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Beta 함수 기반 기온에 따른 양파의 잎 수 증가 예측

이성은*, 문경환, 신민지, 김병혁
국립원예특작과학원 온난화대응농업연구소
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Estimation of Onion Leaf Appearance by Beta Distribution

Seong Eun Lee*, Kyung Hwan Moon, Min Ji Shin, Byeong Hyeok Kim
Research Institute of Climate Change and Agriculture, NIHHS, RDA
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ABSTRACT

Phenology determines the timing of crop development, and the timing of phenological events is strongly influenced by the temperature during the growing season. In process-based model, leaf area is simulated dynamically by coupling of morphology and phenology module. Therefore, the prediction of leaf appearance rate and final leaf number affects the performance of whole crop model. The dataset for the model equation was collected from SPAR chambers with five different temperature treatments. Beta distribution function (proposed by Yan and Hunt (1999)) was used for describing the leaf appearance rate as a function of temperature. The optimum temperature and the critical value were estimated to be 26.0°C and 35.3°C, respectively. For evaluation of the model, the accumulated number of onion leaves observed in a temperature gradient chamber was compared with model estimates. The model estimate is the result of accumulating the daily increase in the number of onion leaves obtained by inputting the daily mean temperature during the growing season into the temperature model. In this study, the coefficient of determination (R^2) and RMSE value of the model were 0.95 and 0.89, respectively.

***Key words*: Onion, Phenology, Temperature, Leaf development, Beta function**

I. Introduction

Onion is herbaceous biennial plant grown for its edible bulb, whose production in Korea is up to 22 thousand hectares with yields reaching up to 1.6 million tons in total as of year 2019 (MAFRA, 2020). Onion production is greatly affected by weather condition and the prices fluctuate according to crop situation, so it is necessary to develop an accurate yield forecasting method.

One of the earliest models modeling the effect of temperature on the rate of development was the growing degree days (GDD) model, which predicts the timing of phenological events by accumulating daily temperatures above the basal temperature and comparing them to predetermined thresholds. The GDD model was simple and easy to use, but as it did not accurately capture the observed plant

* Corresponding Author : Seong Eun Lee (pplm96@korea.kr)

responses, several variants of the model were proposed (Kim *et al*., 2019). In Korea, yield prediction depends on the ‘statistical method’ by multivariate analysis using meteorological factors highly correlated with crop yield, and ‘remote sensing method’ according to the relationship between aerial or satellite imagery and final yield. However, the existing empirical model does not properly reflect the effect of temperature on crop growth, so it is difficult to predict crop production under climate change conditions, and thus it is not practical for farmers. That is because the accumulation of different daily mean temperatures causes changes in the rate of leaf appearance, plant height, and leaf area (Tesfay *et al*., 2011).

The process-based model (PBM), which is a novel method for predicting future productivity in various climatic conditions by simulating plant responses based on the plant physiological processes, adopts phenology, morphology, biomass accumulation and partitioning modules as key components. Phenology is the study of periodic events in biological life cycles and how these are influenced by seasonal and interannual variations in climate. It provides a dimension of timing to the individual processes of leaf area increase, photosynthesis, carbon acquisition and distribution within the model (Hsiao *et al*., 2019).

Most crop models use LAI as a key feature to characterize the growth and development of crops (Ballesteros *et al*., 2014). As onion leaves are involved in the process of bulb initiation and development through photosynthetic carbohydrate accumulation and photoperiodic responses, the prediction of leaf appearance for estimating leaf area is an important part of phenological modeling. In addition, leaf number which preceded bulb development is closely related to final bulb size (Ikeda *et al*., 2019). Therefore, the model for estimating the leaf appearance rate and the final number of leaves is especially important, leaf area is simulated dynamically by coupling of morphology and phenology module in the PBM.

The aim of this study was to calculate the daily leaf increase as a function of temperature, and to create a model that predicts the number of onion leaves at a specific point in time as part of the phenology module which is a key component of the PBM.

II. Materials and Methods

2.1. Plant materials and data collection

Onion seedlings cv. ‘Sun Power’ were planted on November 16, 2020, in the SPAR chamber and temperature gradient chamber (TGC) in Research Institute of Climate Change and Agriculture at a density of 25 plants m^{-2}. An experiment was performed using a SPAR chamber to investigate the effect of temperature on the increase in the number of onion leaves. Five treatments including 10, 15, 20, 25, and 30°C were applied as daily mean temperature. The difference between daytime and nighttime temperatures (DIF) was kept constant at about 6°C. Onion plants were harvested randomly at one month intervals, and the number of appeared leaves, the leaves with visible leaf tip, was investigated until 150 days after planting. Based on the results, the development pattern according to the temperature treatment during the entire cultivation period was compared in order to calculate the daily leaf number increase. Then, the relative appearance rate of onion leaves according to temperature was calculated using TableCurve 2D program (ver. 4). Field data sets for model performance evaluation were collected from TGC experiments. The changes in the daily mean temperatures of the five regions were monitered with temperature sensors inside the TGC, and recorded using CR-1000 data logger (Fig. 1). Fertilizer application and pest management for onion cultivation were performed according to the Rural Development Administration standard management guideline.

