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Effects of agricultural byproducts, DDG and MSG, on the larval development of mealworms

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Abstract

Distillers dried grain (DDG) and makgeolli spent grain (MSG) are agricultural byproducts to produce alcoholic beverage. However, they are known to contain enough nutrients. Mealworm is a promising insect resource for an animal feed ingredient as well as alternative human food. With low cost, DDG and MSG were investigated as a feed ingredient for rearing high quality mealworms. DDG and MSG were mixed with wheat bran and compared to control feed (only wheat bran) for its effects on larval survivorship, larval weight, duration for developmental period, pupation rate, and pupal weight. When DDG added, larval survivorship was reduced to 50~70% compared to the control group. Larvae fed on DDG were heavier from third to sixth week. Especially, larvae with 50% DDG were 28% heavier than the control group at the third week. For the larval period, the 50% DDG group was 11% less than that for the control. The pupal weight for the 30% DDG group was 7% heavier than that for the control group. Pupation rates for all the DDG groups were higher than 90%. When compared to the control, larval survivorship for the 70% MSG group was low, but the 50% and 70% MSG groups were high during the seventh and eighth weeks because of delayed development. After the eighth week, larvae with 70% MSG showed the highest larval weight increase as 9~18% compared to the control group. Except 70% MSG group, all of MSG groups showed more than 90% pupation rates. We confirmed that adding 30~50% of DDG or MSG to conventional wheat bran have a strong potential to replace the conventional wheat bran insect feed for quality insect production.

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Introduction

Insect has been used as nutritious diet for domestic animals as well as human. Moreover, insects can be fed on agricultural byproduct with low cost. As the price for the conventional protein ingredients - meat, fish and soybean – has been increasing, insects have been focused as an alternative protein source for animal feed and human diet (Ng *et al*., 2001; Ravzanaadii *et al*., 2012). Among various insects, mealworms, *Tenebrio molitor* (Coleoptera: Tenebrionidae), have been spotlighted with its high content of fat, proteins, various amino acids, unsaturated fatty acid, and minerals (Kim *et al*., 2014; Kim

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et al., 2016; Huang *et al.*, 2006; Huang *et al.*, 2007; Huang *et al.*, 2011; Ye *et al.*, 1997; Yoo *et al.*, 2013). To produce the same amount of protein, mealworm requires relatively lower cost than cattle and swine (He *et al.*, 2006; Huang *et al.*, 2005; Huang *et al.*, 2011; Kim *et al.*, 2014; Kim *et al.*, 2016; Tian and Xu, 2003; Wu *et al.*, 2008; Zanuncio et al., 2000). In addition, mealworm rearing is environmental-friendly because mealworm can utilize agricultural byproducts – wheat straw, tangerine shell, spent mushroom substrate, and brewer's spent grain - that have usually been trashed. Therefore, many studies have been conducted to build a strong foundation for mealworm mass-rearing (Kim *et al.*, 2014; Kim *et al.*, 2016; Li *et al.*, 2012).

Spent grain including distillers dried grain (DDG) and makgeolli spent grain (MSG) are byproducts from starch saccharification for alcoholic beverage production. These materials have been used as alternative feed for concentrated feed and roughage source for ruminants. Especially, it was reported that spent grain increased the milk production from milk cows and supplied unidentified growth factors (Lee *et al.*, 2001). The main ingredients of spent grain are crude fat, crude protein, roughage, fungus body of fermentation yeast, and various minerals, so it is suitable for animal feed as well as many studies have been conducted to investigate possible usages (Choi *et al.*, 2008; Ganesan *et al.*, 2007; Song, 2005). Makgeolli spent grain (MSG) is a byproduct from makgeolli production that mainly contains starch and protein. In addition to starch and proteins, it contains various nutrients including fibers, minerals, vitamins, alcohol, organic acids, enzymes, and yeast (Cho *et al.*, 1998; Lee *et al.*, 2009). Particularly, MSG is containing 20% protein, so it has an advantage as a low price protein source (Kim *et al.*, 2011; Lee *et al.*, 2015; Seo *et al.*, 2013). The MSG has been used for baking bread with high fiber content, manufacturing edible film with MSG protein, producing yeast spores, making dough enhancer, and improving noodle quality by adding MSG (Cho *et al.*, 1996; Cho *et al.*, 1998; Jeong and Park, 2006; Kim *et al.*, 2007; Lim *et al.*, 2004).

