Japanese Journal of Plant Science ©2008 Global Science Books

Edible Canna: A Prospective Plant Resource from South America

Katsu Imai*

School of Agriculture, Meiji University, Kawasaki, Kanagawa 214-8571, Japan

Correspondence: * **imai@isc.meiji.ac.jp**

ABSTRACT

Edible canna (*Canna edulis* Ker-Gawl.) is a prospective monocotyledonous plant originated and domesticated in the Andean region and now cultivated in widely scattered locations from subtropical to tropical regions of the world without intensive improvement. The growth habit of this plant is perennial, although its actual life cycle is 7 to 12 months depending on the location of cultivation. The underground organ (rhizome) accumulates substantial starch and is used for foodstuffs such as noodles and biscuits. Investigations on physicochemical properties of edible canna starch are in progress but its utilization has not yet been generalized. The aboveground parts grow up to 3-m tall with large elliptical leaves and occasionally they are used for feeding livestock. Stems initiate and grow from rhizomes directly without branching. Wild plants of this species are seen on the edges of moist thickets so that they grow well on moist soils with a large quantity of mineral nutrient absorption. Photosynthetic characteristics indicate that edible canna is a C_3 species adapted to a broad range of light environments and warm temperature and possesses a medium rate of net photosynthesis. After the middle growth stage, stands of edible canna maintain a high leaf area index with a moderately high crop growth rate and its potential productivity is equivalent or superior to that of cassava and potato. However, scientific analytical studies and intensive cultivation practices are limited at present. In this review, the author introduces edible canna's history, morphogenic characteristics, photosynthesis, dry-matter and starch productivity and utilization and points out the need for multidisciplinary studies toward the future development.

Keywords: *Canna edulis*, canopy architecture, dry-matter production, photosynthesis, rhizome, yield
Abbreviations: CGR, crop growth rate; **E**, transpiration rate; **LAI**, leaf area index; **Pn**, net photosynthetic rate; **PPFD**, photosynthetic photon flux density

CONTENTS

INTRODUCTION ... 46
MORPHOLOGICAL AND ANATOMICAL FEATURES ... 47
Aboveground organs ... 47
Roots and rhizomes ... 48
CANOPY ARCHITECTURE ... 49
PHOTOSYNTHESIS ... 49
PRODUCTIVITY ... 49
Dry-matter production ... 49
Nutrient absorption ... 50
Starch accumulation ... 50
PROPAGATION ... 50
BASES OF UTILIZATION ... 50
Direct food ... 50
Starch source ... 50
Livestock feeding ... 51
Pharmaceutical and chemical uses ... 51
PERSPECTIVES ... 51
ACKNOWLEDGEMENTS ... 51
REFERENCES ... 51
JAPANESE ABSTRACT ... 53

INTRODUCTION

Edible canna (*Canna edulis* Ker-Gawler, family Cannaceae) is cultivated in a small scale in subtropical and tropical regions of the world without intensive improvement. It is probably one of the first plants to have been domesticated in the Andean region (National Research Council 1989). From archaeological evidence, the arid Peruvian coast is one of the earliest places of cultivation dating back to about 2500 B.C. (Gade 1966). It has been suggested that the wild type was domesticated in mountainous areas from Columbia to Ecuador and rapidly transmitted through the Andean region into the west coast and northern Chili. However, the center of cultivation might be moved closer to the rain forest fringes because the underground stems and the hygrophilous leaves indicated the adaptation of this species to savannas (Gade 1966). Through the natural range of this species, wild plants have been collected mostly from the edges of moist

Received: 31 October, 2008. Accepted: 10 December, 2008.

Invited Review

Fig. 1 Flowering edible canna, flower cluster (bottom left) and stock-base with rhizomes (bottom right)

thickets. They do not occur in densely forested areas, nor are they usually found in cold or extremely arid environments (Ugent *et al*. 1984). Therefore, climate at the early settlement of edible canna in the desert coast of Peru might not have been very arid.

The genus *Canna* is comprised of five elemental species (Khoshoo and Mukherjee 1970) but its systematics seems imperfect to obtain a consensus. Edible canna includes diploid (2n = 18) and triploid (2n = 27) plants of *C. edulis* and the latter includes autotriploids (Khoshoo and Mukherjee 1970; Ishiki *et al*. 1997) and segmental allopolyploids (Khoshoo and Mukherjee 1970; Mukherjee and Khoshoo 1971; Koyama 1984). By examining herbarium specimens and living materials, Segeren and Maas (1971) were convinced that *C. edulis* is synonymous to *C. indica*, though Tomlinson (1969) distinguished *C. edulis* from *C. indica* by comparing the cultivated specimen of *C. indica* at Achimota, Ghana and the pickled material of *C. edulis* preserved at the Royal Botanic Gardens, Kew. Prince and Kress (1997) presumed that edible canna is a triploid of *C. indica*. The edible canna cultivated in Vietnam and other Southeast Asian countries is a triploid and has a rather narrow range of variation and the randomly amplified polymorphic DNA analysis suggests that it is closest to Columbian triploid cultivar (Hermann *et al*. 1999), though there is an argument that it is not *C. edulis* but *C. discolor* (Tanaka 1998, 2004).

As shown in **Fig. 1**, edible canna grows vigorously up to about 3 m in height with large leaf blades on a stem without branching and its tall canopy results in a large biomass that is used as green fodder to feed cattle and swine. The main edible part is the rhizome which accumulates starch so that from ancient times, it was used as a simple foodstuff by boiling or grilling although at present, the starch is used for local food industries as the source of noodles, biscuits and extender for baby food (Lai *et al*. 1980; National Research Council 1989; Lai and Tsai 1990; Imai 1996; Hermann *et al*. 1999).

In practical cultivation, edible canna grows well in loose, loamy soil which contains much humus and tolerates excess moisture by rain and irrigation but does not tolerate ill-drained soil (Chung and Ripperton 1924; Cada *et al*. 1941; Lu *et al*. 1983b, 1984c). This species is tolerant to pests except for rust (*Puccinia thaliae*) disease (Jeeva *et al*. 2004) and grasshoppers, Japanese beetle (*Popillia japonica*) and cut worm sometimes attack plants (Chung and Ripperton 1924). In South America, *Canna* is used in folk remedy (e.g. leaves are used to clear ulcers and rheumatism; Roth and Lindorf 2002).

Knowledge about edible canna is very poor, especially on photosynthesis and production processes toward biomass and rhizome yield. In this review, the experimental results published by the author's group that were obtained in central Japan, a temperate region where typical seasonal changes occur, are presented. The author distinguished the growth stages of edible canna as early (late April to early July), middle (early July to early September when stems elongate vigorously) and late (after early September when flower-buds and starch accumulation initiate).

MORPHOLOGICAL AND ANATOMICAL FEATURES

Aboveground organs

Edible canna grows up to 3 m tall at the late growth stage. On the main stem it has 12~14 elliptical leaves in Sabah (5° 15′ N 117° 0′ E), Malaysia and 20~22 leaves in Kanagawa (35° 26′ N 139° 30′ E), Japan with a rather round-shaped terminal leaf. This difference derives from the differences in temperature and day-length during the growth because Sabah and Kanagawa are located in the Torrid Zone and the Temperate Zone, respectively (unpublished data). Normal growth occurs at temperatures above 9°C, although the plant tolerates brief periods of temperatures down to 0°C (National Research Council 1989).

