used as a feed ingredient for Hanwoo steers.

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