Rearing *T. molitor* has been getting interested because it has strong potential as animal feed. Therefore, the standard protocol for mass-rearing of insects is needed as insect farmers are getting increased. In this study, we investigated the effects of DDG and MSG on developmental characteristics including larval survivorship, larval weight, developmental period, pupation rate, pupal weight. With this study, we can determine the optimal feed for rearing insect with DDG and/or MSG.

Materials & Methods

Insects

T. molitor have been kept in insect rearing facilities at National Institute of Agricultural Science for more than five generations at 25±3°C with 50~60% RH and 14L:10D light condition. The room temperature was controlled by automated thermostat and monitored by thermometer, and the light condition was set for the optimal growth rate of *T. molitor* based on previous studies (Kim *et al.*, 2016). Larvae of *T. molitor* were maintained in the plastic box (27 cm × 36 cm × 8 cm (length × width × height)) filled with 0.8 cm of wheat bran as a food source and fresh cabbage leaves or carrots as a water source that was replace every two weeks.

Feed with different contents of distillers dried grain (DDG) and makgeolli spent grain (MSG)

Larvae of *T. molitor* were fed wheat bran based on the standard rearing protocols (Kim *et al.*, 2014). To test the effects of DDG and MSG on the growth of *T. molitor* larvae, different amounts of DDG and MSG were mixed with wheat bran. DDG and MSG were dried at 80°C for 24 h. Dried DDG and the dried MSG were ground by Hi-Jet Milling Machine (HJM-10100, Hansung Pulverizing Machinery CO. LTD., Gwangju-si, Gyounggi-do, Republic of Korea). These powders were mixed with wheat bran with different amounts by its weight.

Larval growth of *T. molitor* with different diets

The seventh or eighth larvae that were 60 d after hatching were tested their growth rate with different diets. For each group, 30 larvae were tested in a plastic container (10 × 4 cm (diameter × height)) with three biological replications. All the larvae were fed wheat bran with different amounts of DDG and MSG. We put 5 grams of cabbage leaves as a water source twice per week to all the plastic containers. As a control diet, we used wheat bran without any DDG and MSG based on the standard rearing condition (Kim *et al.*, 2014). Each group of larvae fed on different amounts of DDG and MSG was compared its survivorship, average larval weight, duration for each development stage, pupation rate, and pupal weight.

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Results & Discussion

Larval survivorship

The larval survivorships for different amounts of DDG or MSG mixed with wheat bran groups were compared to the control group fed on 100% wheat bran. The larval survivorship was checked until all the larvae pupated. Therefore, the survivorships for the control group, 30% DDG group, and 50% DDG group were checked for 16 wk, and the survivorship for the 10% DDG group for 18 wk, and that for the 70% DDG group for 19 wk. For the MSG groups, the survivorships for the 10% MSG and 50% MSG group were checked for 16 wk, that for the 30% MSG group for 14 wk, and that for the 70% group for 13 wk. Conventionally, the mealworm farmers sell mealworms five wk after 7~8th instar larvae. At the fourth week, the survivorships for the 10% DDG and 30% DDG group were 100%, and that for the 50% DDG group was 96.67±3.33% (mean±S.D.) that was higher than that for the control group (95.56±7.70% (mean±S.D.)). All the DDG groups showed significantly lower survivorship compared to that for the control group at the sixth week (Fig. 1). At the fourth week, the survivorship for the 30% MSG group was the highest as 97.78±1.92% (mean±S.D.), that for the 70% MSG group was the lowest as 88.89±5.09% (mean±S.D.). However, the survivorship for the 70% MSG group was significantly higher than that for the control during 6 ~ 8th week, and that for the 50% MSG group was higher at the seventh week (Fig. 2).

