Research article

Assessment of microclimate conditions under artificial shades in a ginseng field

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A B S T R A C T

Background: Knowledge on microclimate conditions under artificial shades in a ginseng field would facilitate climate-aware management of ginseng production.
Methods: Weather data were measured under the shade and outside the shade at two fields located in Gochang-gun and Jeongeup-si, Korea, in 2011 and 2012 seasons to assess temperature and humidity conditions under the shade. An empirical approach was developed and validated for the estimation of leaf wetness duration (LWD) using weather measurements outside the shade as inputs to the model.
Results: Air temperature and relative humidity were similar between under the shade and outside the shade. For example, temperature conditions favorable for ginseng growth, e.g., between 8°C and 27°C, occurred slightly less frequently in hours during night times under the shade (91%) than outside (92%). Humidity conditions favorable for development of a foliar disease, e.g., relative humidity > 70%, occurred slightly more frequently under the shade (84%) than outside (82%). Effectiveness of correction schemes to an empirical LWD model differed by rainfall conditions for the estimation of LWD under the shade using weather measurements outside the shade as inputs to the model. During dew eligible days, a correction scheme to an empirical LWD model was slightly effective (10%) in reducing estimation errors under the shade. However, another correction approach during rainfall eligible days reduced errors of LWD estimation by 17%.
Conclusion: Weather measurements outside the shade and LWD estimates derived from these measurements would be useful as inputs for decision support systems to predict ginseng growth and disease development.

1. Introduction

Panax ginseng Meyer is well grown under high levels of shade because it is adapted to shade conditions [1]. For example, the understory of a temperate forest is common habitat for wild ginseng. Artificial shades provide an ideal environment for growth of ginseng in a field.

The microclimate conditions of ginseng grown under shade structures would be different from those of other field crops. For example, most of direct beam solar radiation would be blocked by the shade, which would allow ginseng growth under a shade condition. Wind speed would be slower under the shade, which would limit evaporation of water droplets on leaves. These changes would create microclimate conditions favorable for the development of plant diseases [2,3] as well as ginseng growth. For example, yield of ginseng is often limited by outbreaks of foliar disease including *Alternaria panax* which causes considerable damage in ginseng production in Korea as well as North America [2].

Measurement of microclimate conditions under artificial shade would be helpful for the management of ginseng production because these conditions determine risks of foliar disease as well as growth of ginseng. Still, measurements of weather variables under the shade

would require considerable labor and cost for installation and maintenance of electrical sensors. Alternatively, weather data could be obtained from national weather services for management of crop. For example, Korea Meteorological Administration provides digital forecast data at a township scale, which is about 5 km of spatial resolution. However, these data represent weather conditions in an open field.

Little effort has been made to assess and to estimate microclimate conditions under the shade in a ginseng field for application of a decision support system to ginseng management. Because microclimate is considered altering by artificial shades in a ginseng field, it is essential to examine if weather data obtained outside the shade could represent microclimate conditions for ginseng management or not. Furthermore, a model to estimate microclimate conditions under the shade could be developed using knowledge on the relationship between under the shade and outside the shade. For example, reasonable estimates of leaf wetness duration (LWD) under the shade, which is an important factor for the development of foliar diseases, could be obtained using weather measurements outside the shade as inputs to an LWD model.

The objectives of this study were: (1) to assess microclimate conditions between under the shade and outside the shade in a ginseng field; and (2) to develop correction schemes for improving the estimation of LWD under the shade using an existing LWD model. Reliable microclimate data at a ginseng field would facilitate the operation of a decision support system for effective and timely ginseng management, e.g., yield prediction model or disease warning system.

2. Materials and Methods

2.1. Shade settings at experiment sites

Microclimate variables including temperature, humidity, and LWD were analyzed at two commercial ginseng fields located in Gochang-gun (N 35° 25′ 07′, E 126° 39′ 45′) and Jeongeup-si (N 35° 34′ 23′, E126° 46′ 28′), Jeollabuk-do, Korea. Four-yr-old and 5-yr-old ginsengs were growing at Jeongeup and Gochang, respectively. Shade structure was a rear line link type at both sites. Two types of shade netting, i.e., single and double netting, were used depending on site and season. The double shading net used at the Gochang site had a two-layer black polyethylene (P.E.) net on top of three-layer black and blue P.E. net throughout the growing season in 2011. At the end of season in 2011, the two-layer P.E. net was removed on May 19, 2012. Later, the two-layer P.E. net was installed again until the end of the 2012 season. At the Jeongeup site, a single shade netting of three-layer black and blue P.E. net was installed at the beginning of 2011 season. From May 19, 2011 onwards, a two-layer black P.E. net was added and used throughout the 2011 season at the same site. In 2012, double shading nets were used throughout the growing season at the Jeongeup site.

