Odor Components and the Control of Odor Development in Ornamental Cabbage

Kyutaro Kishimoto1*, Hiroyuki Maeda2, Tomoaki Haketa2 and Naomi Oyama-Okubo1

1NARO Institute of Floricultural Science, Tsukuba 305-8519, Japan
2Plant Breeding & Experiment Station, Takii & Company, Limited, Konan 520-3231, Japan

Ornamental cabbage (Brassica oleracea L. var. acephala DC. f. tricolor Hort) belong to Brassicaceae and are treated like annual ornamental plants in horticulture. Cultivars with beautiful cream-colored, purple, or pale pink leaves are used as cut flowers, potted plants, and bedding plants. In Japan, ornamental cabbages are shipped from autumn through winter; the display of potted plants and cut flowers of ornamental cabbage is considered part of the typical scenery in the cold season. Recently, the sale of cut flowers and potted plants for New Year celebrations has increased (Mizutani and Yamanaka, 2011; Takemoto, 2008). In Europe, Japanese cultivars of ornamental cabbage are harvested as cut flowers between August and November. According to our own data, the trade price of a cut flower has remained at around 20 yen in recent years. The main producing country is the Netherlands; some 50 million cut flowers are exported from there to other European countries every year. Cultivation in Europe has been recently growing and becoming economically important in addition to that of Japan.

Scent is an important property of marketable ornamental flowers (Dudareva and Pichersky, 2006). In questionnaire surveys conducted in Osaka and Wakayama prefectures, Japan, in 1993 and 1994, 20% of consumers chose “fragrance” as an important quality of cut flowers as gifts (Tsuji, 2000). On the other hand, unpleasant scents and excessive fragrance undermine the commercial value of the flower. When grown outdoors, Narcissus tazetta is recognized by its pleasant scent, whereas the smell emitted by a bouquet of narcissuses, especially in confined spaces where volatiles accumulate, becomes highly unpleasant (Vainstein et al., 2001). For similar reasons, cut flowers of oriental hybrid lilies tend to be avoided in restaurants (Oyama-Okubo et al., 2011). The concentration of a particular compound in a mixture of volatiles has marked effects; for example, a high level of indole has a very unpleasant odor, reminiscent of fecal matter, but at high dilutions, it is perceived as floral and pleasant (Vainstein et al., 2001). Thus, appropriate control of the scent levels of cut flowers is important for the flower’s commercial value.

Key Words: dimethyl disulfide, GC-MS, isothiazolinonic germicide, odor, ornamental cabbage.

Received; September 15, 2013. Accepted; January 24, 2014.
First Published Online in J-STAGE on April 23, 2014.
* Corresponding author (E-mail: cucumber@affrc.go.jp).

© 2014 The Japanese Society for Horticultural Science (JSHS), All right reserved
In Europe, unpleasant odors of cut flowers of Japanese ornamental cabbage cultivars have often become a problem in florist shops. We received a request for an odor suppression method. Unfortunately, the odor-active components have not been identified so far. In general, sulfur-containing compounds such as dimethyl sulfide, its derivatives, and isothiocyanates are known as unpleasant scent components in Brassicaceae (Spadone et al., 2006; Wright et al., 2006; Yukawa et al., 2003). Levels of unpleasant odor compounds are increased by mechanical damage (Spadone et al., 2006; Tulio et al., 2002) and microbial growth (Cho et al., 2009; Forney et al., 1993) in the plant tissue; in other words, the unpleasant smell intensifies when the plants rot. However, ornamental cabbage in Europe does not seem to be damaged by specific diseases or wounding.

We were able to reduce the odor of cut flowers of Lilium cv. ‘Casa Blanca’ by applying inhibitors of the biosynthetic pathways of odor components (Oyama-Okubo et al., 2011). To solve the problem with cut flowers of ornamental cabbage, we used the same strategy. We investigated scent components emitted from cut flowers of ‘Hatsubeni’ and ‘Haresugata’, two major ornamental cabbage cultivars in Europe and Japan, by gas chromatography-mass spectrometry (GC-MS). The main odor-active compound was identified from emission levels and sensual features of the detected scent components. In addition, we investigated the potential of odor inhibition by chemical control using biosynthesis inhibitors.

