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Breed and Season-Specific Methane Conversion Factors Influence Methane Emission Factor for Enteric Methane of Dairy Steers

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Abstract: This study determined the breed and the season-specific methane (CH_4) conversion factor (Y_m) and the emission factor (EF) for the enteric CH_4 of dairy steers. The Y_m values for Holstein and Jersey steers at different seasons were calculated using the IPCC 2006 equations by incorporating the input and/or output value of the chemical composition of feed, methane production, methane yield, dry matter intake, and methane energy emission. EFs were categorized into five types depending on the 2019 refinement to the IPCC 2006 Tier 2 equations used. EF_A was calculated from Equation 10.21A (New), while other EFs were estimated from the Equation 10.21 which were designated according to the gross energy intake (GEI) and Y_m as EF_B (GEI_i and Y_m), EF_C (GEI_{ii} and Y_m), EF_D (GEI_{ii} and $Y_{m\ (6.3)}$), and EF_E (GEI_{ii} and $Y_{m\ (4.0)}$). The calculated overall Y_m for Holstein and Jersey steers were 4.90 and 7.49, while the recorded EF of group EF_A were 56.44 and 67.42 kg CH_4/head/year for Holstein and Jersey steers, respectively. For Holstein steers, EF_D was overestimated (75.91 vs. 48.20~58.15), while in Jersey steers, the EF_F underestimated the EF (kg CH_4/head/year) compared to others (40.15 vs. 63.24~73.28) ($p < 0.05$). Mixed analysis revealed that the breed influenced EFs of all the EF groups, while the season, and the breed × the season influenced EFs of group EF_C, EF_D, and EF_F. The overall results recommended using the breed-specific Y_m for the estimation of the EF for enteric methane in dairy steers.

Keywords: enteric methane emission; methane conversion factor; methane emission factor; Holstein steers; Jersey steers

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1. Introduction

Methane (CH_4), a greenhouse gas (GHG), has a global warming potential 28 times higher than CO_2 and N_2O [1]. Livestock produces around 18% of the anthropogenic GHGs [2]. CH_4 production also represents 2–12% of the dietary gross energy losses [3]. Therefore, mitigation of enteric CH_4 is of great concern, and several mitigation strategies have so far been practiced. However, the methane conversion factor (Y_m; % of gross energy intake) might affect the CH_4 emission factor (EF; kg CH_4/head/year), through a higher or lower estimation of it than the actual EF for enteric CH_4 in cattle [4]. To fulfill the Paris agreement on the reduction of global warming up to 1.5 °C, many countries have set their domestic emission reduction, especially from the enteric emission, to certain percentages by 2030 to achieve the carbon net zero condition. However, the wrong selection of the Y_m that leads to the wrong estimation of the EF will greatly hamper the achievement of the target set by the Paris agreement. The Intergovernmental Panel on Climate Change (IPCC) calculated the Tier 1 default value of the EF and developed guideline equations for the calculation of the EF using the Tier 2 recommended default value of the Y_m [5,6]. Many countries use the IPCC Tier 1 default EF or that calculated by using the IPCC Tier 2 equations, while some countries, such as the EU, Germany, Japan, Australia, and the Netherlands, have already developed a country-specific Tier 3 model [7]. The Republic of Korea also estimated the EF based on the IPCC 2006 and the 2019 Tier 2 approach for dairy cattle and Korean beef cattle (Hanwoo) [8–11]. Ibidhi et al. [10] reported the EF for the enteric methane in Korean dairy cattle as 139, 83, and 33 kg/head/year for milking cows, heifers, and growing animals, respectively. They used the IPCC Tier 2 recommended Y_m of 6.3 for growing animals and heifers, while using 5.8 for milking cows. They only considered one dairy breed (Holstein), and therefore did not consider the breed-specific Y_m. The steers of dairy breeds significantly contributes to beef production globally [12,13]. Therefore, the enteric emission of dairy steers should be taken into consideration to mitigate greenhouse gas emission. However, the EF value for dairy breed steers has not yet been documented. Seasonal influence of the Y_m on the EF has not been studied yet. Furthermore, a comparative assessment of different emission categories according to the different Y_m values has not been performed. Therefore, this is the first approach to investigate the influence of breed-specific and season-specific Y_m on the EF for enteric CH_4 of dairy steers in Korea to avoid the chances of incorrect estimation of the EF.

