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Assessment of Four-Seasonal Quality and Yield of Cut Flower Roses Grafted onto *Rosa* Rootstocks

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Abstract: Cut roses are ornamental crops that are produced year-round, and the quality and yield of these cut flowers vary depending on the temperature and light intensity of the four seasons. Grafting improves productivity by increasing adaptability to negative environments, such as high temperature and low light intensity. The effectiveness of grafting depends on the type of the scion and rootstock. In order to confirm the effectiveness of stenting on roses, two varieties of cut roses (*Rosa hybrida* cv. Pink Beauty and Pink Shine) were grafted onto three rootstocks (*R. multiflora* Natal Briar, *R. indica* Major, and *Rosa multiflora* Hort. No. 1), which are widely used in cut rose, and the quality and yield of the cut flowers were investigated year-round according to the four seasons; then, principal component analysis (PCA) was performed. The *Rosa hybrida* cv. Pink Beauty (PB) used as the scion showed high yield and excellent growth in autumn when the light intensity was high and the temperature was low. The PB grafted onto the *R. multiflora* Natal Briar (NA) rootstock showed improved growth in spring, autumn and winter, excluding summer, and had the effect of lengthening the stem. The growth of PB grafted onto *R. indica* Major (RI) rootstock was also improved in spring, autumn, and winter, except summer, and in particular, the stem was lengthened and thickened. The *rosa hybrida* cv. Pink Shine (PS) was a variety whose yield of cut flowers increased in summer when the temperature was high. The PS grafted onto the three rootstocks gave a higher yield of cut flowers than the PS scion. The graft of PS/Natal Briar gave longer stems than the PS scion, and the graft of PS/Major gave thicker stems than the PS scion. PS grafted onto the *Rosa multiflora* Hort. No. 1 (N1) rootstock gave more petals than the PS scion. As such, cut roses grafted onto the *Rosa canina* cv. Natal brier (NA) improved the stem length, increasing the adaptability to relatively high temperatures, and the *Rosa indica* cv. Major (RI) improved the stem length and stem diameter, enhancing the adaptability to relatively low temperatures.

Keywords: abiotic stress; biplot; growth; light intensity; temperature; yield

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Citation: Kwon, O.-H.; Choi, H.-G.; Kim, S.-J.; Kim, W.-H. Assessment of Four-Seasonal Quality and Yield of Cut Flower Roses Grafted onto *Rosa* Rootstocks. *Agriculture* **2022**, *12*, 1848. https://doi.org/10.3390/agriculture12111848

Academic Editor: Yuan Huang

Received: 5 September 2022
Accepted: 2 November 2022
Published: 4 November 2022

1. Introduction

The quality and productivity of horticultural crops are affected by the growing environment; in particular, differences in the seasonal temperature and light intensity are large, so the cultivation environment in winter and summer places abiotic stress on horticultural crops [1]. There are four distinct seasons in South Korea; the temperature is too high in summer and the temperature and light intensity are low in winter. Grafting is a widely used cultivation technique to improve the growth of horticultural crops by increasing their adaptability to negative environments, such as high and low temperatures, and low light intensity [2,3]. The success rate of grafting varies depending on the grafting method and environment [4–6]. The improvement of adaptability to a negative environment via grafting affects the quality and yield of horticultural crops. In particular, the productivity can be increased by improving the tolerance through grafting in a negative environment induced by salt stress [7], and the nutrient absorption of grafted plants using rootstock with excellent root nutrient absorption was improved, thereby increasing the adaptability to negative soil environments [8]. It has also been reported that the rootstock improves qualities such as the stem length, stem diameter, and flower weight of roses [9]. Korean consumers prefer cut roses with large flowers and long stems. In particular, in Korea, the length of the stem is an important indicator of quality grade [10].

The quality and yield of grafted horticultural crops such as rose [11,12] melon [13] and tobacco [14] vary depending on the characteristics of the scion and the rootstock. In Korea, the three rootstocks Natal Briar (*R. multiflora*), Major (*R. indica*), and Hort No. 1 (*Rosa multiflora*) are widely used for grafting to improve the growth of cut roses. However, there is not enough information about the quality and yield of roses grafted using these rootstocks.

Although it is difficult to investigate the effects of grafting on cut roses because they are continuously grown year-round in a greenhouse, we confirmed the characteristics of scion cut roses (*Rosa hybrida* cv. Pink Beauty) grafted onto these three types of rootstock [15]. Additionally, the characteristics of spray rose (*Rosa hybrida* cv. Pink Shine) grafted onto three different rootstocks grown in summer have been reported [16]. Nevertheless, there is still insufficient information on how the effect of grafting differs according to the characteristics of scions and rootstocks in relation to environmental conditions such as temperature and light intensity according to the season. Therefore, in this study, we analyzed the grafting characteristics according to the types of two scion and three rootstocks in relation to environment, with temperature and light alterations during the four seasons. However, it is difficult to analyze the grafting characteristics measured throughout the year via various factors such as environment, scion, and rootstock. One method that can be used to analyze the effects of these various factors is principal component analysis (PCA), as the best-known technique of multivariate data analysis [17]. PCA involves data reduction and transforming the raw data into principle components or factors [18]. Principal component analysis analyzes the correlation structure between variables by determining the variation in the original variable after obtaining low-dimensional independent factors [19], and also takes into account the correlations among several variables that are simultaneously analyzed, thus allowing the interpretation of better summarized information [20]. The PCA-based biplot is organized into a graph wherein all elements are chosen to exactly match the dot product of the vectors corresponding to the row and column. A biplot is useful for data analysis as it allows one to visually evaluate the structure of large data matrices. Agriculturally, it is used in various fields, such as those related to the quality of fruit [21], disease [22,23], breeding [24], classification [25] and soil ingredients [20].

Therefore, this study was conducted to find out how the quality and yield characteristics of grafted cut roses differ depending on the type of rootstock in a greenhouse environment where the light intensity and temperature change according to the seasons.

2. Materials and Methods

2.1. Plant Materials and Growth Conditions

The two scions used in this study were the standard rose cultivar *Rosa hybrida* cv. Pink Beauty (PB) and the spray rose cultivar *Rosa hybrida* cv. Pink Shine (PS). The three rootstocks used in this study were *Rosa multiflora* cv. Hort. No. 1 (N1), *Rosa canina* cv. Natal Briar (NA), and *Rosa indica* cv. Major (RI). *Rosa multiflora* cv. Natal Briar is native to South Africa, *Rosa indica* cv. "Major" is differentiated in Israel, and *Rosa multiflora* cv. Hort. No. 1 is prevalent in Korea.

The yield and flower quality were measured using fifteen different individual plants, including the non-grafted scion rose cultivars (PB and PS), and six grafted rose flowers (PB/N1, PB/NA, PB/RI, PS/N1, PS/NA, and PS/RI).