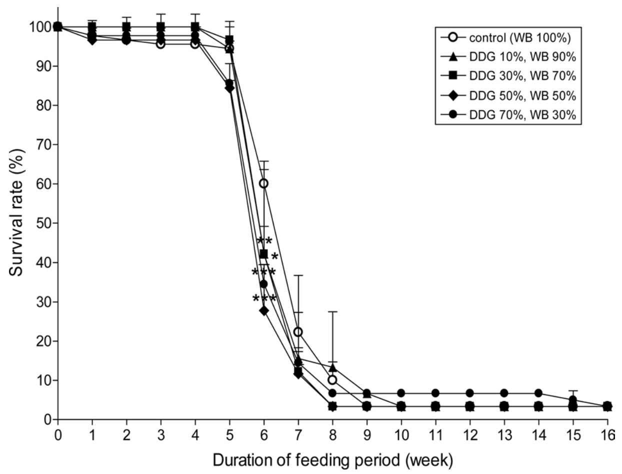

Fig. 1. Survivorship of Tenebrio molitor larvae related to the supplement of DDG.
Values are mean±S.D.
One way ANOVA, Tukey's multiple comparison test, *, p<0.05; **, p<0.01; ***, p<0.001

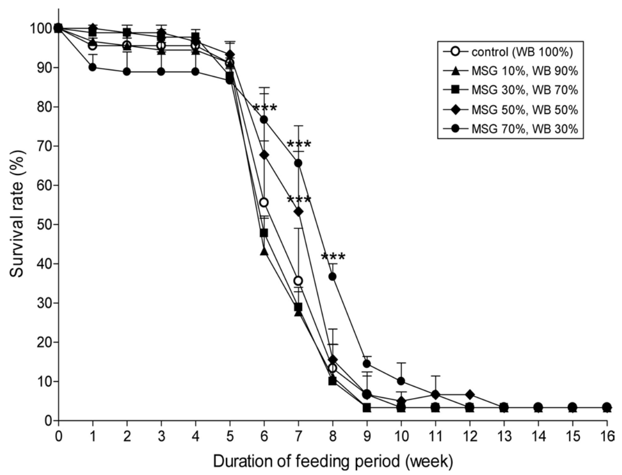

Fig. 2. Survivorship of *Tenebrio molitor* larvae related to the supplement of MSG.
Values are mean±S.D.
One way ANOVA, Tukey's multiple comparison test, ***, p<0.001

Larval weight

The larval weight was observed for 16 wk with different diets. The larval weights for the 10% DDG, 30% DDG, and 50% DDG group were significantly higher than that for the control group from the third to the sixth week (Fig. 3). The larval weight for the 70% MSG group was significantly lower than that for the control group during fourth and fifth week, but it was relatively

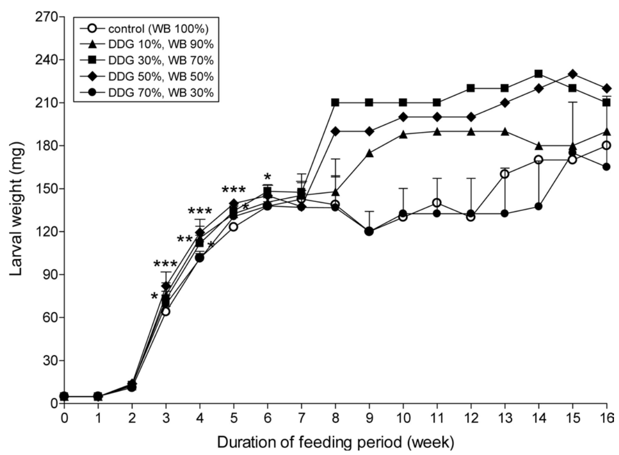

Fig. 3. Average larval weight of *Tenebrio molitor* related to the supplement of DDG.
Values are mean±S.D.
One way ANOVA, Tukey's multiple comparison test, *, p<0.05; **, p<0.01; ***, p<0.001