Edible canna has a flower cluster (compound inflorescence) above the terminal leaf. As for floral differentiation, Roth and Lindorf (2002) described that the genus *Canna* is neutral to day length. However, the author noticed that this species is a quantitative short-day plant by (a) applying a short-day treatment for potted plants and (b) comparing the days and leaf numbers from emergency to flowering under different latitude (e.g. Malaysia and Japan) (unpublished data).

The leaves are large and thick with a layer of water storage cells (hypodermal cells) beneath the adaxial and abaxial epidermal cells (**Fig. 2**). These cells are thought to be adapted to savanna conditions (Gade 1966) and in fact, edible canna is relatively drought-tolerant caused by hypodermal cells to shrink under a low soil-water level (10% water holding capacity; Brück *et al*. 2001). However, Sakamoto and Imai (2001) considered that another function of the water storage cells is to provide turgor pressure to support unrolling of the large leaf. The leaf has two layers of palisade cells, and dispersed spongy cells (parenchyma) like a dicotyledon and characteristically, oblique-cells present as elongated cells with round ends arranged obliquely to the long axis and forming an abaxial hypodermal tissue in the midrib (**Fig. 3**). Vascular bundle sheath cells are not well developed (Tomlinson 1969; Sakamoto and Imai 2001). Stomatal frequency on adaxial and abaxial leaf surfaces are 20~30 and 50~100, respectively (Imai and Ichihashi 1986). In 'reddish-purple' color plants, anthocyanin is allocated in vacuoles of epidermal cells imparting such a color to aerial parts (Tomlinson 1969).

In the early growth stage, the stem is stunted and with the passage of time it begins to elongate, especially under a hot environment. The number of unfolding leaves is more closely related with the number of days after seedling emergence than with the effective cumulative temperature, and the slope of the regression line for the number of leaf unfolding changes in early September when the floral initiation

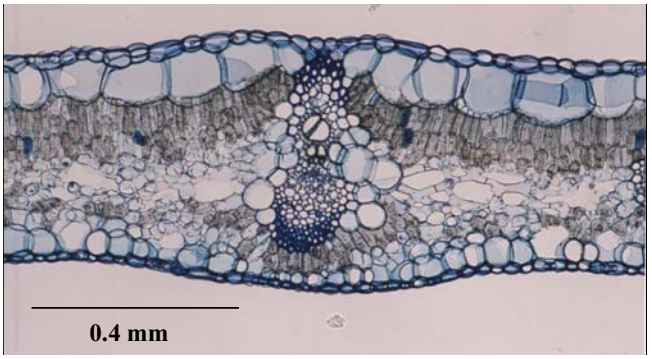

Fig. 2 Transverse section of a part of leaf-blade.

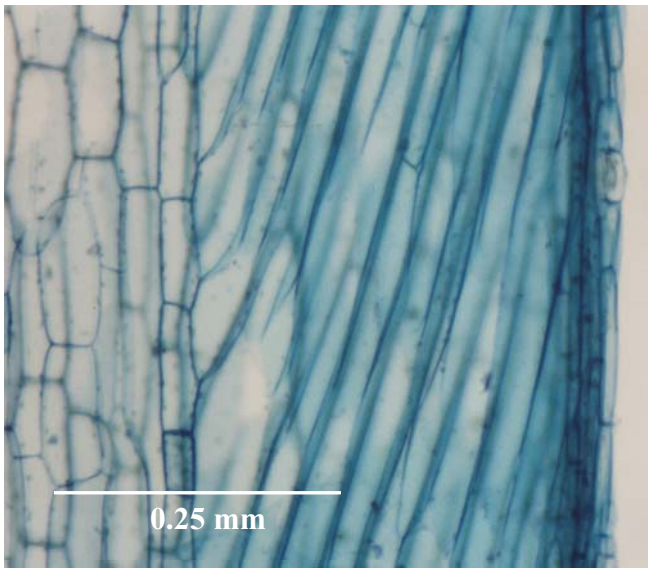

Fig. 3 Oblique-cells (right) beside the midrib (left).

and starch accumulation to rhizomes begin; from Y = 0.142X - 0.324 (r = 0.991***) to Y = 0.078X + 6.528 (r = 0.972***), where Y is the number of leaves on main stem and X is days after the seedling emergence (Imai *et al*. 1996). The stem emerges from its own underground rhizome without branching (Imai *et al*. 1993). Edible canna exudes mucilage at cut surfaces from mucilage canals in the aerial stem and rhizome (Tomlinson 1969).

As edible canna maintains high LAI during the latter half of its growth (mid August to early November), a non-destructive measurement of leaf area is necessary to study dry-matter production under field conditions. Leaf area is estimated as a product of the regression equation by leaf-length × leaf-width because its leaf form is a simple ellipsoid. This method is accurately applicable by multiplying 0.704 with leaf-length × leaf width. LAI can be obtained rapidly by estimating the mean leaf area per sample stem selected on the basis of the number of green leaves per stem (Kato *et al*. 1989).

Roots and rhizomes

Edible canna has fibrous roots which is typical to monocotyledons (**Fig. 4**). The root system is comprised of thick adventitious roots and thinner primary and secondary lateral roots. In mature adventitious roots, the polyarch stele with many vessels and the cortex with lacunae are unique features. There is no clear nodal structure in the stele of the rhizome and an intimate interconnection of node and stellar vascular bundle is not observed. There is no regularity of the development of adventitious roots as seen in gramineous species. Compared with *Musa* species, these features are rather similar but the number of primordia and thickness of adventitious roots, the number of vascular bundles, and the size of lacunae are smaller in edible canna (Hosoi and Imai 2001). The adventitious roots generate in pairs simultaneously near the nodes of rhizomes. The 'horizontal roots' running shallow underground and the 'vertical roots' growing deep in soil are clearly distinguished. The roots generated from the basal and apical side of the nodes of the rhizome tend to develop into 'vertical roots' and 'horizontal roots', respectively. The 'vertical roots', especially those near the rhizome, have superior tissue structure and physical characteristics compared with the 'horizontal roots' and the area of the cross section of the central cylinder and the number of vascular bundles largely contribute to the tensile strength of the root. The area of the cross section of the cortex also contributes to the bending rigidity of the root. The breaking force related to tensile strength and the second moment related to bending rigidity of the roots are larger than those in other herbaceous plants (Hosoi and Imai 2002). The basal-side roots generated from the basal side of the nodes of the rhizome are thicker and have more superior tissue structure than the apical-side roots generated from nodes of the apical side, from an early developmental stage. The shape of the root system is 'clumpy' in the early growth stage and it shifts to 'mushroom' after the middle growth stage, which is unique among monocotyledons (**Fig. 5**). The mushroom-shaped root system is formed by differences in root characteristics in sets of adventitious roots determined at an early growth stage (most of the apical-side roots become 'horizontal roots' and *ca*. 80% of the 'vertical roots' are derived from basal-side roots), and performs superior supporting functions of aboveground parts in terms of the massive root-soil structure and the functional share based on physical differences between vertical and horizontal roots: Whenever wind blows, dense and hard horizontal roots have a high resistance against the swaying motion (horizontal force), while vertical roots have a high tensile strength against the upward, pulling force (Hosoi and Imai 2003b).

