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SCIENTIFIC ARTICLE

Evaluation of open-pollinated offspring in *Cyclamen persicum* using vegetative phenology models in a primitive breeding population

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Abstract

Cyclamen is commercially cultivated to produce the pot and garden flowering plants by sowing the seeds, and the number of leaves is an important trait for the beginning of the initiations of flower buds and flowering. The yield potential is affected by the life cycle of a plant and the plant breeders can have good decisions making with the prediction of plant phenology. In this study, a polynomial function was proposed for modeling behavior of cyclamen offspring during the vegetative growth. This modeling is based on information on environmental changes and plant morphology up to the flowering stage. For this purpose, 30 pots (individuals) from a 121-individual population, which were the same in the size, were considered for sampling of data. The data were recorded as time series that include temperature (°C), relative humidity (%), leaf width (mm) and number of leaves. The output of this model is the number of leaves and the recorded inputs are the time (growth cycle; days), temperature, relative humidity and leaf width. Using the Quantum-behaved Particle Swarm Optimization (QPSO) algorithm, the constant coefficients of the proposed function (linear model) was calculated to match the input and output values to each other. To illustrate the robustness and efficiency of model, the growth rates of all individuals were compared using this proposed model. The result of root mean square error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2) between the estimated and observed values for each individual showed that 63% of the tested open-pollinated (OP) population is marketable. Therefore, phenology model could be a good estimation of the vigor of the OP population for commercial production. It should be noted that in obtaining the model, only five individuals were used randomly as training data, and the obtained model was fitted to the others as test dataset without changing the coefficients. Furthermore, a Gaussian model of the whole dataset showed that the OP seeds of cyclamen could be utilized to produce the potted flowering cyclamen without any worry about non-uniformity of harvest for the market if the optimum temperature would be adjusted.

Keywords: Primulaceae, flowering, growth rate, humidity, model, temperature.

Resumo

Avaliação da prole de polinização aberta em *Cyclamen persicum* usando modelos de fenologia vegetativa em uma população reprodutiva primitiva

O ciclâmen é cultivado comercialmente para produzir vasos e plantas com flores de jardim por semeadura, e o número de folhas é uma característica importante para o início do início dos botões florais e da floração. O potencial de rendimento é afetado pelo ciclo de vida da planta e os melhoristas de plantas podem tomar boas decisões com a previsão da fenologia vegetal. Neste estudo, uma função polinomial foi proposta para modelar o comportamento da progênie de ciclâmen durante o crescimento vegetativo. Esta modelagem é baseada em informações sobre mudanças ambientais e morfologia da planta até a fase de floração. Para tanto, foram considerados para amostragem de dados 30 vasos (indivíduos) de uma população de 121 indivíduos, de mesmo tamanho. Os dados foram registrados em séries temporais que incluem temperatura (°C), umidade relativa (%), largura da folha (mm) e número de folhas. A saída deste modelo é o número de folhas e as entradas registradas são o tempo (ciclo de crescimento; dias), temperatura, umidade relativa e largura da folha. Usando o algoritmo Quantum-behaved Particle Swarm Optimization (QPSO), os coeficientes constantes da função proposta (modelo linear) foram calculados para combinar os valores de entrada e saída entre si. Para ilustrar

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a robustez e eficiência do modelo, as taxas de crescimento de todos os indivíduos foram comparadas usando o modelo proposto. O resultado da raiz do erro quadrático médio (RMSE), erro absoluto médio (MAE) e coeficiente de determinação (R2) entre os valores estimados e observados para cada indivíduo mostrou que 63% da população testada de polinização aberta (OP) é comercializável. Portanto, o modelo fenológico pode ser uma boa estimativa do vigor da população OP para a produção comercial. Ressalta-se que na obtenção do modelo, apenas cinco indivíduos foram utilizados aleatoriamente como dados de treinamento, e o modelo obtido foi ajustado aos demais como conjunto de dados de teste, sem alteração dos coeficientes. Além disso, um modelo gaussiano de todo o conjunto de dados mostrou que as sementes OP de ciclâmen poderiam ser utilizadas para produzir o ciclâmen em flor em vaso sem qualquer preocupação com a não uniformidade da colheita para o mercado se a temperatura ideal fosse ajustada.

Palavras-chave: Primulaceae, floração, taxa de crescimento, umidade, modelagem, temperatura.