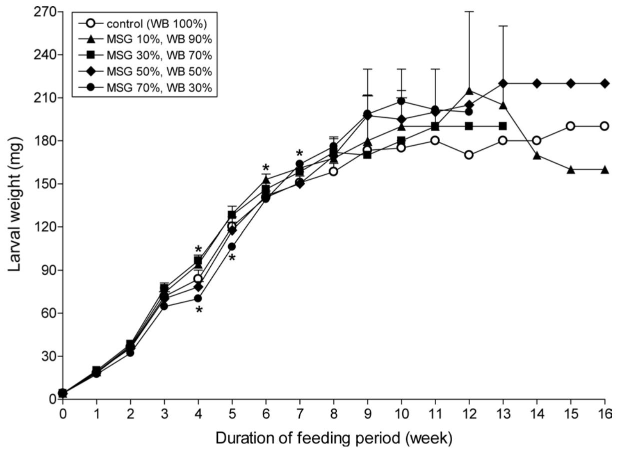

Fig. 4. Average larval weight of *Tenebrio molitor* related to the supplement of MSG.
Values are mean±S.D.
One way ANOVA, Tukey's multiple comparison test, *, $p<0.05$

higher than the control group after the seventh week. The 30% MSG group at the fourth week and the 10% MSG group at the sixth week showed relatively high larval weight (Fig. 4). The maximum larval weight increase was calculated by the percentage for the weight increase of the experimental groups compared to the maximum larval weight of the control group (Table 1 and 2). When larval weight per individual for the all DDG group were compared to the control group, the 50% DDG groups was the highest group as 15.35 ~ 36.49%, the 30% DDG group was the highest group at sixth and eighth weeks, and the 10% DDG group was the highest group at the seventh week. Except the sixth and eighth weeks, the 30% DDG group showed lower weight increase rate. For the larval weight per individual, the 30% MSG group was the highest group as 2.10 ~ 7.53% from the first week to the fifth week, and the 10% MSG group was the highest group from sixth to eighth week. Especially, the 10% MSG group showed the highest weight increase as 19.71%. The 70% MSG group was lower than the control for the most of the weeks except the seventh and eighth weeks. This group showed the lowest weight at the fourth week as 24.75% lower than the control group.

Developmental duration

The larval duration was determined by the period from the 7~8th larvae (ca. 60 d after hatching) to pupae. The status of larvae was checked once per a week. The larval duration for the 50% DDG group was significantly shorter than that for the control group as well as the other DDG groups was relatively short when compared to the control group (Table 3). The larval durations for the all MSG groups were relatively longer than that for the control group. Especially, the larval duration for the 70% MSG group was the longest among the all MSG groups (Table 4).

Pupation rate

The pupation rate for the all DDG groups was more than 90%. Especially, pupation rate for 30% DDG group was higher than any other groups (Table 3). The pupation rate for the MSG groups was also more than 90% except the 70% MSG group (Table 4).

Pupal weight

The pupal weight for the 30% DDG group was relatively heavier than the control group, but all other DDG groups were less than the control group (Table 3). All the MSG group showed heavier pupal weight than the control group. Especially, the 10% and 70% MSG groups were significantly heavier than the control group as 10~20 % (Table 4).

The pupal weight change is summarized in table 5. The 10% DDG and 30% DDG groups showed the highest weight increase as 30.00% at the fifth week compared to the control group. The weight increase was the maximum with the 50% DDG group (23.15%) at the sixth week, the 30% DDG group (12.68%) at the seventh week, and the 70% DDG group at the eighth week. At the eighth week, the weight increase was relatively lower than other weeks, and the 10% DDG group and 50% DDG group were lower than the control group. For the MSG groups weight increase at the ninth week, the 10% MSG group showed the highest as 25.58%, and the other MSG groups also showed higher weight increase at the ninth week (Table 6). The 70% MSG group was higher than other groups at the sixth week (8.29%) and the eighth week (7.29), and the 10% MSG group showed the highest weight increase (19.76%) at the seventh week.

Tenebrio molitor prefers decaying grains and milled cereals that are moist. Also, this beetle can feed on fresh products including meal, flour, bran, grain, course cereals, bread, crackers, mill sweepings, meat scraps, feathers and dead insects (Ghaly and Alkoaik, 2009). With wheat bran mixed with the agricultural byproducts – dried-citrus pulp, this feed can be used as fattening

Table 1. Larval weight changes with different contents of DDG as a feed supplement.