**Materials and Methods**

**Plant materials**

The experiment was conducted in 2011. The ornamental cabbage cultivars ‘Hatsubeni’ and ‘Haresugata’ were grown at the test site of Takii & Company (Konan, Shiga prefecture, Japan). The seeds were germinated at 15°C in April. Seedlings with three or four leaves were planted in a greenhouse without controlling temperature, humidity, or light conditions in May. As base fertilizer for the seedlings, potassium, phosphate, and nitrogen were applied at 8 kg per 1000 m² each. In August, the cut flowers (Fig. 1) were transported without water to NARO, the Institute of Floricultural Science (Tsukuba, Ibaraki prefecture, Japan). The day after harvest, each cut flower was trimmed to 45 cm and placed in 1 L distilled water. The cut flowers were incubated at 28°C and 70% relative humidity under a photosynthetic photon flux density of about 30 µmol m⁻²·s⁻¹ and a 12/12 h photoperiod.

**Analysis of odor components**

The volatiles emitted from the cut flowers were collected using a dynamic headspace sampling system (Oyama-Okubo et al., 2005). A cut flower or its vase water (1 L) within a glass jar was covered with a Tedlar Bag (5 L volume; GL Science, Tokyo, Japan). A constant stream of air filtered through activated charcoal was pumped through the bag at a flow rate of 500 mL·min⁻¹. The volatiles were trapped on a Tenax TA tube (180 mg; Gerstel Inc., Linthicum, MD, USA).

The trapped volatiles were analyzed by GC-MS (Agilent 5973; Agilent Technologies, Wilmington, DE, USA) coupled to a Thermal Desorption System 2 (TDS2; Gerstel Inc.) (Oyama-Okubo et al., 2011). The thermal desorption conditions were heating from 30°C to 250°C at 60°C·min⁻¹, holding for 10 min at 250°C, and cryofocusing at −100°C in the cold injection system (CIS; Gerstel Inc.). Following desorption of the Tenax column, the CIS was heated to 300°C at a rate of 12°C·s⁻¹ in splitless mode to transfer the analytes to the gas chromatograph (GC) equipped with a capillary DB-1 column (60 m length, 0.32 mm i.d., 1.00 µm film thickness; Agilent Technologies). Helium was used as a carrier gas at a flow rate of 1.0 mL·min⁻¹. The temperature program of the oven was set to 45°C for 2 min, then increased by 3°C·min⁻¹ to 220°C, and kept at this temperature for 10 min. Interface and ion source temperatures were 250°C. Ionization was performed in electron impact mode at 70 eV, and a mass scan range of 30–350 m/z was monitored. Volatile compounds were identified using the Wiley 9th/NIST 2011 library search system provided with the GC-MS software (Agilent Technologies) and crosschecked by comparing the mass spectra and retention times with authentic samples analyzed under the same conditions. The amount of each volatile was calculated using calibration curves based on the peak areas of authentic samples in total ion chromatography (purity was > 95%, Tokyo Chemical Industry, Tokyo, Japan; range of detection: 0.1–100 pg). Sensual features of the scent compounds were described by referring mainly to the Joint Food and Agriculture Organization of the United Nations/World Health Organization Expert Committee on Food Additives, Search Online Edition: “Specifications for Flavourings” (http://www.fao.org/ag/agn/jecfa-flav/search.html?lang=en, January 20, 2014).

The odor components dissolved in the vase water were trapped using a magnetic stir bar that had been coated with a partitioning phase of polydimethylsiloxane (Twister; Gerstel Inc., Mülheim, Germany). The coated bar stirred the vase water for 1 h; then, the trapped com-

---

![Fig. 1. Ornamental cabbage cultivars. A, ‘Hatsubeni’; B, ‘Haresugata’.](image-url)
pounds were analyzed using GC-MS coupled to a TDS2 (Oyama-Okubo and Tsuji, 2013). The thermal desorption conditions were heating from 30°C to 220°C at 60°C·min⁻¹, holding for 10 min at 220°C, and cryofocusing at −50°C in the CIS. Following thermal desorption from a Twister, the CIS was heated to 300°C at a rate of 12°C·s⁻¹ in splitless mode to transfer the analytes to a GC equipped with a capillary DB-1 column. The GC-MS conditions were described above.