In the main growth season, shoots emerge from rhizomes but when temperature declines or water shortage begins in the late growth stage, rhizomes begin to accumulate starch and swell. Under a tropical rainforest climate, however, the newly formed rhizomes do not accumulate starch and newly emerged shoots are vigorous even if many stems reach the flowering stage (pers. obs.).

Fig. 4 Adventitious roots which generate in pairs (right) from the rhizome and a part of root (left).

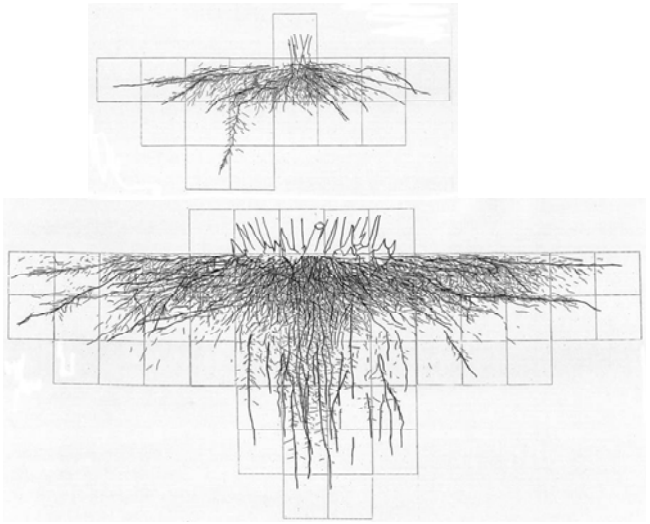

Fig. 5 Root system at early (upper) and late (lower) growth stages. From: **Hosoi J, Imai K** (2003b) Morphological and anatomical characteristics of adventitious roots and the root distribution in edible canna. *Japanese Journal of Crop Science* **72**, 431-435, ©2003, with kind permission from The Crop Science Society of Japan, Tokyo, Japan.

CANOPY ARCHITECTURE

Koyama (1984) emphasized that edible canna could conserve soil because its rapid leaf growth cover the soil surface and thus prevented soil erosion caused by heavy rain; its large fraction of leaf debris is a source of natural compost.

Oka *et al*. (1987) reported good canopy architecture of edible canna: The light extinction coefficient (k) of the stand was low (0.48) and equivalent to that of corn (0.40), irrespective of high LAI (7.11). To clarify ontogenetic changes of production structure which contribute to its high yield capacity, Imai *et al*. (1994) grew edible canna from late April to mid-November at a 100 cm × 50 cm spacing. The plants reached maximum height (*ca*. 2.8 m) by mid-September, at which time the LAI exceeded 10 and reached a maximum of 11.2 before declining as the plant matured. The k value of the canopy changed from 1.34 (typical of broad-leaf plants) in the early growth to 0.45 (typical of grasses) in the late growth stages. These indicated that in the early growth, edible canna developed planophyll leaves which maximized light interception under low LAI but as the plant grew, the upper leaves became more upright, which enabled light to penetrate deep into the tall canopy. The initiation of shoots and the azimuth angle of leaves as the plants grew appeared to be such that light interception by the crop canopy was maximized.

At the late growth stage, edible canna sometimes lodges when strong wind blows (e.g. typhoon) because of its large aboveground parts. Hosoi and Imai (2004) and Kiya and Imai (2008) considered physical factors of lodging using mathematical models (Hozyo 1976; Karizumi 1987). The projected side-view area of aboveground parts (leaves and stems) which reflects growth vigor was large and was determined by three parameters (plant height, width of stock base, stand angle). The causal factors of lodging were ascribed to the large projected area in terms of external force such as wind and to the own-weight-moment in terms of internal force which was added by its aerial weight. The external force (unit: N) is expressed as $W = (\rho V^2) / 2 \times Cd \times S$, where ρ is air density (kg / m^3), V is wind speed (m / s), Cd is resistance coefficient which depends on species, form and wind speed, and S is perpendicularly projected area of plants (m^2) (Karizumi 1987). The internal force (unit: N · m) is expressed as $M = Wa \times L \times \cos \theta$, where Wa is aboveground fresh-weight (N), L is distance between ground level and gravity center of stem (m), and θ is stem angle (rad) (Hozyo 1976). The increase in stem inclination which related to lodging was due to the swelling of rhizomes. The shortening of plant height to *ca*. 2 m at the late growth stage was preferable for a high yield from the risk of lodging; this shortening mitigated 10-20% of external force and *ca*. 50% of internal force.

PHOTOSYNTHESIS

Light responses of leaf gas-exchange characteristics in edible canna were examined under controlled environments (Imai and Ichihashi 1986). When plants were grown under 650 μmol m^{-2} s^{-1} PPFD, and measured at 1000 μmol m^{-2} s^{-1} PPFD, the rates of net photosynthesis (Pn) and transpiration (E) attained maxima (15.1 μmol CO_2 m^{-2} s^{-1} and 3.4 mmol H_2O m^{-2} s^{-1}, respectively) about three days from the leaf unrolling and afterward, gradually declined. When plants were grown under relatively low light intensity (290 μmol m^{-2} s^{-1} PPFD), the days to the maximum Pn and E were delayed slightly but sustained a longer period. However, the rates and light responses of Pn and E are similar and did not saturate at 1000 μmol m^{-2} s^{-1} PPFD irrespective of light intensity during growth. In another field experiment (Ishida and Imai 2004), Pn saturated at *ca*. 1500 μmol m^{-2} s^{-1} PPFD. Therefore, edible canna was ascribed to a medium-efficient, sun plant tolerant to shading, which could enable cultivation under a broad range of light environments. The temperature dependence of Pn of edible canna showed a typical response with a maximum at around 28°C and a high CO_2 compensation point (50 μmol mol^{-1}), clearly indicating the C_3 photosynthesis adapted to a warm climate (Imai and Ichihashi 1986; Ishida and Imai 2003).

In a field experiment in Japan, Kato and Imai (1996) observed that in late-July and mid-August when LAI attained 7 and 9, respectively, about 70% of the leaf area was occupied by the upper 4 leaves with a maximum Pn of 19.1 μmol CO_2 m^{-2} s^{-1}. When plants began rapid growth in late-July, the Pn of leaves inside the canopy decreased with decreasing light due to mutual shading. Leaf area and Pn of the upper 4 leaves substantially contributed to the dry-matter production after the middle growth stage.