Weeks	Feeds	Larvae (n=90)		
		Average Larval Weight (mg)	Maximum Larval Weight (mg)	Percentage of Maximum Larval Weight Gain (%)
1	Control (100% WB)	11.17±0.69	11.97	
	DDG 10%, WB 90%	12.21±1.28	13.37	11.70
	DDG 30%, WB 70%	12.81±0.51	13.40	11.95
	DDG 50%, WB 50%	13.88±0.80	14.80	23.64
	DDG 70%, WB 30%	12.94±0.44	13.34	11.45
2	Control (100% WB)	27.63±2.69	30.67	
	DDG 10%, WB 90%	32.89±4.44	36.67	19.57
	DDG 30%, WB 70%	32.78±2.41	34.33	11.96
	DDG 50%, WB 50%	37.81±3.79	40.33	31.52
	DDG 70%, WB 30%	30.55±1.52	32.00	4.35
3	Control (100% WB)	63.98±3.82	66.67	
	DDG 10%, WB 90%	75.89±5.48	84.00	25.99
	DDG 30%, WB 70%	72.89±5.48	77.00	15.49
	DDG 50%, WB 50%	82.10±9.72	91.00	36.49
	DDG 70%, WB 30%	69.46±6.25	76.67	15.00
4	Control (100% WB)	101.62±4.66	107.00	
	DDG 10%, WB 90%	115.67±8.17	124.00	15.89
	DDG 30%, WB 70%	111.78±5.72	117.00	9.35
	DDG 50%, WB 50%	119.29±9.30	125.67	17.45
	DDG 70%, WB 30%	100.98±3.63	105.00	-1.87
5	Control (100% WB)	123.06±0.05	123.10	
	DDG 10%, WB 90%	132.53±5.30	137.24	11.49
	DDG 30%, WB 70%	134.41±3.46	138.33	12.37
	DDG 50%, WB 50%	139.65±2.81	142.00	15.35
	DDG 70%, WB 30%	130.49±0.86	131.48	6.81
6	Control (100% WB)	137.82±3.03	141.18	
	DDG 10%, WB 90%	140.58±1.38	141.50	0.23
	DDG 30%, WB 70%	148.18±4.59	153.33	8.61
	DDG 50%, WB 50%	145.11±7.28	152.00	7.66
	DDG 70%, WB 30%	137.94±5.69	144.17	2.12
7	Control (100% WB)	142.77±3.81	146.00	
	DDG 10%, WB 90%	145.28±15.01	160.00	9.59
	DDG 30%, WB 70%	147.50±6.61	152.50	4.45
	DDG 50%, WB 50%	137.50±17.68	150.00	2.74
	DDG 70%, WB 30%	136.89±11.93	150.00	2.74
8	Control (100% WB)	138.75±19.45	152.50	
	DDG 10%, WB 90%	147.86±11.11	155.71	2.10
	DDG 30%, WB 70%	210.00±0.00	210.00	37.70
	DDG 50%, WB 50%	190.00±0.00	190.00	24.59
	DDG 70%, WB 30%	136.67±34.03	175.00	14.75

Table 2. Larval weight changes with different contents of MSG as a feed supplement.

