RESEARCH ARTICLE

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Effects of Dry and Wet Shipping Conditions on Quality, Vase Life, and Physiological Responses of *Chrysanthemum morifolium* 'Baekma' Cut Flowers

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Abstract

This study was conducted to identify the effects of NaOCl, ClO_2, and Chrysal OVB, which are the solutions used for shipping, on the quality and vase life of chrysanthemum 'Baekma' cut flowers. We also aimed to analyze correlations with vase life by analyzing chlorophyll fluorescence and spectral reflectance of cut flowers subjected to dry and wet shipping. Compared to dry shipping, the wet shipping treatments using solutions of NaOCl, ClO_2, and Chrysal OVB resulted in an increase of fresh weight and flower width, with the leaves remaining in fresh states after transport for 4 days. In holding solution, the cut flowers transported with 50 $mg \cdot L^{-1}$ NaOCl had a greater fresh weight and flower diameter as well as a longer vase life of 26 days compared with dry and wet shipping conditions with tap water, ClO_2, and Chrysal OVB solution. The cut flowers treated with wet shipping conditions by NaOCl had lower values of ABS/RC and DIo/RC and higher values of Fm/Fo, Fv/Fo, Fv/Fm, TRo/ABS, ETo/TRo, ETo/ABS, Pi_ABS, and ETo/RC among chlorophyll fluorescence parameters compared to those subjected to dry shipping conditions. Among the parameters, the Fv/Fm and ETo/RC exhibited statistically significant correlations with the vase life of cut flowers. In terms of spectral reflectance, the wet shipping treatment with 50 $mg \cdot L^{-1}$ NaOCl resulted in lower values of CRI, G, MCARI, NPCI, and SIPI that represent the ratio of contents of carotenoid and chlorophyll compared to the dry shipping treatment, whereas SRPI resulted in higher values. Among these parameters, the CRI, SRPI, and NPCI manifested a statistically significant correlation with vase life of cut flowers. Therefore, it was concluded that wet shipping with 50 $mg \cdot L^{-1}$ NaOCl helped maintain quality and vase life of cut flowers of chrysanthemum 'Baekma' compared to dry or wet shipping with Chrysal OVB and ClO_2 that were used commercially. In addition, the Fv/Fm and ETo/RC, representing chlorophyll fluorescence, and CRI, SRPI, and NPCI, representing spectral reflectance, were found to be feasible indicators predicting the vase life of cut flowers.

Additional key words: chlorophyll fluorescence, chrysal OVB, ClO_2, NaOCl, spectral reflectance

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Introduction

It is necessary to determine control conditions that will maintain the quality and vase life of cut flowers of chrysanthemum at the cultivation, harvest, and distribution stages. Environmental conditions including light, temperature, and humidity, and soil environment comprising drainage of water and accumulation of salts in the stage of cultivation, the flowering state (Yoo and Roh, 2015a) and pre-treatment after harvest (Yoo et al., 2016) in the stage of harvesting are involved in the conservation of quality of cut flower. And the pre-cooling (Kim et al., 2012), storage method (Yoo et al., 2014), and shipping conditions (Yoo and Roh, 2015a) in the stage of distribution are concerned in the changes of physiological responses and vase life of cut flower.

Dry shipping is commonly used for cut flowers in the stages from harvest to distribution, but the long period employed for export to overseas countries degrades the quality and compromises the vase life of cut flowers. For Korean cut chrysanthemums exported to Japan, dry shipping takes 3–5 days from harvesting to flower auction in Japan, resulting in cut flowers with withered leaves, unbloomed flowers, and a shortened vase life (Lee and Lee, 2015). To solve such problems, some distributors have been employing wet shipping for the delivery of cut flowers. Ichimura et al. (2009) reported that cut flowers delivered via wet shipping stay fresh longer due to the supply of moisture, whereas dry shipping deteriorates the quality and vase life of cut flowers due to poor water absorption by the penetration of air into vessel of stem when they are inserted into holding solutions.