2. Materials and Methods

2.1. Determination of Methane Conversion Factor (Y_m)

For determining the methane conversion factor (Ym), input data were gathered from the raw data of our previous studies, which are presented in Tables 1 and 2 [14,15]. A total of 48 measurement data (including 24 Holstein and 24 Jersey steers) of four different seasons, winter, spring, summer, and autumn (six per breed in each season), were used to determine the Ym following the IPCC (2006) equations [5]. In addition to the season, this study included the age group of dairy steers such as 1.5–2 years and >2 years.

Table 1. Input data of chemical composition of feed.

Parameters	Winter	Spring	Summer	Autumn	Overall	References
DM % (g)	66.30 (663.00)	66.30 (663.00)	66.30 (663.00)	73.06 (730.60)	69.68 (696.80)	[14,15]
CP % (g)	17.99 (119.27)	17.99 (119.27)	17.99 (119.27)	19.86 (145.10)	18.93 (132.19)	[14,15]
CF % (g)	12.55 (83.21)	12.55 (83.21)	12.55 (83.21)	9.23 (67.43)	10.89 (75.32)	[14,15]
EE % (g)	4.44 (29.44)	4.44 (29.44)	4.44 (29.44)	4.60 (33.61)	4.52 (31.52)	[14,15]
Ash % (g)	7.42 (49.19)	7.42 (49.19)	7.42 (49.19)	7.56 (55.23)	7.49 (52.21)	[14,15]
ADF %	16.91	16.91	16.91	14.29	15.60	[14,15]

DM, dry matter; CP, crude protein; CF, crude fiber; EE, ether extract; ADF, acid detergent fiber.

The Y_m was calculated as,

$$Y_m = [(MEE/GEIi) \times 100] \quad (1)$$

$$MEE = (MP/1000) \times 55.65 \quad (2)$$

$$GEI_i = DMI \times GE_i \quad (3)$$

$$DMI = MP/MY \quad (4)$$

where, Y_m, methane conversion factor (% of gross energy intake; GEI); MEE, methane emission energy (MJ/d); GEI_i, gross energy intake (MJ/d); MP = methane production (g/d) which was measured by the GreenFeed system; the factor 55.65 (MJ/kg CH_4) is the energy content of the methane; DMI = dry matter intake (Kg/d); GE_i = gross energy content of the feed (MJ kg^{-1} DM); MY = methane yield (g CH_4/Kg DMI).

The GEi was calculated according to MAFF [16] as,

$$GEi = 0.0226CP + 0.0407EE + 0.0192CF + 0.0177NFE \quad (5)$$

where, GEi = gross energy content of the feed (MJ kg^{-1} DM); CP = crude protein (g/kg DM); EE = ether extract (g/kg DM); CF = crude fiber (g/kg DM); NFE = nitrogen free extract (g/kg DM), calculated from [NFE% = 100% − (% EE + % CP + % Ash + % CF)].

Table 2. Input data for the calculation of gross energy intake, methane conversion factor, and methane emission factor.