Weeks	Feeds	Larvae (n=90)		
		Average Larval Weight (mg)	Maximum Larval Weight (mg)	Percentage of Maximum Larval Weight Gain (%)
1	Control (100% WB)	18.49±2.59	21.03	
	MSG 10%, WB 90%	19.08±2.02	21.38	1.66
	MSG 30%, WB 70%	20.12±2.22	22.00	4.61
	MSG 50%, WB 50%	19.33±2.08	21.67	3.04
	MSG 70%, WB 30%	17.55±1.05	18.52	-11.94
2	Control (100% WB)	36.50±4.53	41.38	
	MSG 10%, WB 90%	37.41±2.85	40.34	-2.51
	MSG 30%, WB 70%	38.54±4.02	42.33	2.30
	MSG 50%, WB 50%	35.63±5.23	40.33	-2.54
	MSG 70%, WB 30%	32.20±2.84	34.07	-17.67
3	Control (100% WB)	71.76±9.39	82.41	
	MSG 10%, WB 90%	74.29±6.62	79.31	-3.76
	MSG 30%, WB 70%	77.34±6.58	84.14	2.10
	MSG 50%, WB 50%	70.12±8.51	78.33	-4.95
	MSG 70%, WB 30%	64.71±4.33	68.52	-16.85
4	Control (100% WB)	83.88±10.75	96.21	
	MSG 10%, WB 90%	94.18±3.88	98.62	2.50
	MSG 30%, WB 70%	96.66±6.57	103.45	7.53
	MSG 50%, WB 50%	78.39±6.40	84.48	-12.19
	MSG 70%, WB 30%	70.10±3.22	72.40	-24.75
5	Control (100% WB)	120.21±11.94	133.33	
	MSG 10%, WB 90%	129.09±1.77	130.77	-1.92
	MSG 30%, WB 70%	128.11±10.91	138.85	4.14
	MSG 50%, WB 50%	117.65±9.57	126.07	-5.45
	MSG 70%, WB 30%	106.27±2.80	109.26	-18.05
6	Control (100% WB)	140.47±7.83	149.46	
	MSG 10%, WB 90%	153.03±6.63	160.64	7.48
	MSG 30%, WB 70%	146.27±7.13	153.00	2.37
	MSG 50%, WB 50%	141.64±2.26	144.04	-3.63
	MSG 70%, WB 30%	139.26±7.25	144.30	-3.45
7	Control (100% WB)	150.78±8.03	160.00	
	MSG 10%, WB 90%	161.07±4.21	165.71	3.57
	MSG 30%, WB 70%	158.44±3.24	161.43	0.89
	MSG 50%, WB 50%	150.10±5.14	156.00	-2.50
	MSG 70%, WB 30%	163.71±0.33	163.91	2.44
8	Control (100% WB)	158.39±8.33	164.29	
	MSG 10%, WB 90%	167.78±25.89	196.67	19.71
	MSG 30%, WB 70%	172.00±2.83	174.00	5.91
	MSG 50%, WB 50%	169.44±6.03	173.33	5.50
	MSG 70%, WB 30%	176.02±9.34	186.00	13.21

Table 3. Averages of larval duration, pupal weight, and pupation rate with different contents of DDG as a feed supplement. Values are mean±S.D. One way ANOVA, Tukey's multiple comparison test, *, $p<0.05$

Feeds	Larval Duration (wk.)	Pupal Weight (mg)	Pupation Rate (%)
Control (100% WB)	7.64±0.80	132.10±6.29	93.89±7.12
DDG 10%, WB 90%	6.57±0.53	127.96±5.14	93.33±8.82
DDG 30%, WB 70%	6.63±0.29	137.00±14.37	96.67±3.33
DDG 50%, WB 50%	6.23±0.17*	129.83±4.75	94.44±7.70
DDG 70%, WB 30%	6.56±0.28	130.41±3.26	95.56±1.92

Table 4. Averages of larval duration, pupal weight, and pupation rate with different contents of MSG as a feed supplement. Values are mean±S.D. One way ANOVA, Tukey's multiple comparison test, *, $p<0.05$; **, $p<0.01$

Feeds	Larval Duration (wk.)	Pupal Weight (mg)	Pupation Rate (%)
Control (100% WB)	7.64±0.80	132.10±6.29	93.89±7.12
MSG 10%, WB 90%	8.01±0.41	150.06±12.89*	92.22±1.92
MSG 30%, WB 70%	7.84±0.20	143.65±2.22	96.67±3.33
MSG 50%, WB 50%	8.53±0.57	149.35±3.70	94.44±3.85
MSG 70%, WB 30%	9.33±0.13**	160.14±11.23**	85.56±7.70

Table 5. Pupal weight gain with different contents of DDG as a feed supplement.

