Market quality of late winter/early spring peony *Paeonia* after controlled dormancy: dummy regression modelling

Abstract

There is a shortage of herbaceous peony cut flowers in the world market in late winter/early spring. The quality of these prestige flowers, when cultivated in warm climate regions and stored in cooling chambers during dormancy, is influenced by pre-dormancy, dormancy, and post dormancy conditions. In this article, various regimes of peony dormancy with constant and variable temperatures were studied. Containers with plants of cv. 'Sarah Bernhardt' were exposed to a pre-dormancy temperature of 15°C and, after two weeks, transferred to cooling chambers in order to keep dormancy under four constant or diurnal temperature regimes. On three different dates, plants from each treatment were transferred to a greenhouse for release from dormancy and the beginning of sprouting. During commercial harvest, data on height and thickness of flower stems, number of harvested flowers per plant, and dates of harvested flowers were collected. Using these data, the index of market quality of peony flowers was defined and regressed on dummy variables that reflected chilling regimes and dormancy duration. Statistically significant differences in market quality were shown between the treatments with the lower storage temperatures 2^0C, 2-10^0C, and 2-15^0C, and the reference treatment with a storage temperature of 2 - 20^0C. Statistically significant differences were also shown between the treatments with the shorter storage period of 6 weeks, 4 days or of 8 weeks, on the one hand, and the reference treatment with the storage of 9 weeks, 3 days, on the other. Close results were obtained for the treatments with the constant temperature of 2^0C and with the diurnal alternating temperature of 2-10^0C. Therefore, growers can expect economic gains from saving energy during dormancy under a suitable temperature regime.

Key words peony; dormancy; cooling chambers; market quality; dummy regression

1. Introduction

1.1. Market for cut flowers

The world market for cut flowers has undergone substantial growth in the last few decades - by tens of percent in developed countries, and by tenfold in developing countries. In Europe, the value of the market for cut flowers has been $26 - 31 billion in recent years, or more than half of the world's cut flower production ([1], [2]). The global value of cut flower exports accounted for $17 billion in recent years [3]. In the fast growing economy of India, there has been tremendous growth in floriculture in terms of area, production and export. Cut flower production in this country increased by 138 times from 1993-94 to 2012-13 ([4], [5]). In China, the volume of export of cut flowers amounted to 16.1 billion units in 2015 [6]. For Kenya, Ecuador, and Ethiopia, countries that take the first three places in the supply of cut flowers from developing countries to the EU, the export value in recent years amounted to $760 million. In addition to cut flower farms, developing countries have built supply chains for transportation production, mainly, to the flower auctions in Europe [7].

1.2. Marketing of peonies. Production in countries with warmer climates

The growth in production and export of cut flowers was stimulated by an increased demand for prestigious cut flowers year-round due to the growth of globalization. Peonies belong to such prestigious flowers. Their prices in the Netherlands FloraHolland, the world largest flower auction, rose by 26% in 2009-2012. In this period, peony prices reached a level of 209% of the average flower price in this auction and occupied the 15-16th position among all cut flowers sold in this auction. Peony prices in Plantion, a market in the Netherlands that operates on a smaller scale than FloraHolland, also showed a tendency to increase in 2011-2013 ([8], [2]).

Because of the long period of cold temperatures needed for flower production, Paeonia spp. produced for the cut flower market are grown mostly in field production [9]. Growing peonies in countries with various climates allows the supplying of the flowers to the market during most of the year. Peonies are sold from April (supply from Southern France, other Southern Europe countries) to November-December when the flowers are supplied from countries from the southern hemisphere - Chile where peony is the most important ornamental flower exported from the country [10]. New Zealand has developed an efficient transport network producing highly perishable peonies in the South Island, getting them to Auckland and to overseas markets within 24 hours [11]. In Alaska peonies bloom from mid to late summer, July and August. Shortening the dormancy period is one of the advances that has led to indoor cultivation ([9], [12]). For subtropical climates, the molecular mechanism of bud dormancy in peonies was studied in the article of Zhang et al. [13]. They noted that bud dormancy is a crucial developmental process that allows peonies to survive unfavorable environmental conditions.