For longer transportation periods, wet shipping using a mixed solution of 8-hydroxyquinoline sulfate with fructose extended the vase life by 3.6 days and increased the flower diameter of cut roses (Hu et al., 1998). In addition, wet shipping of *Lilium* Oriental hybrid 'Medusa' extended the vase life of cut flowers by 2 days compared to dry shipping in the simulation of the exporting environment (Lim et al., 2016), and pretreatment with 2 $mL \cdot L^{-1}$ Chrysal SVB under wet conditions right after harvest and before delivery resulted in extended vase life and reduced stem bending (Lee and Kim, 2016). For the case of cut flowers of chrysanthemum 'Baekma', the treatment conducted with the solution of 100 $mg \cdot L^{-1}$ NaOCl for 1 day right after harvest was effective in increasing the quality of cut flowers (Roh et al., 2017). Thus, pretreatment agents such as Chrysal or bactericides are used as solutions for wet shipping of cut flowers.

Measuring chlorophyll fluorescence is a means of nondestructively determining the effect of environmental stress such as damage induced by salt, cold, frost, high temperature, dryness, and air pollution, as well as assessing physiology relevant to photosynthesis (Smillie and Nott, 1982; Omasa et al., 1987; Bhandari et al., 2018; Zha et al., 2018; Zhou et al., 2018). For the cases of the *Lilium* Oriental hybrids 'Siberia' and chrysanthemum 'Baekma', it was reported that the value of Fv/Fm, one of the parameters of chlorophyll fluorescence, appeared higher in cut flowers of favorable quality or reduced leaf yellowing compared to cut flowers of degraded quality (Choi et al., 2014; Roh et al., 2018). In addition, the spectral reflectance of a leaf provides the information on stress or senescence of plants through measurement of the chlorophyll-to-carotenoid ratio (Peñuelas et al., 1995; Barták et al., 2016).

This study was conducted to identify the effect of dry and wet shipping with solutions of NaOCl, ClO_2, and Chrysal OVB upon the quality and vase life of cut flowers of chrysanthemum 'Baekma'. We analyzed the correlations between chlorophyll fluorescence, spectral reflectance, and vase life of cut flowers after dry and wet shipping.

Materials and Methods

Plant Material

The plant material used in this study was *Chrysanthemum morifolium* 'Baekma', which was cultivated at an agricultural company located in Jeonju City, Jeollabukdo Province, and harvested at flowering stage 3 (Yoo and Roh, 2015a) on the

7th of August. The stems of chrysanthemum were cut into 80 cm pieces and immediately dipped into tap water (pH 6.4, EC 0.09 $dS \cdot m^{-1}$). They were delivered to Mokpo National University by a refrigerated truck at 5°C and stored at 5°C in a cold storage room for 1 day. Taking into account the time required for the delivery to flower auction in Japan, this experiment conducted a simulated transport of cut flowers in cold storage at 5°C for 4 days.

Vase Life and Quality of Cut Flowers Treated with Dry and Wet Shipping

The cut flowers were treated with dry (control) and wet shipping methods in simulated transport. In the dry shipping method, cut flowers were laid horizontally in a corrugated paperboard box. In the wet shipping method, cut flowers were placed vertically into a wet container filled with wet solution inside a corrugated paperboard box (Roh et al., 2018). The wet solution was treated with tap water (pH 6.6, EC 0.1 $dS \cdot m^{-1}$), 50 $mg \cdot L^{-1}$ NaOCl, 2 $mg \cdot L^{-1}$ ClO_2 (Vital Oxide®, Danbibio Ltd., Korea), and 3 $mL \cdot L^{-1}$ Chrysal OVB (Chrysal International B.V., Netherlands). Fresh weight and flower diameter were examined after 4 days of simulated transport and then the five cut flowers were put into holding solution of 50 $mg \cdot L^{-1}$ NaOCl (three replicates). The cut flowers were placed in a controlled chamber under conditions of 12-hour day-length, light intensity of 80 $\mu mol \cdot m^{-2} \cdot s^{-1}$, relative humidity of 50 – 60%, and temperature of 20°C. Qualities of the cut flowers, such as fresh weight and flower diameter, were examined by methods introduced by Yoo and Roh (2015a) on every fourth day, while the vase life of the cut flowers was appraised every day.