The roses were planted in a rockwool medium (25 × 100 × 75 cm, Grodan, Roermond, The Netherlands) and cultivated in a soilless culture system. The composition of the nutrient solution from the Japan National Institute of Vegetable and Tea Science (JNIVT) was as follows: macroelements (NO_3-N:NH_4-N:P:K:Ca:Mg:S = 16:1.33:4:8:8:4:4 me·L^{-1}), microelements (Fe:Mn:B:Zn:Cu:Mo = 2:0.5:0.25:0.2:0.05:0.05 mg·L^{-1}). All the roses were cultivated following the "arching" technique, by which 2–3 stems with a total of 30 leaves are bent horizontally in order to promote basal shoot formation and to decrease plant canopy and light interception

The experiments were carried out in a glass greenhouse located in the Rural Department Administration of South Korea (35°50′02″ N, 127°02′04″ E). The environmental conditions in the greenhouse, using installed equipment (consisting of convective heating, ceiling and wall windows, and ventilation fans), were set to day and night temperatures of $\leq$ 30 °C and $\geq$18 °C, respectively. Additionally, when the temperature was $\geq$35 °C in the greenhouse, the temperature was lowered using a 30% shading curtain. The light intensity and temperature in the greenhouse were logged at 1 h intervals using a data log (WatchDog 1650; Spectrum Technologies Inc., Aurora, IL, USA). Figure 1 shows the light intensity and temperature at noon in the greenhouse for cultivating a cutting and grafting cut roses during the four seasons.

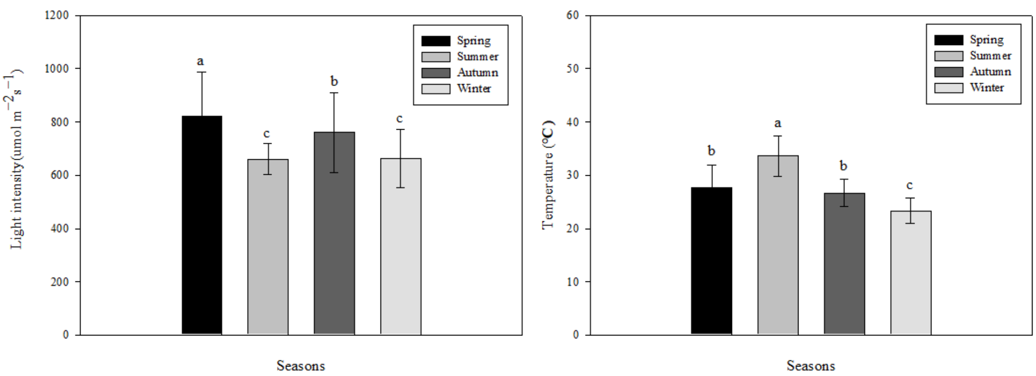

Figure 1. Light intensity and temperature at noon in the greenhouse used in this study. Vertical bars are standard deviations (n = 60). Small letters at the data points indicate mean separation between the values by Duncan's multiple test at p = 0.05.

2.2. Yield and Quality

The stem length is an important quality standard for cut roses [10]. Therefore, cut roses with stem lengths over 40 cm were sequentially investigated until reaching full bloom. The yield of flowering stems and the quality of cut roses were assessed daily during the four seasons from September 2019 to June 2020.

2.3. Experimental Design and Statistical Analysis

This grafting experiment was replicated three times. Each replication consisted of five plants for each treatment (two cuttings and six grafts). The grafting treatment results such as yield and quality of cut flowers were analyzed using analysis of variance with Duncan's multiple range test using a significance level of $p \leq 0.05$ in the SAS 9.4 program (SAS Institute Inc., Cary, NC, USA). The data analyses were performed using a principal component analysis (PCA) biplot, using the statistical R software (R Foundation, Institute for Statistics and Mathematics, Vienna, Austria). These methods aim at reducing the multivariate space in which objects (growth and environment parameters) are distributed. The two scions and three rootstocks used for grafting are classified according to their effects.

3. Results

3.1. Yield and Quality of Cut Roses

In the grafted rose *Rosa hybrida cv*. Pink Beauty, the quality parameters of cut flowers such as stem length, stem diameter, flower size, number of petals, and number of leaves were affected by season and the characteristics of the rootstock types (Table 1). In particular, the stem lengths of grafted roses were significantly increased compared to those of the cuttings (PB) in autumn, winter, and spring. In autumn, winter, and spring, the stem lengths of PB/N1 were longer than those of PB and other grafted roses, and the stem lengths and stem diameters of PB/RI were improved compared to the cutting (PB). However, the *Rosa hybrida cv*. Pink Beauty (PB) grafted roses had fewer petals than non-grafted roses (PB), and there was no difference in yield between any treatments in spring, summer and winter. In autumn, when the yield of cut flowers was higher than in other seasons, the production of cut roses produced from PB/NA was the highest among the cuttings and grafted roses.

In *Rosa hybrida cv*. Pink Shane (PS), the stem length was affected by the season, but there was no effect resulting from grafting (Table 2). However, the number of cut flowers of *Rosa hybrida cv*. Pink Shine (PS) grafted onto *Rosa canina* cv. Natal brier (NA) increased more than that of cuttings (PS) in summer and autumn, and the numbers of cut flowers of *Rosa hybrida cv*. Pink Shine (PS) grafted with *Rosa indica* cv. Major (RI) increased more than those of cuttings (PS) in winter and spring. Additionally, the number of petals of *Rosa hybrida cv*. Pink Shane (PS) grafted onto *Rosa multiflora* cv. Hort. No. 1 (N1) was greater than that of the cuttings (PS).

3.2. Biplot Given by the Principal Component Analysis (PCA) of Yield and Growth on Grafted Standard Type Rose Rosa Hybrida cv. Pink Beauty

The PCA-based biplot is a method of geometrically analyzing information in multivariate data. In a biplot graph, if the position of the variable and the direction of the arrow are close, it means that the correlation is high [21]. Tables 1 and 2 were used for biplot-based PCA. The biplot analysis was performed within two main principle factors (PC1 and PC2) for the cutting (PB) and the three grafted PB in four seasons by rootstock types. The principal components of PB explained 93.0% of the cumulative variance—PC1 explained 68.6%, accounting for stem length (SL), length of flower neck (FSL), fresh weight (FW), and yield of stem (YI), and PC2 indicated 24.4%, accounting for stem diameter (SD) and number of leaves (LN) (Figure 2A).

PB showed excellent growth in spring, autumn, and winter, when the light intensity was high and the temperature was relatively low. However, in the summer, when the temperature was high, the stems were short and thick, and the yields of cut flowers decreased. The principal components on PB/N1 explained 92.6% of the cumulative variance—PC1 detailed 66.4%, accounting for temperature (TE), number of petals (PN), FW and SD, while PC2 indicated 24.4%, accounting for SD and yield of stem (YI) (Figure 2B). PB/N1 had the best quality in winter when the temperature was low, and the yield of cut flowers was high in autumn. In summer, the number of petals on PB/N1 increased. The principal components on PB/NA explained 93.6% of the cumulative variance; PC1 detailed 79.0%, accounting for TE, SL, SD, FW and light intensity (LI), while PC2 indicated 14.6%, accounting for yield (YI) and no. petals (PN) (Figure 2C). The quality of PB/NA was excellent in spring, autumn, and winter, and in particular, the yield of cut flowers on PB/NA increased in autumn. The principal components on PB/RI explained 92.8% of the cumulative variance; PC1 detailed 72.5%, accounting for TE, LN, FW and the diameter of the lower neck (FSD), while PC2 indicated 20.3%, accounting for yield (YI), stem diameter (SD) and petals (PN) (Figure 2D). The quantity of PB/RI was the highest in autumn out of the four seasons, and the quality of cut roses was excellent in spring and winter.