Breed	Parameters	1.5–2 Years			>2 Years			Overall	References
		Winter	Spring	Mean	Summer	Autumn	Mean		
Holstein	MP (g/d)	162.42	165.74	164.31	129.55	165.46	144.94	154.63	[14,15]
	MY (g/Kg DMI)	12.93	10.95	11.80	10.49	9.69	10.15	10.97	[14,15]
	BW (Kg)	529.72	593.01	565.89	673.65	718.34	692.80	629.34	[14,15]
	MBW (Kg)	680.00	680.00	680.00	680.00	680.00	680.00	680.00	[17]
	WG (Kg/d)	0.86	1.72	1.35	0.81	1.35	1.04	1.20	[14,15]
Jersey	MP (g/d)	154.92	180.56	167.74	187.30	226.49	204.10	184.71	[14,15]
	MY (g/Kg DMI)	18.32	16.40	17.36	15.60	16.89	16.16	16.80	[14,15]
	BW (Kg)	389.74	439.03	414.39	515.73	567.47	537.91	472.03	[14,15]
	MBW (Kg)	470.00	470.00	470.00	470.00	470.00	470.00	470.00	[18]
	WG (Kg/d)	0.32	1.38	0.85	1.15	1.01	1.09	0.96	[14,15]
Both	Cf_i	0.32	0.32	0.32	0.32	0.32	0.32	0.32	[6]
	C	1.00	1.00	1.00	1.00	1.00	1.00	1.00	[6]

GEI, gross energy intake; Y_m, methane conversion factor; EF, methane emission factor; MP, methane production; MY, methane yield; DMI, dry matter intake; BW, body weight; MBW, mature bodyweight; WG, average weight gain of the animal population; Cf_i, a coefficient for calculating NE_m; C, a coefficient with a value of 1.0 for castrated.

2.2. Determination of Methane Emission Factor (EF)

For determining the methane emission factor (EF), input data were retrieved from the raw data of our previous experiments and other sources, which are presented in Tables 1 and 2 [6,14,15,17,18]. Based on the 2019 Refinement to the [1] Tier 2 [6], the EF was calculated from the recorded value as well as the GEI prediction equations and categorized into the following five types: EF_A, EF_B, EF_C, EF_D, and EF_E.

$$EF_A = [DMI \times (MY/1000) \times 365] \text{ [IPCC Tier 2, Equation 10.21A (New)]} \quad (6)$$

$$EF_B = \{GEI_i \times (Y_m/100) \times 365\}/55.65 \text{ [IPCC Tier 2 Equation 10.21]} \quad (7)$$

$$EF_C = \{GEI_{ii} \times (Y_m/100) \times 365\}/55.65 \text{ [IPCC Tier 2 Equation 10.21]} \quad (8)$$

$$EF_D = \{GEI_{ii} \times (Y_{m(6.3)}/100) \times 365\}/55.65 \text{ [IPCC Tier 2 Equation 10.21]} \quad (9)$$

$$EF_E = \{GEI_{ii} \times (Y_{m(4.0)}/100) \times 365\}/55.65 \text{ [IPCC Tier 2 Equation 10.21]} \quad (10)$$

where EF_A = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21A (New); EF_B = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_i and Y_m; EF_C = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_{ii} and $Y_{m.}$; EF_D = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_{ii} and $Y_{m\,(6.3)}$; EF_E = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_{ii} and $Y_{m\,(4.0)}$; DMI = dry matter intake (Kg/d); MY = methane yield (g/Kg DMI); MP = methane production (g/d); GEI_i = gross energy intake (MJ/d) calculated from GE of feed; Y_m = methane conversion factor (developed); GEI_{ii} = gross energy intake (MJ/d) calculated from IPCC prediction equation; $Y_{m\,(6.3)}$ = methane conversion factor 6.3 (DE 62–71%); $Y_{m\,(4.0)}$ = methane conversion factor 4.0 (DE $\geq$ 72%); The factor 55.65 (MJ/kg CH_4) is the energy content of the methane.

The GEI_{ii} was calculated as,

$$GEI_{ii} = [\{(NE_m/REM) + (NE_g/REG)\}/DE] \quad (11)$$

where GEI_{ii} = gross energy intake (MJ/d); NE_m = net energy required by the animal for maintenance, MJ day^{-1}; NE_g = net energy needed for growth, MJ day^{-1}; REM = ratio of net energy available in the diet for maintenance to digestible energy; REG = ratio of net energy available for growth in a diet to digestible energy consumed; DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy; DE/GE).

