Feeding Value and *In situ* Digestibility of Edible Canna for Silage

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**Abstract**: To assess the potentiality of edible canna (*Canna edulis* Ker-Gawl.) as economically and environmentally sound animal feed, the feeding value of silage prepared from aboveground parts was examined, in parallel with studies on *in situ* digestion in the rumen among three local varieties. Contents of crude protein, acid and neutral detergent fibers and crude ash in canna silage were significantly higher, and that of nonstructural carbohydrate was significantly lower than in corn silage. The pH of corn and ‘yellow flower’ canna silages were significantly lower (3.8–3.9) than either ‘green stem’ or ‘red stem’ canna silage (4.4–4.9). The contents of lactic acid, acetic acid, total organic acid and the Flieg’s score of ‘yellow flower’ canna silage were equivalent or superior to those of corn silage. The rate of disappearance of dry matter in the rumen was significantly higher for corn silage than for canna silage, while the disappearance of neutral detergent fiber in canna silage was more rapid during the first 12 hours of incubation, but less rapid thereafter. The effective degradability of dry matter and organic matter of canna silage in the rumen was significantly higher than that of corn. Silage made from edible canna has a potential as a feed for ruminants.

**Key words**: *Canna edulis*, Feed analysis, *In situ* digestibility, Rumen, Silage fermentation.

In Korea, both concentrates and bulky feed are mostly imported, and the profitability of livestock farming is declining due to increased cost of production. As the cereals in these feedstuffs are also suitable for human consumption, we should not ignore the possibility of increased costs in the future, due to market competition, if total food supply decreases by global warming or loss of arable land area. Grazing of forested areas, which occupy more than 65% of Korean national land, would not only reduce costs associated with animal production, but also contribute to the development of useful plant resources (Lee et al., 1995). The use of woodlands and grasslands for raising livestock would also help to reduce the environmental pollution associated with intensive livestock production. However, grazing of national forests is largely limited by laws and regulations at present, and alternative means of reducing costs must be found. Although agricultural by-products, human diet and animal waste are important organic resources, they are often abandoned and end up in the waste stream. Jo et al. (1997, 1999) have initiated studies on the use of such abandoned materials as animal feeds. In the current economic circumstances, the exploitation of new feeding materials are worthy of consideration by farmers engaged in animal husbandry. The aboveground parts (leaves and stems) of edible canna are just one example with potential as a feed for livestock.

Edible canna (*Canna edulis* Ker-Gawl.; family Cannaceae) was domesticated in the Peruvian Andes, and is now a minor crop cultivated in tropical and subtropical countries (National Research Council, 1989). It grows up to 3-m tall, with many unbranched shoots and yields many starchy rhizomes (Lai et al., 1980; Imai et al., 1993). Favorable stand geometry and a large LAI can lead to a net productivity as high as 40 t ha⁻¹ in 6 months (Imai et al., 1993, 1994). While its rhizome is used as a good source of starch (Hermann et al., 1997), it has also been suggested that the aboveground parts would be a good source of silage (Tamaki et al., 1994). The objective of this study was to develop the utility of edible canna as a new material for animal feeding through examination of feeding value and *in situ* digestibility of its silage.

**Materials and Methods**

1. **Plant material and silage making**

Three local varieties of edible canna, ‘yellow flower’, ‘green stem’ and ‘red stem’ were used in this study. The first was introduced from Indonesia and the latter two from Taiwan. On 5 April 1999, rhizomes (each of ca. 200 g) were planted and cultivated at a spacing of 1 m × 0.5 m at the experimental farm of Daegu University as described by Imai et al. (1993). Chemical fertilizers with each of 6 g m⁻² N, P and K were applied one day before planting. On 5 September, the aboveground parts were harvested and chopped into 3-cm pieces. By this time, plants grew up to ca. 2.5 m and the main stem had 16-17 expanded leaves. To compare the quality of silage, we cultivated corn (*Zea mays* L.) as a control. Chemical analyses of these materials were performed to assess their potential as animal feeds.
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mays L. cv. GW-737), harvested (at yellow-ripe stage), and treated it in the same way as edible canna. Feed composition of the plant materials was examined with the samples oven-dried at 60º C for 48 h (Table 1).