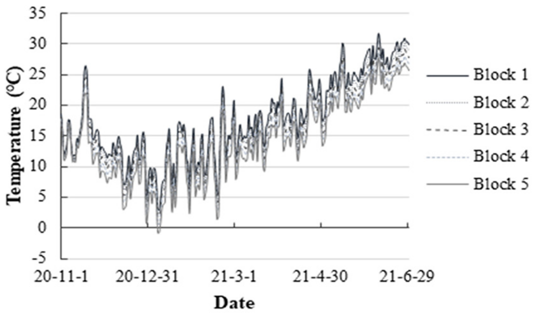

Fig. 1. Changes in daily mean temperature according to the distance from the entrance in temperature gradient chamber (33°28'06.6"N 126°31'03.8"E).

2.2. Parameterization, calibration and evaluation of the model

The percentage of leaf development over time was estimated by Equation 1 (Eq. 1). Where, d is the leaf development rate (%), x is the number of days after planting (days), and a means the number of days required to reach 50% of the maximum number of leaves.

$$d = \frac{1}{1+e^{-(x-a)/b}} \quad \text{(Eq. 1)}$$

Next, based on the results obtained from the SPAR chambers, three parameters, including optimum temperature (T_{opt}) and ceiling temperature (T_{max}), and the maximum growth rate described by leaf number increase (R_{max}), were estimated by applying the beta distribution function proposed by Yan and Hunt (1999). Where, r is the rate of daily leaf increase (Eq. 2).

$$r = R_{max}\left(\frac{T_{max}-T}{T_{max}-T_{opt}}\right)\left(\frac{T}{T_{opt}}\right)^{\frac{T_{opt}}{T_{max}-T_{opt}}} \quad \text{(Eq. 2)}$$

For the evaluation of the model, the estimated number of appeared leaves was calculated based on the daily mean temperature collected from each TGC block. Then, the estimated value was compared with the actual leaf number of onion plants grown in the TGC. The equation finally derived through calibration process is as follows (Eq. 3). Model performance was tested based on the coefficient of determination (r^2), and RMSE value using SAS statistical package (version 9.4, SAS Institute, Cary, NC). Where, N is the estimated leaf number, and i (or k) means the days after planting.

$$N = c\sum_{i=1}^{k}(r_i) \quad \text{(Eq. 3)}$$

Description and value of each parameter included in the model equation are summarized in Table 1.

III. Results and discussion

3.1. Leaf development and temperature effect on leaf appearance

Onion leaves are involved in the process of bulb initiation and development through photosynthetic carbohydrate accumulation and photoperiodic responses. The percentage of onion leaf development rate obtained from SPAR chamber with five different temperature treatments was presented in Figure 2. The growth pattern of onion bulb shows a classical

Table 1. Parameters of leaf number accumulation model in onion

Equation	Parameter	Description	Value
Eq. 1	a	required days to reach 50% of maximum leaf number	115
	b	constant	35.8
Eq. 2	R_{max}	maximum rate of leaf number accumulation	0.105
	T_{opt}	optimum temperature at R_{max}	26.0
	T_{max}	critical temperature for leaf number accumulation	35.3
Eq. 3	c	constant	0.218

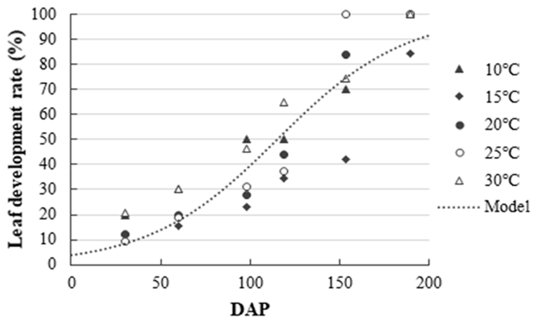

Fig. 2. Onion leaf development over time after planting. It shows a typical sigmoid curve regardless of the temperature treatment.

sigmoid curve, and bulb formation is well known to be influenced by photoperiod (Chope *et al*., 2012). The model (Eq. 1) estimated that it would take about 150 days to reach 75% of the final leaf number.