Differences in Chlorophyll Fluorescence and Spectral Reflectance between Dry and Wet Shipping

To assess the physiology of cut flowers after simulated transport with dry shipping and wet shipping in 50 $mg \cdot L^{-1}$ NaOCl for 4 days, the chlorophyll fluorescence and spectral reflectance of the leaves located 40 cm below from top of cut flowers were measured. The chlorophyll fluorescence analyzer (FluorPen FP100, Photon Systems Instruments, Czech Republic) was used to measure chlorophyll fluorescence of cut flowers acclimated to darkness for 30 minutes from which the various parameters were calculated (Lee et al., 2014; Oh et al., 2014). A spectroradiometer (PolyPen RP 410, Photon Systems Instruments, Czech Republic) was used to measure spectral reflectance, and then various parameters were calculated.

Correlation and Statistical Analysis

For all of the data, ANOVA (analysis of variance) was carried out using IBM SPSS ver. 18.0. Mean values of each treatment were compared by conducting least significant difference (LSD), Duncan's multiple range test (DMRT), or t-test. The Pearson's method was used for the correlation analysis between chlorophyll fluorescence, spectral reflectance, and vase life of cut flowers.

Results and Discussion

Vase Life and Quality of Cut Flower Treated with Dry and Wet Shipping

After simulated transport for 4 days with dry (control) and wet shipping in solutions of tap water, NaOCl, ClO_2, and Chrysal OVB, fresh weight and flower diameter of cut flower in chrysanthemum 'Baekma' were measured. Dry shipping led to a 14.3% decrease in the fresh weight of cut flowers compared to that at the point of harvest, wherein withered leaves were found on the lower part of the stems (Fig. 1A). On the other hand, wet shipping in solution of tap water, Chrysal OVB, NaOCl, and ClO_2 contributed to an increase in the fresh weight of cut flowers by 102.3%, 104.1%, 105.0%, and 108.2%, respectively, and maintenance of fresh leaves (Fig. 2B and 2D). The flower diameter decreased by 4.5% in dry shipping and increased by 1.5 – 3.0% in wet shipping (Fig. 1B). Such results suggest that the cut flowers treated with solutions for wet shipping were able to keep fresh weight and flower diameter by continuous moisture uptake, which resulted in fresh cut flowers, as was reported by Ichimura et al. (2009). In the case of dry shipping of cut flowers of Oriental hybrid lily and rose for 3 days, the cut flowers had bent necks, and this was attributed to the exposure to moisture stress during transportation (Ruting, 1991; Lee and Kim, 2016).

The cut flowers of chrysanthemum 'Baekma' transported for 4 days were inserted into the holding solution to examine the changes in fresh weight and flower diameter. The fresh weight of cut flowers increased rapidly up to the fourth or eighth day for all treatments; thereafter, the fresh weight of cut flowers tended to decrease slightly (Fig. 1A). Cut flowers subjected to dry shipping tended to show a fresh weight of 113.4% in solutions on the fourth day, which was lighter than the fresh weight of cut flowers subjected to wet shipping conditions, and it remained lighter than the fresh weight of cut flowers of the other treatments. The fresh weight of cut flowers treated with ClO_2 solution for wet shipping tended to increase up to 126.9% on the fourth day and then it decreased gradually. On the contrary, the fresh weight of cut flowers

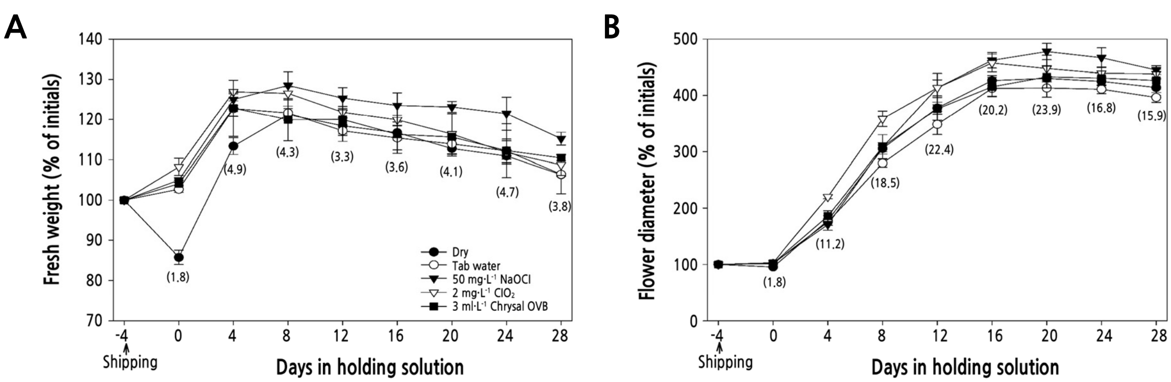

Fig. 1. Changes in fresh weight (A) and flower diameter (B) of cut flowers of chrysanthemum 'Baekma' in holding solution at 4 days after simulated transport with dry and wet shipping. Vertical bars indicate standard error ($n = 3$). Numbers in parentheses indicate LSD value at $p \leq 0.05$.