Introduction

The *Cyclamen* (Primulaceae) is a geophytes plant, with 22 species, is native to the Mediterranean region. *C. persicum* having various flower colors, patterns, and shapes, is one of the most popular flowering plants (Mizunoe and Ozaki, 2015). Breeding programs can be done by hybridization, radiation or gene transformation (Gaur et al., 2018). One of the major breeding programs in the world is through hybridization. Implementation of breeding programs through hybridization requires a rich genetic source with an appropriate population of parental plants. To get started, supplying a large size of parent populations will make very high costs for breeders. In the world, many farmers are producing new open-pollinated cultivars and hold old ones and these have been replaced by hybrid cultivars. The open-pollinated cultivars have usually fewer yields than hybrids, but are more suitable for medium- to low-input systems in agriculture. The genetic variability in OP cultivars is more, the high genetic variability the more adaptability as well as the farmer can develop its own seeds, reduce remarkably the costs of production. These properties make interesting the improved open-pollinated cultivars (Lana et al., 2017). Therefore, using open-pollinated (OP) varieties can be cost-effective to begin the genetic programs.

Plant models can be introduced as a helpful tool to evaluate the effects of various parameters, including climate, management conditions, on plant development and yield. Therefore, it can help to (a) recognize the best dates of planting, (b) determine the timing and concentration of fertilization, (c) aid precision agriculture, and (d) study potential effects of climate changes in plants (Lana et al., 2017). Usually, phenology models are applied with assuming no change in cultivar characteristics, but with environmental changes and sowing date to estimate a crop phenology. However, it can be said that the effects of cultivar changes can indirectly show the differences between the observed and simulated reactions in crop phenology (Rezaei et al., 2018). These same authors parameterized a phenology model with cultivar-specific information obtained in a two-year variety trial for historic and modern cultivars based on long-term records of plant responses of winter wheat in Germany. Temperature changes were reported as one of the possible factors of the changes in plant phenology, and the plant development affected by temperature and time as effective factors has been investigated for more than 300 years (Tonnang et al., 2018).

Phenology models are beneficial tools for targeting the germplasm to specific environments. It decreases the risk of crop losses and decisions making about the timing of fungicides (Coffi and Rossi, 2018), pesticides (Zaza et al., 2018), and fertilizers (Arora et al., 2007). Herndl (2008) stated that estimating the times of development has the importance to accurately model the morphogenesis and yield components in wheat. For modeling crop growth, understanding plant growth phases can help predict the physiological reactions and target the inputs to have maximum yield. Prediction of plant phenology is important for plant breeders because the yield potential is affected by the life cycle of a plant (Herndl, 2008). For example, this author stated that breeding cultivars of wheat must be adjusted for more appropriate dates in the specific environmental conditions and this can be performed based on phenological predictions.

The growth and development of plants are affected by climatic conditions. Three parameters are considered as climatic conditions, including rainfall, temperature, and relative humidity. Plants can have more available water in soil at high humidity and low temperatures. Relative humidity influences on water relations in plants and then plant growth. For example, rainfall, temperature and relative humidity affect stem diameter, plant height and leaf numwber in wild *Athrixia phylocoides* DC. (Tshikhudo et al., 2019). Plants display various responses to relative humidity, including rapid responses, developmental changes, and evolutionary adaptations (Grantz, 1990; Hirai et al., 2000).

The growth rate and the production of leaves in many plants are affected by temperature. Biologically, leaf emergence follows a Gaussian function by increasing temperature. Monitoring of leaf emergence can be a criterion for non-destructive measurement of plant growth and development. For instance, for scheduling Easter lilies to be in flowering, growers adjust the temperature to progress leaf development (Karlsson and Werner, 2001a), and the optimum temperature for cyclamen growth is 16-20 °C (Karlsson and Werner, 2001b; Rhie et al., 2006; Oh et al., 2008). Flower initiation in some plants is closely associated with the number of the developed leaves or specific physiological age. Furthermore, continuous flower production depends on leaf emergence (Karlsson and Werner, 2001b).

Single leaf photosynthesis in crops showed a little response to humidity (2.0-0.5 kPaVPD). An increase of photosynthetic rate could be observed with the enhancement of humidity in approximately whole plants. The transpiration cannot be always satisfied by the water uptake by plants during the low humidity before stomatal closure. This behavior has been reported in rice and barley. The effects of humidity on the leaf will affect the carbon assimilation. Based on a report, high humidity could enhance the leaf area dry weight, although the net assimilation rate was decreased. However, some crops may be affected by remarkably high humidity (less than 0.3 kPaVPD). For instance, the lower dry weight of plants grown in greenhouse at high humidity was reported in tomato (Grange and Hand, 1987). In another report about tomato, the growth of leaves was remarkably reduced in high humidity conditions (Holder and Cockshull, 1990) and in rice, high relative humidity had additive effect on growth (Hirai et al., 2000). That said, stomata respond to both temperature and humidity (Aphalo and Jarvis, 1991).

Between humidity and temperature effects on plant growth may be an interaction, for example, in the Pakchoi, growth of plants under high temperature correlates with relative humidity levels. In these plants, very high or low relative humidity remarkably would decrease net photosynthetic efficiency, dry weight, leaf area at high temperature. The optimum relative humidity was reported for this plant by 60% (Han et al., 2019).