2.2. Measurement and analysis of microclimate variables

A set of sensors was deployed to measure air temperature, relative humidity (RH), precipitation, and wind speed in ginseng fields (Table 1). A pair of sensors was used to measure air temperature and RH under the shade and outside the shade. An anemometer was installed at 3 m high to measure wind speed outside the shade. In 2011, measurements of weather variables were averaged for 60 min. In 2012, those measurements were averaged for 30 min. Because of sensor malfunctions, temperature and humidity at Gochang in 2012 were measured only from a single set of sensors under the shade.

Unpainted flat panel sensors were used to detect occurrence of wetness under the shade. Because unpainted sensors tended to detect less wetness duration when small water droplets were formed on the

Table 1
List of sensors installed to assess microclimate in the ginseng field

Measurement type	Sensor
Air temperature and RH	HMP45, Vaisala, Helsinki, Finland
Wind speed	03001 wind sentry anemometer, Campbell Scientific, Logan, Utah, USA
Precipitation	TE525WS, Campbell Scientific, Logan, Utah, USA
Leaf wetness duration	Model 237, Campbell Scientific, Logan, Utah, USA
Data logger	CR10X, Campbell Scientific, Logan, Utah, USA

RH, relative humidity

sensors [4], a pair of wetness sensors was installed [5,6]. It was assumed that wetness occurred when wetness was detected by at least one sensor. Hours with wetness occurrence was classified to a "wet" hour. Remaining hours were identified as a "dry" hour.

To assess microclimate conditions altered by the shade, air temperature and RH measurements under the shade and outside the shade were compared. It was assumed that a temperature between 8°C and 27°C would represent a favorable condition for ginseng growth based on the Ecocrop database of the Food and Agriculture Organization (http://ecocrop.fao.org). Quayyum et al [7] reported that conidia of *A. panax* could geminate under temperature at 25°C and RH > 70%. Thus, it was assumed that RH > 70% would represent a humidity condition favorable for disease development. The frequencies of hours during which temperature and humidity conditions favorable for ginseng growth and disease development were met were compared between under the shade and outside the shade.

Occurrence of wetness on leaves would differ between days without rainfall, e.g., dew eligible days, and with rainfall, e.g., rainfall eligible days (Appendix 1). Daily data sets were classified into dew eligible days and rainfall eligible days depending on occurrence of rainfall (> 0.25 mm/d) to analyze LWD. Because wetness would occur readily during night time, time period from 12:00 PM to 11:59 AM the next day was used to assess LWD in a 24 h period. In addition, hours from 18:00 PM to 8:00 AM the next day were defined as a night-time period.

2.3. Correction schemes for a model to estimate LWD under the shade

The empirical model suggested by Kim et al [8] was used to estimate LWD under the shade in ginseng fields. It was reported that the empirical model based on a fuzzy logic system had greater spatial portability than other LWD models [9]. This empirical model depends on net radiation, vapor pressure deficit, and wind speed at a sensor surface, which are derived from air temperature, RH, and wind speed measured in an open field [8]. Outputs of the empirical model can be adjusted to a specific condition on occurrence of wetness [10,11]. For example, a correction factor of the empirical model has been used to improve LWD under semiarid climate conditions [12].

Lee et al [13] suggested that errors of the empirical model could be reduced under the shade when a correction scheme would be applied to the model (Appendix 1). A set of correction schemes for the empirical model were applied to take into account microclimate conditions under the shade in estimation of LWD. Kim et al [14] suggested that the empirical model could be adjusted to unpainted sensors as follows:

$$F_U = f_U \cdot F \tag{1}$$

where F_U represents the corrected estimates of wetness occurrence to output value, F, of the empirical model for unpainted sensors. The

correction factor, f_U, for unpainted sensors were calculated as follows [15]:

$$f_U = 0.95 + \beta \cdot C_{RH} \qquad (2)$$

where C_{RH} represents humidity effect on wetness estimation using an unpainted sensor. β represents the adjustment coefficient for C_{RH}. The value of C_{RH} is determined using RH as follows [10]:

$$C_{RH} = \left[max\left\{ 0.0, \frac{RH - \gamma}{100 - \gamma} \right\} \right]^2 \qquad (3)$$

where γ indicates the threshold of RH. The values of β and γ were 0.05 and 80%, respectively [9]. When RH is $> 80\%$, f_U becomes close to 1, which results in similar outcomes of the original model. Otherwise, the outcomes of the unpainted sensor correction to empirical (F_{dew}) model are $\sim$95% of the original model outcomes. The F_{dew} model was used for dew eligible days without going through a calibration process because this correction scheme has been reported in a previous study [14].