Fig. 2. Quality of cut flowers of the chrysanthemum 'Baekma' at 4 days after simulated transport with dry and wet shipping. A, Dry shipping; B, Tap water; C, 50 mg·L^{-1} NaOCl; D, 2 mg·L^{-1} ClO_2; E, 3 ml·L^{-1} Chrysal OVB. WL, wilted leaf.

treated with NaOCl solution for wet shipping had the highest fresh weight of 128.5% on the eighth day and maintained this fresh weight compared to the other treatments (Fig. 1A). The flower diameter generally tended to increasing up to the 16th or 21st day of treatment and thereafter decreased gradually. The diameter was small in dry shipping and wet shipping conditions using tap water and Chrysal OVB (413–430%). On the other hand, the cut flowers in wet shipping conditions treated with NaOCl had the biggest flower diameter on the 20th day (478%) and kept this diameter longer than others thereafter (Fig. 1B). Vase life of cut flower was the shortest up to 23.6 or 24.8 days in dry shipping and in wet shipping treated with tap water. The wet shipping with NaOCl solution produced the longest vase life of 26.0 days; however, there was no significant difference in vase life between wet shipping with ClO_2 (25.6 days) and Chrysal OVB (25.6 days) (Figs. 3 and 4).

Bang (1999) reported that cut flowers treated with wet shipping had a larger fresh weight, smaller flower diameter, and longer vase life than those treated with dry shipping in cut rose 'Red Sandra'. In cut carnation 'Nora', dry shipping caused the vase life and fresh weight to decrease by 2 days and by 34%, respectively, compared to wet shipping (Uda et al., 2000). The solutions for wet shipping comprise bactericides, saccharides, and other components wherein the addition of bactericides is essential. When cut flowers were transported with wet shipping, the freshness of cut flowers was well maintained in the treatment with 8-hydroxyquinoline sulfate solution for standard cut rose 'Bridal Pink' (Hu et al., 1998), with aluminum sulfate solution for spray cut rose 'Lovely Lydia' (Lee, 2011), and with silver thiosulfate solution for cut carnation 'Nora' (Uda et al., 2000).

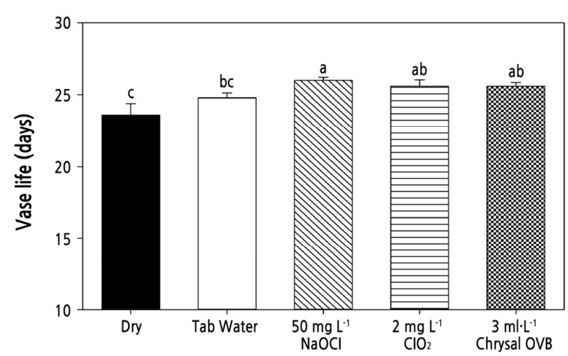

Fig. 3. Vase life of cut flowers of the chrysanthemum 'Baekma' in holding solution after 4 days of simulated transport with dry and wet shipping. Vertical bars indicate standard error ($n = 3$). Lowercase letters indicate mean separation at $p \leq 0.05$ by Duncan's multiple range test.

Fig. 4. Quality of cut flowers of the chrysanthemum 'Baekma' at 28 days in holding solution after 4 days of simulated transported with dry and wet shipping. A, Dry shipping; B, Tap water; C, 50 mg·L^{-1} NaOCl; D, 2 mg·L^{-1} ClO_2; E, 3 ml·L^{-1} Chrysal OVB. WL, withered leaf.