As a result of market studies, a high potential market for peony flowers in the international markets in early spring was recommended [14]. The high economic value of peony motivated agro-technical research aimed at filling this market niche in countries with warmer climates. At the experimental farm in Suwon, Korea (lat. 37° N), dormant rootstocks bloomed from late February to March, after being exposed to a temperature of 0ºC for 6 weeks from November 6 [15]. In Israel, the effects of chilling and subsequent growth conditions on peony development and flower quality were studied. The best chilling (constant temperatures) and subsequent growth conditions for peony cv. 'Sarah Bernhardt' determined in the article by Kamenetsky et al [16] enabled reducing the period between dormancy release and flowering to 53-54 days. One of the studied methods of growing peony in warmer climates was the forcing of dormancy in tunnels (plants grown in natural soil) or in chilling chambers (with plants grown in containers) under constant or diurnal temperature regimes ([17], [18]). Artificial cooling can also facilitate the management of crops with chilling requirements under conditions of climate warming. It was confirmed in the study of Ogundeji and Jordaan [19] on deciduous fruit.

1.3. Aims and stages of the study

As argued in the article of Cohen et al [25]: (1) in peony, internal mechanisms interconnect with chilling requirements for dormancy release; (2) chilling accumulation under diurnal fluctuations of natural soil temperatures might consist of two stages: the major one occurring under low soil temperatures at night, while the second stage responding positively to moderate higher day temperatures. The present article aims at modeling and examining statements (1) and (2) using agro-technical and phenology data for various dormancy regimes with constant and alternating temperatures, and of different duration. We estimated market quality of peony flowers for various dormancy regimes. The estimated 'quality' was used as a dependent variable in regression models. The new data obtained in this work were exploited for every studied peony plant and for four quality parameters of flowering: growth and thickness of flower stems, date of harvest, and number of flowers. Production variables like "number of flowers" have been used for various crops in regression models with explanatory climatic variables: for example, with air and soil temperature in the study of cotton [20]. Additional plant characteristics (growth and thickness of flower stems and date of harvest) important for market quality and valuation of peony are added to this production variable. Using these data, we calculate an index of peony market quality and develop a novel model of dummy regression of market quality on dormancy conditions and duration.

The model is estimated using the data for 96 flowering plants. The analysis of data obtained for treatments that differ only in their temperature regime – say, under constant low temperature throughout the day and under diurnal alternating temperatures that demand less electricity – might have a practical implication for farmers. Besides the new data obtained in this work, the novelty of this study lies in: (1) suggesting an index of market quality of peony flowers; (2) developing a dummy regression model of the influence of dormancy conditions on this index and interpreting the results of the model estimation in terms of the differences in market quality.

2. Materials and Methods

2.1. Data

For the treatments used in this study, rhizomes of *P. lactiflora* cv. 'Sarah Bernhardt' were planted in containers. On 4 October 2015, all containers were exposed to a pre-dormancy temperature of 15°C. After two weeks, on 18 October, the containers were divided into four equal groups and transferred to cooling chambers to keep dormancy under four different temperature regimes.

Treatment 1 was performed under a constant temperature of 2^{o}C throughout the day. Other temperature regimes were 2^{o}C for 16 hours, and 10^{o}C, 15^{o}C, or 20^{o}C during the other 8 hours on diurnal bases: treatments 2, 3, and 4, respectively. A similar experimental design was used in our previous article, [18] but in that study only data on stem length after dormancy break were available. The summary of the temperature regimes for various treatments of the current study is presented in Table 1.

Table 1. Temperatures and dates of the dormancy treatments.

Treatment	Begin pre-dormancy	Begin dormancy	Dormancy temperature	Transfer to greenhouse

			low, 16 hours	high, 8 hours	date 1	date 2	date 3
1	4-Oct-15	18-Oct-15	2^{o}C	2^{o}C	2-Dec-15	12-Dec-15	22-Dec-15
2	4-Oct-15	18-Oct-15	2^{o}C	10^{o}C	2-Dec-15	12-Dec-15	22-Dec-15
3	4-Oct-15	18-Oct-15	2^{o}C	15^{o}C	2-Dec-15	12-Dec-15	22-Dec-15
4	4-Oct-15	18-Oct-15	2^{o}C	20^{o}C	2-Dec-15	12-Dec-15	22-Dec-15

The containers stayed in cooling chambers for 46 days for transfer date 1, 56 days for date 2, and 66 days for date 3. For every treatment, air and soil temperatures in the chilling chambers were recorded every 10 minutes. For treatment 1 the temperature was constant at 2^{o}C. For other treatments the temperature changed during the day as is shown in Table 2.