Table 1. The quality and yield of cut roses for *Rosa hybrida* cv. Pink Beauty (PB) and PB grafted onto *Rosa multiflora* cv. Hort. No. 1 (PB/N1), PB grafted onto *Rosa canina* cv. Natal brier (PB/NA), and PB grafted onto *Rosa indica* cv. Major (PB/RI) in four seasons [15].

Season	Treatment	Stem Length (cm)	Length of Flower Neck (cm)	Stem Diameter (mm)	Diameter of Flower Neck (mm)	Flower Height (mm)	Flower Diameter (mm)	No. of Leaves (ea)	Fresh Weight (g)	No. of Petals (ea)	Yield of Stem (/Plant)
Spring	PB	54.8 ± 4.0 ef [z]	8.5 ± 0.2 bc	5.5 ± 0.3 e	4.8 ± 0.1 cd	32.5 ± 1.2 ab	5.5 ± 0.1 bc	8.9 ± 0.6 f	44.4 ± 4.8 d	58.8 ± 0.2 bcd	4.9 ± 0.9 bcdef
	PB/N1	61.4 ± 6.0 c	9.0 ± 0.2 ab	5.8 ± 0.4 cde	5.1 ± 0.1 abc	33.6 ± 1.0 ab	5.6 ± 0.2 abc	9.4 ± 0.3 def	53.0 ± 7.0 abc	56.2 ± 1.3 def	4.5 ± 1.1 cdef
	PB/NA	70.8 ± 3.5 a	9.4 ± 0.6 a	6.5 ± 0.4 abc	5.3 ± 0.2 ab	31.4 ± 1.2 c	5.8 ± 0.1 ab	10.7 ± 0.7 ab	59.7 ± 6.7 ab	48.1 ± 2.1 i	4.0 ± 1.1 ef
	PB/RI	65.4 ± 1.1 abc	8.7 ± 0.2 abc	6.6 ± 0.4 ab	5.4 ± 0.2 ab	34.4 ± 0.8 a	5.9 ± 0.1 a	9.9 ± 0.5 cde	60.4 ± 2.9 a	50.5 ± 0.8 ghi	4.3 ± 0.7 def
Summer	PB	50.5 ± 3.6 efg	7.8 ± 0.3 d	5.9 ± 0.8 bcde	4.3 ± 0.3 ef	23.1 ± 1.3 d	4.6 ± 0.2 d	9.4 ± 0.1 def	34.1 ± 6.9 e	56.5 ± 2.4 cdef	3.6 ± 0.4 f
	PB/N1	49.8 ± 2.4 fg	7.4 ± 0.3 de	5.9 ± 0.2 cde	4.4 ± 0.1 ef	22.7 ± 0.7 d	4.3 ± 0.1 d	9.4 ± 0.4 def	32.9 ± 1.2 e	64.5 ± 2.3 a	3.9 ± 0.9 ef
	PB/NA	48.6 ± 2.2 g	8.0 ± 0.6 cd	5.4 ± 0.6 e	4.1 ± 0.3 f	23.4 ± 1.9 d	4.7 ± 0.2 d	8.1 ± 0.1 g	31.0 ± 5.2 e	52.2 ± 0.5 fghi	3.9 ± 0.7 ef
	PB/RI	50.5 ± 0.9 efg	7.0 ± 0.5 e	6.3 ± 0.4 abcd	4.3 ± 0.3 ef	23.1 ± 0.6 d	4.6 ± 0.4 d	9.3 ± 0.2 def	35.4 ± 4.3 e	54.9 ± 2.2 defg	4.0 ± 0.3 ef
Autumn	PB	62.4 ± 0.3 bc	8.6 ± 0.4 bc	6.3 ± 0.1 abcd	5.0 ± 0.1 bc	31.4 ± 2.6 c	5.5 ± 0.4 bc	10.1 ± 0.3 bcd	53.8 ± 5.7 abc	61.1 ± 7.2 abc	5.5 ± 0.5 abcd
	PB/N1	60.4 ± 1.8 cd	9.1 ± 0.6 ab	5.7 ± 0.3 de	4.6 ± 0.2 de	31.6 ± 1.7 c	5.4 ± 0.0 c	9.3 ± 0.4 def	47.5 ± 2.9 cd	62.3 ± 0.8 ab	6.6 ± 0.1 a
	PB/NA	67.7 ± 3.8 ab	9.1 ± 0.5 ab	6.5 ± 0.2 abc	5.1 ± 0.3 abc	32.9 ± 1.1 ab	5.7 ± 0.3 ab	10.9 ± 0.7 a	59.1 ± 2.6 ab	53.7 ± 4.2 efgh	5.7 ± 0.5 abc
	PB/RI	65.3 ± 0.2 abc	9.0 ± 0.3 ab	6.3 ± 0.1 abcd	5.1 ± 0.1 abc	33.1 ± 0.2 ab	5.6 ± 0.1 abc	10.0 ± 0.1 bcd	59.7 ± 1.8 ab	55.1 ± 2.6 defg	6.2 ± 0.2 ab
Winter	PB	55.6 ± 4.3 de	8.5 ± 0.2 bc	5.7 ± 0.2 de	4.9 ± 0.1 cd	33.2 ± 0.3 ab	5.5 ± 0.1 bc	9.1 ± 0.5 ef	46.5 ± 3.9 cd	58.5 ± 1.0 bcde	4.9 ± 0.6 bcdef
	PB/N1	63.3 ± 3.3 bc	8.9 ± 0.4 ab	6.0 ± 0.2 bcde	5.1 ± 0.1 abc	32.5 ± 0.2 ab	5.5 ± 0.2 bc	9.5 ± 0.4 def	51.9 ± 2.7 bcd	56.1 ± 2.0 def	4.7 ± 1.2 cdef
	PB/NA	70.7 ± 3.1 a	9.5 ± 0.6 a	6.4 ± 0.2 abc	5.3 ± 0.2 ab	32.2 ± 1.0 ab	6.0 ± 0.1 a	10.6 ± 0.5 abc	57.8 ± 1.3 ab	48.0 ± 2.3 i	4.2 ± 0.9 def
	PB/RI	67.1 ± 1.2 ab	8.8 ± 0.3 ab	6.7 ± 0.3 a	5.4 ± 0.2 a	33.2 ± 1.5 ab	5.8 ± 0.1 ab	10.1 ± 0.2 bcd	58.8 ± 1.9 ab	49.2 ± 0.3 hi	5.3 ± 0.8 abcde
Effect (p value) [y]	Season	0.000	0.000	0.170	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Rootstock	0.000	0.002	0.000	0.003	0.189	0.001	0.001	0.000	0.000	0.396
	Interaction	0.001	0.329	0.011	0.010	0.297	0.676	0.000	0.019	0.084	0.657

[z] Values followed by different letters within a column are significantly different (DMRT, $p < 0.05$. $n = 15$). [y] p values were determined by two-way ANOVA.