For making silage, three replications of fresh materials from each variety were sealed into 20 L gas-tight plastic containers and after the extraction of air by a vacuum pump, they were kept at the room temperature for 90 days in the dark.

2. Measurements of in situ digestibility
(1) Animal feeding
Three pregnant dairy cows equipped with rumen fistulas were used for examination of in situ digestibility. The cows (each 500 kg) were fed a formula feed twice a day (0600 and 1800) to allow an intake of 20 g dry matter per 1 kg animal weight. The percentage compositions of the feed were broken corn grain 23, soybean meal 5.3, wheat flour 4, rapeseed meal 2.7, corn silage 21, corn gluten meal 3, wheat bran 4, rice straw 35 and mineral mixture 2, and crude protein 12.7, neutral detergent fiber (NDF) 47.7, acid detergent fiber (ADF) 27.9 and nonstructural carbohydrate (NSC) 30.0. The cows had free access to mineral block and water and were kept inside the tether barn during the experimental period.

(2) In situ digestion
The digestibility in the rumen was measured via the fistula. Ten grams of silage was packed in Dacron bag (10 cm × 20 cm; 53 µm pore diameter) and incubated for 48 h. The bag was inserted into the rumen at feeding time. At the end of the digestion period, the bag was taken out, immediately put into cooled water to terminate microbiological activity and washed thoroughly. Residues inside the bag were oven-dried at 60ºC for 48 h.

(3) Measurements of the digestibility of nutrients, degradation rate, and effective degradability of silage in the rumen
1) Percentage disappearance of nutrients (dry matter, organic matter and neutral detergent fiber) was calculated as follows;
\[
\text{Percentage disappearance} = \left(\frac{\text{Weight of nutrients before digestion} - \text{Weight of nutrients after digestion}}{\text{Weight of nutrients before digestion}}\right) \times 100.
\]

2) Degradation rate of nutrients was determined by the non-linear regression program of SAS (PROC NLIN) according to Marquardt (1963). The degradation rate (P; %), coefficients a, b, and c were estimated from the equation of Ørskov and McDonald (1979);
\[
P = a + b (1 - e^{-ct}),
\]
where, a and b are components that are degraded rapidly and gradually, respectively, c is the degradation coefficient, e is the base of natural logarithm and t is the time of fermentation in the rumen.

We recalculated b using equation \(B = (a + b) - A\) (A: disappearance rate of dry matter at time 0) according to Ørskov and Ryle (1990). Then, the lag time (L) was calculated after Michalet-Doreau and Ould-Bah (1992);
\[
L = \frac{1}{c} \ln \left(\frac{b}{B}\right).
\]

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### Table 1. Feed composition of aboveground parts in three varieties of edible canna and corn (% dry matter).

| Plant material       | Crude protein | Acid detergent fiber | Neutral detergent fiber | Crude ash | Crude fat | Nonstructural carbohydrate |
|----------------------|---------------|----------------------|-------------------------|-----------|-----------|---------------------------|
| Edible canna         |               |                      |                         |           |           |                           |
| 'Yellow flower'      | 9.1           | 33.5                 | 52.2                    | 14.9      | 2.9       | 20.9                      |
| 'Green stem'         | 11.8          | 32.4                 | 59.9                    | 14.5      | 3.2       | 10.6                      |
| 'Red stem'           | 8.9           | 32.6                 | 54.2                    | 16.5      | 2.6       | 17.8                      |
| Corn                 | 4.7           | 29.6                 | 45.9                    | 5.0       | 3.2       | 41.1                      |
| LSD (0.05)           | 3.1           | 2.4                  | 5.3                     | 7.5       | ns.       | 11.4                      |

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### Table 2. Feed composition of silage from three varieties of edible canna and corn (% dry matter).

| Source of silage     | Crude protein | Acid detergent fiber | Neutral detergent fiber | Crude ash | Crude fat | Nonstructural carbohydrate |
|----------------------|---------------|----------------------|-------------------------|-----------|-----------|---------------------------|
| Edible canna         |               |                      |                         |           |           |                           |
| 'Yellow flower'      | 10.1          | 30.5                 | 54.6                    | 16.0      | 3.4       | 16.0                      |
| 'Green stem'         | 11.2          | 32.9                 | 58.3                    | 18.0      | 3.6       | 8.9                       |
| 'Red stem'           | 9.9           | 33.8                 | 63.4                    | 17.1      | 3.1       | 6.6                       |
| Corn                 | 4.9           | 29.2                 | 48.7                    | 5.6       | 3.8       | 37.1                      |
| LSD (0.05)           | 3.8           | 3.6                  | 5.8                     | 2.6       | ns.       | 4.8                       |
where, $\ln$ is the natural logarithm.