PRODUCTIVITY

Dry-matter production

Imai *et al*. (1993, 1994) cultivated edible canna for three successive seasons from late April to early to mid-November (*ca*. 6.5 months) under field conditions to clarify its productivity in the temperate climate of Japan. The growth of the aerial part of the plant was substantially accelerated by a hot environment from mid-July to late August, and the plant grew up to 2.7~2.8 m in height. It grew 20~22 leaves on its main stem, and 9~19 shoots with 29~35 newly formed rhizomes at a 100 cm × 50 cm spacing. Edible canna maintained high LAI (>9) for about 2 months from late August to early November with a maximum of 11.5~12.7. Accumulation of dry-matter to newly formed rhizomes began in mid-August and continued until the final harvest in November, when frost damage on the leaf canopy occurred. The whole plant and rhizome dry weight attained at 2578~3968 g m^{-2} and 954~1644 g m^{-2}, respectively, so that the harvest index (the fraction of the dry-matter production that is allocated to the harvested parts with economic importance) was as low as 0.37~0.43 when compared with other root and tuber crops such as cassava (0.5~0.7; Kawano 2003), sweet potato (0.6~0.7; Osaki *et al*. 1995) and potato (0.65~0.8; Osaki *et al*. 1996). Crop growth rate (CGR) was 12.7~19.3 g m^{-2} d^{-1} and interestingly, very high maximum CGR (35.3~43.6 g m^{-2} d^{-1}) was obtained from mid-September to early October. These values are higher or comparable to those of other productive crops (potato, 23; sugarbeet, 31; Napiergrass, 39; corn, 29~52; Loomis and Connor 1992). A tall stand with high LAI and good architecture resulted in high productivity during the latter half of ontogenesis. Yamamoto *et al*. (2007) obtained similar results (3369~3597 g m^{-2} dry-matter, 17.1~18.9 g m^{-2} d^{-1} CGR, 9.6~15.2 LAI) in southwest Japan. Oka *et al*. (1987) and Piyachomkwan *et al*. (2002), respectively, grew edible canna in Thailand and had lower whole plant dry-matter (*ca*. 1800 and 2190~2580 g m^{-2}) but higher harvest index (*ca*. 0.5 and 0.58~0.64) than the authors' results. Hermann *et al.* (1997) obtained data in a greenhouse experiment in Quito (2400 m) for 26 accessions of edible canna collected from the Andes in which the whole plant dry-matter ranged between 800 and 5400 (mean: 2400) g m^{-2} yr^{-1} with harvest indexes of 0.35~0.74 (mean: 0.56) but in a commercial field of a highland (2350 m), whole plant dry-matter was as low as 1591 g m^{-2} with a LAI of 3.32. In Taiwan, Lu and Dah (1983c, 1984a) obtained higher rhizome yields under prolonged cultivation periods because rhizomes are vegetative storage organ.

Plant spacing is an important factor for crop production. Toyohara (1987) examined this and concluded that 100 cm × 50 cm was the best, but according to Lu and Dah (1984d) the best was 60 cm × 50~60 cm. Soil moisture is another important factor. Murao and Nishiyama (1987) grew edible canna under 3 moisture levels of soil and observed that plants were tolerant to high moisture but the root-shoot ratio decreased, whereas it had poor yield under low moisture.

To clarify the effect of seed-rhizome weight on the vegetative growth and yield of new rhizomes in edible canna, Intabon *et al*. (1993) planted seed-rhizomes weighing

20~500 g fresh weight. Shoots from heavier seed-rhizomes required fewer days to emerge from the soil and had more rapid growth with greater yield than those from lighter seed-rhizomes. However, this tendency was obscure for seed-rhizomes weighing more than 200 g. From an economical viewpoint, they recommended the use of seed-rhizomes weighing about 200 g. This does not conflict with the findings of Lu and Dah (1983a, 1984b) who obtained results claiming that among 4 seed-rhizome sizes (20, 50, 100, 200 g), the largest size gave the highest yield.

Nutrient absorption

According to its high potential productivity, edible canna absorbs a large quantity of mineral nutrients. Imai *et al.* (1990) measured macro- and micronutrients in different organs with growth. The N contents in leaves and stems were 1.5~3.6% and 0.4~2.2%, respectively. On the whole plant basis, the absorbed N was *ca*. 240 kg ha^{-1}, which indicated the need of a large quantity of fertilizer to obtain high dry-matter. Interestingly, the K contents of stems (6~14%) ranked high when compared with other root and tuber crops (highest values: potato, 17.6%; sweet potato, 6.0%; taro, 3.3%; cassava, 3.3%; Reuter and Robinson 1997). Edible canna has 'vertical' roots which penetrate deep in soil, and the 'horizontal' roots which run shallow underground (Hosoi and Imai 2002). When compared at different stages of growth, distances from stock and direction of elongation, the respiration rate of roots decreased with age but the difference between the two types of roots was not observed. Therefore, the nutrient absorption was considered to be performed mainly by a large quantity of horizontal roots (Hosoi and Imai 2003a).

Starch accumulation

Kishi and Imai (1995) found that edible canna started to accumulate starch somewhat later than dry-matter increment in rhizomes and attained 40% of rhizome dry-matter (i.e. equivalent to 400 g starch m^{-2}) after 6 months' growth. Piyachomkwan *et al*. (2002) obtained similar starch yield (414~489 g m^{-2}) in Thailand, though Aoi and Tanoue (1989) and Yamamoto *et al*. (2007) obtained far higher starch yield (700~900 and 574~681 g m^{-2}) in southwest Japan. Gallant *et al*. (1982) also reported higher starch content (75~80%) in edible canna. These differences depend on the growth duration, planting density, nutrient supply and other conditions. The average size of starch grains ranges from 41~86 μm (Lu *et al*. 1985; Nomura *et al*. 1999) to 60~145 μm (Gallant *et al*. 1982) and this is larger than potato (50 μm), sweet potato (18 μm) and cassava (17 μm). The amylose content of the starch shows large variation: 13.8% (Pérez and Lares 2005), 19~25% (Thitipraphunkul *et al*. 2003a, 2003b), 27% (Gallant *et al*. 1982) and 38.0% (Soni *et al*. 1990). This may include the effect of growth temperature (i.e. higher temperatures decrease amylose content; Matsue *et al.* 2002) or the effect of ploidy level in this species, though not examined before, or simply the problem of confusion in plant materials (i.e. closely resembled *Canna* species). The size of starch granules tended to increase with the development of rhizomes from the immature to the mature stage and the full size granule seemed to have a rounder shape (Puncha-arnon *et al*. 2007).