Table 2. The quality and yield of cut roses for *Rosa hybrida* cv. Pink Shine (PS) and PS grafted onto *Rosa multiflora* cv. Hort. No. 1 (PS/N1), PS grafted onto *Rosa canina* cv. Natal brier (PS/NA), and PS grafted onto *Rosa indica* cv. Major (PS/RI) in four seasons.

Season	Treatment	No. of Florets (ea)	Stem Length (cm)	Stem Diameter (mm)	Flower Height (cm)	Flower Diameter (mm)	No. of Petals (ea)	No. of Leaves (ea)	Fresh Weight (g)	Yield of Stem (/Plant)
Spring	PS	7.2 ± 0.1 abcd [y]	54.6 ± 5.3 cd	5.8 ± 0.2 abc	2.5 ± 0.0 bc	20.0 ± 0.3 abcd	61.6 ± 2.2 de	9.4 ± 0.3 bc	77.5 ± 14.5 ab	4.2 ± 0.5 bcdef
	PS/N1	7.3 ± 0.3 ab	52.7 ± 0.3 cd	5.8 ± 0.1 abc	2.4 ± 0.0 c	21.2 ± 0.1 a	79.8 ± 3.3 abc	8.7 ± 0.1 def	60.8 ± 1.0 b	4.3 ± 0.3 bcde
	PS/NA	7.6 ± 0.6 a	56.9 ± 6.4 abcd	6.1 ± 0.7 a	2.4 ± 0.0 c	20.9 ± 1.0 ab	77.0 ± 16.5 abcd	7.9 ± 0.6 f	62.7 ± 8.7 b	4.0 ± 0.7 bcdef
	PS/RI	7.7 ± 0.4 a	53.3 ± 6.3 cd	5.6 ± 0.3 abc	2.4 ± 0.1 c	20.0 ± 0.5 abcd	74.5 ± 6.5 bcd	8.3 ± 0.5 f	60.9 ± 9.1 b	5.0 ± 0.5 ab
Summer [z]	PS	5.8 ± 0.2 e	52.0 ± 0.6 cd	5.1 ± 0.1 c	2.3 ± 0.0 c	18.6 ± 0.8 cde	49.9 ± 4.0 ef	8.4 ± 0.2 def	39.0 ± 2.6 c	4.4 ± 0.8 abcd
	PS/N1	6.1 ± 0.3 fg	49.3 ± 0.8 d	5.1 ± 0.0 c	2.2 ± 0.2 c	17.7 ± 1.5 efg	64.0 ± 16.9 cde	8.2 ± 0.3 f	41.5 ± 4.1 c	5.3 ± 0.3 a
	PS/NA	6.2 ± 0.4 efg	54.0 ± 1.9 cd	5.2 ± 0.2 c	2.3 ± 0.0 c	16.6 ± 0.6 fg	39.9 ± 1.4 f	8.3 ± 0.3 f	39.8 ± 3.6 c	4.9 ± 0.1 ab
	PS/RI	6.3 ± 0.6 defg	50.5 ± 0.2 d	5.2 ± 0.1 bc	2.3 ± 0.0 c	16.0 ± 0.4 g	49.2 ± 2.5 ef	8.5 ± 0.2 def	41.4 ± 1.8 c	4.9 ± 0.1 ab
Autumn	PS	7.2 ± 0.3 abc	64.2 ± 2.3 a	6.3 ± 0.3 a	2.7 ± 0.0 a	18.7 ± 1.1 bcde	79.0 ± 2.7 abc	10.5 ± 0.3 a	80.6 ± 3.4 a	3.7 ± 0.4 cdef
	PS/N1	7.0 ± 0.8 abcde	58.8 ± 3.8 abc	6.2 ± 0.8 a	2.8 ± 0.0 a	19.6 ± 0.5 abcd	89.7 ± 13.0 ab	9.4 ± 0.8 bcd	73.3 ± 17.8 ab	4.9 ± 0.9 ab
	PS/NA	7.2 ± 0.7 abc	62.8 ± 5.7 ab	6.1 ± 0.2 a	2.9 ± 0.1 a	18.1 ± 0.2 defg	67.8 ± 5.3 cd	10.6 ± 0.7 a	72.5 ± 13.6 ab	4.7 ± 0.6 abc
	PS/RI	6.8 ± 0.2 abcdef	60.0 ± 6.2 abc	6.0 ± 0.3 a	2.9 ± 0.0 a	18.9 ± 0.7 abcd	79.7 ± 5.4 abc	9.9 ± 0.7 ab	71.4 ± 11.1 ab	4.4 ± 0.3 abcd
Winter	PS	6.4 ± 0.6 cdefg	55.2 ± 1.2 bcd	5.6 ± 0.1 abc	2.7 ± 0.0 ab	20.1 ± 0.3 abc	93.0 ± 4.3 a	9.9 ± 0.6 ab	64.3 ± 4.1 ab	3.3 ± 0.7 ef
	PS/N1	6.5 ± 0.1 bcdefg	53.4 ± 3.2 cd	5.7 ± 0.8 abc	2.7 ± 0.2 ab	20.1 ± 2.5 abc	89.8 ± 13.6 ab	8.4 ± 0.6 ef	65.5 ± 15.7 ab	3.1 ± 0.5 f
	PS/NA	7.0 ± 0.3 abcde	56.2 ± 5.7 bcd	6.0 ± 0.4 a	2.8 ± 0.1 a	19.6 ± 1.1 abcd	71.2 ± 2.4 cd	9.3 ± 0.5 bcd	66.2 ± 8.8 ab	3.4 ± 0.9 def
	PS/RI	6.9 ± 0.2 abcdef	60.1 ± 6.9 abc	5.9 ± 0.2 ab	2.7 ± 0.1 a	19.5 ± 1.2 abcd	79.6 ± 5.5 abc	9.7 ± 0.8 ab	65.1 ± 2.6 ab	3.5 ± 0.5 def
Effect(p value) [x]	Season	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Rootstock	0.221	0.147	0.736	0.002	0.133	0.001	0.002	0.048	0.066
	Interaction	0.801	0.783	0.863	0.027	0.547	0.098	0.027	0.731	0.251

[z] Adopted from Kwon and Choi (2022) [16]. [y] Values followed by different letters within a column are significantly different (DMRT, $p < 0.05$. $n = 15$). [x] p values were determined by two-way ANOVA.