In this study, the cut flowers of chrysanthemum 'Baekma' were found to have increased vase life, fresh weight, and flower diameter by 2.4 days, 8.7%, and 47.6%, respectively, in wet shipping with 50 $mg \cdot L^{-1}$ NaOCl solution compared to dry shipping. Recently, it was reported that the use of NaOCl and ClO_2, as holding solutions or pretreatment agents after harvest of cut flowers of chrysanthemum, was effective in keeping cut flowers fresh (Lee and Lee, 2015; Yoo and Roh, 2015b; Yoo et al., 2016). It was estimated that wet shipping with NaOCl solution promoted the moisture uptake in cut flowers by preventing the proliferation and penetration into the vessels of microorganisms during transport (Roh et al., 2018) and thus was effective at maintaining freshness and extending the vase life of cut flowers. In addition, NaOCl was verified as an effective solution for wet shipping compared to the commercial product Chrysal OVB, which is used globally. Thus, it was concluded that the development of wet solution products using NaOCl for long-distance transport of cut flowers of chrysanthemum would be necessary.

Difference in Chlorophyll Fluorescence by Dry and Wet Shipping

The chlorophyll fluorescence in leaves of cut flowers was measured after transport for 4 days with dry and wet shipping conditions. The chlorophyll fluorescence parameters ABS/RC and DIo/RC were higher in leaves exposed to drought stress by dry shipping compared to leaves treated with NaOCl solution for wet shipping. However, the Fm/Fo, Fv/Fo, Fv/Fm, ETo/TRo, ETo/ABS, Pi_ABS, and ETo/RC values appeared lower in dry shipping than in wet shipping conditions (Table 1).

In the leaves of red pepper and *Oplopanax elatus* exposed to drought stress, the values of chlorophyll fluorescence parameters such as ABS/RC, DIo/RC, and TRo/RC appeared high, while the values of parameters such as Fv/Fm, ETo/TRo, ETo/ABS, Pi_ABS, and ETo/RC appeared low (Yoo et al., 2013; Lee et al., 2014). The increases in ABS/RC, DIo/RC, and TRo/RC, which represent the energy flux in photochemical reaction center, indicate that the reaction center is inactive (Falqueto et al., 2010; Spoustová et al., 2013). Thus, the appearance of relatively higher values of ABS/RC and DIo/RC was estimated to be attributable to the inactivation of the photochemical reaction center in leaves because of drought stress caused dry shipping cut flowers of chrysanthemum 'Baekma'.

The Fv/Fm, ETo/TRo, and ETo/ABS parameters represent quantum efficiency of photosystem Ⅱ, and they tend to decrease during high temperature or drought stress (Guo et al., 2006; Lee et al., 2014). In the simulated transport of *Lilium* Oriental hybrid 'Siberia' after harvest, Fv/Fm, which represents the value of maximum quantum yield, was higher in the

Table 1. Comparison of chlorophyll fluorescence parameters in leaves of cut chrysanthemum 'Baekma' at 4 days after simulated transport with dry and wet shipping

Treatment	Chlorophyll fluorescence parameters[z]									
	Fm/Fo	Fv/Fo	Fv/Fm	ETo/TRo	ETo/ABS	Pi_ABS	ABS/RC	TRo/RC	DIo/RC	ETo/RC
Dry shipping	4.81	3.81	0.79	0.61	0.49	2.37	2.58	2.05	0.54	1.25
Wet shipping	5.24	4.24	0.81	0.66	0.53	3.34	2.43	1.96	0.46	1.29
Significance	**	**	**	*	*	*	*	ns	*	*

[z]Fm/Fo : Ratio of maximal and minimal fluorescence yield, Fv/Fo : Ratio of photochemical and non-photochemical de-excitation fluxes of excited chlorophyll, Fv/Fm: Maximum quantum yield of PSⅡ photochemistry, ETo/TRo: Probability of trapped exciton moving an electron beyond Q_A^-, ETo/ABS: Probability of an absorbed exciton moving an electron beyond Q_A^-, Pi_ABS: Performance index on absorption basis, ABS/RC: Absorption flux of photons per reaction center, TRo/RC: Trapping of electrons per reaction center, DIo/RC: Dissipation of electrons per reaction center, ETo/RC: Electron flux per reaction center beyond Q_A^-.

[ns, *, **]Non-significant or significant by t-test at $p \leq 0.05$ or 0.01, respectively.

pretreatment with promalin that exhibited better vase life and quality of cut flowers than the control (Choi et al., 2014). Also, when cut flowers of chrysanthemum were transported by dry shipping, the Fv/Fm value due to drought stress was lower than that of chrysanthemum transported by wet shipping (Roh et al., 2018). In this study, it was suggested that the relatively low values of Fv/Fm, ETo/TRo, and ETo/ABS seem attributable to decreased quantum efficiency in the photosystem Ⅱ due to drought stress caused by dry shipping of the cut flowers of chrysanthemum 'Baekma'.