PROPAGATION

Edible canna distributed in Asia is thought to be triploid (Lu *et al*. 1985; Lai and Tsai 1990; Tanaka 1998; Hermann 1999) so that it is impossible to breed by crossing. In general, it is propagated by the division of rhizomes with an appropriate size. To obtain more productive plants, we can propagate and screen plantlets *in vitro*. However, such trials are scarce as to edible canna at present. Kromer (1979) and Kromer and Kukulczanka (1985) propagated *Canna indica* by *in vitro* culture of the subterranean organ and apical meristem and obtained substantial plantlets under combinations of plant growth regulators with MS (Murashige and Skoog 1962) and ½MS medium. However, they could not obtain successive callus proliferation from them. Hoski and Sasaki (1991) propagated edible canna by a longitudinal shoot-split method *in vitro*, though this had a slow propagation rate (*ca.* 1.8 shoots per month). Sakai and Imai (2005, 2007) cultured terminal buds aseptically with different combinations of auxins, cytokinins, and culture media to establish a tissue culture system for this species. The combination of naphthaleneacetic acid (NAA) or indole-3-butyric acid (IBA) with 6-benzylaminopurine (BA) induced optimal explant growth, and when the explants grew substantially, 2,3,5-triiodobenzoic acid promoted lateral shoot growth. For explant growth, the optimal concentration of NAA was 0.1~0.5 mg L^{-1} and that of BA was 0.5~1 mg L^{-1}. Some of the explants formed callus-like or protocorm-like tissues. Among the three culture media, B5 medium (Gamborg *et al.* 1968) gave the highest survival rate of explants (92%), followed by ½MS (72%) and MS (52%). Gellan gum was a superior supporting/gelling material for explant growth compared to a filter paper-bridge with liquid medium or agar. These results indicate that multiple plantlet propagation can be performed routinely, while callus proliferation remains an endeavor: Callus is an important stage for multiple shoot formation and also for somaclonal variation. Ishiki *et al*. (1997, 1998, 1999) examined the chromosome and karyotype of edible canna in the Andean region and confirmed the distribution of diploid and triploid plants. Therefore, it may be possible to breed new type plants by crossing which have higher yield than triploid plants in Asia.

BASES OF UTILIZATION

Direct food

As indicated before, edible canna has been consumed from ancient times until now, though less frequently, as a part of home-consuming plants in conventional agriculture (Gade 1966; Ugent *et al*. 1984; National Research Council 1989). A directly boiled and/or grilled rhizome is sufficiently edible, though not as tasty in the author's impression when compared with potato, sweet potato and taro. Cooked meat of rhizomes is better used for dishes or for making cakes. Rhizomes may be a useful resource on the occasion of famine if people plant in their backyard. At present, starch is ordinarily processed from rhizomes for use as food (Lai *et al*. 1980; Koyama 1984; National Research Council 1989; Imai 1996).

Starch source

Because canna starch is a potential candidate for industrial utilization as a new base starch, its physicochemical properties are being studied and compared with different starch sources. During rhizome development, from the immature to mature stage, there were no significant changes in pasting and thermal properties, crystalline structure or chemical composition of canna starch (Puncha-arnon *et al*. 2007). According to Gallant *et al*. (1982), edible canna starch has a B-type X-ray diffraction pattern (typical to root and tuber starches) but has a high digestibility rather close to A-type starch (cereal type which is smaller in size and easy to digest by α-amylase). However, Inatsu *et al*. (1983) reported that edible canna starch (Ca-starch) obtained from Taiwan was tolerant to enzymatic digestion and showed the same B-type with potato. On the other hand, the average degree of polymerization of amylose was 3100, less than that of potato (5500). Fujimoto *et al*. (1990) noticed that edible canna starch tended to be decomposed by amylase slower than that of sweet potato, ascribed to its larger size. Thitipraphunkul *et al*. (2003b) studied canna starches from Thailand and Japan and reported that they were all B-type and the degrees of polymerization of amylose was 1590~1650 and the mole % of branched fraction of amylose was 13

~16%. Amylopectin contained a high concentration of organic phosphorus (391~420 ppm), almost all of which was allocated to the B-chain.

Edible canna starch in Vietnam has a wide range of gelatinization temperature and a high transition enthalpy. The viscosity of hot paste is quite low and stable, whereas the cool paste has high viscosity and weak resistance against retrogradation. During refrigeration and frozen storage, the paste released much expelled water, which showed low stability during storage with high syneresis. However, it was an excellent source of transparent noodle (Hung and Morita 2005). Gelatinization occurs at higher temperature and the retrogradiation of paste occurs faster than that of potato (Inatsu *et al*. 1983). Viscograms of canna starch paste are quite stable during cooking and have a high setback with a high tendency for retrogradation (Thitipraphunkul *et al*. 2003a). Compared to corn starch, edible canna starch had higher swelling power and solubility, three times larger Brabender viscosity and higher retrogradation (Soni *et al*. 1990). However, the level of retrogradation on canna starch was similar to that of mung bean (*Vigna radiata*) (Thitipraphunkul *et al*. 2003b).

Tanoue *et al*. (1989) examined the gelling characteristics of canna starch to make noodle. Because canna starch is 'Ca-starch', its breakdown is small after swelling. The gel of canna starch was the hardest among potato, sweet potato and kuzu starches and had a hard texture for mastication. As a source for noodles, canna starch was slightly inferior to mung bean starch. Piyachomkwan *et al*. (2002) reported that canna starch had a higher peak viscosity at a high temperature and gelatinized paste rapidly formed a good gel on cooling and was more stable than cassava. Also, Pérez *et al*. (1997, 1998) described that edible canna starch made from Venezuela accessions developed higher viscosity and gel firmness than cassava starch at the same concentration. It produced clear paste and could substitute cassava starch. According to Pérez and Lares (2005), the stability during cooking of canna starch was noteworthy and could be an interesting feature to consider from an industrial viewpoint.

Livestock feeding

Fresh aboveground parts are a good source for livestock feeding. For example, when the author fed sheep with water, salt and fresh aboveground parts of edible canna at the late growth stage (5 kg day^{-1}), their body weight (*ca*. 45 kg) was maintained constant and in good health. Under free feeding, they consumed *ca*. 6.5 kg day^{-1} and increased their body weight (unpublished data). Of course, rhizomes are applicable but these are better to use for the starch industry and the dregs of rhizomes may be used for livestock feeding. There are local uses of edible canna for feeding cattle and swine (Chung and Ripperton 1924; Chandrapal Singh and Das 1986; National Research Council 1989).

Silage made from edible canna has potential as a feed for ruminants, though a high water content of aboveground parts is a problem that needs to be solved. Jun *et al*. (2006) examined the feeding value of silage prepared from aboveground parts, parallel with *in situ* digestion in the rumen, among three local varieties of edible canna and compared it with silage from corn at yellow ripe stage. Crude protein contents (9.9~11.2%), acid and neutral detergent fibers (30.5~33.8, 54.6~63.4%) and crude ash and fat (16.0~18.0, 3.1~3.6%) in canna silage were higher, and that of nonstructural carbohydrate (6.6~16.0%) was lower than in corn silage. The acid (lactic, acetic and total organic) contents and the Flieg's score of canna silage were equivalent or superior to those of corn silage. The effective degradability of dry matter and organic matter of canna silage in the rumen was similar to corn. Tamaki *et al*. (1994) reported that cattle preferred the canna silage than the silage from corn plus sorghum.