A new correction scheme to the empirical model was developed for rainfall eligible days. During rainfall, rain drops deposited on a leaf through the shade could cause estimation errors of LWD by the model. Under strong wind speed conditions, rain drops would penetrate through the shade. Such a rain drop on a leaf surface does not result from the energy exchange between a leaf surface and the atmosphere, which would result in underestimation error of the original model. To take into account the effect of wind under the shade, the correction factor for false negative estimates of the original model on rainfall eligible days, f_{R-} was defined as follows:

$$f_{R-} = 1 + \rho \cdot (1 - \mu_{SLOW}) \qquad (4)$$

where ρ indicates the coefficients of f_{R-}. The membership function, μ_{SLOW}, used for the empirical model was used to quantify the degree of "slow" wind speed. μ_{SLOW} was calculated as follows [8]:

$$\mu_{SLOW}(w) = \begin{cases} 1 - 2*\left(\frac{w}{3.5}\right)^2 & for\ w < 1.725 \\ 2*\left(\frac{w}{3.5}\right)^2 & for\ w \leq 3.5 \\ 0 & for\ w > 3.5 \end{cases} \qquad (5)$$

where w indicates wind speed (m/s) at a given hour.

Another correction scheme for false alarm estimates of the empirical model on rainfall eligible days, f_{R+}, was developed using RH and wind speed. The fate of rain drops remaining on ginseng leaves would depend on microclimate conditions altered by the shade. As humid and calm conditions would be created more easily under the shade, evaporation of free water on the leaf would be restricted even during daytime in a ginseng field. As a result, the original model would overestimate LWD under such a condition because it was developed for an open field condition. Based on Eq. (2), f_{R+} was defined to adjust the outcome of the original model to such a condition as follows:

$$f_{R+} = 0.95 + \beta \cdot [\tau \cdot C_{RH} + (1 - \tau) \cdot \mu_{SLOW}] \qquad (6)$$

where τ represents the relative effect of humidity on overestimation error by the original model.

The correction factor for rainfall eligible days, f_R, was defined as follows:

$$f_R = \begin{cases} f_{R-} & F < 0.5 \\ f_{R+} & F \geq 0.5 \end{cases} \qquad (7)$$
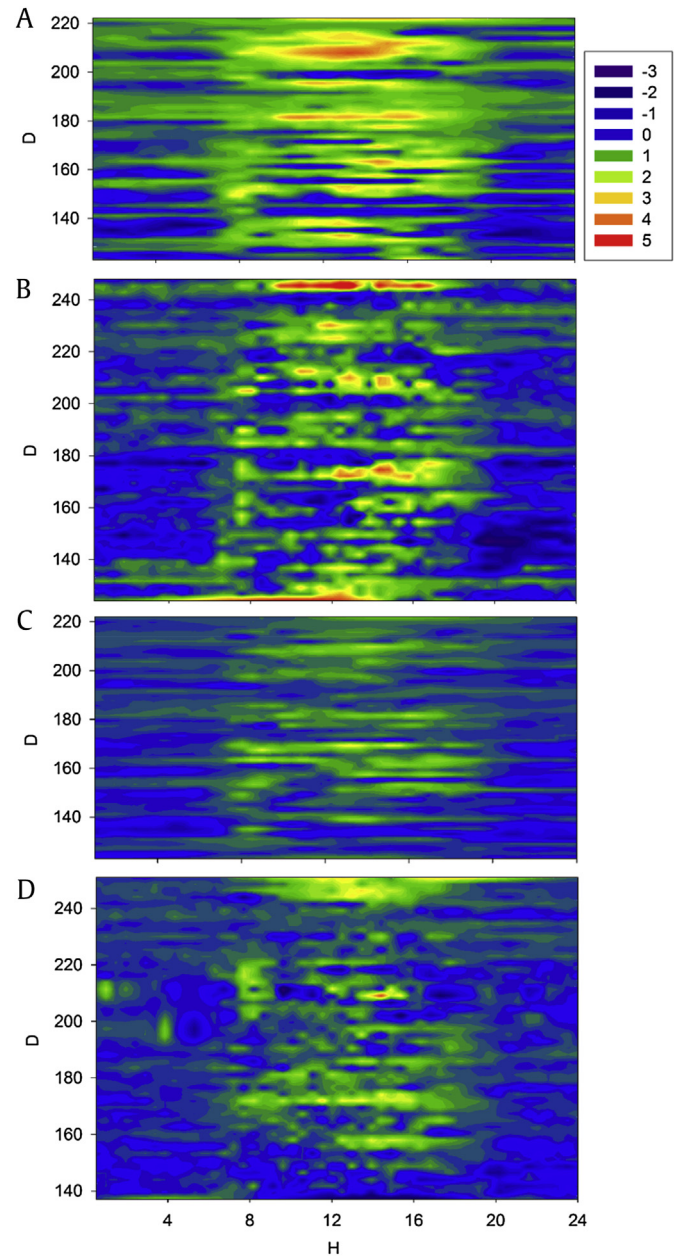