Chemical treatment

A final concentration of 500 μM 4-cyclopropyl-6-methyl-2-phenylaminopyrimidine (cyprodinil; Syngenta Japan, Tokyo, Japan), 1 mM aminoxyacetic acid hemihydrochloride (AOA; Wako Pure Chemical, Osaka, Japan), or 500 μL·L⁻¹ isothiazolinonic germicide (CIMIT/MIT; Rohm and Haas Japan, Tokyo, Japan), which is composed of 1.15% 5-chloro-2-methyl-4-isothiazolin-3-one and 0.35% 2-methyl-4-isothiazolin-3-one, were added to the vase water of cut flowers. The concentrations applied corresponded to the recommendations of the manufacturers; in the case of AOA, we followed Oyama-Okubo et al. (2011).

Statistical analysis

To determine whether there were differences in the odor component emissions with and without chemical (or physical) treatment, we used two-way randomized-block analysis of variance (ANOVA), considering chemical (or physical) treatments and measurement days as the independent variables (fixed factors), individual plants (or vase water) as the block (random factors), and odor component emissions as the dependent variable. If a significant difference was detected in the interaction by ANOVA, all treatments were compared by multiple testing (Tukey-Kramer HSD test). These statistical analyses were conducted with the JMP software package (version 6.0.3; SAS Institute, Cary, NC, USA).

## Results and Discussion

### Identification of odor components

Ornamental cabbage cultivars, ‘Hatsubeni’ and ‘Haresugata’, were harvested in August (Fig. 1), the harvest season for ornamental cabbage in Europe. During the week after harvest, we always noted a characteristic cabbage-like odor, which was particularly strong in the cut stem and the stale vase water. To identify the odor-active components, the volatiles emitted from cut flowers of both cultivars were investigated by GC-MS, and six scent components were detected (Table 1). Among them, three sulfur-containing compounds—carbon disulfide, methyl thiocyanate, and dimethyl disulfide—were expected to be odor-active components based on their sensual features (Table 1). The emitted amounts of dimethyl disulfide (2.1 ± 0.3 pmol·g⁻¹FW·h⁻¹, n = 6) were significantly larger than those of the other two compounds (< 0.1 pmol·g⁻¹FW·h⁻¹ each). In addition, the odor threshold value of dimethyl disulfide was the

| Compounds | Detection site | Description of the scent | Odor threshold value (ppb) |
|-----------|----------------|--------------------------|----------------------------|
| Allyl isothiocyanate | Vase water | Mustard-like pungent odor | Not available |
| Carbon disulfide | Headspace of leaves | Disagreeable and sweet odor | 50' |
| Dimethyl disulfide | Headspace of leaves, Headspace of vase water, Vase water | Onion-like pungent odor of Brassicaceae plant or rotten milk | 0.16–1.2 |
| Dimethyl trisulfide | Vase water | Cabbage-like powerful odor | 10' |
| 2,4-Dithiapentane | Vase water | Fresh mustard-like odor | 300' |
| (E)-2-Hexenal | Headspace of leaves | Strong fruity, green, vegetable-like aroma | 30 |
| Methyl thiobutanenitrile | Vase water | Garlic-like and cooked cabbage-like sulfur odor | 40' |
| 4-Methyl thiobutanenitrile | Vase water | Pungent and unpleasant odor of Brassicaceae plant | Not available |
| Methyl thiocyanate | Headspace of leaves | Unpleasant and sweet odor | 2.5 |
| 3-Methyl thiopropyl isothiocyanate | Vase water | Raddish-like, irritating aroma | 5 |
| α-Pinene | Headspace of leaves | Characteristic odor of pine. It is turpentine-like | 2.5–62 |
| β-Pinene | Headspace of leaves | Characteristic turpentine odor with dry, woody or resinous aroma | 140 |