Table 2. Excerpt from air temperatures (collected every 10 minutes) in chilling chambers during dormancy of peony.

Date and time	Treatment			
	1	2	3	4
12/15/15 12:00:00	2.0	2.6	6.1	7.8
12/15/15 12:10:00	2.0	2.6	6.0	7.7
12/15/15 12:20:00	2.0	2.5	6.0	7.5
…	…	…	…	…
12/16/15 12:00:00	2.0	2.4	5.7	8.7
12/16/15 12:10:00	2.0	2.4	5.7	8.5
12/16/15 12:20:00	2.0	2.3	5.7	8.3
…	…	…	…	…

Every day the temperature in the chilling chamber rose from the lowest value (2^{o}C) to the highest value. It was different for each one of treatments 2, 3, 4. Each time, the rise or decrease in temperature took 5-6 hours (Fig. 1).

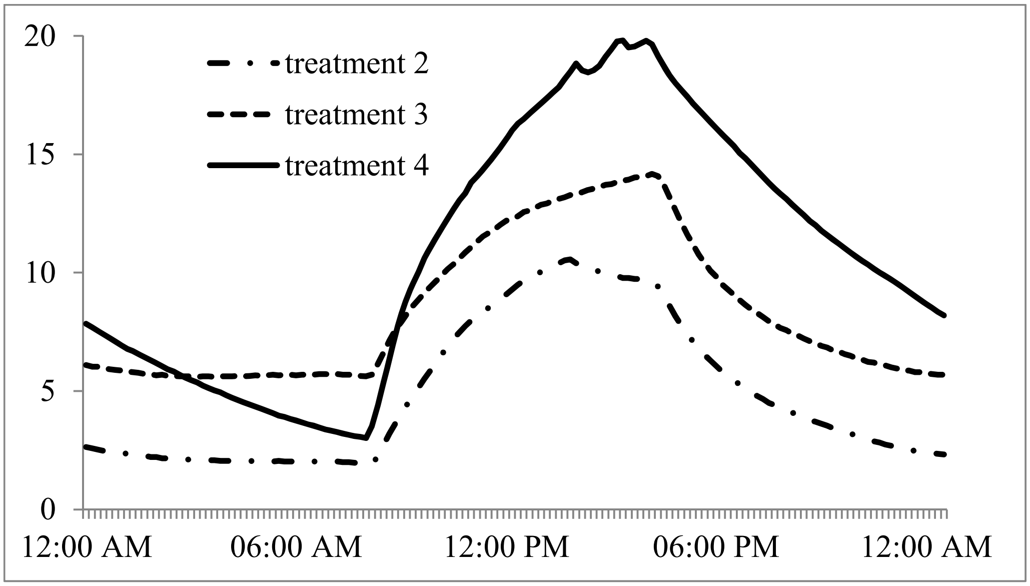

Fig. 1. Fluctuations of air temperatures in cooling chambers during dormancy of peony: example of one of the days of the chilling period.

On dates 1, 2, and 3 eight containers from each treatment were transferred to a greenhouse for release of dormancy and the beginning of sprouting. During the period of commercial harvest, from 22 February to 07 April, every day two phenology parameters of peony flowers were measured - height and thickness of flower stems. A total of more than 600 phenology measurements were made for 96 flowering plants. This was besides the number of harvested flowers and the dates the harvested flowers were collected for every plant.

2.2. Modelling market quality of flowers and contingency analysis

For modelling market quality, we used a method of dummy variables of the type Yes/No [21], which is widely used in regression analysis in various fields. These were used as determinants of dormancy conditions related to treatments, and the dates of dormancy release. For every one of four categories of treatments or three categories of dormancy release, the corresponding dummy variable received the value “1” if it belonged to this category or “0” if it did not. More specifically, the three variables of "belonging to a certain treatment" were defined as follows:

DTreatI - the plant from treatment I, 1(yes)/0(no), I = 1, 2, 3.