The NE_m was calculated as,

$$NE_m = Cf_i \times (\text{Weight})^{0.75} \quad (12)$$

where NE_m = net energy required by the animal for maintenance, MJ day^{-1}; Cf_i = coefficient of 0.322 for steers (coefficients for calculating NE_m), MJ day^{-1} kg^{-1}; Weight = live-weight of animal, kg.

The NE_g was calculated as,

$$NE_g = [22.02 \times \{BW/(C \times MW)\}^{0.75} \times WG^{1.097}] \quad (13)$$

where NE_g = net energy needed for growth, MJ day^{-1}; BW = average live body weight (BW) of animals in the population (kg); C = a coefficient with a value of 1.0 for castrated cattle; MW = mature body weight of an adult animal in moderate body condition, kg; WG = average daily weight gain of the animals in the population, kg day^{-1}.

The REM was calculated as,

$$REM = [1.123 - (4.092 \times 10^{-3} \times DE) + \{1.126 \times 10^{-5} \times (DE)^2\} - (25.4/DE)] \quad (14)$$

where REM = ratio of net energy available in the diet for maintenance to digestible energy; DE = digestible energy of feed expressed as a percentage of gross energy [(DE/GE) ×100].

The REG was calculated as,

$$REG = [1.164 - (5.16 \times 10^{-3} \times DE) + \{1.308 \times 10^{-5} \times (DE)^2\} - (37.4/DE)] \quad (15)$$

where REG = ratio of net energy available for growth in a diet to digestible energy consumed; DE = digestible energy of feed expressed as a percentage of gross energy.

The DE (as %) was calculated as,

$$DE\ (\text{as }\%) = (DE/GE) \times 100 \quad (16)$$

where DE (as %) = digestible energy as a percentage of gross energy; DE = digestible energy (MJ/Kg); GE = gross energy content (18.45 MJ/Kg).

The DE was calculated according to NRC [19] as,

$$DE = [(TDN\% \times 0.04409) \times 4.184] \quad (17)$$

where DE = digestible energy (MJ/Kg); TDN = total digestible nutrient (% of DM); The 4.184 is the conversion factor from Mcal/Kg to MJ/Kg.

The TDN was calculated as,

$$TDN = 88.936 - (0.653 \times ADF) \quad (18)$$

where TDN = total digestible nutrient (% of DM); ADF = acid detergent fiber (% of DM).

2.3. Statistical Analysis

The data of the different EFs in each breed, season, and age group were analyzed using the general linear model (GLM) of SAS (version 9.4; SAS Institute Inc., Cary, NC, USA) along with Duncan's multiple range test [20]. Likewise, the data of different seasons, and age groups in each breed were also analyzed using the general linear model (GLM) of SAS (version 9.4; SAS Institute Inc., Cary, NC, USA) along with Duncan's multiple range test [20]. Additional analysis of the different EFs data based on breed, season, and the interaction between breed and season were performed using the Mixed procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC, USA) [20]. The model included the fixed effects of breed, season, and an interaction term of breed and season, and the random effects included individuals nested within breeds. Statistical significance was set at $p < 0.05$.

3. Results

The calculated values of DMI (kg/d), GE_i (MJ/kg), GEI_i (MJ/d), MEE (MJ/d), Y_m, TDN %, DE (both MJ/kg and %), NE_m (MJ/d), NE_g (MJ/d), REM%, REG%, and GEI_{ii} (MJ/d) of both breeds are presented in Table 3. The overall calculated Y_m for Holstein and Jersey steers were 4.90 and 7.49, respectively. In terms of season, the calculated Y_m of Holstein in winter, spring, summer, and autumn were 5.87, 4.97, 4.77, and 3.98, respectively. The calculated Y_m of Jersey were 8.32, 7.45, 7.09, and 6.94 in winter, spring, summer, and autumn, respectively. The overall estimated MEE, NE_m, and NE_g for Holstein were 8.61, 40.41, and 25.38 (MJ/d), respectively, while the values of the same parameters for Jersey were 10.28, 32.54, and 21.87 (MJ/d), respectively. Furthermore, the overall calculated GEI_i and GEI_{ii} of Holstein were 178.97 and 183.72 (MJ/d), while the values of the same parameters for Jersey were 139.88 and 153.05 (MJ/d), respectively.