Pharmaceutical and chemical uses

In South America, *Canna* is used in folk remedies: leaf; to clear ulcers and rheumatism and as a diuretic and antiabortion, stipe; to recover from sickness and to regain high spirits, rhizome; as an emollient cataplasm, a diuretic and demulcent (Roth and Lindorf 2002). *Canna* exudes gum from cut surfaces of the stalk and this is used for an emulsifying agent (Strittmatter 1955). Recently, Yun *et al*. (2004) isolated four phenylpropanoids (caffeic acid, rosemarinic acid, caffeoyl-4'-hydroxyphenyllactic acid, salvianolic acid) and three phenylpropanoid sucrose esters from rhizomes of edible canna. These chemicals may have vast usages as medicine and food additives.

PERSPECTIVES

Among about 17 species of root and tuber crops domesticated in the Andean region, edible canna lacks biodiversity relative to other crops (Flores *et al*. 2003), so that increasing accessions require work for further development of its agricultural traits. The author would like to emphasize that edible canna has a high multipurpose potential and, therefore, there is a need for multidisciplinary studies. For example, edible canna is a prospective source of textile, pulp and viscose (Das *et al*. 1952), and it has not yet been examined as a fuel source, even though its aboveground organs may be a good source of methane while the rhizomes a source of ethanol.

ACKNOWLEDGEMENTS

This work was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology, Japan (No. 15380017).

REFERENCES

* In Japanese
** In Japanese with English abstract

Aoi K, Tanoue H (1989) Cultivation of edible canna in Tanegashima. I. Investigation of planting pattern. *Agriculture and Horticulture* **64**, 866-872*

Brück H, Jureit C, Hermann M, Schulz A, Sattelmacher B (2001) Effects of water and nitrogen supply on water use efficiency and carbon isotope discrimination in edible canna (*Canna edulis* Ker-Gawler). *Plant Biology* **3**, 326-334

Cada E, Nipal S, Cueto DC, Sacdalan I (1941) Cultural studies of arrowroot, edible canna, and turmeric in the College of Agriculture. *The Philippine Agriculturalist* **29**, 696-705

Chandrapal Singh K, Das TK (1986) Nutritive value of canna as a feed for livestock. *Mysore Journal of Agricultural Science* **20**, 208-211

Chung HL, Ripperton JC (1924) Edible canna in Hawaii. *Hawaii Agricultural Experiment Station Bulletin* **54**, 1-16

Das DB, Mitra MK, Wareham JF (1952) Fibre from *Canna orientalis* as a jute substitute. *Journal of Scientific and Industrial Research* **11B**, 541-543

Flores HH, Walker TS, Guimarães RL, Bais HP, Vivanco JM (2003) Andean root and tuber crops: underground rainbows. *HortScience* **38**, 161-167

Fujimoto S, Yamanaka O, Suganuma T, Nagahama T (1990) Starches from Akaza-kazura (*Boussingaultia baselloides*), amerika-sato-imo (*Xanthosoma sagittifolium*) and syokuyo-kanna (*Canna edulis*). *Memoirs of the Faculty of Agriculture, Kagoshima University* **40**, 49-54**

Gade DW (1966) Achira, the edible canna, its cultivation and use in the Peruvian Andes. *Economic Botany* **20**, 407-415

Gallant DJ, Bewa H, Buy QH, Bouchet B, Szylit O, Sealy L (1982) On ultrastructural and nutritional aspects of some tropical tuber starches. *Starch/Stärke* **34**, 255-262

Gamborg OL, Miller RA, Ojima K (1968) Nutrient requirements of suspension culture of soybean root cells. *Experimental Cell Research* **50**, 151-158

Hermann M, Uptmoor R, Freire I, Montallvo JL (1997) Crop growth and starch productivity of edible canna. *CIP Program Report 1995-96*, Centro Internacional de Papa, Lima, Peru, pp 295-301

Hermann M, Quynh NK, Peters D (1999) Reappraisal of edible canna as a high-value starch crop in Vietnam. *CIP Program Report 1997-98*, Centro Internacional de Papa, Lima, Peru, pp 415-424

Hosoi J, Imai K (2001) Morphogenesis of roots in edible canna – with special reference to adventitious roots. *Japanese Journal of Crop Science* **70**, 234-237**

Hosoi J, Imai K (2002) Morhpogenesis and physical characteristics of adventi-

tious roots in edible canna. *Japanese Journal of Crop Science* **71**, 500-505**

Hosoi J, Imai K (2003a) Respiration of adventitious roots in edible canna. *Japanese Journal of Crop Science* **72**, 227-228**

Hosoi J, Imai K (2003b) Morphological and anatomical characteristics of adventitious roots and the root distribution in edible canna. *Japanese Journal of Crop Science* **72**, 431-435**

Hosoi J, Imai K (2004) Physical factors of the lodging judging from the morphogenic viewpouint of aboveground parts and their mitigation in edible canna. *Japanese Journal of Crop Science* **73**, 71-76**

Hosoki T, Sasaki H (1991) *In vitro* propagation of *Canna edulis* Ker. by longitudinal shoot-split method. *Plant Tissue Culture Letters* **8**, 175-178

Hozyo Y (1976) Lodging and stiffness of crop plants. In: Hozyo Y, Hoshikawa K (Eds) *Morphology and Function of Crop Plants* (Vol II), Association for Advancement of Agricultural Science, Tokyo, pp 166-183*

Hung PV, Morita N (2005) Physicochemical properties and enzymatic digestibility of starch from edible canna (*Canna edulis*) grown in Vietnam. *Carbohydrate Polymers* **61**, 314-321

Imai K, Ichihashi T (1986) Studies on matter production of edible canna (*Canna edulis* Ker.). I. Gas exchange characteristics of leaves in relation to light regimes. *Japanese Journal of Crop Science* **55**, 413-418

Imai K, Adachi N, Yoritaka S (1990) Studies on matter production of edible canna: Absorption of mineral nutrients. *Japanese Journal of Crop Science* **59 (Extra 2)**, 89-90*

Imai K, Kawana T, Shimabe K, Intabon K, Tanaka K (1993) Studies on matter production of edible canna (*Canna edulis* Ker.). II. Changes of dry matter production with growth. *Japanese Journal of Crop Science* **62**, 601-608

Imai K, Shimabe T, Tanaka K, Kawana T (1994) Studies on matter production of edible canna (*Canna edulis* Ker.). III. Changes of production structure with growth. *Japanese Journal of Crop Science* **63**, 345-351

Imai K (1996) Fundamentals of food production in the 21st century – Considerations through the studies on matter production of edible canna. In: Eguchi H, Kimura K, Hayakawa S (Eds) *Food Production and Agricultural Environment in the 21st Century,* The Society of Agricultural Meteorology of Japan/ The Japanese Society of Environment Control in Biology, Tokyo, pp 129-134*

Imai K, Senba T, Kato M (1996) Studies on matter production of edible canna: Effects of meteorological factors on the growth of leaves. *Japanese Journal of Crop Science* **65 (Extra 2)**, 277-278*

Inatsu O, Maeda I, Jimi N, Takahashi K, Taniguchi H, Kawabata M, Nakamura M (1983) Edible canna starch I. Some properties of edible canna starch produced in Taiwan. *Journal of the Japanese Society of Starch Science* **30**, 38-47