Treatment 4 served as a reference treatment for all of these variables: if all three DTreatI received value 0, it meant the considered plant was from treatment 4.

Similarly, the two variables of "belonging to a certain date of release of dormancy" were defined as follows:

DTrans1 - the plant transferred on date 1, 1(yes)/0(no),

DTrans2 - the plant transferred om date 2, 1(yes)/0(no).

Date 3 served as a reference date for these variables: if DTrans1 and DTrans2 received value 0, it meant that the considered plant was transferred on date 3.

The summary of the explanatory dummy variables of the model is shown in Table 3.

Table 3. Explanatory dummy variables of the regression model of market quality.

Characteristics	Value of explanatory variables				
of dormancy	DTreat1	DTreat2	DTreat3	DTrans1	DTrans2
Treatment					
1	1	0	0		
2	0	1	0		
3	0	0	1		
4	0	0	0		
Date of transfer					
1				1	0
2				0	1
3				0	0

In the regression model, the above described dummy variables were used to explain the dependent variable of market quality of harvested flowers. The variable of market quality was defined as an index composed of the following measures:

- date of harvest: a calendar date;
- growth stem rate: after transfer from cooling chambers until harvest of the flower, cm/day;
- thickness of a flower stem: thickening from level 1 (the least thick) to 3 (the thickest) after transfer from cooling chambers until harvest of the flower;
- flowers per plant: how many flowers were harvested for this specific plant.

For each of these four measures, all 301 harvested flowers, from 96 flowering plants, were ranked by increasing order, from 1 to 301. First place in this order meant the best result: the earliest harvest date, the highest growth rate, the highest thickness, or the largest number of flowers per plant. For every flower it was denoted:

I1 - rank by date of harvest;

I2 - rank by growth rate;

I3 - rank by thickness;

I4 - rank by number of flowers.

Then the dependent variable of the model - the index of market quality IMARKET - was defined as an average rank. Lower values of IMARKET indicate higher market quality of the flower. The following two versions of IMARKET were examined.

The simple average of the four ranks:

$$\text{IMARKET} = \text{AVERAGE}(I1, I2, I3, I4) \quad (1)$$

The weighted average of the four ranks:

$$\text{IMARKET} = 0.4*I1 + 0.25*I2 + 0.25*I3 + 0.1*I4 \quad (2)$$

The weights in (2) were determined using a survey of growers and specialists from agricultural research and extension stations in Israel related to the growth and export of peony cut flowers (an oral questionnaire at the annual meeting of growers was used). As follows from (2), the maximum weight was assigned to the date of harvest, and the minimum weight - to the number of flowers per plant.

The regression model of market quality of peony flowers is formulated as follows:

$$IMARKET = \alpha + \sum_{I=1}^{3} \beta_I \, DTreatI + \sum_{I=1}^{2} \gamma_I \, DTransI + u \qquad (3)$$

where $\alpha, \beta_I, \gamma_I$ are coefficients of the regression (3) sought , and u is the error term that satisfies the usual assumptions of a linear regression model. The coefficients β_I of the regression show the difference in IMARKET between treatments 1, 2, 3 and reference treatment 4, for the same date. The coefficients γ_I show the difference in IMARKET between the dates 1, 2 and the reference date 3, for the same treatment. Therefore, an estimation of the parameters of the regression model (3) enables concluding regarding the significance of these differences.

Before the regression modelling, a contingency analysis was performed between treatments and dates of transfer, on the one hand, and parameters of market quality of peony flowers, on the other. Statistical significance of the differences between treatments (for the same date of transfer) and between dates of transfer (for the same treatment) was assessed by two-sided t tests.