Table 3. Output data for the calculation of gross energy intake, methane conversion factor, and methane emission factor.

Breed	Parameters	1.5–2 Years			>2 Years			Overall
		Winter	Spring	Mean	Summer	Autumn	Mean	
Holstein	DMI (Kg/d)	12.64	15.07	14.03	12.41	17.11	14.42	14.22
	GEI_i (MJ/d)	154.81	184.57	171.82	151.98	231.65	186.12	178.97
	MEE (MJ/d)	9.04	9.22	9.14	7.21	9.21	8.07	8.61
	Y_m	5.87	4.97	5.36	4.77	3.98	4.43	4.90
	NE_m (MJ/d)	35.55	38.69	37.35	42.58	44.68	43.48	40.41
	NE_g (MJ/d)	15.46	35.97	27.18	17.27	32.02	23.59	25.38
	REM%	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	REG%	0.36	0.36	0.36	0.36	0.37	0.36	0.36
	GEI_{ii} (MJ/d)	138.49	218.75	184.35	161.41	211.97	183.08	183.72
Jersey	DMI (Kg/d)	8.49	11.15	9.82	12.01	13.48	12.64	11.13
	GEI_i (MJ/d)	103.96	136.58	120.27	147.11	182.51	162.28	139.88
	MEE (MJ/d)	8.62	10.05	9.33	10.42	12.60	11.36	10.28
	Y_m	8.32	7.45	7.89	7.09	6.94	7.03	7.49
	NE_m (MJ/d)	28.23	30.87	29.55	34.83	37.43	35.94	32.54
	NE_g (MJ/d)	5.41	29.76	17.58	27.59	25.66	26.76	21.87
	REM%	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	REG%	0.36	0.36	0.36	0.36	0.37	0.36	0.36
	GEI_{ii} (MJ/d)	85.58	178.29	131.93	179.89	173.59	177.19	153.05
Both	GE_i (MJ/Kg)	12.25	12.25	12.25	12.25	13.54	12.89	12.89
	TDN %	77.89	77.89	77.89	77.89	79.60	78.75	78.75
	DE (MJ/kg)	14.37	14.37	14.37	14.37	14.68	14.53	12.89
	DE (as %)	77.88	77.88	77.88	77.88	79.59	78.74	78.74

GEI, gross energy intake; Y_m, methane conversion factor; EF, methane emission factor; GE_i = gross energy content of feed; TDN = total digestible nutrient; DE = digestible energy; DMI = dry matter intake; GEI_i = gross energy intake calculated from GE_i of feed; MEE, methane energy emission; Y_m, methane conversion factor (% of GEI); NE_m, net energy for maintenance; NE_g, net energy for growth; REM, ratio of net energy available in diet for maintenance to digestible energy; REG, ratio of net energy available for growth in a diet to digestible energy consumed; GEI_{ii}, gross energy intake calculated from the IPCC Tier 2 prediction equation.

According to the IPCC Tier 2 equations, the overall calculated EFs varied significantly depending on the type of EF (Table 4). The calculated overall EF of Holstein steers for the types EF_A, EF_B, EF_C, and EF_F were 56.44, 56.44, 58.15, and 48.20 (kg CH_4/head/year), respectively, which were lower than the type EF_D (75.91 kg CH_4/head/year; $p < 0.05$). Except for winter, all other seasons showed similar trends in terms of the different types of EF in Holstein steers ($p < 0.05$). The type EF_F of Jersey steers had the lowest EF value (40.15 kg CH_4/head/year) compared to the others (67.42, 67.42, 73.28, and 63.24 kg CH_4/head/year for EF_A, EF_B, EF_C, and EF_D, respectively; $p < 0.05$). Similar trends were observed in different seasons among the different types of EF in Jersey steers ($p < 0.05$). In terms of season, the EF_D and EF_F of Holstein steers varied significantly among different seasons ($p < 0.05$). Likewise, the EF_C, EF_D and EF_F of Jersey steers showed significant differences among different seasons ($p < 0.05$). In terms of age group, the EF_D of the Holstein steers exhibited the highest value, while the EF_F of the Jersey steers exhibited the lowest value compared to other EF types in both age groups (1.5–2 years and >2 years). The mixed procedure of SAS revealed that breed significantly influenced the EF in all five EF groups, while season, and the interaction between breed and season, significantly influenced the EF of group EF_C, EF_D and EF_F ($p < 0.05$). Though the EF of group EF_A, EF_B and EF_C were significantly influenced by the interaction between breed and age ($p < 0.05$); however, age group had no influence on the EF of different EF groups ($p > 0.05$).