3) Effective degradability (ED) was estimated by the equation of McDonald (1981):
$$ED = A + \frac{(b + c)}{(c + k)} \times \exp^{-\frac{(c + k)}{L}}$$
where, $k$ is the fractional rate of passage from the rumen (% h$^{-1}$), and $A$, $b$, $c$, and $L$ are the same as in the above equations.

3. Feed analysis
Feed analysis was done according to the method of AOAC (1990). The NDF and ADF were obtained according to the method of Goering and Van Soest (1970). Lactic acid content was measured with a spectrophotometer (Hanson Technology, OPRON 2500, Korea), and acetic and butyric acid contents with a gas chromatograph (Varian Star, 3600CX, USA). The Flieg's score was based on the ratio of these organic acids produced (Society for Self-Supplying Feed Quality Assessment, 1994).

4. Statistical analysis
Data were analyzed by the least significant difference (LSD) test using the SAS program (SAS Institute, 2000) at the 5% probability level.

Results

1. Feed composition of silage
The feed composition of silages produced from aboveground parts of three varieties of edible canna and corn, shown in Table 2, was compared with the composition of raw materials shown in Table 1. Contents of crude protein, NDF, crude ash, and crude fat tended to increase, and those of ADF and NSC tend to decrease by silage making. Three local varieties of edible canna were richer in crude protein, ADF, NDF and crude ash, but poorer in NSC than corn.

2. Characteristics of silage fermentation
Table 3 shows the characteristics of silage fermentation in three varieties of edible canna and corn. Water content of edible canna exceeded 90% which was contrastive to that of corn (62%). The pHs of corn (3.8) and ‘yellow flower’ edible canna (3.9) were statistically lower than those of ‘green stem’ (4.4) and ‘red stem’ (4.9) edible canna. Contents of lactic acid (3.2–3.4%), acetic acid (1.2–1.7%) and total organic acids (4.4–5.2%) in corn and ‘yellow flower’ canna were statistically higher than those in ‘green stem’ and ‘red stem’ edible canna (1.1–1.9%, 0.7–0.8% and 1.8–2.7%). For these reasons, the Flick’s score for edible canna was highest in ‘yellow flower’, followed by ‘green stem’ and ‘red stem’. On the other hand, butyric acid was found only in corn silage (0.1%).

3. Disappearance rate of silage dry matter in the rumen
As shown in Fig. 1, the rate of disappearance of silage dry matter increased with time in all the samples and was statistically higher in corn than in edible canna varieties. Interestingly, the disappearance rate of the ‘red stem’ edible canna silage was markedly lower during the first 12 h than that of the ‘yellow flower’ and ‘green stem’ edible canna silages.

| Source of silage | Water (%) | pH  | Lactic acid (%) | Acetic acid (%) | Butyric acid (%) | Total organic acid (%) | Flieg’s score |
|-----------------|-----------|-----|----------------|----------------|------------------|------------------------|--------------|
| Yellow flower   | 90.6      | 3.9 | 3.2            | 1.2            | 0.0              | 4.4                    | 91           |
| Green stem      | 91.0      | 4.4 | 1.9            | 0.8            | 0.0              | 2.7                    | 84           |
| Red stem        | 90.3      | 4.9 | 1.1            | 0.7            | 0.0              | 1.8                    | 74           |
| Corn            | 62.0      | 3.8 | 3.4            | 1.7            | 0.1              | 5.2                    | 77           |
| LSD (0.05)      |           | 1.2 | 0.1            | 0.2            | 0.01             | 0.9                    | --           |

Fig. 1. Disappearance rate of silage dry matter in the rumen. Vertical bars indicate LSD (0.05).
4. Disappearance rate of silage organic matter in the rumen

Figure 2 shows the rate of disappearance of silage organic matter by fermentation in the rumen. This increased progressively and the trend was different from that of dry matter (Fig. 1) during the first 12 h. Also, the rate of disappearance of corn silage was higher than that of edible canna varieties. Among edible cannas, the ‘red stem’ showed a lower disappearance rate of the silage organic matter than the ‘yellow flower’ and ‘green stem’ during the first 24 h.