Phenology models (development rate) are usually utilized to stimulate the timing of events of development in plants. Generally, a relationship is defined between the development rate and the target development time (e.g. flowering date or seed set) that could be routinely recorded from field studies. The most important step in this type of study is the selection of a thermal mathematical model to describe the developmental response to temperature in the target plants (Tonnang et al., 2018). To plan the marketing time of products and crops, we should able to predict developmental stages. A model describing the relations between plant development and some factors that affect it can also be utilized to select the different horticultural practices (Shafyii-Masouleh et al., 2010).

Cyclamen is commercially grown from seeds for producing the pot and garden flowering plants. The seeds used for flower or garden production are either F_1 hybrid. These seeds are naturally more expensive than open-pollinated seeds. Therefore, this work aimed to study the growth process of open-pollinated seeds of cyclamen plants using vegetative phenology model influenced by microclimate of temperature and relative humidity. These relationships help us decide whether to use the OP seeds instead of hybrids. The numbers of leaves are as an important trait for beginning the initiations of flower buds and flowering. Therefore, two important objectives that include a phenology model framework to stimulate exactly vegetative trait of cyclamen OP offspring, and finding the effect size of internal (genotype as leaf width) and external factors (temperature and humidity) affecting the growth variations have been aimed in the study.,

Materials and methods

The open-pollinated offspring (in two-leaf stage) of *C. persicum* were collected and transplanted into cup pots (pot size No. 10; 70 cocopeat: 30 perlite) at a polycarbonate greenhouse in 33.882738 °N, 50.480332 °E, Ornamental Plants Research Center, Mahallat, Markazi Province, Iran on 15 January 2019. The parents of these offspring were unknown (only 6 maternal plants in collecting plot). After producing 4 leaves; plants were transferred to pot No. 14 containing 70% cocopeat and 30% perlite. Fertilization was carried out for one month with 18-18-18 fertilizer (1 mg L^{-1}; 100 mL per pot). Plants were then irrigated with 20-20-20 fertilizer (1 mg L^{-1}; 100-200 mL per pot depending on plant needs and climatic conditions). Iron (Fe) chelated EDDHA (0.0002 mg L^{-1}) were added to the irrigation solution to prevent iron deficiency in plants biweekly

From 20 May 2019, 30 healthy plants were selected for data collection from the 121-individual population. Data were measured or recorded twice-weekly. This information included temperature (°C) and relative humidity (%) (measured by thermometer Beurer, Germany) for each pot (individual), leaf number and leaf width (mm; measured by digital caliper, Mitutoyo, CD-8″ CSX, Japan). After flower buds were observed in more than fifty percent of individuals, vegetative growth measurements were stopped; generally, plants were measured 21 times to flowering.

Plant phenology model was analyzed using MATLAB software, R2018b version to study growth phenology of individual of OP cyclamen affected by temperature (°C) and relative humidity (%). The figures were drawn with the Excel software (2010).

Assumptions

1. Relative humidity could be considered as the primary parameter influencing the development rate of cyclamen. Because, the relative humidity (%) affected dry weights, leaf numbers, flower numbers in most of the ornamental species (Mortensen 1986, 2000). Breeders can select the OP varieties of cyclamen that are insensitive to humidity, because this will be an advantage for greenhouses in arid and semi-arid climates.
2. It is assumed that if the optimum temperature is set for cyclamen OP varieties, timing market would not be a problem because of the diversity of OP varieties. Different hybrid cultivars produced leaves at the same rates in optimum same temperature (Karlsson and Werner, 2001b).
3. Open-pollinated offspring of cyclamen could have a uniform developmental cycle if were grown under optimum climates (especially temperature and relative humidity).
4. Leaf width as a genetic trait of OP varieties can be considered important in variation of growth and development.

Estimation of model parameters

The proposed function in this research is a polynomial of degree 3 (the cubic) with 22 constant values as follows:

$$y_O = x_1(\beta_1 + \beta_2 x_4 + \beta_3 x_2^2 + \beta_4 x_3^2 + \beta_5 x_4^2) + x_1^2(\beta_6 x_2 + \beta_7 x_3 + \beta_8 x_4) + x_2(\beta_9 + \beta_{10} x_1 + \beta_{11} x_3 + \beta_{12} x_4 + \beta_{13} x_3^2 + \beta_{14} x_4^2) + x_2^2(\beta_{15} x_3 + \beta_{16} x_4) + x_3(\beta_{17} x_1 + \beta_{18} x_4 + \beta_{19} + \beta_{20} x_4^2) + x_4(\beta_{21} x_3^2 + \beta_{22}) \quad [1]$$

Where, andareare the input and output (Overall y) of the model, respectively, and also represents constant coefficients of the model. These values are determined by the optimization calculations and the QPSO algorithm.