* Joint FAO/WHO Expert Committee on Food Additives, Search Online Edition: “Specifications for Flavourings” (http://www.fao.org/ag/agn/jecfa-flav/search.html?lang=en, January 20, 2014).
* Burdock (2010).
* Shipe et al. (1978).
* Wright et al. (2006).
* Ruth (1986).
* United States Environmental Protection Agency, Air Toxics Web site, Carborn disulfide (http://www.epa.gov/ttnatw01/hlthef/carbondi.html, January 20, 2014).
* Yukawa et al. (2003).
* Wright et al. (2006).
* Saxby (1996).
* Spadone et al. (2006).
lowest in these compounds (Table 1). Thus, the contribution of dimethyl disulfide to the odor of cut flowers was the largest. Dimethyl disulfide is an unpleasant odor component of some foods, including cruciferous vegetables and dairy products (Matsuura et al., 2005; Shipe et al., 1978; Spadone et al., 2006; Yukawa et al., 2003); its smell is often likened to that of rotten cabbage (Matsuura et al., 2005). We concluded that dimethyl disulfide is the most important odor-active component of cut flowers of ornamental cabbage.

We also investigated odor components dissolved in vase water in which cut flowers had been kept for four days. Seven sulfur-containing compounds were detected in the vase water (Table 1). The cut stem was probably the source of these compounds. Dimethyl trisulfide, 4-methylthiobutanenitrile, and methyl methylthiomethyl disulfide have been reported to cause an unpleasant smell in Brassicaceae (Spadone et al., 2006; Wright et al., 2006; Yukawa et al., 2003). However, except for dimethyl disulfide, these compounds were not detected as headspace volatiles of vase water (Table 1). Thus, dimethyl disulfide is an odor-active component of both vase water and cut flowers.

Dimethyl disulfide emission from cut flowers of ‘Hatsubeni’ and ‘Haresugata’ did not significantly increase during six days (Fig. 2). The emission pattern was not affected by vase water changes (Fig. 2). In contrast, emissions from the vase water increased over four days (Fig. 3). In particular, the emissions by ‘Haresugata’ was increased about 17-fold after three days. If the vase water was not changed during this period, the dimethyl disulfide emission from the vase was 80 times that from the cut flower. Evidently, vase water is a major source of unpleasant scents, and odor development can be prevented by frequent water changes.

**Odor control by chemical treatment**

Our research showed that frequent water changes reduced the emission of unpleasant odors from cut flowers of ornamental cabbage. On the other hand, we have received requests that indicate a high demand to reduce the emission of these odors from the plant itself. Dimethyl disulfide is biosynthesized via methanethiol from L-methionine in higher plants (Boerijan et al., 1994; Goyer et al. 2007; Rébeillé et al., 2006; Schmidt et al., 1985). Cyprodinil is known to inhibit L-methionine biosynthesis, although the molecular mechanism is unclear (Masner et al., 1994). We tested whether cyprodinil inhibits dimethyl disulfide emission from cut flowers of ‘Hatsubeni’ and ‘Haresugata’. Cyprodinil did not inhibit dimethyl disulfide emission (Fig. 4). Furthermore, yellowing of the leaf tip and wilting of the leaves occurred in ‘Hatsubeni’ after six days of treatment (Fig. 5), and similar phenomena were observed in ‘Haresugata’ (data...
K. Kishimoto, H. Maeda, T. Haketa and N. Oyama-Okubo

Six days of treatment (Fig. 5), and a similar phenomenon was observed in ‘Haresugata’ (data not shown). We concluded that neither cyprodinil nor AOA is a suitable inhibitor of dimethyl disulfide-derived odors in ornamental cabbage. These results seem to indicate that the biosynthesis of dimethyl disulfide does not depend on the l-methionine pathway. Intriguingly, dimethyl disulfide has been shown to be derived from methyl sulfenic acid in broccoli (Brassica oleracea var. italica) (Spadone et al., 2006).