3. Results

All the calculations were made in Excel. The results of the contingency analysis between treatments and dates of release indicate that there were significant differences in the index of market quality IMARKET and physical representation of its measures between different treatments and durations of dormancy. These measures were described in Section 2.2: a harvest date (the number of days after 1st January was used), rate of growth and stem thickness, and the number of harvested flowers per flower. The differences were calculated for various treatments and duration of dormancy. For treatments 1 and 2, dormancy duration affected significantly (at a

5% level) the market quality of peony flowers: rows ‘treatment 1 IMARKET’ and ‘treatment 2 IMARKET’. For treatment 3 the differences in market quality between various dormancy periods were not significant: row ‘treatment 3 IMARKET’. For the same dormancy period, the differences between treatments 3 and 1, treatments 3 and 2 were significant at a 5% level. Close results were obtained for treatments 1 (constant temperature 2^{o}C) and 2 (diurnal alternating temperature: 2^{o}C during 16 hours, 10^{o}C during 8 hours) for every date of dormancy release in terms of IMARKET and most of its components. For each of the four measures of IMARKET, similar differences between treatments and dormancy duration were received (Table 4). In this table, the number of all harvested flowers for every pair treatment-date is presented. This number is the sample size used in the analysis of statistical significance.

Table 4. Contingency analysis of peony flowers market quality, for various treatments.

treatment and parameters of market quality	dormancy release		
	date 1	date 2	date 3
treatment 1			
days from 1 Jan - harvest	57	65	67
growth rate, cm/day	0.72	0.70	0.72
thickness	1.87	1.89	2.03
harvested flowers	31	36	37
harvested flowers per plant	3.9	4.5	4.6
IMARKET	94^{a}	135^{b}	175^{c}
treatment 2			
days from 1 Jan - harvest	59	62	69
growth rate, cm/day	0.65	0.71	0.70
thickness	1.86	2.06	1.90
harvested flowers	35	49	31
harvested flowers per plant	4.4	6.1	3.9
IMARKET	108^{a**}	135^{b**}	173^{c}
treatment 3			
days from 1 Jan - harvest	65	69	72
growth rate, cm/day	0.60	0.67	0.56
thickness	1.86	2.15	2.19
harvested flowers	22	27	27
harvested flowers per plant	2.8	3.4	3.4
IMARKET	$154^{a, b, c}$	$184^{a, b, c}$	$215^{a, b, c}$
treatment 4			
days from 1 Jan - harvest	94	96	65
growth rate, cm/day	0.23	0.42	0.74
thickness	1.00	1.00	2.00
harvested flowers	1	4	1
harvested flowers per plant	0.13	0.5	0.13
IMARKET	236	230	162

^{a,b,c} Means within dormancy release dates in a row with no common superscripts differ significantly ($P \leq 0.05$).

** ditto for $P \leq 0.1$.

Confidence intervals of the differences in market quality between treatments and dates of dormancy release, and the most proper specification of IMARKET were obtained using a regression model (3) (Table 5). For the estimation of this model's parameters the weighted IMARKET as defined in (2) was used. For this version of the model the received value of RSqr = 0.37 was greater than the value of RSqr = 0.28 for the version with IMARKET as defined in (1). The results from Table 5 again show that the differences between treatment 4 and other treatments, and date of transfer 3 and other dates of transfer are significant: this follows from the results in columns ‘influence …’ and ‘confidence interval’. This confirms the results from Table 4. All the regression coefficients are significant at a 95% level besides the coefficient DTreat3 for treatment 3. The latter coefficient is significant at 90% (not detailed in Table 5). Recall that for this treatment the differences from Table 4 in market quality between various dormancy durations were not significant. The results for treatments 1 and 2 are almost the same. The results for transfer dates 1 and 2 are considered significantly different from each other because their confidence intervals do not intersect.

Table 5. Results of the regression analysis (model 1)*.

explanatory variable	coefficient of regression (1)	influence on market quality improvement	confidence interval 95%
DTreat1	-85.0	positive	(-124, -46)
DTreat2	-81.7	positive	(-120, -43)
DTreat3	-36.1	positive	(-75, 3)
DTrans1	-68.5	positive	(-82, -55)
DTrans2	-36.0	positive	(-49, -23)

* $R^2 = 0.37$

4. Discussion and conclusion

4.1. Discussion

In this study the influence of dormancy regimes on market quality of late winter/early spring peony was examined using the suggested index of market quality of peony flowers.