Fig. 1. Difference of temperature (°C). Temperature difference between (A) under the shade and (B) outside the shade at Gochang and (C) under the shade and (D) outside the shade at Jeongeup in (A and C) 2011 and (B and D) 2012. X and Y axes represent hour and day and on which temperature under and outside shade was measured, respectively. Positive value of temperature difference represents events such that temperature under the shade was greater than that outside the shade.

The corrected value, F_R, to the outcome of the empirical (F_{rain}) model during rainfall eligible days was defined as follows:

$$F_R = f_R \cdot F. \qquad (8)$$

The value < 0.5 of F_R represented the absence of wetness; otherwise, the presence of wetness was estimated. The value of f_R was determined using daily rainfall data rather than hourly data. This allowed the minimum use of rainfall data, which is an indication of rainfall on a given day. Furthermore, rain drops under the shade could last longer than the duration of rainfall. Thus, the use of hourly rainfall data would require a correction term that embodies energy balance equation, which would add considerable complexity.
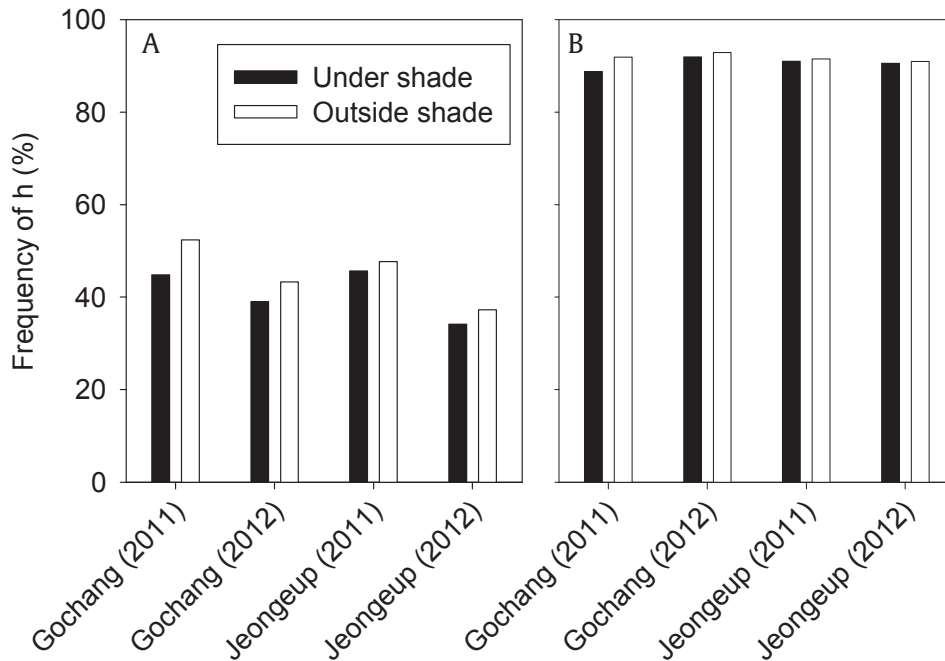
Fig. 2. Frequency of hours during which temperature conditions were favorable for ginseng growth. (A) Daytime and (B) Night time. It was assumed that favorable conditions for ginseng growth occurred at hours when temperatures between 8°C and 27 were measured. Each bar represents the fraction of hours at which criteria for favorable temperature conditions were met during the study period in a year at given sites.

The values of ρ and τ were determined using the simplex algorithm suggested by Nelder and Mead [15]. Twenty-four-hour periods of rainfall eligible days were subject to random sampling. The calibration set consisted of 40% of the periods for each site-year. The remaining data on rainfall eligible days were used for validation. The values of ρ and τ were adjusted to minimize mean values of mean absolute error (MAE) in LWD estimation for 10 random subsets of calibration data. The values of ρ and τ were determined by day- and nighttime because the effect of rainfall on wetness occurrence under the shade would differ by availability of solar radiation. Because the simplex algorithm is one of a local optimization method, the final value of ρ and τ would be dependent on the initial values of these parameters. Thus, simplex search was performed for 1,000 times with the initial values of ρ and τ that were selected randomly at each time. R, which is an open source statistical package (https://www.r-project.org/), was used to determine the values of ρ and τ using the simplex algorithm.