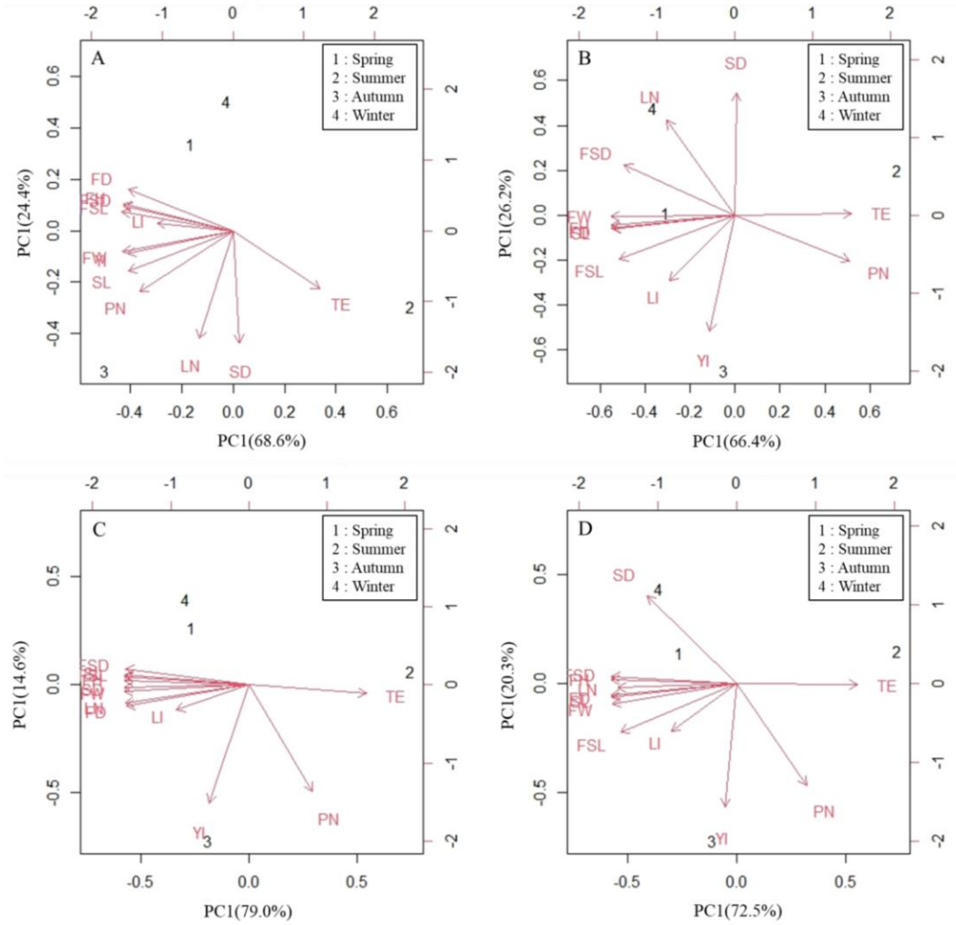

Figure 2. Biplot for the principal component analysis (PCA) of yield and growth on grafted standard type rose *Rosa hybrida* cv. Pink Beauty in four seasons by rootstock type based on the data in Table 1 with the four seasons being identified by numbers 1 to 4 and yield and growth parameter being identified by abbreviation. (**A**): cutting (*Rosa hybrida* cv. Pink Beauty); (**B**): *Rosa hybrida* cv. Pink Beauty (PB) grafted onto rootstock of *Rosa multiflora* cv. Hort. No. 1 (N1) (PB/N1); (**C**): PB grafted onto rootstock of *Rosa canina* cv. Natal brier (NA) (PB/NA); (**D**): PB grafted onto rootstock of *Rosa indica* cv. Major (RI) (PB/RI). FD: flower diameter; FH: flower height; FSD: diameter of flower neck; FSL: length of flower neck; FW: fresh weight; LI: light intensity; LN: no. of leaves; PN: no. of petals; SD: stem diameter; SL: stem length; TE: temperature; YI: yield of stem.

3.3. Biplot Given by the Principal Component Analysis (PCA) of Yield and Growth of Grafted Standard Type Rose Rosa Hybrida cv. Pink Shine in Four Seasons by Rootstock Type

A biplot analysis was performed with two main principle factors (PC1 and PC2) for grafted PS by rootstock types during four seasons. The principal components on PS explained 86.8% of the cumulative variance; PC1 detailed 65.5%, accounting for no. of leaves (LN), flower height (FH) and stem length (SL), while PC2 indicated 21.3%, accounting for yield (YI) and light (LI) (Figure 3A). PS gave a large number of cut flowers in summer and many florets in spring and autumn. In winter, the stems became thicker and the number of petals increased. The principal components on PS/N1 explained 85.7% of the cumulative variance; PC1 detailed 68.3%, accounting for flower height (FH), flower diameter (FD) and fresh weight (FW), while PC2 indicated 17.4%, accounting for yield (YI) (Figure 3B).

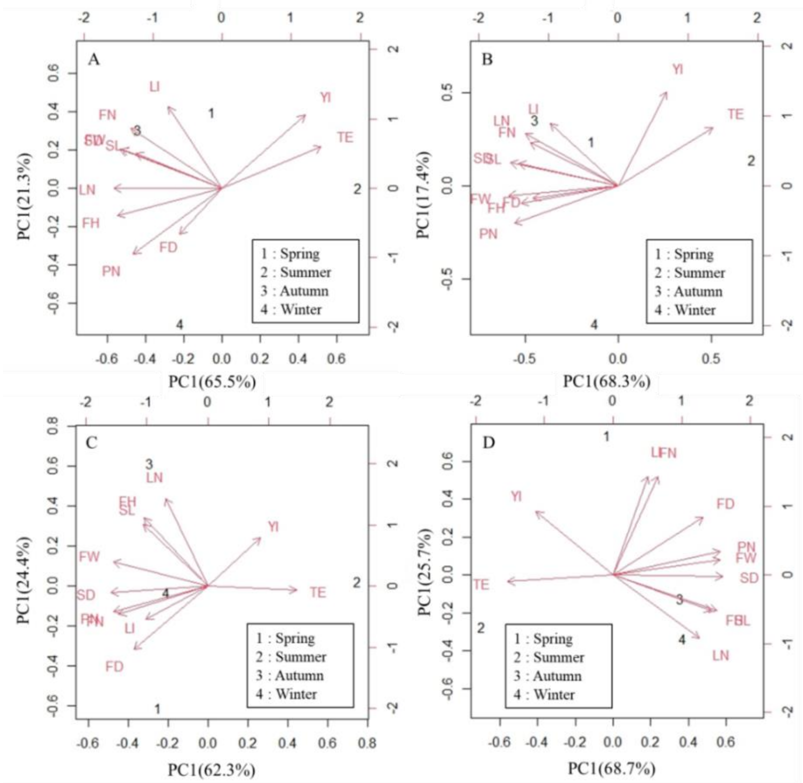

Figure 3. Biplot for the principal component analysis (PCA) of yield and growth on grafted spray type rose *Rosa hybrida* cv. Pink Shine in four seasons by rootstock type based on the data in Table 2 with the four seasons being identified by numbers 1 to 4 and yield and growth parameter being identified by abbreviation. (**A**): cutting (PS); (**B**): PS grafted onto rootstock of *Rosa multiflora* cv. Hort. No. 1 (N1) (PS/N1); (**C**): PS grafted onto rootstock of *Rosa canina* cv. Natal brier (NA) (PS/NA); (**D**): PS grafted onto rootstock of *Rosa indica* cv. Major (RI) (PS/RI). FD: flower diameter; FH: flower height; FN: No. of florets; FW: fresh weight; LI: light intensity; LN: No. of leaves; PN: no. of petals; SD: stem diameter; SL: stem length; TE: temperature; YI: yield of stems.

