論文の内容の要旨

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論文題目　Flower bud opening of bud-cut carnations as affected by PPFD and addition of inorganic salts in opening solution
(強光照射と無機塩によるつぼみ切りカーネーション切り花の強制開花促進)

Carnations cut in early-bud stage are known to have several advantages for production efficiency (Nowak et al., 1983; Halevy, 1987), storage and distribution (Goszczyńska and Rudnicki 1982); i.e., less space for storage and shipment (Kofranek, 1976; Halevy et al., 1978), less damage during postharvest handling, and less susceptibility to ethylene in carnations (Barden and Hanan, 1972; Maxie et al., 1973). However, many growers hesitated to harvest standard type carnations in an early-bud stage because bud-cut carnations have to be opened before they are sold in the market. In order to retard or avoid deterioration of opened flowers after flower bud opening (FBO), the time required for FBO of cut flowers must be reduced. Several methods using specific chemical solutions to drive FBO of bud-cut carnations have been reported (Kofranek, 1976; Goszczyńska and Rudnicki, 1982). However, little attention has been paid to the physical environment, such as light intensity, for post-harvest FBO of ‘tight bud’-cut carnations. Also the addition of inorganic nutrient salt (INS), as in use of hydroponic culture, for post-harvest bud opening has not been reported previously. The flower heads and leaves/stems of cut carnations play a role as a sink or a source for carbohydrates. Considering the significance of carbon balance during post-harvest FBO, CO_2 exchange measurement of flower heads and leaves/stems is necessary under elevated PPFD conditions. The aims of the present experiments were to investigate the time required for FBO of ‘tight bud’-cut carnations by high PPFD and an addition of INS in flower opening solution, and the relationship between carbon/water balance and cut carnations quality during/after FBO of ‘tight bud’-cut carnations.

Red standard carnations (*Dianthus caryophyllus* L cv. Francesco) that had been harvested at 'tight bud' stage [stage III as defined by Cywińska-Smoter *et al*. (1978)] in Yamaguchi (Ex-1), and Nagano (Ex-2, 3) were used. The stems cut-ends of the carnations (n=60) were trimmed to a length of 45cm (Ex-1) and 60cm (Ex-2, 3) in deionized water and separated randomly for FBO treatments. For each FBO treatment, carnations were placed in a transparent cylindrical container [0.33 m in diameter, 0.50 m in height (Ex-1) and 0.70 m in height (Ex-2, 3)], set in a growth chamber, with number of air exchanges of 128 l h^{-1} (Ex-1), 180 l h^{-1} (Ex-2), 25.7 l h^{-1} for flower heads space and 154.3 l h^{-1} for leaves/stems (Ex-3). Cut carnations were placed under PPFDs [30 (P30), 120 (P120), and 250 (P250) μmol m^{-2} s^{-1} for Ex-1, 30 (P30), 150 (P150) μmol m^{-2} s^{-1} for Ex-2, and 30 (P30), 90 (P90) and 150 (P150) μmol m^{-2} s^{-1} for Ex-3] at a bud top level with continuous light from white fluorescent lamps. Air temperature and relative humidity in the containers were controlled at 25±1°C and 87±5% during FBO. Seven (Ex-1, 2) or six (Ex-3) cut carnations were placed in 50 ml of flower opening solution containing 25 mg l^{-1} $AgNO_3$ + 200 mg l^{-1} 8-hydroxyquinolin-citrate (8-HQC) [with 30 g l^{-1} sucrose (S30) or without sucrose (S0) for Ex-1, and with INS in flower opening solution (INS) and without INS (N) for Ex-2]. We tested some FBO treatments of P30-S30, P120-S30 and P250-S30 for Ex-1, P30-INS, P30-N, P150-INS, and P150-N for Ex-2, and P30, P90, and P150 for Ex-3. All Experiments were repeated twice. After FBO, the stems of cut carnations were re-cut in distilled water and placed in deionized water in a chamber (20±1°C) with a 12 h photoperiod at 12 μmol m^{-2} s^{-1} PPFD for 10 d in order to evaluate flower quality. The 5 scores were used for quality evaluation of treated carnations depending on visual quality (Fujiwara et al., 2004). These experiments had been carried out until 6 out of 7 buds (Ex-1, 2) or 5 out of 6 buds (Ex-3) in each treatment were opened more than 75^{o}, which is equivalent to Stage VII according to Cywińska-Smoter *et al*. (1978). CO_2 exchange rate, dark respiration rate, sucrose uptake, flower opening angles and transpiration rate were measured in all experiments. Total net CO_2 exchange (TNCE), integrated gross photosynthesis (IGP), total sucrose uptake (TSU) and total carbon uptake (TCU) rate were calculated for understanding the relationship between FBO/flower quality and these factors.