5. Disappearance rate of silage NDF in the rumen

The rate of disappearance of silage NDF by fermentation in the rumen (Fig. 3) changed in accordance with that of silage dry matter shown in Fig. 1. During the first 6 h, the disappearance rate of edible canna NDF tended to be higher than that of corn NDF but during 6–12 h, the disappearance rate of corn NDF increased extensively and exceeded that of edible canna. However, there was no significant difference by LSD (0.05) test at each fermentation time.

6. Characteristics of dry matter degradation and the effective degradability of silage in the rumen

Table 4 shows the degradation characteristics of dry matter and the effective degradability of silage in the rumen. Among the parameters of dry matter degradation, the terms A (disappearance rate at time 0) and a (estimated value for initial rapid decomposition) were, respectively, largest in silage of corn (42.4 and 42.1), followed by that of ‘yellow flower’ and ‘green stem’ edible canna (36.5–37.5 and 38.3–38.4), and ‘red stem’ edible canna (32.9 and 33.1). The term b (for the fraction which gradually decomposed within a given time) of the silage of ‘yellow flower’ edible canna was 59.7 and the largest among all silages, but c (the degradation constant of b) was the largest in corn silage (0.049). Although the effective degradability (assumed rumen outflow rate at k = 0.08, % h⁻¹) was numerically largest in corn silage (47.9%)}
and edible canna silage was 37.3~40.1%, there was no significant difference among silages.

7. Degradation characteristics and effective degradability of silage organic matter in the rumen

Table 5 shows the degradation characteristics and effective degradability of organic matter in the rumen. The pattern of the ranks for A and a among different silages was similar to that for dry matter and the values of A and a were the largest in corn silage (38.8 and 39.0, respectively) and the smallest in ‘red stem’ edible canna silage (23.8 and 23.8, respectively). The silage of ‘red stem’ edible canna had the largest value of b among all silages (11.9~21.2). The coefficient c and effective degradability were significantly larger in corn silage (0.070 and 46.2%, respectively) than in edible canna silage (0.025~0.033 and 29.1~31.8%, respectively).

8. Degradation characteristics and effective degradability of silage NDF in the rumen

Table 6 shows the degradation characteristics of NDF and effective degradability of silage in the rumen. In the degradation characteristics of NDF, A and a were within a range of 9.2~11.7 and 9.3~12.0, respectively, and there was no significant difference among the different silages; b was the largest in the silage of ‘green stem’ edible canna (75.8) and c was the largest in corn silage (0.041). However, the effective degradability (at k = 0.08) ranged from 13.6 to 15.1% and there was no statistical difference among the different silages.

Discussion

Corn silage is rich in energy content and preferred for good weight increment and milk production of cattle. It is the most important juicy feed for ruminants during the wintertime (Mowat and Slumskie, 1971; Burgess et al., 1993). However, its crude protein content is low and, to produce silage, we must cultivate the raw materials every year. Furthermore, in Korea, corn seeds are mostly imported at present.

On the other hand, edible canna is perennial and can produce ca. 2000 g m\(^{-2}\) DW of aboveground parts within 6 months (Imai et al., 1993, 1994). It is rich in fibers and its silage is highly palatable for cattle (Tamaki et al., 1994). Therefore, there is a further potential to use edible canna as a feedstuff for ruminants in Korea.

Our current study has shown that conversion of edible canna to silage maintained or increased the percentage of crude protein (9.9~11.2%), demonstrating the possibility of making high protein

| Table 5. Degradation characteristics of silage organic matter and its effective degradability in the rumen. |
|---|---|---|---|---|
| Source of silage | Parameters of degradation A | a | b | c \((k = 0.08)\) |
| Edible canna | ‘Yellow flower’ | 28.0 | 28.3 | 16.0 | 0.025 | 31.4 |
| | ‘Green stem’ | 28.2 | 28.7 | 11.9 | 0.033 | 31.8 |
| | ‘Red stem’ | 23.8 | 23.8 | 21.2 | 0.027 | 29.1 |
| Corn | 38.8 | 39.0 | 15.8 | 0.070 | 46.2 |
| LSD (0.05) | 4.1 | 4.3 | 5.2 | 0.030 | ns. |