QPSO optimization algorithm

This algorithm, which is an advanced version of the Particle Swarm Optimization (PSO) algorithm, is based on the theory of particle aggregation and the laws of quantum mechanics and the steps of this algorithm as follows (Omkar et al., 2009):

$$X_{(t+1)} = P_i - \beta * (mBest - X_t) * \ln(l/u) \text{ if } k \geq 0.5 \quad [2]$$

$$X_{(t+1)} = P_i + \beta * (mBest - X_t) * \ln(l/u) \text{ if } k < 0.5 \quad [3]$$

Where,

$$P_i = \varphi * \rho\mathrm{Best_i} + (1 - \varphi) * \mathrm{gBest_i} \quad [4]$$

$$mBest = \frac{1}{N}\sum_{i=1}^{N} pBest_i \quad [5]$$

mBest (Mean Best position) is the mean of all the best positions of the population, k, u and φ are random number distributed uniformly on (0, 1) respectively. Considering that the number of replications and population size are common needs in every evolutionary algorithm, β, called Contraction–Expansion coefficient, is the only parameter in the QPSO algorithm. It can be tuned to control the convergence speed of the algorithms (Omkar et al., 2009; Yang et al., 2018). The results of the optimization are 22 constant values (β) that are presented in Table 1.

QPSO is very easy to be understood and implemented and it has already been tried and tested in various standard optimization problems with excellent results. Also, the QPSO algorithm is proven to be more effective than traditional algorithms mostly (Omkar et al., 2009).

Goodness of fit tests

Any single method does not exist to best evaluate the goodness of fit of an individual model to specific data (Tonnang et al., 2018). R^2 is a statistic that will provide some information about the goodness of fit of a model. In regression, the R^2 is named as the coefficient of determination that is a statistical criterion for understanding that the regression predictions how well to estimate the experimental data (real values) points. An R^2 of 1means goodness of fit tests. Values of R^2 outside the range 0 to 1 are when the model fits the data worse than a horizontal hyper plane. This would observe with choosing the wrong model or applying the nonsensical constraints. R^2 is the correlation coefficient obtained by the following expression:

$$R^2 = 1 - \frac{\sum(y - \hat{y})^2}{\sum(y - \bar{y})^2} \quad [6]$$

Where, is the observed median, y the observed mean and is the predicted value from the function.

Using RMSE (root mean square error) and MAE (mean absolute error), the performance of the regression models was evaluated (Mkhabela et al., 2016). The RMSE shows the weighted variations in residual (errors) between the estimated and observed values and was calculated as the following formula:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E_i - O_i)^2} \quad [7]$$

Where, the *n* is the number of observations, E_i is the estimated values during vegetative growth, and O_i is the observed values during vegetative growth. The MAE measures the weighted average magnitude of the absolute errors and was calculated as follows (Mkhabela et al., 2016):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|E_i - O_i| \quad [8]$$

The MAE is the most natural and unambiguous measure of average error magnitude. However, the RMSE is one of the most widely used error measures (Mkhabela et al., 2016).

Results and Discussion

Vegetative phenology model of genotypes (Genotype experiment)