Weeks	Feeds	Pupae (n=90)		
		Average Pupal Weight (mg)	Maximum Pupal Weight (mg)	Percentage of Maximum Pupal Weight Gain (%)
5	Control (100% WB)	100.00±0.00	100.00	
	DDG 10%, WB 90%	120.00±10.00	130.00	30.00
	DDG 30%, WB 70%	122.50±10.61	130.00	30.00
	DDG 50%, WB 50%	124.67±1.76	126.67	26.67
	DDG 70%, WB 30%	110.83±1.44	112.50	12.50
6	Control (100% WB)	113.89±2.00	115.56	
	DDG 10%, WB 90%	127.04±11.59	138.13	19.53
	DDG 30%, WB 70%	125.74±1.83	127.86	10.64
	DDG 50%, WB 50%	134.38±7.05	142.31	23.15
	DDG 70%, WB 30%	126.11±3.76	128.33	11.05
7	Control (100% WB)	125.50±1.36	126.67	
	DDG 10%, WB 90%	131.19±3.38	135.00	6.58
	DDG 30%, WB 70%	135.46±8.14	142.73	12.68
	DDG 50%, WB 50%	133.61±3.15	135.83	7.23
	DDG 70%, WB 30%	129.40±6.41	133.33	5.26
8	Control (100% WB)	137.83±2.02	140.00	
	DDG 10%, WB 90%	130.00±0.00	130.00	-7.14
	DDG 30%, WB 70%	138.44±7.34	143.33	2.38
	DDG 50%, WB 50%	122.50±10.61	130.00	-7.14
	DDG 70%, WB 30%	137.78±10.18	146.67	4.76

Table 6. Pupal weight gain with different contents of MSG as a feed supplement.

Weeks	Feeds	Pupae (n=90)		
		Average Pupal Weight (mg)	Maximum Pupal Weight (mg)	Percentage of Maximum Pupal Weight Gain (%)
6	Control (100% WB)	121.97±5.76	128.36	
	MSG 10%, WB 90%	127.63±3.28	130.19	1.43
	MSG 30%, WB 70%	131.35±4.87	135.69	5.71
	MSG 50%, WB 50%	126.24±5.89	132.83	3.48
	MSG 70%, WB 30%	128.50±12.62	139.00	8.29
7	Control (100% WB)	129.08±5.13	135.00	
	MSG 10%, WB 90%	147.44±13.85	161.67	19.76
	MSG 30%, WB 70%	139.42±6.69	145.00	7.41
	MSG 50%, WB 50%	142.17±8.01	150.00	11.11
	MSG 70%, WB 30%	144.00±15.10	160.00	18.52
8	Control (100% WB)	148.33±4.71	151.67	
	MSG 10%, WB 90%	149.88±9.07	160.00	5.49
	MSG 30%, WB 70%	142.00±13.86	150.00	-1.10
	MSG 50%, WB 50%	138.82±6.84	144.55	-4.69
	MSG 70%, WB 30%	153.71±8.08	162.73	7.29
9	Control (100% WB)	141.67±2.36	143.33	
	MSG 10%, WB 90%	158.67±18.58	180.00	25.58
	MSG 30%, WB 70%	167.50±0.00	167.50	16.86
	MSG 50%, WB 50%	157.22±6.74	165.00	15.12
	MSG 70%, WB 30%	160.83±6.51	168.33	17.44

feed for horse when the growing stage and the quality of meat (Chae *et al.*, 2013; Kim *et al.*, 2014; Kim *et al.*, 2016). In addition, spent mushroom substrate have also been used as a feed ingredient for swine and cattle, so it could be used for insect rearing as well as it could improve mealworm's immune system to reduce the economic loss from disease (Kim *et al.*, 2013). Especially, winter mushroom spent substrate can be used for mealworm feed to improve insect quality when 40 ~ 50% of winter mushroom spent substrate is mixed with conventional feed (Kim *et al.*, 2014). Even though a byproduct from producing beer, brewer's spent grain (BSG) still has enough nutrition (Aliyu and Bala, 2011; Tang *et al.*, 2009). Therefore, BSG has been investigated as animal feeds, producing high valued compound including xylitol and lactic acid, culturing microorganisms, and extracting raw materials for sugars, proteins, acids and antioxidants (Aliyu and Bala, 2011). Wheat bran with 30 ~ 50% BSG made better quality mealworm compared to the conventional wheat bran feed, so BSG showed its potential as an alternative feed ingredient (Kim *et al.*, 2016).