To indicate the tendency of error, e.g., over- or underestimation of LWD, mean error was determined as the average of difference between measurements and estimates of LWD during each 24-h period. To represent overall error, MAE was also calculated by averaging the absolute values of estimation errors during the 24-h period. Errors of the original model were compared with that of corrected models by dew eligible days and rainfall eligible days.

3. Results

3.1. Temperature and humidity conditions under an artificial shade

Overall, temperature under the shade tended to be warmer than that outside the shade (Fig. 1). In early seasons, the average change of temperature by the shade was relatively small. In the middle of growing season, e.g., from June to August, however, temperature increases under the shade became more evident. For example, hourly average difference of temperature between

under and outside the shade was 0.02°C and 0.51°C in May and July, respectively.

The effect of shade netting on temperature change differed by day and night (Fig. 1). During night times, temperature difference between under the shade and outside the shade was less pronounced. On average, the difference of temperature between under the shade and outside the shade ranged from 0.1°C to 0.4°C by site-years. During daytimes, average warming effect of the shade ranged from 0.4°C to 1.2°C, which was slightly greater than during night.

The temperature conditions favorable for ginseng growth occurred slightly less frequently under the shade than outside (Fig. 2). For example, temperature ranged from 8°C to 27°C occurred for about 90% of hours during night under the shade. However, the same range of temperature was recorded for about 91% of hours during the night outside the shade. During daytime, hours during which temperature ranged from 8°C to 27°C occurred for about 42% and 46% of time periods under the shade and outside the shade, respectively.

Humidity tended to be higher under the shade than outside (Fig. 3). On average, RH was 4% higher under the shade than outside in the early season, e.g., May. In the middle of growing season, however, an increase of RH under the shade occurred less frequently. Occasionally, RH under the shade was lower than that outside the shade during the period.

Humidity conditions favorable for outbreaks of a ginseng foliar disease occurred slightly more frequently under the shade than outside (Fig. 4). For example, the number of hours with RH > 70% under the shade accounted for about 84% of night time periods. Hours with RH > 70% occurred outside the shade for 82% of time periods during night. During daytime, the frequency of hours with RH > 70% was similar between under (31%) and outside the shade (29%).

3.2. Estimation of LWD under the shade using correction factors

During dew eligible days, errors of the corrected (F_{dew}) model were slightly less than those of the original (F_{org}) model developed for an

open field (Table 2). For example, the F_{dew} model and the F_{org} model had the MAE of 2.3 h/d and 3.3 h/d at Jeongeup site during dew eligible days. The MAE of the F_{dew} model was relatively small in 2012 (2.8 h/d) at Gochang site. At Gochang site in 2011, however, the F_{dew} model had considerably larger MAE (4.3 h/d) than the F_{org} model did (3.5 h/d).

When the values of ρ and τ were 0.112 and 0.169, and 0.067 and 0.400, for daylight hours and night times, respectively, the least magnitude of MAE in LWD estimation was obtained for data sets on rainfall eligible days with 3.5 h/d. The corrected (F_{rain}) model for rainfall eligible days reduced relatively more errors than the F_{dew} model did during dew eligible days (Table 3). For example, the MAE of the F_{dew} model increased by 8% at Gochang whereas it decreased by 30% at Jeongeup compared with the F_{org} model. By contrast, the

F_{rain} model reduced the MAE by 33% and 14% at Gochang and Jeongeup in comparison with the F_{org} model although the MAE of the F_{rain} model was slightly greater (4%) than that of the F_{org} model at Jeongeup in 2012.

4. Discussion

Our results indicated that measurements of temperature and humidity outside the shade, and estimates of LWD using these measurements would represent microclimate conditions for ginseng growth and disease development with reasonable accuracy. Thus, it would be practical to operate a decision support system for ginseng management using weather data available for an open field rather than measurements of microclimate variables under the shade. Because weather data in an open field would be available from different sources, e.g., nearby weather stations or site-specific estimation, these data would be useful for effective management of ginseng under given microclimate conditions.

It appeared that temperatures measured outside the shade would be helpful to represent temperature conditions for ginseng growth. For example, the frequency of hours during which the temperature was favorable for ginseng growth differed by about 1% between under and outside the shade during night times. Yu et al [16] reported that root biomass and ginsenocide production tended to be high under a dark condition, which suggested that ginseng growth would be affected by temperature conditions during night time considerably. Because temperature conditions between under and outside the shade were similar during the night, temperature measurements outside the shade would be useful to estimate root growth and ginsenocide production.