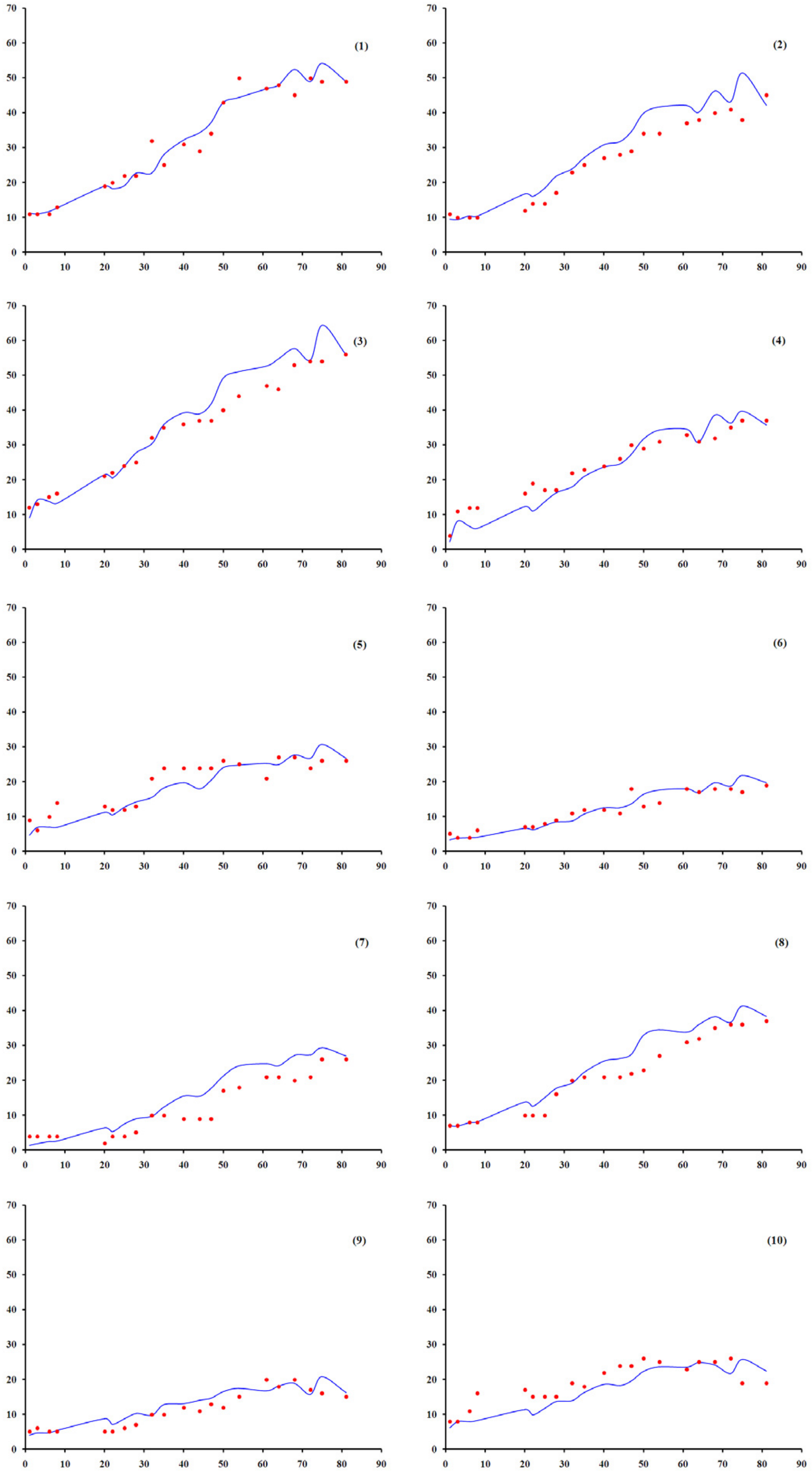
Among 30 individuals tested in a population of open-pollinated offspring (121 individuals) that were assumed to be distinct genotype due to differences in leaf shapes and patterns, a phenology model was trained based on five individual, including OP-1,2,3,4 and 21(combining genotype (leaf width index), temperature and relative humidity effects) and others were tested in this model. Finally, among 30 phenology models, the phenology models of 20 individuals that were alive and producing leaves over 81 days (21 times of data collection) were reported in Figure 1 (numbering 1 to 20 represents 20 different genotypes, i.e. OP -1-20.

In cyclamen, the average of leaves is an important factor for the flower bud emergence; therefore, leaf number was recorded as a target trait to estimate the uniformity of growth of an open-pollinated population by estimating the phenology model of each individual (offspring vigor) under a microclimate of temperature and relative humidity. Cyclamen seedlings must be sufficiently large for transplanting after 8 to 9 weeks from planting seeds and flower bud visible occurs after an additional 8 weeks. The temperatures of 14 to 16 °C are more suitable after visible bud. It is expected that cyclamens are in the flowering phase after 6 to 7 months from planting seeds (Karlsson and Werner, 2001a).

According to Figure 1, despite the variation in the number of leaves that can be observed in the open-pollinated offspring, however, out of 30 individuals, 20 genotypes (70% of the test population) were plants that had the ability to produce flowering plants for the market (they were healthy plants with optimum growth). This means that the variation in leaf number does not prevent the marketable of OP- seedlings of cyclamen and they will flower and will be ready to market. Therefore, given the reasonable price of OP seeds compared to hybrid seeds, using these seeds with 70% efficiency can be economical for the farmer after a cost-benefit analysis. Especially for a product that does not matter the color and shape uniformity, and only uniformity of production time is important to market a diverse product in terms of color and shape of leaf and flower and plant size, then OP-seeds would be suitable selections. Phenology models can be defined as important tools to predict, evaluate and understand the duration of crop growth under environmental conditions. Moreover, these simulation models can be used with future climate changes and future breeding targets (Tonnang et al., 2018).

According to Table 1, the models were able to predict plant phenology behavior well with high coefficients of determination (with R^2 above 70%) in 63% of the test population. Model accuracy in estimating plant growth vigor based on RMSE was high (between 110% and 630%) and it can be said that prediction of individual-to-individual behavior of genotypes based on leaf production (vegetative growth) has been successfully performed. Therefore, phenology model could be a good estimation of the vigor of the OP population for commercial production. The MAE parameter also confirms this viewpoint more accurately.