In the spring and autumn when the light intensity was high, PS/N1 showed an increased number of florets and a longer stem length. In winter, when the temperature was low, the flower height and the number of petals increased. In summer, when the temperature was high, the yield of cut flowers increased. The principal components on PS/NA explained 86.7% of the cumulative variance; PC1 detailed 62.3%, accounting for TE, SD and FW, while PC2 indicated 24.4%, accounting for YI, LN and PN (Figure 3C). PS/NA showed better quality in spring, summer, and autumn, when the light intensity was higher and the temperature was lower than in summer, and the yield of cut roses was higher in summer and autumn. The principal components on PS/RI explained 94.4% of the cumulative variance; PC1 detailed 68.7%, accounting for stem diameter (SD), fresh weight (FW), no. of petals (PN) and temperature (TE), while PC2 indicated 25.7%, accounting for no. of flowers, FN and light (LI) (Figure 3D). PS/RI showed excellent quality in the winter when the temperature was low, and the yield of cut roses increased in the summer and spring, when the temperature was high.

3.4. Greenhouse Biplot of the Principal Component Analysis (PCA) of Yield and Growth of Grafted Standard Type Rose Rosa Hybrida cv. Pink Beauty between Rootstock Types in Four Seasons

A biplot analysis was performed with two main principle factors (PC1 and PC2) of the growth parameter for grafted PB between rootstock types during four seasons. The principal components in spring explained 97.0% of the cumulative variance; PC1 detailed 78.0%, accounting for no. of petals (PN), yield (YI), stem length (SL), and flower weight (FW), while PC2 indicated 19.0%, accounting for FD (Figure 4A).

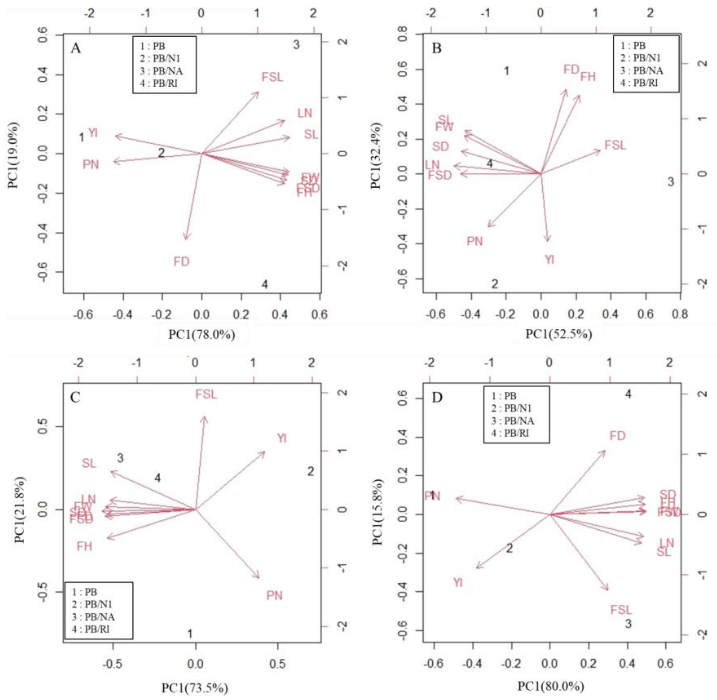

Figure 4. Biplot of the principal component analysis (PCA) of yield and growth of grafted standard type rose *Rosa hybrida* cv. Pink Beauty between rootstock types in four seasons based on the data in Table 1 with cutting and grafted rose being identified by numbers 1 to 4 and yield and growth parameter being identified by abbreviation. (**A**): spring; (**B**): summer; (**C**): autumn; (**D**): winter. PB: cutting on *Rosa hybrida* cv. Pink Beauty; PB/N1: *Rosa hybrida* cv. Pink Beauty grafted onto rootstock of *Rosa multiflora* cv. Hort No 1; PB/NA: *Rosa hybrida* cv. Pink Beauty grafted onto rootstock of *Rosa canina* cv. Natal brier; PB/RI: PB grafted onto rootstock of *Rosa indica* cv. Major. FD: flower diameter; FH: flower height; FSD: diameter of flower neck; FSL: length of flower neck; FW: fresh weight; LN: no. of leaves; PN: no. of petals; SD: stem diameter; SL: stem length; YI: yield of stem.

Compared to PB in spring, PB/NA showed a longer stem length, and PB/RI showed improved quality, such as an increased weight as the stem and flower thickness increased. However, the number of cut flowers of grafted roses decreased. The principal components in summer explained 84.9% of the cumulative variance; PC1 detailed 52.5%, accounting for stem diameter (SD), diameter of flower neck (FSD), no. of leaves (LN), fresh weight (FW) and stem length (SL), while PC2 indicated 32.4%, accounting for flower diameter (FD), flower height (FH) and yield (YI) (Figure 4B). In summer, when the temperature was high, PB/N1 showed more petals and a greater yield of cut flowers compared to PB. The principal components in autumn explained 96.3% of the cumulative variance; PC1 detailed 73.5%, accounting for fresh weight (FW), stem length (SL), flower height (FH), and no. of leaves (LN), while PC2 indicated 21.8%, accounting for yield (YI) and no. of petals (PN) (Figure 4C). In autumn, PB/RI and PB/NA had longer and heavier stems than PB, and PB/N1 showed more cut flowers than PB. The principal components in winter explained 95.8% of the cumulative variance; PC1 detailed 80.0%, accounting for stem diameter (SD), flower height (FH) stem length (SL) and no. of flowers (PN), while PC2 indicated 15.8%, accounting for flower diameter (FD) and yield (YI) (Figure 4D). In winter, PB/N1 showed an increased yield of cut roses compared to PB, PB/NA showed longer flower necks and greater flower heights than PB, and PB/RI showed improved flower diameter and stem thickness compared to PB.

3.5. Biplot of the Principal Component Analysis (PCA) of Yield and Growth of Grafted Spray Type Rose Rosa hybrida cv. Pink Shine between Rootstock Types in Four Seasons

A biplot analysis was performed with two main principle factors (PC1 and PC2) of the growth parameter for the grafted cut rose PS between rootstock types during four seasons. The principal components in spring explained 84.5% of the cumulative variance; PC1 detailed 53.3%, accounting for no. of petals (PN), no. of flowers (FN), fresh weight (FW), flower height (FH) and no. of leaves (LN), while PC2 indicated 31.2%, accounting for stem length (SL), stem diameter (SD) and yield (YI) (Figure 5A). Grafted cut roses showed increased numbers of florets and petals in spring. In particular, PS/NA showed longer and thicker stems compared to PS, and PS/RI increased its yield of cut flowers compared to PS (Table 2, Figure 5A).