The difference of humidity conditions between under the shade and outside the shade was considerably small, which suggested that humidity measurements outside the shade would be helpful to represent humidity conditions for disease development under the shade. For example, hours with RH > 70% occurred slightly more frequently (by 2%) under the shade than outside. Nevertheless, the difference in both temperature and humidity conditions between under and outside the shade become relatively large occasionally. In such cases, it would be difficult to predict the risk of disease outbreak reliably using weather data measured outside the shade. Thus, it would be worthwhile to examine site-year variation in differences of microclimate conditions between under and outside the shade in further studies, which would help assessment of microclimate conditions favorable for disease development using an empirical approach.

Application of correction schemes to the empirical LWD model based on a fuzzy logic system was effective especially during rainfall eligible days. For example, the magnitude of MAE decreased by 33% at Gochang in 2011 after the correction scheme for rainfall eligible days was applied to the original model. The corrected model for dew eligible days reduced the MAE of LWD estimation by 10% on average. However, the correction scheme caused more errors in LWD estimation at Gochang in 2011 and Jeoungeup in 2012, which suggested that further studies would be merited to assess spatial portability of correction approaches.

It appeared that effectiveness of the correction scheme was associated with rainfall conditions for both dew eligible days and rainfall eligible days. The correction scheme for rainfall eligible days was less effective when rainfall contributed relatively small portion of LWD in a season, e.g., in terms of rainfall frequency and periods of LWD during rainfall eligible days. For example, the corrected model had a slightly higher error in LWD estimation at Jeongeup in 2012 than the original model; although the difference between corrected and original model was about 4%. However, the correction scheme for dew eligible days was more effective at sites where LWD would
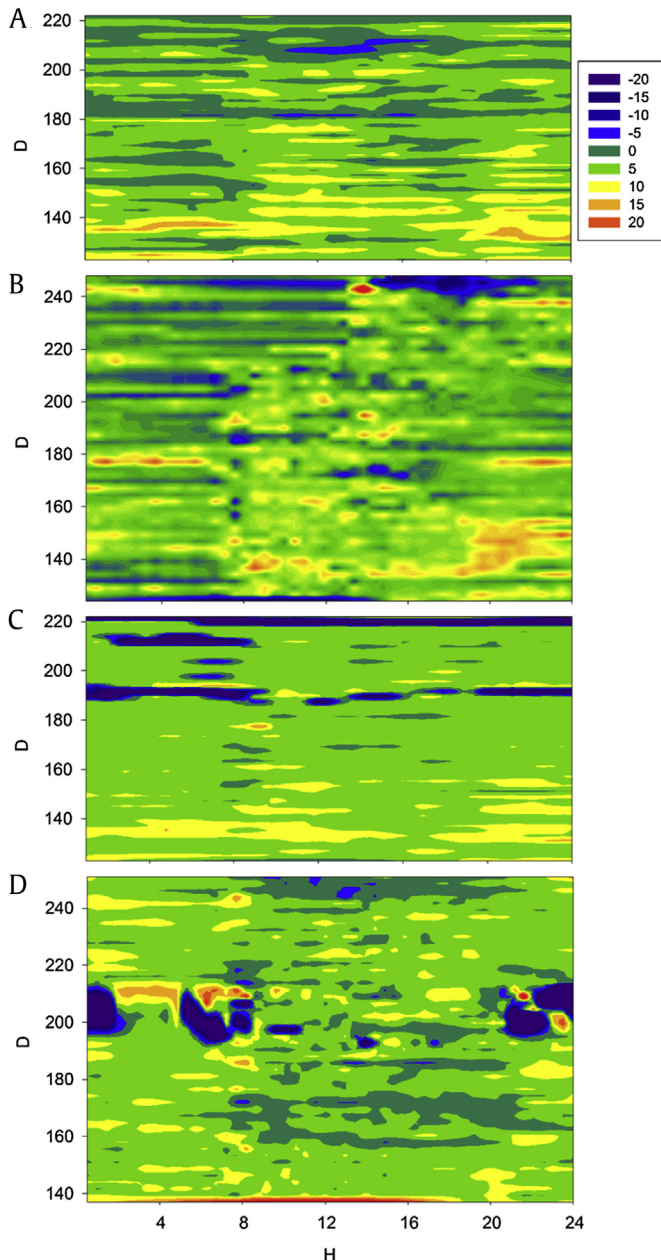