Different approaches, including statistical, mathematical and machine learning are usually utilized to promote the explanation of plant architecture, growth and development, and their interactions with the environment (Fisher and Lieth, 2000; Shafyii-Masouleh et al., 2010; Tonnang et al., 2018). Shafyii-Masouleh et al. (2010) modeled the effect of GA_{4+7} on the development of flower bud in lily cv. Menorca based on exponential models. Tonnang et al. (2018) stated that understanding the phenology of maize could help determine the crop adaption to a special region for being mature and setting seed within a growing season). Furthermore, it can help hybrid seed production by determining suitable planting dates of lines to ensure flowering synchrony. In addition, they explained that the accurate simulation of phonological development is basic to understand crop adaption and performance potential. Fisher and Lieth (2000) offered the exponential models for the effects of temperature on the growth and development of *Lilium* and they created a decision system as computer software for growers to predict and estimate flowering date to the Easter.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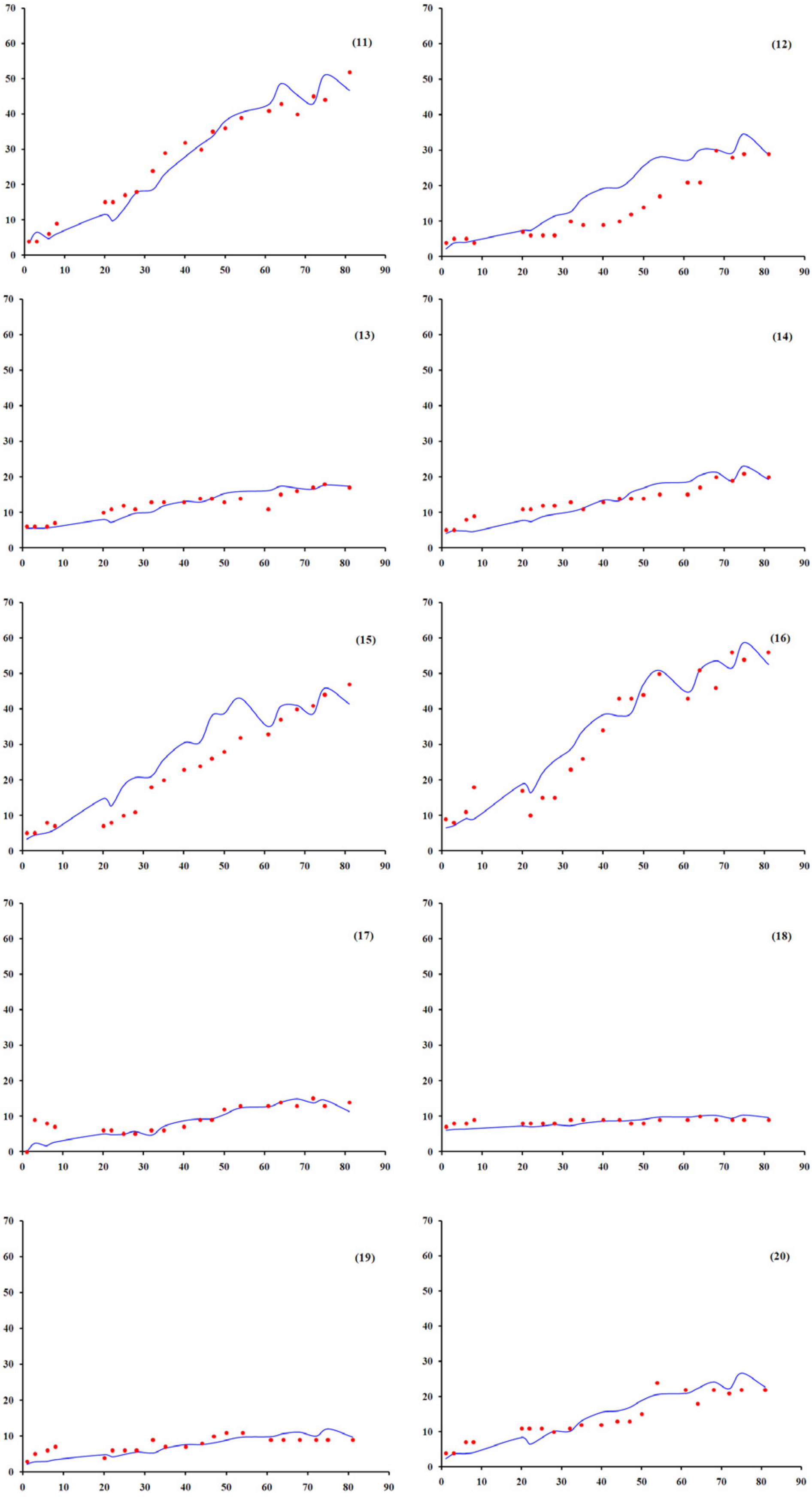

Figure 1. Phenology model of *Cyclamen* plant growth based on leaf number (vertical axis) on time (days; horizontal axis) in 20 individuals of 121-individual population of open-pollinated offsprings. The blue lines represent the estimated values (model data using effects of genotype, temperature and relative humidity) and the red circles are the observed values (experimental data, including effects of genotype, temperature and relative humidity).

Table 1. Estimated parameters of the model for 20 open-pollinated offspring of *Cyclamen* during vegetative phase.