The prediction of leaf appearance rate for estimating leaf area is an important part of phenological modeling. Leaf number which preceded bulb development is closely related to final bulb size (Ikeda *et al*., 2019). The differences in air temperature induces variations in leaf number, plant height, leaf area (Tesfay *et al*., 2011). Yin and his colleagues have adopted the beta function as a nonlinear modeling approach to describe crop development as a function of temperature (Yin *et al*., 1995). Figure 3 describes the relationship between temperature and relative growth rate estimated by simplified form of the beta distribution function. The parameter values determined by the beta function showed that the increase in the number of onion leaves would be fastest at 26°C (R_{max}=0.105), and would be stopped at 35.3°C. This is largely consistent with the previous study of Brewster (1979) that reported that the relative growth rate and leaf area ratio of onion were greatest at 27°C, and a linear increase in relative growth rate (R_w) was observed between 10 and 19°C. In both experiments, R_w was lower than the maximum at 31°C (Brewster, 1979). Similarly, the greatest decrease occurs in onion yield due to both excessive temperature and frequent incidence of these temperatures (Kalbarczyk and Kalbarczyk, 2014).

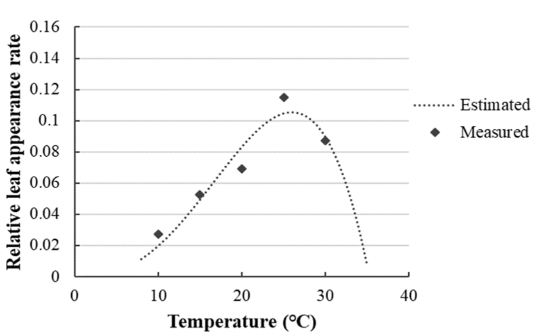

Fig. 3. Relative leaf accumulation rate in onion. Beta distribution function was used to describe the leaf appearance pattern depending on the temperature.

3.2. Evaluation of model performance

Figure 4 shows the comparison of the predicted value derived from the onion leaf appearance model with the observed leaf appearance in the TGC. While the initial model overestimated the number of appeared leaves, when 0.2175 was applied as a coefficient, the cumulative value of the daily leaf number increase calculated by the daily mean temperature provided a satisfactory prediction of the actual number of onion leaves. The calibrated model explained 95% of variability in leaf number data obtained from TGC experiment (R^2=0.95) with RMSE 0.89. Although the onion leaf appearance model developed in this study is based on the beta

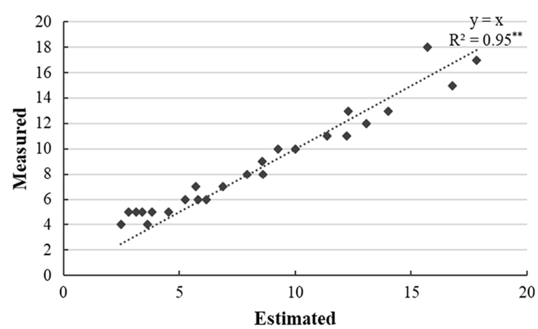

Fig. 4. Relationship between measured and estimated value for the increase in the number of leaves of ‘Sun Power’ onion grown in a temperature gradient chamber.

function, it is expected to provide a more accurate prediction by complementarily combining with other modules (eg. soil water and mineral nutrients) of the process-based model in a whole crop level.

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적 요

생물계절은 작물의 발달 시기를 결정하며, 생육기 온도에 의해 크게 영향을 받는다. 과정 기반 모델(PBM)에서 엽면적은 생물계절 및 형태 모듈의 결합에 의해 동적으로 시뮬레이션된다. 따라서 잎 발달 속도 또는 최종 잎 수의 예측은 전체 작물 모델의 성능에 영향을 주게 된다. 기온에 따른 잎 축적 속도 결정을 위한 데이터는 SPAR 챔버로부터 수집되었다. 온도의 함수로서 발달 속도를 설명하기 위해 베타 분포 함수(Yan and Hunt(1999)에 의해 제안됨)가 사용되었으며, 최적온도와 임계온도는 각각 26.0°C와 35.3°C로 추정되었다. 모델 추정치는 기온 모델에 생장기의 일평균 기온을 입력하여 얻은 양파 잎의 일별 증가량을 누적한 결과이며, 모델 평가를 위해 온도구배하우스에서 관찰된 양파 잎의 누적 개수를 모델 추정치와 비교하였다. 본 연구에서 잎 수 추정 모델의 결정계수(R^2)와 RMSE 값은 각각 0.95와 0.89였다.

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