The market quality index was regressed on dummy variables that reflected chilling temperatures and duration of the dormancy. Dates and duration of pre-dormancy and dormancy (Table 1) were chosen so that the dates of flower harvest fell in the main within the period of February through March when the supply of peony to the market is not sufficient: Table 4, rows 'days from 1 Jan - harvest'. To the best of our knowledge, in the published research on peony dormancy only single measures like the number or length of shoots, or the number of flowers, and other factors were analyzed after dormancy results, and only peony dormancy regimes with constant temperatures were studied (the exception being our previous article [18]). Despite the difference in the approach of modeling and statistical analysis, many of the results in the published research were found consistent with the results of our regression modelling of the index IMARKET (Table 5).

In one of the first studies, in which the question of how much chilling is required to break dormancy of peony was examined [22], the author received the first harvest of flowers in February-March after artificial cooling in Davis, California. Byrne et al. concluded that dormancy can be broken by storing dormant plants for a minimum of 4 weeks at 6^0C. Increasing the storage time to six weeks (in our study, from 6 weeks 4 days and more), or reducing the storage temperature to just above freezing (in our study the best results were obtained for constant 2^0C and for variable temperature 2^0C - 10^0C) increased the total number of shoots that grew after forcing (transferred to a greenhouse).

Returning to Table 4, rows ‘days from 1 Jan - harvest’, and to characteristics of the treatments from Table 1, the results can be detailed using the example of treatment 1. The period between transfer from cooling chambers and harvest is 86, 84, and 76 days for transfer dates 1 (46 days), 2 (56 days), and 3 (66 days in cooling chamber). But in terms of calendar dates of harvest (as is used in our approach of market quality in this study), the shorter storage time gains the advantage: 26 February, 6 March, and 8 March, respectively.

A similar experimental design - storage of dormant peony plants at different temperatures for different duration, and measuring various parameters of plant development in the post-dormancy period, with flowering in February-March - was employed in other research conducted in warmer climates. In the study of Iversen and Weiler [23] the results of peony growing and flowering (treatments on Long Island, USA) after storage at 4.5^0C and applying a daily photoperiod were compared. The difference in results for 6 and 12 weeks of chilling storage was non-significant for seven of eight studied parameters. In our study, the index of market quality was significantly better for: 1) transfer date 1 (6 weeks 4 days) compared to transfer date 2 (8 weeks), 2) both transfer dates 1 and 2 compared to transfer date 3: rows ‘DTrans1’, ‘DTrans2’, ‘DTrans3’ in Table 5. Similarly, in the research of three peony varieties ([24]; Palmerstone, New Zealand) the mean number of shoots and flowers increased as plants were subjected to colder chilling temperatures (1, 4, or 7^0C), or longer chilling periods (3, 6, 9, or 12 weeks). No significant differences were identified between treatments of 9 weeks or more, for all studied temperature regimes and varieties. Similar results were obtained by Rhie et al. ([15] in Suwon, Korea) for chilling temperatures 0, 5, or 10^0C regarding plant development parameters of percent of sprouting, number of shoots and flowers, and height during flowering. Under subtropical mild climatic conditions, results of dormancy release were found to be the best for chilling regimes of 2^0C (7 weeks 4 days) and 6^0C (10 weeks) when higher temperatures were less effective ([16].

4.2. Conclusions

The regression model of the peony flower market quality showed significant differences between the treatments with the lower storage temperatures 2^0C, 2-10^0C, and 2-15^0C, against the reference treatment with storage temperatures of 2 - 20^0C. The latter temperature was too high for successful storage of dormant plants as compared to the lower temperatures. Similarly, the model showed significant differences between treatments with the shorter storage duration of 6 weeks 4 days, and of 8 weeks, as opposed to the reference treatment (less successful regarding market quality) with a storage duration of 9 weeks 3 days. Data of the commercial harvest in February-March were used for the estimation of the model's parameters.

Very similar results between treatments with the constant temperature of 2^0C and with the diurnal alternating temperature 2-10^0C were obtained in our study. This is in line with the results of our previous article ([25]; obtained in northern Israel) for the same constant and alternating temperatures. In both studies dormancy under diurnal alternating temperatures provided practically the same results in terms of plant development and flower quality as those obtained for constant temperatures. The practical importance of these results lies in the economic gains that farmers can expect due to the saving of energy during dormancy in chilling chambers.

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