The production of dimethyl disulfide in broccoli is promoted by rot with bacterial growth (Cho et al., 2009; Forney et al., 1993). Germicides applied to cut flowers prevent the rot of plant tissues and vase water, and maintain flower quality. We tested whether CMIT/MIT, an isothiazolinonic germicide used with cut flowers, inhibits dimethyl disulfide emission from ‘Hatsubeni’ and ‘Haresugata’ flowers. CMIT/MIT at 500 μL·L⁻¹ significantly decreased emissions except after three days of treatment in ‘Haresugata’ (Fig. 4). Adverse effects that could have been ascribed to the treatment were not detected. On the contrary, rot and browning of the cut stem appeared reduced (Fig. 5). Regardless of the presence or absence of CMIT/MIT, the cut flowers did not develop visible damage except for the cut stem (Fig. 5). Apparently rot development induced odors before rot symptoms became visible, and dimethyl disulfide emission seem to be reduced by inhibition of the rot with CMIT/MIT. When the CMIT/MIT concentration was increased to 1 mL·L⁻¹ in ‘Hatsubeni’, no significant enhancement of the positive effects was detected, and wilting of the leaves was observed (data not shown).

Pyridoxal phosphate is a coenzyme derived from vitamin B6 and an essential cofactor for methanethiol biosynthesis by l-methionine γ-lyase (Goyer et al., 2007; Rébeillé et al., 2006). AOA binds covalently to pyridoxal phosphate and acts as a nonspecific transaminase inhibitor (Dante Roa et al., 1964; Wood and Peesker, 1973). AOA is also known to decrease the odor of cut flowers of Lilium cv. ‘Casa Blanca’ (Oyama-Okubo et al., 2011). However, AOA increased dimethyl disulfide emission in ‘Haresugata’ after six days of treatment (Fig. 4). Furthermore, plant rot occurred in ‘Hatsubeni’ after six days of treatment (Fig. 5), and a similar phenomenon was observed in ‘Haresugata’ (data not shown). We concluded that neither cyprodinil nor AOA is a suitable inhibitor of dimethyl disulfide-derived odors in ornamental cabbage. These results seem to indicate that the biosynthesis of dimethyl disulfide does not depend on the l-methionine pathway. Intriguingly, dimethyl disulfide has been shown to be derived from methyl sulfenic acid in broccoli (Brassica oleracea var. italica) (Spadone et al., 2006).

The production of dimethyl disulfide in broccoli is promoted by rot with bacterial growth (Cho et al., 2009; Forney et al., 1993). Germicides applied to cut flowers prevent the rot of plant tissues and vase water, and maintain flower quality. We tested whether CMIT/MIT, an isothiazolinonic germicide used with cut flowers, inhibits dimethyl disulfide emission from ‘Hatsubeni’ and ‘Haresugata’ flowers. CMIT/MIT at 500 μL·L⁻¹ significantly decreased emissions except after three days of treatment in ‘Haresugata’ (Fig. 4). Adverse effects that could have been ascribed to the treatment were not detected. On the contrary, rot and browning of the cut stem appeared reduced (Fig. 5). Regardless of the presence or absence of CMIT/MIT, the cut flowers did not develop visible damage except for the cut stem (Fig. 5). Apparently rot development induced odors before rot symptoms became visible, and dimethyl disulfide emission seem to be reduced by inhibition of the rot with CMIT/MIT. When the CMIT/MIT concentration was increased to 1 mL·L⁻¹ in ‘Hatsubeni’, no significant enhancement of the positive effects was detected, and wilting of the leaves was observed (data not shown).

If the emission of unpleasant odors from vase water can be chemically controlled, the requirement for frequent water changes could be reduced. Therefore, we investigated CMIT/MIT effects on dimethyl disulfide emission from vase water. The treatment markedly inhibited emissions (Fig. 6), and we could clearly sense a reduction of the unpleasant smell. We concluded that CMIT/MIT is a promising inhibitor for the control of odor development from vase water. Many bacteria can synthesize dimethyl disulfide, and l-methionine is a primary sulfur source in its biosynthetic pathway (Bonnarme et al., 2001; Liu
bacterial populations developing in rotting water may have contributed to the dimethyl disulfide emission.