Table 4. Emission factors (kg CH_4/head/year) of Holstein and Jersey steers according to the IPCC Tier 2 equations.

Breed	Season or Age	EF_A	EF_B	EF_C	EF_D	EF_E	SEM	*p* Value
Holstein	Overall	56.44 ^{b}	56.44 ^{b}	58.15 ^{b}	75.91 ^{a}	48.20 ^{b}	3.296	<0.0001
Jersey	Overall	67.42 ^{a}	67.42 ^{a}	73.28 ^{a}	63.24 ^{a}	40.15 ^{b}	3.996	<0.0001
Holstein	Winter	59.28 ^{a}	59.28 ^{a}	53.39 ^{a}	57.23 ^{az}	36.33 ^{bz}	1.811	<0.0001
	Spring	60.49 ^{b}	60.49 ^{b}	71.56 ^{b}	90.39 ^{ax}	57.39 ^{bx}	3.948	0.001
	Summer	47.29	47.29	50.40	66.70 ^{y}	42.35 ^{y}	4.424	0.058
	Autumn	60.40 ^{b}	60.40 ^{b}	55.38 ^{b}	87.59 ^{ax}	55.61 ^{bx}	5.121	0.026
	SEM	6.154	6.154	6.082	1.830	1.162		
	p value	0.383	0.383	0.153	<0.0001	<0.0001		
Jersey	Winter	56.55 ^{a}	56.55 ^{a}	46.36 ^{by}	35.36 ^{by}	22.45 ^{cy}	2.769	<0.0001
	Spring	65.90 ^{ab}	65.90 ^{ab}	86.37 ^{ax}	73.67 ^{ax}	46.78 ^{bx}	5.518	0.009
	Summer	68.37 ^{a}	68.37 ^{a}	83.12 ^{ax}	74.33 ^{abx}	47.20 ^{cx}	3.610	<0.0001
	Autumn	82.67 ^{a}	82.67 ^{a}	78.59 ^{ax}	71.73 ^{ax}	45.54 ^{bx}	5.209	0.007
	SEM	5.754	5.754	6.418	0.737	0.468		
	p value	0.088	0.088	0.004	<0.0001	<0.0001		
SEM		5.954	5.954	6.250	1.283	0.815		
Breed		0.017	0.017	0.003	<0.0001	<0.0001		
Season		0.155	0.155	0.003	<0.0001	<0.0001		
Breed × Season		0.167	0.167	0.045	<0.0001	<0.0001		
Holstein	1.5–2 years	59.97 ^{bc}	59.97 ^{bc}	63.77 ^{ab}	76.18 ^{a}	48.37 ^{c}	4.494	0.006
	>2 years	52.91 ^{b}	52.91 ^{b}	52.54 ^{b}	75.65 ^{a}	48.03 ^{b}	4.618	0.002
	SEM	4.335	4.335	5.131	5.492	3.488		
	p value	0.287	0.287	0.148	0.949	0.948		
Jersey	1.5–2 years	61.22 ^{a}	61.22 ^{a}	66.36 ^{a}	54.52 ^{ay}	34.61 ^{by}	5.911	0.009
	>2 years	74.50 ^{a}	74.50 ^{a}	81.18 ^{a}	73.22 ^{ax}	46.49 ^{bx}	3.211	<0.0001
	SEM	4.625	4.625	6.291	4.442	2.821		
	p value	0.063	0.063	0.170	0.036	0.036		
SEM		4.480	4.480	5.711	4.967	3.154		
Breed		0.019	0.019	0.021	0.043	0.043		
Age		0.503	0.503	0.780	0.120	0.120		