Intabon K, Kato M, Imai K (1993) Effect of seed-rhizome weight on growth and yield of edible canna (*Canna edulis* Ker.). *Japanese Journal of Crop Science* **62**, 111-115

Ishida Y, Imai K (2003) Gas exchange characteristics in leaves of edible canna with special reference to carbon dioxide concentration. *Proceedings of the Kanto Branch, The Crop Science Society of Japan* **18**, 94-95*

Ishida Y, Imai K (2004) Role of stomata and leaf tissues on gas exchanges in edible canna. *Proceedings of the Kanto Branch, The Crop Science Society of Japan* **19**, 68-69*

Ishiki K, Arellano J, Salgado V (1997) Karyotype of achira (*Canna edulis*) cultivated in South America. *Japanese Journal of Tropical Agriculture* **41 (Extra 2)**, 3-4*

Ishiki K, Arellano J, Salgado V (1998) Yield of achira (*Canna edulis*) cultivated in South America. *Japanese Journal of Tropical Agriculture* **42 (Extra 1)**, 69-70*

Ishiki K, Arellano J, Salgado V (1999) Starch content of achira (*Canna edulis*) cultivated in South America. *Japanese Journal of Tropical Agriculture* **43 (Extra 2)**, 79-80*

Jeeva ML, Hegde V, Makeshkumar T, Sriram S, Nair RR, Edison S, Mathur N (2004) Rust of Queensland arrowroot (*Canna edulis*) caused by *Puccinia thaliae*: a new record for India. *Plant Pathology* **53**, 261

Jun H, Jo I, Hwangbo S, Lee J, Imai K (2006) Feeding value and *in situ* digestibility of edible canna for silage. *Plant Production Science* **9**, 408-414

Karizumi N (1987) *Illustrations of Tree Roots*, Seibundo Shinkosha, Tokyo, pp 101-112

Kato M, Inthavongsa K, Imai K (1989) An estimation of leaf area in edible canna (*Canna edulis* Ker.). *Japanese Journal of Crop Science* **58**, 753-758

Kato M, Imai K (1996) Studies on matter production of edible canna (*Canna edulis* Ker.). IV. Leaf unrolling and changes in leaf photosynthetic rates with growth under field conditions. *Japanese Journal of Crop Science* **65**, 253-259

Kawano K (2003) Thirty years of cassava breeding for productivity - biological and social factors for success. *Crop Science* **43**, 1325-1335

Khoshoo TN, Mukherjee I (1970) Genetic-evolutionary studies on cultivated cannas. VI. Origin and evolution of ornamental taxa. *Theoretical and Applied Genetics* **40**, 204-217

Kishi Y, Imai K (1995) Starch accumulation during the growth of edible canna. *Proceedings of the Kanto Branch, The Crop Science Society of Japan* **10**, 57-58*

Kiya R, Imai K (2008) A fundamental study on the mitigation of lodging injury in edible canna. *Japanese Journal of Crop Science* **77 (Extra 1)**, 300-301*

Koyama T (1984) *Plant Resources Studies*, Kodansha, Tokyo, pp 152-155*

Kromer K (1979) Biological activity of endogenous and influence of exogenous growth regulators on *Canna indica* regeneration *in vitro*. *Acta Horticulturae* **92**, 295-300

Kromer K, Kukulczanka K (1985) *In vitro* cultures of meristem tips of *Canna indica* L. *Acta Horticulturae* **167**, 279-285

Lai KL, Tsai YZ, Wang TY (1980) Studies on the edible canna in Taiwan: Botanical characteristics and economical use of edible canna. *Journal of the Agricultural Association of China, New Series* **111**, 1-13

Lai KL, Tsai YZ (1990) Cultivation and processing of edible canna in subtropical Taiwan. *Acta Horticulturae* **275**, 117-122

Loomis RS, Connor DJ (1992) *Crop Ecology: Productivity and Management in Agricultural Systems*, Cambridge University Press, Cambridge, pp 34-42

Lu AN, Dah PN (1983a) Effects of tuber size and planting depth on the growth and yield of edible canna. *Annual Report, Dryland Food Crops Improvement, No. 24*, Department of Agriculture and Forestry, Republic of China, pp 311-313 (In Chinese with English abstract)

Lu AN, Dah PN (1983b) Yield trial of edible canna varieties. *Annual Report, Dryland Food Crops Improvement, No. 24*, Department of Agriculture and Forestry, Republic of China, pp 314-315 (In Chinese with English abstract)

Lu AN, Dah PN (1983c) Effect of planting and harvesting dates on tuber yield of edible canna. *Annual Report, Dryland Food Crops Improvement, No. 24*, Department of Agriculture and Forestry, Republic of China, pp 316-318 (In Chinese with English abstract)

Lu AN, Dah PN (1984a) Effect of planting and harvesting dates on yield of edible canna (II). *Annual Report, Dryland Food Crops Improvement, No. 25*, Department of Agriculture and Forestry, Republic of China, pp 264-266 (In Chinese with English abstract)

Lu AN, Dah PN (1984b) Effect of tuber size and planting depth on yield of edible canna (II). *Annual Report, Dryland Food Crops Improvement, No. 25*, Department of Agriculture and Forestry, Republic of China, pp 267-269 (In Chinese with English abstract)

Lu AN, Dah PN (1984c) Yield trial of edible canna (II). *Annual Report, Dryland Food Crops Improvement, No. 25*, Department of Agriculture and Forestry, Republic of China, pp 270-271 (In Chinese with English abstract)

Lu AN, Dah PN (1984d) Effect of planting density on tuber production of edible canna (II). *Annual Report, Dryland Food Crops Improvement, No. 25*, Department of Agriculture and Forestry, Republic of China, pp 272-273 (In Chinese with English abstract)

Lu AN, Kao TC, Dah PN, Hong TS (1985) Studies on the agronomical characteristics of edible canna tuber. *Bulletin of Taichung District Agricultural Improvement Station* **10**, 101-104 (In Chinese with English summary)

Matsue Y, Sato H, Uchimura Y, Ogata T (2002) Influence of environmental temperature during the ripening period on the amylase content and whiteness of low-amylose rice. *Japanese Journal of Crop Science* **71**, 463-468**

Mukherjee I, Khoshoo TN (1971) Genetic-evolutionary studies on cultivated cannas. V. Intraspecific polyploidy in starch yielding *Canna edulis*. *Genética Ibérica* **23**, 35-42

Murao M, Nishiyama K (1987) Effect of different soil moisture condition on growth and yield of *Canna edulis*. In: *Development, Technique and Cooperation in Agriculture: Memoirs of the 30th Anniversary,* Department of International Agricultural Development, Tokyo University of Agriculture, Tokyo, pp 28-34**

Murashige T, Skoog F (1962) A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiologia Plantarum* **15**, 473-497

National Research Council (1989) *Lost Crops of the Incas: Little-Known Plants of the Andes with Promise for Worldwide Cultivation*, National Academy Press, Washington, DC, pp 27-37