Among the S30 treatments, the higher the PPFD, the more rapidly the flowers opened. The average periods required for FBO were 6.75, 6.5, 6.0, and 7.0 d for P30-S30, P120-S30, P250-S30 and P250-S0, respectively (Ex-1). Flowers in the S30 treatments were considered as satisfactorily marketable products. These results indicate that PPFD of 120 and 250 μmol m^{-2} s^{-1} combined with 30 g l^{-1} sucrose in flower opening solution was effective for reducing the time required for post-harvest FBO of 'tight bud'-cut carnations.

Although there was no significant difference in flower-opening angle between INS and N treatments during FBO, bud-cut carnations in both experiments tended to open more rapidly in INS treatments (Ex-2). Cut carnations absorbed more flower opening solution at the INS treatment during FBO treatment because absorbed INS would decrease water potential of petals. Mean flower quality scores were high (4.0) at the end of all FBO treatments (Ex-2). To ascertain the relationship between INS and FBO, the amount of each component of the absorbed INS should be investigated. Addition of an optimal concentration, or a different constituent of INS in the flower opening solution may further accelerate FBO of 'tight bud'-cut carnations.

Carnations under P150 treatments stored greater quantity of carbohydrates than those in P30 treatments, by the end of FBO. Greater TCU resulted from increased TSU and TNCE under higher PPFD, which also contributed to reduce the time for FBO of ‘tight bud’-cut carnations. Hourly average of TSU in P150 treatments, which is proportional to the uptake of flower opening solution, was twice as much as that in P30 treatments, indicating that under higher PPFD transpiration increased. ‘Tight bud’-cut carnations placed under high PPFD (P150) did not show stem blockage or water deficiency during FBO even though they were cut. FBO of ‘tight bud’-cut carnations by higher PPFD could be accelerated by increased rates of TSU and TNCE, stimulated by the addition of INS. Enhancing TCU will improve FBO of ‘tight bud’-cut carnations, help them retain their quality after opening.

Gross photosynthesis of bud-cut carnations were increased in higher PPFD treatment and water balance was kept positively during FBO, showing that flower opening solution uptake of cut carnations was greater than amount of transpiration during FBO treatment (Ex-3). Absorbed sucrose in petals could be hydrolyzed with glucose or fructose and these monosaccharides would decrease the water potential in cells of petals. Cells will be expanded and cut carnations will open rapidly. FBO of ‘tight bud’-cut carnations correlated with fresh weight increment of them with correlation coefficients of 0.80 for P30, 0.78 for P90, and 0.89 for P150 treatment during FBO treatment (Ex-3). The mean flower quality scores of opened carnations after FBO closely correlated with TCU with correlation coefficients of 0.94 and 0.98 during 10-d flower quality evaluation. The elevated PPFD shifted the climacteric peak ahead under the same temperature condition. Even though the climacteric peak was shifted ahead in higher PPFD treatment, their quality for 10 d after FBO was better than that in lower PPFD treatment. Present proposed FBO technique might be applied to other kinds of cut flowers, depending on the physiological and morphological characteristics.

The high PPFD combined with 30 g l^{-1} sucrose and an addition of INS in flower opening solution was effective for reducing the time required for FBO of ‘tight bud’-cut carnations, maintaining their high quality during/after FBO. FBO of ‘tight bud’-cut carnations correlated with fresh weight increment (opening solution uptake), and the mean flower quality scores of opened carnations after FBO closely correlated with TCU during 10 d flower quality evaluation. High PPFD showed beneficial effects on positive carbon/water balance for post-harvest FBO of ‘tight bud’-cut carnations and preservation of flower quality after FBO. Though the climacteric peak of cut carnations was shifted ahead by increasing PPFD, carnations quality after FBO in higher PPFD was better than that in lower PPFD treatments. These results showed that the positive carbon/water balance by elevated PPFD reduced the time required for FBO of ‘tight bud’-cut carnations, and contributed to the preservation of their quality.