Genotype	Temperature (°C)[a]	Relative humidity (%)[b]	R^2	MAE	RMSE
OP-1	30.9±3.22	37.24±5.15	0.9440	2.286	3.5318
OP-2	31±3.33	37.38±5.25	0.9405	3.862	4.8665
OP-3	31.07±3.42	38.05±5.21	0.9675	3.438	4.4364
OP-4	31.14±3.44	38.10±5.92	0.9522	2.920	3.5662
OP-5	31.25±3.57	37.29±5.50	0.8273	2.991	3.5862
OP-6	31.25±3.64	37.71±5.56	0.8940	1.487	2.0470
OP-7	31.36±3.71	37.57±5.25	0.9006	3.846	4.4669
OP-8	31.53±3.85	37.71±5.12	0.9487	3.137	4.0933
OP-9	29.68±2.03	37.86±6.62	0.8372	2.033	2.4588
OP-10	29.98±2.26	38.29±5.89	0.7444	3.295	3.9447
OP-11	29.88±2.18	37.81±5.48	0.9498	3.277	3.8360
OP-12	30.19±2.44	38.19±5.63	0.8201	4.780	6.2396
OP-13	30.23±2.39	37.90±5.82	0.7932	1.517	2.0368
OP-14	30.53±2.68	38.38±6.24	0.8722	2.110	2.4993
OP-15	30.41±2.88	38.52±5.80	0.8761	5.251	6.3566
OP-16	30.66±2.86	38.48±5.75	0.9153	4.439	5.2533
OP-17	28.89±1.76	36.43±8.09	0.7437	1.653	2.4735
OP-18	29.01±1.78	37.05±8.04	0.4433	0.960	1.1057
OP-19	29.23±1.83	37.38±8.08	0.6352	1.592	1.8863
OP-20	29.50±1.93	37.57±8.23	0.8763	2.463	2.8421

Constant values (β_{1-22})[c]

β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{11}
1.122	-0.065	-0.034	0.302	2.988	11.415	0.718	2.053	14.467	1.003	1.495
β_{12}	β_{13}	β_{14}	β_{15}	β_{16}	β_{17}	β_{18}	β_{19}	β_{20}	β_{21}	β_{22}
5.381	-0.238	1.666	7.070	1.203	3.196	1.424	0.951	0.922	1.375	4.896

[a] The average temperature ± SD (standard deviation) during the vegetative growth.

[b] The average of relative humidity ± SD during the vegetative growth.

[c] The constant values for all individuals are the same.

Contributions of genotype, temperature and relative humidity on cyclamen vegetative phenology (Combined analysis)

For a more accurate estimation of which environmental (temperature and humidity) and internal (genotype, i.e. leaf width index) factors influenced on plant behavior, and for a more accurate evaluation of the results of the phenology models in Figure 1, a combined analysis with fixing of one or two factors were performed. Then how to behave by genotypes were plotted as a trend line on the Gaussian model (it has not been reported here) (Figure 2). For combined analysis, the Gaussian model was used because the dataset was different toward primary dataset for the genotype phenology model (linear model). No standard method exists to select competing models or the modeling framework. The decision on a model selection should not be based on statistics alone, but a combination of statistics and scientist's experience and identifying a suitable model may present the best results (Tonnang et al., 2018).

According to Figure 2 and Table 2, it can be said that the best estimate and the fitted estimation to the observed data is the effect of temperature and relative humidity (38%), followed by temperature alone (36%) and then genotype and temperature (32%). Humidity alone had very little effect (2%) on cyclamen phenology behavior. Therefore, the OP cyclamen seeds can be safely introduced for commercial production of flowering pots by adjusting the greenhouse temperature conditions without facing the problem of uniformity of time production to market.