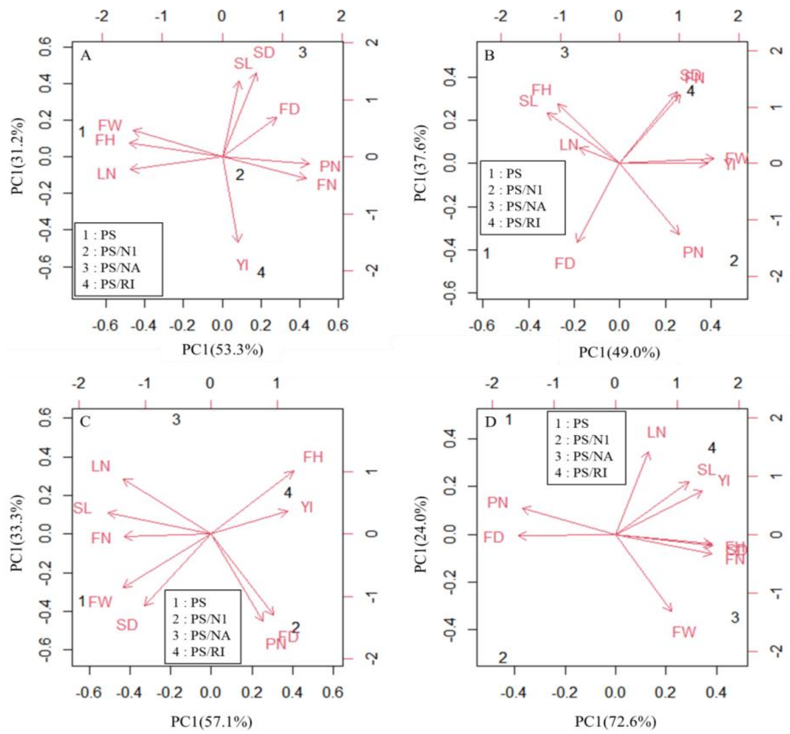

Figure 5. Biplot of the principal component analysis (PCA) of yield and growth of grafted spray type *Rosa hybrida* cv. Pink Shine between rootstock type in four seasons based on the data in Table 1 with cutting and grafted rose being identified by numbers 1 to 4 and yield and growth parameter being identified by abbreviation. (**A**): spring; (**B**): summer; (**C**): autumn; (**D**): winter. PS: cutting on *rosa hybrida* cv. Pink Shine; PS/N1: *Rosa hybrida* cv. Pink Shine (PS) grafted onto rootstock of *Rosa multiflora* cv. Hort. No. 1; PS/NA: PS grafted onto rootstock of *Rosa canina* cv. Natal brier; PS/RI: PS grafted onto rootstock of *Rosa indica* cv. Major. FD: flower diameter; FH: flower height; FN: no. of florets; FW: fresh weight; LI: light intensity; LN: no. of leaves; PN: No. of petals; SD: stem diameter; SL: stem length; TE: temperature; YI: yield of stem.

The principal components in summer explained 86.7% of the cumulative variance; PC1 detailed 52.5%, accounting for stem diameter (SD), no. of leaves (LN), fresh weight (FW), and stem length (SL), while PC2 indicated 32.4%, accounting for flower diameter (FD), flower height (FH) and yield (YI) (Figure 5B). In summer, the numbers of petals and cut flowers of PS/N1 were higher than those of PS (Table 2, Figure 5B). The principal components in autumn explained 96.3% of the cumulative variance; PC1 detailed 73.5%, accounting for flower weight (FW), stem length (SL), flower height (FH) and no. of leaves (LN), while PC2 indicated 21.8%, accounting for length of flower neck (FSL), yield (YI) and no. of petals (PN) (Figure 2C). In autumn, PS/RI and PS/NA showed longer and heavier stems than PS, and PS/N1 showed an increased yield of cut flower compared to PS. The principal components in winter explained 95.8% of the cumulative variance; PC1 detailed 80.0%, accounting for stem diameter (SD), flower height (FH), no. of petals (PN) and stem length (SL), while PC2 indicated 15.8%, accounting for flower diameter (FD) and yield (YI). In winter, the yield of cut flowers of PS/N1 increased compared to PS, PS/NA showed greater flower heights and thicker stems than PS, and PS/RI showed thicker flowers and stems than PS.

3.6. Biplot of the Principal Component Analysis of Total Yield and Growth on Grafted Cut Rose Rosa hybrida cv. Pink Beauty and Pink Shine between Rootstock Types Year-Round

A biplot analysis was performed with two main principle factors (PC1 and PC2) for grafted PB by rootstock types year-round (Figure 6A). The principal components in winter explained 93.2% of the cumulative variance; PC1 detailed 72.3%, accounting for stem diameter (SD), flower height (FH), no. of petals (PN) and yield (YI), while PC2 indicated 20.9%, accounting for flower diameter (FD) and length of flower neck (FSL). When comparing the total yield of cut flowers and the quality of the cuttings for three roses grafted on PB in one year, PB/NA and PB/RI showed higher quality, with improved stem length and stem diameter compared to PB. In particular, PB/NA showed the excellent effect of an elongated stem length, and PB/RI showed a greater width of flowers and stems (Table 2, Figure 6A). The biplot analysis performed with two main principle factors (PC1 and PC2) for grafted PS by rootstock types year-round (Figure 6B). The principal components in winter explained 91.3% of the cumulative variance; PC1 detailed 52.4%, accounting for stem diameter (SD), flower diameter (FD) and stem diameter (SD), while PC2 indicated 38.9%, accounting for no. of leaves (LN) and yield (YI). When comparing the cuttings and three grafted roses of PB, the yield of cut flowers on the grafted roses was improved. Additionally, PS/NA showed an improved quality via stem length and diameter, and PS/N1 showed an increased number of petals and thicker flower diameter (Table 2, Figure 6B).

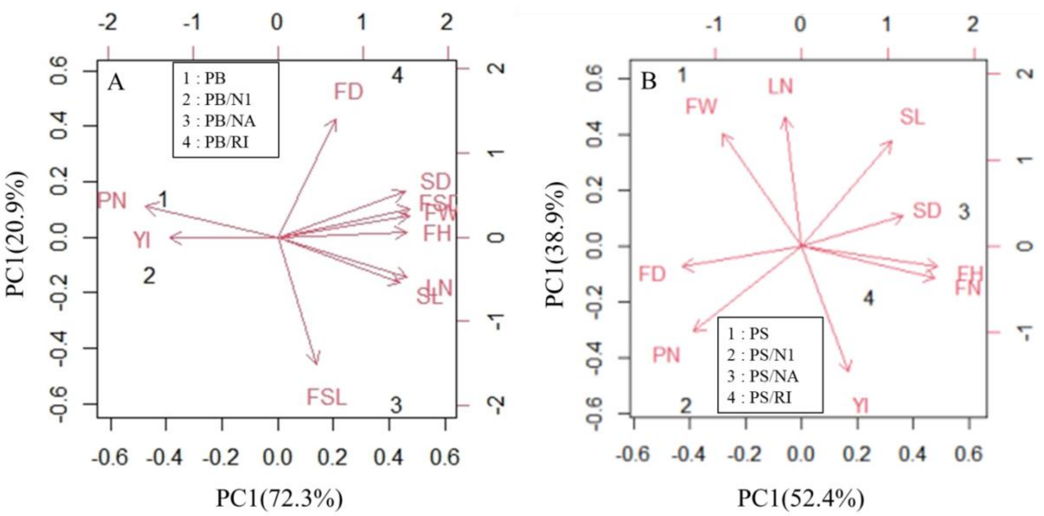

Figure 6. Biplot of the principal component analysis (PCA) of total yield and growth on grafted cut rose *Rosa hybrida* cv. Pink Beauty and Pink Shine between rootstock types year-round based on the data in Table 1, 2 with cutting and grafted rose being identified by numbers 1 to 4 and yield and growth parameter being identified by abbreviation. (**A**): cutting and grafted roses on *rosa hybrida* cv. Pink Beauty; (**B**): cutting and grafted roses on *rosa hybrida* cv. Pink Shine. PB: cutting on the *rosa hybrida* cv. Pink Beauty; PB/N1: *Rosa hybrida* cv. Pink Beauty grafted onto rootstock of *Rosa multiflora* cv. Hort No 1; PB/NA: *Rosa hybrida* cv. Pink Beauty grafted onto rootstock of *Rosa canina* cv. Natal brier; PB/RI: *Rosa hybrida* cv. Pink Beauty grafted onto rootstock of *Rosa indica* cv. Major. PS: cutting