Fig. 3. Difference of relative humidity (%). Relative humidity differences between (A) under and (B) outside the shade at Gochang and (C) under and (D) outside the shade Jeongeup in (A and C) 2011 and (B and D) 2012. X and Y axes represent hour and day and on which relative humidity under and outside shade was measured, respectively. Negative value of humidity difference represents events such that humidity under the shade was lower than that outside the shade.
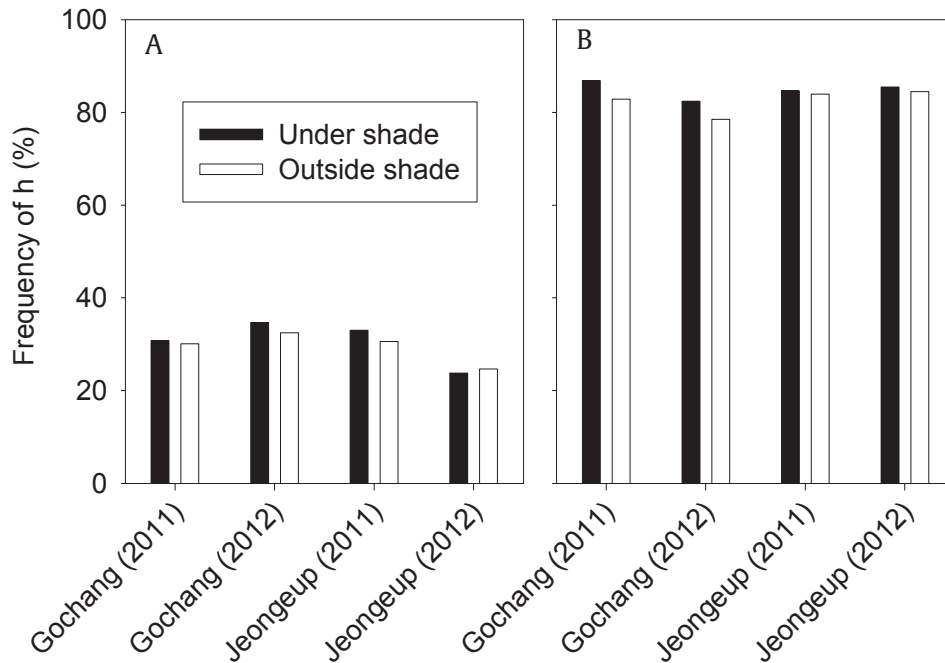
Fig. 4. Frequency of hours during which humidity conditions were favorable for disease development. (A) Daytime and (B) night time. It was assumed that favorable conditions for ginseng disease development occurred at hours when relative humidity > 70% was measured. Each bar represents the fraction of hours at which criteria for favorable humidity conditions were met during the study period in a year at given sites.

be relatively short during rainfall eligible days. For example, duration of wetness during rainfall eligible days explained about 93% of variation in LWD estimation error using the corrected model for dew eligible days ($p = 0.03$).

Management of ginseng would benefit from ginseng growth models that uses weather data obtained from outside the shade. For example, Souther and McGraw [11] used a stochastic model to project the effect of harvest and climate change on extinction risk of wild-harvested ginseng using climate data in an open field. A mechanistic model of ginseng growth could simulate characteristics of ginseng canopy, e.g., leaf temperature, based on energy balance between soil, crop canopy, and atmosphere using weather measurements outside the shade as inputs to the model.

Because thermal and optical properties of materials and setting could be parameterized to the mechanistic model, the impact of artificial shade on microclimate under the shade could be simulated for identification of the optimal materials and settings under given climate conditions. It seemed that temperature and humidity change by the shade would be affected by the number of shade

nettings. For example, less temperature change and greater humidity change were recorded in May during which a single layer of shade netting was installed for about 20 days. Using the mechanistic model that simulates energy exchange between soil, shade in a ginseng field, and atmosphere, it would be possible to estimate canopy temperature under given climate conditions [17]. Such estimates would be useful for determining the preferred settings for artificial shades, e.g., the number of layers and materials of shades.

Disease warning systems often depends on wetness duration and air temperature as input variables [5,18−21]. Because temperature was relatively similar between under the shade and outside the shade, errors of LWD estimates would affect reliability of a decision support system for disease risk management. Although a large error of LWD estimation occurred during rainfall eligible days, the correction scheme to the LWD model could minimize such errors. Thus, it would be advantageous to use a combination of the corrected and original models for estimation of LWD using weather data measured outside the shade as inputs to the disease warning systems. Still, few studies have been conducted

Table 2
Estimation errors of leaf wetness duration by fuzzy (F_{org}) model and corrected fuzzy (F_{dew}) model at Gochang (G) and Jeongeup (J) sites during dew-eligible days in 2011 and 2012 seasons