In summary, dimethyl disulfide is the major odor component in cut flowers of ornamental cabbage that is emitted from the plants as well as vase water. This study suggests that rotting plants and vase water are causes of dimethyl disulfide emission. The isothiazolinic germicide, CMIT/MIT, inhibits both rot and dimethyl disulfide emission from plants and especially from vase water. CMIT/MIT seems a suitable reagent to solve the problem of odor development in ornamental cabbage. In Japan, problems with unpleasant odors from ornamental cabbage have not been reported. However, the demand for cut flowers of ornamental cabbage is increasing (Takemoto, 2008), and efficient odor control techniques may be required in the near future.

Acknowledgments

We thank Dr. Kazuo Ichimura, Masayoshi Nakayama at NARO and Dr. Rika Ozawa at Center for Ecological Research, Kyoto University for valuable suggestions and comments.

Literature Cited

Arfi, K., S. Landaud and P. Bonnarme. 2006. Evidence for distinct \( \text{l-} \)-methionine catabolic pathways in the yeast Geotrichum candidum and the bacterium Brevibacterium linens. Appl. Environ. Microbiol. 72: 2155–2162.

Boerjan, W., G. Bauw, M. Van Montagu and D. Inzé. 1994. Distinct phenotypes generated by overexpression and suppression of \( S- \)-adenosyl-\( \text{l-} \)-methionine synthetase reveal developmental patterns of gene silencing in tobacco. Plant Cell 6: 1401–1414.

Bonnarme, P., C. Lapadatescu, M. Yvon and H. E. Spinnler. 2001. \( \text{l-} \)-Methionine degradation potentialities of cheese-ripening microorganisms. J. Dairy Res. 68: 663–674.

Burdock, G. H. 2010. Fenaroli’s handbook of flavor ingredients, Six edition. CRC Press, Boca Raton.

Cho, M. A., Y. P. Hong, J. W. Choi, Y. B. Won and D. H. Bae. 2009. Effect of packaging film and storage temperature on quality maintenance of broccoli. Korean J. Hort. Sci. Technol. 27: 128–139.

Dante Roa, P., J. K. Tews and W. E. Stone. 1964. A neurochemical study of thiosemicarbazide seizures and their inhibition by amino-oxyacetic acid. Biochem. Pharmacol. 13: 477–487.

Dudareva, N. and E. Pichersky. 2006. Biology of floral scent. CRC Press, Boca Raton.

Forney, C. F., P. D. Hildebrand and M. E. Saltveit, Jr. 1993. Production of methanethiol by anaerobic broccoli and microorganisms. Acta Hort. 343: 100–104.

Goyer, A., E. Collakova, Y. Shachar-Hill and A. D. Hanson. 2007. Functional characterization of a methionine \( \gamma \)-lyase in Arabidopsis and its implication in an alternative to the reverse trans-sulfuration pathway. Plant Cell Physiol. 48: 232–242.

Liu, M., A. Nauta, C. Francke and R. J. Siezen. 2014. Comparative genomics of enzymes in flavor-forming pathways from amino acids in lactic acid bacteria. Appl. Environ. Microbiol. 74: 4590–4600.

Masner, P., P. Muster and J. Schmid. 1994. Possible methionine biosynthesis inhibition by pyrimidinamine fungicides. Pestic. Sci. 42: 163–166.
Oyama-Okubo, N. and T. Tsuji. 2013. Analysis of floral scent compounds and classification by scent quality in Tulip cultivars. J. Japan. Soc. Hort. Sci. 82: 344–353.

Oyama-Okubo, N., T. Ando, N. Watanabe, E. Marchesi, K. Uchida and N. Nakayama. 2005. Emission mechanism of floral scent in Petunia axillaries. Biosci. Biotechnol. Biochem. 69: 773–777.