on the *rosa hybrida* cv. Pink Shine; PS/N1: *Rosa hybrida* cv. Pink Shine grafted onto rootstock of *Rosa multiflora* cv. Hort. No. 1; PB/NA: *Rosa hybrida* cv. Pink Shine grafted onto rootstock of *Rosa canina* cv. Natal brier; PB/RI: *Rosa hybrida* cv. Pink Shine grafted onto rootstock of *Rosa indica* cv. Major. FN: No. of florets; FD: flower diameter; FH: flower height; FSD: diameter of flower neck; FSL: length of flower neck; FW: fresh weight; LN: no. of leaves; PN: no. of petals; SD: stem diameter; SL: stem length; YI: yield of stem.

4. Discussion

Recently, cut rose varieties have been bred in Korea [26–28]. However, newly bred rose varieties do not adapt well to negative environments, such as high and low temperatures and low light intensity. As a result of this experiment, it was confirmed that the adaptability to negative environments was increased by grafting the cut roses that are poorly adapted to the environment (Tables 1 and 2). Similar to our results, when grafting plants that have a good characteristic but are vulnerable to the environment, the quality and yield of cut roses can be improved by enhancing their adaptability to negative environments, such as high temperatures [29,30], low temperatures [31] and low light intensity [32]. According to previous reports on the advantage of grafting, the effect of grafting depends on the characteristics of the scion and root [11], and the characteristics of the rootstock are expressed differently on grafted cut roses depending on the type of scion [33]. In other words, in order to maximize the effect of grafting, it is very important to ensure mutual bonding between the scion and the rootstock. However, research reports on the quality characteristics of flowers of grafted cut roses are rare. Additionally, the degree of mutual bonding between the scion and the rootstock tends to vary depending on the cultivation environment's conditions.

PCA analysis was used not only to classify genetic resources for breeding through correlation analysis on various traits [24], but also to select breeds suitable for regions with different environmental conditions [34]. Therefore, in this study, we have confirmed using PCA analysis that the different effects of grafting depend on the cut rose varieties and rootstock types used during four seasons.

The PB variety showed the best growth in the autumn, when the light intensity was high and the average temperature was relatively low (Table 1, Figures 1 and 2A). In addition, growth was good even in winter, when both light intensity and temperature were low, but all growth was lowered in summer when the temperature was high. Therefore, the PB variety is considered to be a more adaptable variety in a low temperature environment. PB/N1 showed longer stems and more leaves than the PB scion in spring and winter (Figure 2A,C). The quality of cut flowers on PB/NA was improved compared to the PB scion in spring, autumn and winter, and the stems were especially long (Figures 2A,C,D and 6A). Additionally, PB/RI showed improved quality in spring, autumn, and winter compared to the PB scion, and in particular, the stem became longer and thicker.

The PS spray-type cut rose showed long stems and a lot of florets in spring and autumn, when the light intensity was high (Table 2, Figures 1 and 3A). However, the PS produced a large number of cut flowers in the summer when the temperature was high (Table 2, Figures 1 and 3B). This may be because the PS, a spray rose, belongs to the floribunda rose line, a garden rose that is adaptable to harsh environments [26,35].

The grafted PS showed a greater yield of cut flowers than the non-grafted PS (Table 2, Figure 6B). In particular, PS/RI showed a higher yield of cut flowers than the PS scion in all seasons (Table 2, Figure 5). PS/NA showed longer stems than the PS scion, and PS/RI gave thicker stems than the PS scion. PS/N1 gave more petals than the PS scion (Figure 6B).

In order to prevent the temperature inside the greenhouse from rising due to the high summer temperatures in Korea, shading is implemented as a general method of cultivation, which creates an unsuitably low light intensity condition for roses. Due to these summer growth environmental characteristics, cut flowers, such as PB scion grafted onto rootstocks, did not grow normally in the environment of high temperatures and low light intensity in summer. Similar to our results, it was reported that high temperatures and low light intensity inhibit the growth of roses [36].

It was confirmed that the growth and yield of grafted cut roses were different according to the type of scion and rootstock due to different environmental characteristics in the seasons, such as in winter, autumn and spring. In addition, it is known that the effect of grafting on the quality and yield of cut flowers differs due to the interactions of types and amounts of hormones, such as auxin, gibberelin, and cytokinen, produced at different levels depending on the type of scion and the rootstock [37–39]. Although it was not possible to analyze the hormones generated in the grafted roses in this experiment, it is known that gibberellin promotes stem elongation, auxin thickens stems, and cytokinin improves yield [40,41]. Based on the growth responses of grafted roses according to these hormones, it is judged that the grafting of cut roses, such as in scion/NA rootstock, promotes the production of gibberellins, increasing the adaptability to relatively high temperatures. In addition, it is considered that grafted cut rose, such as scion/RI rootstock, promote the production of gibberellins, auxins, and cytokinins, while improving their adaptability to relatively low temperatures.

Therefore, it is thought that the differences in the mutual bonding and grafting efficiency of scion and rootstock according to the season in our experiment are due to changes in the amounts of hormone secretion.

5. Conclusions

The conclusions on the grafting effect of the cut roses grafted onto three different rootstocks over four seasons are as follows: First, the quantity and yield of roses vary depending on the variety and the seasons, which showed changes in temperature and light intensity. Second, the grafting effect varies depending on the types of rootstock and the differences in cultivation environmental conditions. Third, cut roses grafted onto the *Rosa canina* cv. Natal brier (NA) showed improved stem lengths, with increased adaptability to relatively high temperatures, and the *Rosa indica* cv. Major (RI) showed improved stem lengths and stem diameters, with enhanced adaptability to relatively low temperatures. Finally, since the effect of grafting differs depending on the type of rootstock, it should be applied after properly considering the effects and the timing required by the variety.

Author Contributions: O.-H.K. contributed to the data analysis, original draft and writing, and to growing cut flower roses; H.-G.C. and W.-H.K. contributed to the design of experiments, conceptualization, data analysis, data curation, and writing. S.-J.K. grew cut flower roses. All the authors have read and agreed to the published version of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was carried out with the support of the "Cooperative Research Program for Agriculture Science & Technology Development (Project No. PJ01340801 and PJ01628201)", Rural Development Administration, Republic of Korea.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data generated in this study are available in the article.

Acknowledgments: We would like to express our thanks to the anonymous reviewers for their useful comments.

Conflicts of Interest: The authors declare no conflict of interest.

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