All the DDG groups showed 0.5 ~ 0.7 times less survivorship than the control group because of the high pupation rate at the sixth week which is usual for the mass-rearing facilities. The larval weight for the DDG groups from third to sixth week was heavier than the control group. The 50% DDG group was 28%, 17%, and 13% heavier than the control group for the third, forth, and fifth week. The 30% DDG group was 8% heavier than the control group for the sixth week. The larval duration for the 50% DDG group was 11% shorter than the control group. The other DDG groups also showed relatively shorter than the control group. The pupal weight for the 30% DDG group was 7% heavier than the control group and the other DDG groups were also relatively heavier than the control group. The pupation rate was higher than 90% for the all DDG groups. Until the sixth week, the larval survivorship for the 70% MSG group was 10% lower than the control group, but the 50% and 70% MSG groups showed 20 ~ 80% higher survivorship that the control group caused by the delayed larval development of larvae. After the eighth week, the larval weight increase for the 70% MSG group was the highest as 9 ~ 18%. The larval duration for the 30% MSG group was 5% shorter than the control group, but 70% MSG group was 9% longer. The pupal weight for the all MSG groups was higher than the control group. Especially, the 70% MSG group showed 18% heavier pupal weight than the control group. The pupation rate for the all the MSG groups except the 70% MSG group was more than 90%. The pupation rate for the 70% MSG group was 8% less than the control group.

Distillers dried grains with soluble (DDGS) contains higher concentration of nutrients such as protein, fat, vitamins, minerals, and fiber than its parent grain (Fastinger *et al.*, 2006). The crude protein content of DDGS is relatively high, ranging from 30% (Belyea *et al.*, 2004), and helps to provide essential amino acids in the feed for monogastric animals which are unable to synthesize the essential amino acids (Song, 2005). Corn DDGS imported for assorted feed has been used as a feed ingredient for dairy cows, beef cattle, pigs, and poultry, because it is known as same nutritional value as corn (Choi *et al.*, 2008). In Japan, many researches have been investigated on the physiological function of sake as well as sake lees. Based on diverse researches, sake lees have been started to be used as functional food because it has been identified for its function as health functional food including alleviating diabetes, high blood pressure, and osteoporosis, preventing cerebral infarction, cardiac infarction, and artery hardening, improving allergic constitution and whitening (Kim and Cho, 2006; Saito *et al.*, 1994).

MSG is usually known as rice wine lees that is a byproduct from producing makgeolli by rice, water, malt and yeast. Generally, MSG that can be obtained ca. 20% of weight as the rice for producing makgeolli contains diverse nutritional factors including starch, protein, fibers, minerals, vitamins, and enzymes (Lee *et al.*, 2009). MSG can be used for baking high fiber bread, producing dough enhancer for bakery and noodles (Cho *et al.*, 1998; Jeong and Park, 2006; Kim *et al.*, 2007; Lee *et al.*, 2009). MSG has been known for its function as anti-diabetic and anti-cancer effects and preventing cardiovascular disorders and high blood pressure (Lee *et al.*, 2008; Lee *et al.*, 2009; Seo *et al.*, 2013).

DDG and MSG improve the larval growth of mealworm even though they are agricultural byproducts that have been widely used as animal feed as well as human health food. In this research, 30 % and 50% of DDG and MSG have strong potential to be used as insect feed with improving insect quality.

Insect farms have been expanded for the last ten years because mealworms were broadly used as a feed ingredient as well as a life feed for pets in Korea. In addition, there are increasing mass rearing facilities as the insect market is growing. However, mealworm is relatively expensive than conventional feed for swine, cattle, poultry, and fish, so finding an affordable quality food source for mealworm and developing automated mass-rearing system is needed to reduce the production cost. In this study, two agricultural byproducts with high nutrition values - DDG and MSG – are tested to reduce the production cost and to improve the quality of mealworm for better application. With this result, we expect to contribute to improving the farmers' income.

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