The Pi_ABS parameter is an indicator representing the degree of reduction of electron acceptors in photosystem I, and it has been reported that it decreased owing to the decrease in capacity of NADPH and ATP synthesis by photophosphorylation in accordance with decreasing electron transfer of the photosystem by drought stress (van Heerden et al., 2007; Boureima et al., 2012). In this study, the Pi_ABS value in the leaves of cut flowers of chrysanthemum 'Baekma' was lower due to drought stress caused by dry shipping, resulting in reduced photosynthetic ability by decreasing electron transport and reduced quality of cut flowers.

Difference in Spectral Reflectance by Dry and Wet Shipping

Growth stages and the physiology of plants can be identified by the spectral reflectance from irradiation of light to plants; in particular, spectral reflectance has been used as a means for measuring physiological phenomena such as drought stress and senescence of leaves. Cut flowers of chrysanthemum 'Baekma' were transported for 4 days by dry and wet shipping, and then the spectral reflectance of leaves of cut flowers was examined. Among the parameters of spectral reflectance, the values of CRI, G, MCARI, NPCI, and SIPI appeared higher due to drought stress in dry shipping compared to wet shipping with NaOCl solution, whereas the SRPI value appeared lower. There also was a significant difference between treatments (Table 2). On the contrary, the values of NDVI, SR, MCARII, NPQI, and PRI parameters exhibited no statistical significance.

Sanger (1971) reported that the ratio of carotenoids, the photosynthetic pigments, to chlorophyll a decreased in healthy plants, whereas it increased in senescing and unhealthy plants. The NDVI and PRI parameters, which represent the ratio and content of carotenoids and chlorophyll, were lower in sunflower leaves exposed to moisture stress or lacking nutrients than in healthy leaves, whereas the NPCI value, which represents the ratio of chlorophyll to total pigments, appeared high in unhealthy leaves (Peñuelas et al., 1994). The values of NDVI and SRPI parameters appeared lower during drought stress than in the wet state for the Argentinean lichens such as *Parmotrema conferendum* and *Ramalina celastri* (Barták

Table 2. Comparison of spectral reflectance parameters in leaves of cut chrysanthemum 'Baekma' at 4 days after simulated transport with dry and wet shipping

Treatment	Spectral reflectance parameters[z]								
	NDVI	SR	CRI	G	MCARI	SRPI	PRI	NPCI	SIPI
Dry shipping	0.77	7.56	2.73	1.59	0.42	0.71	0.02	0.17	0.81
Wet shipping	0.77	7.72	2.39	1.44	0.30	0.78	0.03	0.13	0.79
Significance	ns	ns	**	*	*	*	ns	*	*

[z]NDVI: Normalized difference vegetation index = (Rnir-Rred)/(Rnir+Rred), SR: Simple ratio index = (Rnir/Rred), CRI: Carotenoid reflectance index = (1/R510-1/R550), G: Greenness index = (R554/R677), MCARI: Modified chlorophyll absorption in reflectance index = [(R700-R670) − 0.2 × (R700-R550)] × (R700/R670), SRPI: Simple ratio pigment index = (R430/R680), PRI: Photochemical reflectance index = (R531-R570)/(R531+R570), NPCI: Normalized pigment chlorophyll index = (R680-R430)/(R680+R430), SIPI : Structure insensitive pigment index = (R800-R445)/(R800-R680).

[ns, *, **]Non-significant or significant by t-test at $p \leq 0.05$ or 0.01, respectively.

et al., 2016).

In this study, the CRI and SIPI values, which represent the contents and ratio of carotenoids and chlorophyll, appeared high in the leaves of cut flowers of chrysanthemum 'Baekma' transported with dry shipping compared to wet shipping. Also, the NPCI and MCARI values, which represent the ratio of chlorophyll to total pigments, were higher in the leaves of cut flowers transported by dry shipping rather than wet shipping. These results were concluded that more carotenoids and other pigments than chlorophyll were synthesized due to drought stress to leaves by dry shipping, which resulted in negative on vase life and the quality of cut flowers.