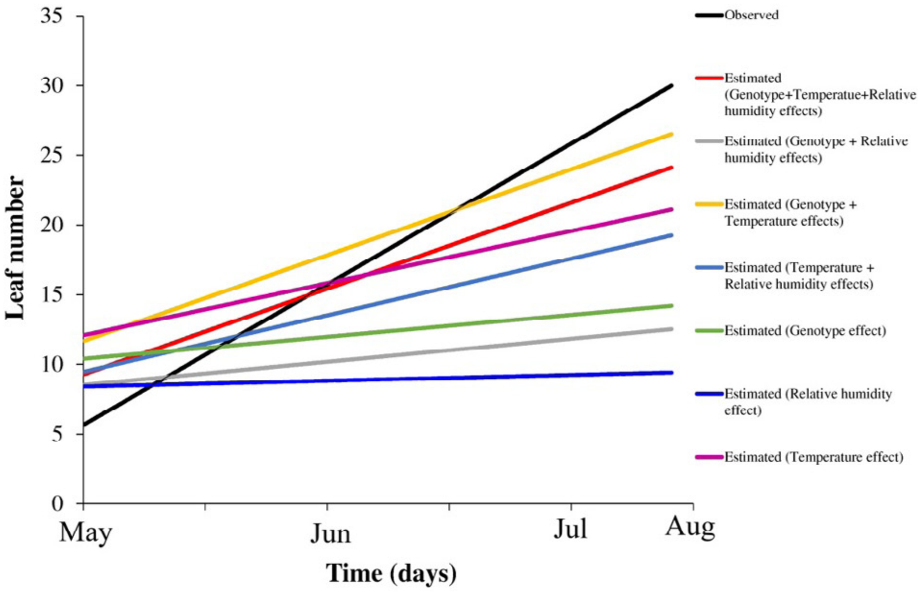

Figure 2. Combined analysis (trend analysis) of cyclamen vegetative phenology model with the fixed effects in separate analyses.

Cyclamen is an ornamental production that is produced in the winter and all growers and researchers are following to keep the optimum temperature (16-20 °C) by heating. They are looking for a substitute to compensate for the high cost of heating. This shows the importance of this environment factor to produce high quality potted cyclamen. For instance, this can be also observed in a report by Oh et al. (2008). They suggested increasing photoperiod (12 h) and daily light integral for compensation of low temperature or even promoting temperature effects. Rhie et al. (2006) stated that the optimum temperature for cyclamen growth and early flowering are 18-20 °C and 16-17 °C, respectively. They underlined the temperature as an important factor in winter greenhouse growing of potted cyclamen to flower in spring. They stated that the energy can be prepared even with long-day treatment replaced by heating. Karlsson and Werner (2001b) also studied the effects of temperature in *C. persicum* varieties, including Miracle Salmon and Miracle White. They reported that leaf canopy extended when the temperature increased from 8 to 20 °C in both cultivars. Oh et al. (2004) reported a greater number of leaves in cyclamen by increasing temperature and photosynthetic photon fluxes from 20/10 to 30/20 °C (day/night) and from 250 to 650 μmol m^{-2}. s^{-1}. Furthermore, the same report can be observed in the results of Kang et al. (2008). They also looked for the compensation for temperature by night interruption and cycling light for supplying energy for cyclamen under the low-temperature regime.

Table 2. Results of the trend of models in the combined analysis and coefficients of determination (R^2).

Model (Estimated)[*]	**Fixed variables**	**Trend line of model**	R^2
General model (Gen+Temp+RH effects)	-	y = 0.030x + 9.264	0.316
Gen + RH effects	Temp	y = 0.008x + 8.515	0.078
Gen + Temp effects	RH	y = 0.030x + 11.66	0.329
Temp + RH effects	Gen	y = 0.020x + 9.454	0.382
Gen effect	Tem + RH	y = 0.007x + 10.39	0.085
RH effect	Gen+ Temp	y = 0.002x + 8.399	0.023
Temp effect	Gen + RH	y = 0.018x + 12.07	0.367
Observed			
	Trend line function		R^2
	y = 0.050x + 5.630		0.330

[*] Gen, Temp and RH are the abbreviations of genotype, temperature and relative humidity, respectively.

According to Table 1, relative humidity promoted the temperature effects on cyclamen growth. That said, growth is typically decreased by low levels of humidity (Grantz, 1990). Therefore, temperature could be introduced during potted flowering cyclamen as the main factor and other factors could be having promoting effects on temperature. For example, good quality of potted cyclamens typically is evaluated based on a compact plant shape with short petioles. That reported, leaf petiole in cyclamen is elongated under endogenous bioactive GAs and low levels of photosynthetic photon flux (PPF) and high temperature. Good compactness of potted cyclamens in greenhouses produces with decreasing temperature and then increasing PPF (Oh et al., 2015).

Conclusions

Based on R^2 in the models, goodness of fit tests shows that interaction of temperature and RH % (38%) more that the temperature alone (36%), genotype × temperature (32%). Moreover, RH% has inconsiderable effect (2%) on cyclamen phenology model. In addition, model accuracy to estimate plant growth based on RMSE and MAE was high for prediction of individual-to-individual behavior of genotypes. Therefore, using phenology models in the OP population, we could show that the utilization of OP seeds of cyclamen would be safe for commercial production of potted cyclamen. It means that growers can produce about 70% uniform production for the market as timing as well as having variation and diversity of shape, pattern and color of leaves and flowers. Finally, it can be stated that the results approved assumptions 1, 2, and 3 of study and especially assumption 2. It means that temperature is the critical parameter (assumption 2), and relative humidity is a promoting parameter for temperature effect on the developmental rate of cyclamen plants (assumption 1), and if these two parameters will be optimum, different genotypes have uniform rate of growth and development (assumption 3).

Author Contribution

SSSM: performed the greenhouse experiments and recorded the data and wrote the paper and edited it and its integrity, **JJM**: performed the mathematical modeling and analyzed the data and wrote all mathematical subjects.

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