Table 4. *Cont.*

Breed	Season or Age	EF_A	EF_B	EF_C	EF_D	EF_E	SEM	*p* Value
	Breed × Age	0.035	0.035	0.051	0.101	0.101		

EF_A = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21A (New); EF_B = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_i and Y_m; EF_C = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_{ii} and Y_m; EF_D = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_{ii} and $Y_{m\,(6.3)}$; EF_E = methane emission factor (kg CH_4/head/year) based on the IPCC Tier 2 Equation 10.21 with GEI_{ii} and $Y_{m\,(4.0)}$; $^{a, b, c}$ in the same row indicate the significant differences ($p < 0.05$) of data among five different EFs. $^{x, y, z}$ in the same column indicate the significant differences ($p < 0.05$) of data among four seasons, and between two age groups in each breed; SEM, standard error of the mean.

4. Discussion

Enteric CH_4 emission from livestock has a significant role in global warming. The amount of CH_4 emission (kg) per animal per year is designated as the EF, while the percentage of gross energy intake used for the conversion of CH_4 is represented as the Y_m. This Y_m is the crucial component for the calculation of the EF for enteric CH_4. For the reduction of possible errors in the estimates of Y_m and the EF for different livestock, and feed combinations, a country or a region specific Y_m is developed [21]. However, breed and/or season-specific Y_m and the EF for enteric CH_4 are less documented. Therefore, this is the first attempt to determine breed and season-specific Y_m for dairy steers to minimize the errors while estimating the EF for enteric CH_4. The Y_m is one of the key components for calculating the EF according to the IPCC Tier 2 Equation 10.21 of the 2019 Refinement to the IPCC 2006. The IPCC Tier 2 recommended the Y_m for non-dairy cattle to be 6.3% and 4.0%, depending on the DE% of 62–71 and $\geq$72, respectively [6]. Lee et al. [22] calculated the Y_m for the dairy cattle of Korea as 6.43%, 7.33%, and 5.13% in calf, heifer, and lactating cow, respectively. Kaewpila and Sommart [4] also developed the Y_m for Zebu beef cattle fed low-quality crop residues and by-products in tropical regions through meta-analysis. They reported that the default IPCC Tier 2 Y_m (6.5 ± 1.0%) underestimated the Y_m up to 26.1% compared to the value of refined model (8.4 ± 0.4%). Likewise, in the present study, the overall calculated Y_m was 4.90 for Holstein steers, which was 22.22% lower than Y_m value of 6.3%, and 22.50% higher than Y_m value of 4.0%. In contrast, the overall calculated Y_m for Jersey steers was 7.49, which was 18.89% and 87.25% higher than Y_m values of 6.3% and 4.0%, respectively. The variation in the Y_m was also observed while considering season. The reason for the variation in the Y_m might be due to the GE content of the feed, the DMI, and the MEE, which varied in both breeds as well as in different seasons. The GE content, the feed-specific factor, varied among different seasons; however, the DMI by different breeds influences the GEI that leads to the variation of Y_m by breeds. The MEE, another crucial component to calculate the Y_m, depends on the amount of MP by different breeds.