Oyama-Okubo, N., M. Nakayama and K. Ichimura. 2011. Control of floral scent emission by inhibitors of phenylalanine ammonia-lyase in cut flower of Lilium cv. ‘Casa Blanca’. J. Japan. Soc. Hort. Sci. 80: 190–199.

Rébeillé, F., S. Jabrin, R. Bligny, K. Loizeau, B. Gambonnet, V. Van Wilder, R. Douce and S. Ravelon. 2006. Methionine catabolism in Arabidopsis cells is initiated by a γ-cleavage process and leads to S-methylcysteine and isoleucine synthases. Proc. Natl. Acad. Sci. USA 103: 15687–15692.

Ruth, J. H. 1986. Odor thresholds and irritation levels of several chemical substances: a review. Amer. Ind. Hyg. Assoc. J. 47: A142–A151.

Saxby, M. J. 1996. A survey of chemicals causing taints and off-flavors in foods. p. 41–71. In: M. J. Saxby (ed.). Food taints and off-flavors, Second edition. CRC Press, Boca Raton.

Schmidt, A., H. Rennenberg, L. G. Wilson and P. Filner. 1985. Formation of methanethiol from methionine by leaf tissue. Phytochemistry 24: 1181–1185.

Shipe, W. F., R. Bassette, D. D. Deane, W. L. Dunkley and E. G. Hammond. 1978. Off flavors of milk: Nomenclature, standards, and bibliography. J. Dairy Sci. 61: 855–869.

Sooch, M., K. Singh, R. Kumar and P. Singh. 2002. Effect of chemicals on vase life of gerbera. p. 321–322. In: R. L. Misra and S. Misra (eds.). Floriculture research trend in India. Proceedings of the national symposium on Indian floriculture in the new millennium. CAB Direct, Wallingford, Oxfordshire.

Spadone, J. C., W. Matthey-Doret and I. Blank. 2006. Formation of methyl (methylthio)methyl disulfide in broccoli (Brassica oleracea L. var. italic). Dev. Food Sci. 43: 309–314.

Takemoto, T. 2008. Effects of decapitation and defoliation just after pinching on the plant form of pot cultured flowering cabbage. Hort. Res. (Japan) 7: 223–226 (In Japanese with English abstract).

Tomita, B., H. Inoue, K. Chihaya, A. Nakamura, N. Hmamura, K. Ueno, K. Watanabe and Y. Ose. 1987. Identification of dimethyl disulfide-forming bacteria isolated from activated sludge. Appl. Environ. Microbiol. 53: 1541–1547.

Tonooka, M., Y. Homma, H. Nukui and S. Ohba. 2012. Effect of scape cutting of flower longevity of gerbera cultivar. Hort. Res. (Japan) 11 (Suppl. 1): 209 (In Japanese).

Tsuji, K. 2000. The trends of cut-flowers consumption and consumer’s buying behavior. Bulletin of the Wakayama Research Center of Agriculture, Forestry and Fisheries 1: 111–120 (In Japanese).

Tulio, A. Z. Jr., H. Yamanaka, Y. Ueda and Y. Imahori. 2002. Formation of methanethiol and dimethyl disulfide in crushed tissues of Broccoli florets and their inhibition by freeze-thawing. J. Agric. Food Chem. 50: 1502–1507.

Vainstein, A., E. Lewinsohn, E. Pichersky and D. Weiss. 2001. Floral fragrance. New inroads into an old commodity. Plant Physiol. 127: 1383–1389.

Wood, J. D. and S. J. Peesker. 1973. The role of GABA metabolism in the convulsant and anticonvulsant actions of amino-oxyacetic acid. J. Neurochem. 20: 379–387.

Wright, J. M., M. E. C. Whetstine, R. E. Miracle and M. Drake. 2006. Characterization of a cabbage off-flavor in whey protein isolate. J. Food Sci. 71: C86–C90.

Yukawa, C., T. Ichi, Y. Shibahara and K. Shinbo. 2003. Deodorized colorant of Brassicaceae plant. Europian Patent EP1293539A1.