Site	Season	N[1]	ME[2]		MAE[2]		ME(night)[3]		ME(day)[3]	
			F_{org}	F_{dew}	F_{org}	F_{dew}	F_{org}	F_{dew}	F_{org}	F_{dew}
G	2011	62	−0.1	−2.9	3.5	4.3*	0.2	−2.6	−0.3	−0.3
	2012	84	1.9	−0.4	3.0	2.8	2.1	−0.4	−0.1	−0.1
	All	146	1.1	−1.5	3.2	3.5	1.3	−1.3	−0.2	−0.2
J	2011	60	2.5	0.1	4.0	2.6*	2.7	0.4	−0.2	−0.3
	2012	75	2.3	0.5	2.7	2.1*	2.4	0.6	0.0	0.0
	All	135	2.4	0.3	3.3	2.3*	2.6	0.5	−0.1	−0.2

[1] N is the total number of a given period in the data set
[2] Mean error and mean absolute error indicate mean error and mean absolute error per 24-h period
[3] Night and day represent time period from 18:00 PM to 8:00 AM the next day and from 8:00 AM to 18:00 PM in a given day, respectively
* Indicates significant difference at the 0.05 level between mean absolute error of fuzzy and corrected fuzzy models

Table 3
Estimation errors of leaf wetness duration by fuzzy (F_{org}) model and corrected fuzzy (F_{rain}) model at Gochang (G) and Jeongeup (J) sites during rainfall eligible days over 2011 and 2012 seasons in validation

Site	Season	N[1]	ME[2]		MAE[2]		ME(night)[3]		ME(day)[3]	
			F_{org}	F_{dew}	F_{org}	F_{dew}	F_{org}	F_{dew}	F_{org}	F_{dew}
G	2011	22	−7.1	−3.7	7.4	5.0*	−4.1	−1.6	−3.0	−2.0
	2012	23	−3.1	−1.3	4.8	4.3	−0.4	0.0	−2.7	−1.3
	All	45	−5.0	−2.5	6.0	4.6*	−2.2	−0.8	−2.8	−1.7
J	2011	23	−0.4	1.4	3.7	3.2	1.0	1.8	−1.4	−0.3
	2012	20	2.0	2.6	3.7	3.9	2.8	2.7	−0.8	−0.1
	All	43	0.7	2.0	3.7	3.5	1.8	2.2	−1.1	−0.2

[1] N is the total number of a given period in the data set
[2] Mean error and mean absolute error indicate mean error and mean absolute error per 24-h period
[3] Night and day represent time period from 18:00 PM to 8:00 AM the next day and from 8:00 AM to 18:00 PM in a given day, respectively
* Indicates significant difference at the 0.05 level between mean absolute error of fuzzy and corrected fuzzy models

to develop and validate a decision support system in a ginseng field, which merits field case studies to examine feasibility of disease warning systems using the LWD model for ginseng management.

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgments

Appendix 1

Occurrence of leaf wetness was considerably longer during rainfall eligible days than dew eligible days at experimental sites (Fig. A1). For example, LWD was about 57% and 15% longer during rainfall eligible days at Gochang and Jeongeup, respectively. The frequent rainfall did not necessarily cause longer wetness duration. For example, the period of LWD during rainfall eligible days was less in 2011 than in 2012 at Jeongeup, although rainfall frequently occurred in 2011 than in 2012 at the site.
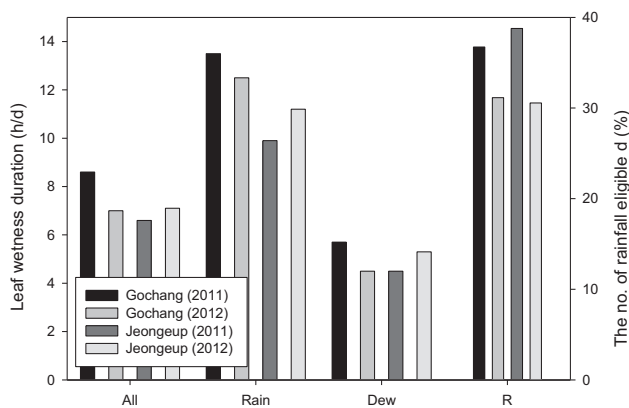

Fig. A1. Occurrence of wetness duration during all days (all), rainfall eligible days (rain), and dew eligible days (dew), and the frequency of rainfall eligible days (R) at Gochang and Jeongeup sites over 2011 and 2012 seasons. Dew eligible days represents days on which no rainfall occurred in a 24-h period. Rainfall eligible days were the remaining days other than dew eligible days during the study period. Each bar on wetness occurrence represents daily wetness duration on average during the corresponding site-year. R, rainfall eligible days.

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