Note: Abbreviations are the same as those in Table 4.

| Table 6. Degradation characteristics of silage neutral detergent fiber and its effective degradability in the rumen. |
|---|---|---|---|---|
| Source of silage | Parameters of degradation A | a | b | c \((k = 0.08)\) |
| Edible canna | ‘Yellow flower’ | 11.5 | 11.3 | 22.1 | 0.016 | 15.0 |
| | ‘Green stem’ | 10.7 | 11.6 | 75.8 | 0.003 | 13.6 |
| | ‘Red stem’ | 11.7 | 12.0 | 17.1 | 0.019 | 15.0 |
| Corn | 9.2 | 9.3 | 17.5 | 0.041 | 15.1 |
| LSD (0.05) | ns. | ns. | 24.6 | 0.012 | ns. |

Note: Abbreviations are the same as those in Table 4.
silage from the aboveground parts of this perennial crop. Contents of fiber and crude ash were also significantly higher than those of corn silage (Table 2). In particular, fermentation characteristics of ‘yellow flower’ edible canna were comparable to those of corn silage. The pH of its silage was 3.9 which remained stable with microbial activity, and contents of lactic acid and total organic acids were 3.2 and 4.4%, respectively, and comparable to those of corn silage (3.4 and 5.2%, respectively). Although the high water content of edible canna might be favorable for production of butyric acid, the butyric acid appeared only in corn silage at a level of 0.1%.

According to Flick’s score, the quality of silage was the best in ‘yellow flower’ followed by ‘green stem’, corn and ‘red stem’. This may indicate the variation of silage quality among local varieties of edible canna.

In situ degradation is a recently established and representative biological method for assessment of the quality of bulky feeds (Ferri et al., 1998; Huntington and Givens, 1998). In the present study on the rate of disappearance of silage nutrients in the rumen, dry matter and organic matter in corn, which had a lower NDF content, were degraded at a markedly higher rate than those in edible canna. Among three local varieties of edible canna, the ‘red stem’ (high in NDF content) showed the lowest disappearance rate in the first 24 h of fermentation. The slower rate was ascribed to the negative correlation between fiber content and disappearance rates of dry matter and organic matter. While the degradation rate of NDF in the rumen from time 0 to 48 h was low in both corn and edible canna silage. The effective degradabilities of dry matter and organic matter in corn, which had a lower NDF content, were degraded at a markedly higher rate than those in edible canna. Among three local varieties of edible canna, the ‘red stem’ (high in NDF content) showed the lowest disappearance rate in the first 24 h of fermentation. The slower rate was ascribed to the negative correlation between fiber content and disappearance rates of dry matter and organic matter. While the degradation rate of NDF in the rumen from time 0 to 48 h was low in both corn and edible canna silage. The effective degradabilities of dry matter and organic matter in corn, which had a lower NDF content, were degraded at a markedly higher rate than those in edible canna. Among three local varieties of edible canna, the ‘red stem’ (high in NDF content) showed the lowest disappearance rate in the first 24 h of fermentation. The slower rate was ascribed to the negative correlation between fiber content and disappearance rates of dry matter and organic matter.

As for the decomposition characteristics of dry matter and organic matter of silage in the rumen (Tables 4 and 5), the disappearance rate at time 0 and the coefficient a were the lowest in ‘red stem’ silage. The effective degradabilities of dry matter and organic matter of silage were higher in corn (47.9 and 46.2%) than in edible canna varieties (37.3–40.1 and 29.1–31.8%). We conclude that the slower rate of degradation of edible canna, which is rich in cell wall materials, should be due to the higher proportion of materials which decompose gradually.

Nevertheless, the results from the present study showed that the quality of silage of edible canna was equivalent or superior to that of corn. The utilization of such plant resource reduces costs for the farmer and contributes to an environmentally-adapted animal husbandry. However, as indicated by in situ experiment, edible canna is rich in cell wall constituents and the rate of digestion of nutrient is rather low. Therefore, further studies are needed to enable better use of edible canna. Studies on edible canna varieties, which are more suitable for silage quality, selection of appropriate harvest time before the occurrence of lignification, pre-wilting of herbage before silage making, examination of metabolism using different animals, etc., should contribute to the better use of edible canna as a feed for ruminants.

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