Nomura K, Yoneda K, Uchiyama H, Koyama T (1999) Comparison of growth characteristics among several species of *Canna* spp. *Japanese Journal of Tropical Agriculture* **43**, 97-102**

Oka M, Boonseng O, Watananonta W (1987) Characteristics of the dry matter and tuber production of Queensland arrowroot (*Canna edulis* Ker.). *Japanese Journal of Tropical Agriculture* **31**, 172-178

Osaki M, Ueda H, Shinano T, Matsui H, Tadano T (1995) Accumulation of carbon and nitrogen compounds in sweet potato plants grown under different nitrogen application rates. *Soil Science and Plant Nutrition* **41**, 547-555

Osaki M, Matsumoto M, Shinano T, Tadano T (1996) A root-shoot interaction hypothesis for high productivity of root crops. *Soil Science and Plant Nutrition* **42**, 289-301

Pérez E, Lares M, González Z (1997) Some characteristics of sagu (*Canna edulis* Kerr) and zulu (*Maranta* sp.) rhizomes. *Journal of Agricultural and Food Chemistry* **45**, 2546-2549

Pérez EE, Breene WM, Bahnassey YA (1998) Variations in the gelatinization profiles of cassava, sagu and arrowroot native starches as measured with different thermal and mechanical methods. *Starch/Stärke* **50**, 70-72

Pérez E, Lares M (2005) Chemical composition, mineral profile, and functional properties of canna (*Canna edulis*) and arrowroot (*Maranta* spp.) starches. *Plant Foods for Human Nutrition* **60**, 113-116

Piyachomkwan K, Chotineeranat S, Kijkhunasatian C, Tonwitowat R, Prammanee S, Oates CG, Sriroth K (2002) Edible canna (*Canna edulis*) as a complementary starch source to cassava for the starch industry. *Industrial Crops and Products* **16**, 11-21

Prince LM, Kress WJ (1997) Cannaceae. In: *Asahi Encyclopedia, Plants of the World* (Vol X), The Asahi Shimbun, Tokyo, pp 168-169*

Puncha-arnon S, Puttanlek C, Rungsardthong V, Pathipanawat W, Uttapap D (2007) Changes in physicochemical properties and morphology of canna starches during rhizomal development. *Carbohydrate Polymers* **70**, 206-217

Reuter DJ, Robinson JB (Eds) (1997) *Plant Analysis: An Interpretation Manual*, CSIRO Publishing, Collingwood, Victoria, 572 pp

Roth I, Lindorf H (2002) *South American Medicinal Plants: Botany, Remedial Properties and General Use*, Springer, Berlin, pp 162-166

Sakai T, Imai K (2005) Effects of growth regulators on shoot-tip culture of edible canna. *Proceedings of the Kanto Branch, The Crop Science Society of Japan* **20**, 66-67*

Sakai T, Imai K (2007) The influence of growth regulators and culture medium composition on shoot-tip cultures of edible canna. *Environment Control in Biology* **45**, 155-163

Sakamoto Y, Imai K (2001) Leaf structure and function in edible canna (1). *Japanese Journal of Crop Science* **70 (Extra 1)**, 176-177*

Segeren W, Maas PJM (1971) The genus *Canna* in northern South America. *Acta Botanica Neerlandica* **20**, 663-680

Soni PL, Sharma H, Srivastava HC, Gharia MM (1990) Physicochemical properties of *Canna edulis* starch - Comparison with maize starch. *Starch/Stärke* **42**, 460-464

Strittmatter DA (1955) A preliminary investigation of canna gum. *Journal of the American Pharmaceutical Association* **44**, 411-414

Tamaki M, Kishi T, Endoh Y, Kobashi K, Nakamura N (1994) Feeding values of Queensland arrowroot for silage. *Japanese Journal of Grassland Science* **40**, 333-335*

Tanaka N (1998) Economic botanical notes on edible canna (Cannaceae) in south Vietnam. *The Journal of Japanese Botany* **73**, 319-324

Tanaka N (2004) The utilization of edible *Canna* plants in southeastern Asia and southern China. *Economic Botany* **58**, 112-114

Tanoue H, Aoi K, Shimozono H (1989) Cultivation of edible canna in Tanegashima. II. Processing characteristics of the starch. *Agriculture and Horticulture* **64**, 971-976*

Thitipraphunkul K, Uttapap D, Piyachomkwan K, Takeda Y (2003a) A comparative study of edible canna (*Canna edulis*) starch from different cultivars. Part I. Chemical composition and physicochemical properties. *Carbohydrate Polymers* **53**, 317-324

Thitipraphunkul K, Uttapap D, Piyachomkwan K, Takeda Y (2003b) A comparative study of edible canna (*Canna edulis*) starch from different cultivars. Part II. Molecular structure of amylose and amylopectin. *Carbohydrate Polymers* **54**, 489-498

Tomlinson PB (1969) *Anatomy of the Monocotyledons* (Vol III), Clarendon Press, Oxford, pp 365-373

Toyohara H (1987) Studies on the *Canna edulis* for starch crop. In: *Development, Technique and Cooperation in Agriculture: Memoirs of the 30th Anniversary,* Department of International Agricultural Development, Tokyo University of Agriculture, Tokyo, pp 18-27**

Ugent D, Pozorski S, Pozorski T (1984) New evidence for ancient cultivation of *Canna edulis* in Peru. *Economic Botany* **38**, 417-432

Yamamoto Y, Tanaka N, Hayafuji M, Iwahara Y, Miyazaki A (2007) Growth and productivity of edible canna 3 lines in warm southwest Japan. *Japanese Journal of Tropical Agriculture* **51 (Extra 1)**, 95-96*

Yun YS, Satake M, Katsuki S, Kunugi A (2004) Phenylpropanoid derivatives from edible canna, *Canna edulis*. *Phytochemistry* **65**, 2167-2171

JAPANESE ABSTRACT

食用カンナはアンデス地域起源の多年生単子葉草本で，積極的な改良はほとんど受けることなく，熱帯・亜熱帯各地で小規模に栽培されている。栽培期間は地域により異なり，7～12ヶ月である。根茎はデンプンを含み，その物理的・化学的性質の研究は進んできたが，抽出されたデンプンの用途については，麺類やビスケットの類を除きまだ一般化されていない。高さ3 m にも達する茎葉部は家畜の飼料となる。楕円形の大型の葉を着生する茎は根茎から生じ，分枝はしない。この植物の野生型は自生地では湿気のある林縁に見かけられ，栽培型も多湿の土壌を好み，旺盛に無機養分を吸収する。また，光合成の面からは，多様な光環境と温暖な気候に適応した，中庸な純光合成速度を有する陽生のC_3植物である。生育後期の個体群は高い葉面積指数を有し，良好な個体群成長速度を維持することができ，キャッサバやジャガイモに匹敵またはそれを上廻る生産能力を有しているものと考えられるが，科学的な解析研究や集約栽培上における知見がごく限られている。この総説では，食用カンナの来歴，形態形成に関わる特徴，光合成，乾物およびデンプン生産能力，利用の側面等について紹介し，多面的研究開発の必要性を指摘した。