To check the feasibility of the breed-specific Y_m of 4.9 and 7.49 for Holstein and Jersey steers, respectively, we calculated the EFs according to the IPCC Tier 2 Equation 10.21A (New) and Equation 10.21 of 2019 Refinement to the IPCC 2006. The Republic of Korea uses the default EF for enteric methane in North America due to similar farm management strategies, and the current default IPCC Tier 1 and Tier 1a EF for mature male/females, calves, growing steers/heifers, and feedlot non-dairy cattle is 64 kg/head/year [6], which were 53 and 47 in 2006 and 1997, respectively [5,23]. The EF of Korean beef cattle (Hanwoo) was calculated earlier based on the IPCC Tier 2 of the 2019 Refinement to the IPCC 2006, and was found to be 47, 61, and 43 kg/head/year for heifers, males (>1 year), and males (<1 year), respectively [8]. Jo et al. [9], calculated the EF for enteric methane of growing-finishing Hanwoo steers according to IPCC 2006 Tier 2, Tier 2DMI, and the Japanese Tier 3 model and found the values to be 43.4, 46.8, and 57.1 Kg/head/year, respectively, for growing steers, while 33.9, 29.3, and 72 Kg/head/year, respectively, for finishing steers. Widiawati et al., [24] reported that the IPCC 2006 Tier 2 prediction of the EF for enteric CH_4 of beef cattle in Indonesia was 33.14 kg/head/year which was lower than the default value for Asian beef cattle (47 kg/head/year). However, the above mentioned study did not consider dairy steers, and used the IPCC recommended default Y_m for the estimation of the EF. In this study, we calculated the EF of Holstein and Jersey steers based on the observed IPCC Tier 2 Equation 10.21A (New) and Equation 10.21 of the 2019 Refinement to the IPCC 2006 and categorized the EF into the following five types: EF_A, EF_B, EF_C, EF_D, and EF_E. In the case of Holstein steers, the overall EF_A (calculated from the IPCC Tier 2, Equation 10.21A (New)) and EF_B (calculated from the IPCC Tier 2, Equation 10.21 for GEI_i and Y_m) was 56.44 Kg/head/year. In contrast, the overall EF_A and EF_B was 67.42 Kg/head/year for Jersey steers. The EF_D in Holstein steers overestimated (34.50%) the EF (75.91 Kg/head/year) compared to EF_A, while EF_A, EF_B, EF_C, and EF_E exhibited similar values indicating that the value of 4.90 can be used as the Y_m for Holstein steers. The EF_E lower estimated (40.45%) the EF (40.15 Kg/head/year) in Jersey steers compared to EF_A, while EF_A, EF_B, EF_C, and EF_D exhibited similar values, suggesting that the value of 7.49 can be used as the Y_m for Jersey steers. In the present study, it was also revealed that the breed of dairy steers significantly influenced the EFs in all EF groups. This is in agreement with Thakuri et al. [25], who followed the IPCC Tier 2 methodology and developed the country-specific enteric methane EF for local and improved cattle breeds in Nepal (33, and 46 kg/head/year, respectively) which differ significantly between breeds. They further reported the net CH_4 flux was about 15% higher than the default value (254 ± 51 v 221 ± 66 Gg/yr). The seasonal variation of the EFs was also observed in the present study, which was not reported earlier. The variation in the EF between Holstein and Jersey steers and/or among different seasons linked to the breed-specific and/or among the different seasons Y_m, which might be due to the variation in methane emissions by different breeds in different seasons.

5. Conclusions

In conclusion, the Y_m values for both Holstein and Jersey steers were calculated from the Y_m equation of IPCC 2006 by using the input values of the chemical composition of feed, MP, and MY. The EFs were estimated by the IPCC Tier 2 Equation 10.21A (New) and Equation 10.21 of the 2019 Refinement to the IPCC 2006. The calculated overall Y_m for Holstein and Jersey steers were 4.90 and 7.49, respectively, while the EF_A was 56.44 and 67.42 Kg/head/year for Holstein and Jersey steers, respectively. The EF_D of Holstein steers was overestimated while the EF_F of Jersey steers underestimated the EF compared to others. According to Mixed analysis, all the EF groups were influenced by the breed of dairy steers; however, the season, and the interaction between the breed and the season, influenced the EFs of group EF_C, EF_D, and EF_F. Overall, this study recommended using the breed-specific Y_m for the calculation of the EF of enteric methane for Holstein and Jersey steers in the Republic of Korea. Future study will have to consider the large amount of nationwide data to reduce the error and the uncertainty.

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