Correlation between Vase Life of Cut Flowers, Chlorophyll Fluorescence, and Spectral Reflectance

The correlation between chlorophyll fluorescence parameters and vase life of cut flowers was examined. Positive correlations between vase life and Fm/Fo, Fv/Fo, Fv/Fm, ETo/TRo, ETo/ABS, Pi_ABS, and ETo/RC were found, whereas negative correlations between vase life and ABS/RC, TRo/RC, and DIo/RC were found (Table 3). Among the above parameters, Fv/Fm and ETo/RC exhibited statistically significant correlation with the vase life of cut flowers.

The correlation between spectral reflectance parameters and vase life of cut flowers was also examined, wherein positive correlations between vase life and NDVI, SR, SRPI, and PRI and negative correlations between vase life and CRI, G, MACRI, NPCI, and SIPI were found (Table 3). Among the parameters, CRI, SRPI, and NPCI exhibited statistically significant correlations with vase life of cut flowers.

Chlorophyll fluorescence and spectral reflectance parameters are used as indicators predicting states of physiology, moisture stress, senescence, and photosynthesis ability. Among chlorophyll fluorescence parameters, it was reported that Fv/Fm, ETo/ABS, ETo/TRo, and Pi_ABS can be used as indicators for early diagnosis and evaluation of moisture stress for plants such as *Oplopanax elatus*, *Vitis amurensis*, and *Sesamum indicum* (Boureima et al., 2012; Wang et al., 2012; Lee et al., 2014). Peñuelas et al. (1995) reported that the spectral reflectance parameters SRPI and SIPI are indicators of the physiology state for some crops. Barták et al. (2016) mentioned that the MCARI would be the most effective indicator reflecting the state of moisture stress of plants. In this study, Fv/Fm and ETo/RC, among chlorophyll fluorescence

Table 3. Correlation coefficient between physiological responses and vase life in cut chrysanthemum 'Baekma'

	Chlorophyll fluorescence parameters^z									
	Fm/Fo	Fv/Fo	Fv/Fm	ETo/TRo	ETo/ABS	Pi_ABS	ABS/RC	TRo/RC	DIo/RC	ETo/RC
Vase life	0.74	0.74	0.87*	0.44	0.51	0.64	−0.75	−0.61	−0.75	0.81*

	Spectral reflectance parameters^y								
	NDVI	SR	CRI	G	MACRI	SRPI	PRI	NPCI	SIPI
Vase life	0.35	0.35	−0.81*	−0.67	−0.32	0.84*	0.23	−0.84*	−0.58

^{z}Fm/Fo : Ratio of maximal and minimal fluorescence yield, Fv/Fo : Ratio of photochemical and non-photochemical de-excitation fluxes of excited chlorophyll, Fv/Fm: Maximum quantum yield of PS Ⅱ photochemistry, ETo/TRo: Probability of trapped exciton moving an electron beyond Q_A, ETo/ABS: Probability of an absorbed exciton moving an electron beyond Q_A^-, Pi_ABS: Performance index on absorption basis, ABS/RC: Absorption flux of photons per reaction center, TRo/RC: Trapping of electrons per reaction center, DIo/RC: Dissipation of electrons per reaction center, ETo/RC: Electron flux per reaction center beyond Q_A.
^{y}NDVI: Normalized difference vegetation index = (Rnir-Rred)/(Rnir+Rred), SR: Simple ratio index = (Rnir/Rred), CRI: Carotenoid reflectance index = (1/R510-1/R550), G: Greenness index = (R554/R677), MCARI: Modified chlorophyll absorption in reflectance index = [(R700-R670) − 0.2 × (R700-R550)] × (R700/R670), SRPI: Simple ratio pigment index = (R430/R680), PRI: Photochemical reflectance index = (R531-R570)/(R531+R570), NPCI: Normalized pigment chlorophyll index = (R680-R430)/(R680+R430), SIPI : Structure insensitive pigment index = (R800-R445)/(R800-R680).
*Significant at $p < 0.05$.

parameters, and CRI, SRPI, and NPCI, among spectral reflectance parameters, appeared to have highly significant correlations with the vase life of cut flowers. Therefore, we suggest that these parameters can be used as indicators to predict vase life of cut flowers in chrysanthemum 'Baekma'.

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