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Modeling Winter Dormancy of Tea Buds and Simulation in Southern Japan

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Abstract

As part of the research aimed at elucidating the cause of low tea yields in the first crop in southern Japan, the relation of climatic conditions to winter bud dormancy was investigated using mature 'Yabukita' (*Camellia sinensis* (L.) O. Kuntze) plants at the Makurazaki Station (N 31° 16.1´) of the National Institute of Vegetable and Tea Science (NIVTS), Japan, as a model. The number of days required for flushing (RDF), when winter tea branches were kept under optimal artificial conditions (25°C, 14-hour daylength and 80% relative humidity), was used as an indicator for expressing the degree of winter bud dormancy. RDF was well predicted by the model [–aT–bD+c (T: mean temperature, D: daylength and a,b,c: parameters)] with the lowest standard error (1.71) and the lowest value of Akaike's Information Criterion (AIC = 124.06). The simulation of winter bud dormancy indicated that tea grown in Okinawa located in the southernmost region of Japan (N 26° 13´) is highly susceptible to sudden flushing during winter. The results suggested that urgent measures should be taken to alleviate low tea yields in the first crop in southern Japan.

Discipline: Agricultural environment / Crop production / Tea industry
Additional key words: *Camellia sinensis*, flushing, cold tolerance, daylength

Introduction

Tea is a perennial woody plant originating in subtropical regions. Tea is, thus, susceptible to cold during winter in northern temperate zones like the Japanese mainland. Japanese tea breeders, therefore, in an effort to overcome this susceptibility, have succeeded in breeding new cultivars with cold tolerance that are highly adaptable to winter temperatures. These cultivars exhibit special features in winter such as bud dormancy[2,5,6,27,29–31], freezing tolerance[21,23,25] and an accumulation of photosynthates[18]. 'Yabukita', which is planted in about 80% of the tea fields in Japan, is a cold-acclimated cultivar.

Islands like Okinawa (N 26° 13´) located in the southernmost region of the Japanese archipelago are considered to be frontiers for tea cultivation. Farmers who live in these regions have introduced standard Japanese cultivars such as 'Yabukita'. However, the cultivars exhibit sudden flushing in winter and tea yields and quality are low in the first crop. It was assumed that these problems occur when tea buds are exposed to relatively high temperatures in winter, which are not suitable for bud dormancy. To test this assumption, the present study was carried out to reveal the influence of climatic conditions such as temperature and daylength on bud dormancy.

Numerous reports support the concept that temperature[3,14,15,19,20,22,26,28] and daylength[2,5,6,27,29–31] regulate tea growth and winter bud dormancy. In this study, we developed a model for expressing bud dormancy to enable the prediction of the influence of climatic conditions on bud dormancy. The use of a model is advantageous because one can predict tea bud dormancy even in areas where tea is not cultivated. Secondly, one can analyze the effect of each climatic factor by comparing the parameters individually.

To begin, a clear definition of the term "dormancy" is needed. Dormancy in plants covers many phenomena and is used differently by different researchers. For example, the state in which new tea leaves temporarily stop expanding at the Banjhi stage is defined as bud dormancy. This phenomenon occurs when the leaf opening

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speed is higher than the formation speed of leaf primordia[13]. We do not, however, use this definition of bud dormancy in the present study. Instead, we define bud dormancy or winter bud dormancy as the state where apical or lateral buds do not flush or elongate in winter, even when kept under optimal growth conditions.

Materials and methods

The experiment was carried out at the Makurazaki Station of the National Institute of Agriculture and Tea Science (NIVTS). The cultivar 'Yabukita' (*Camellia sinensis* (L.) O. Kuntze, var. *sinensis*) was used in the experiment. Autumn skiffing was carried out in a zone at 3.5 cm above the final harvesting level on October 25, 1999. Five branches (about 10 cm in length) with the topmost lateral buds were collected every 3.5 days (5 days maximum and 3 days minimum) from a tea field, and used for detecting bud dormancy from November 15, 1999 to March 24, 2000 (except for the period from December 22, 1999 to January 7, 2000), with 3 replications. The detection of bud dormancy was carried out as follows. The cut branches were kept in a conical flask immersed in water in a climatized chamber (25°C, 14-hour day length and 80% relative humidity), and the flushing rate of the topmost lateral buds was examined every 2 days. The number of days required for 80% of the lateral buds to undergo flushing (referred to as RDF hereafter) was counted, and used as an indicator of the degree of bud dormancy. The flushing date was defined as that when the scale leaves covered the winter tea buds that were just opening and fresh new leaves appeared.

For the model, data sets of daily mean air temperatures were collected from the weather station of NIVTS. The possible duration of sunshine was referred to as daylength. The functions expressing the degree of dormancy (RDF) were determined according to the method of Nakano[10] who used temperature, daylength or both as explanatory variables as follows:

$y = -a(T-b)$ (1)

$y = -a(D-b)$ (2)

$y = a(T-b)(D-c)$ (3)

$y = -aT-bD+c$ (4)

where y indicates the degree of bud dormancy; a,b and c are parameters and T and D are the temperature and daylength, respectively. T and D are the moving average values of daily mean temperature and daylength for the 5 days preceding the day of examination (including the day of examination), respectively. These models were constructed using effective temperature or effective daylength for the development of bud dormancy. Parameter b or c in models (1), (2) and (3) is considered to be a critical point for the development of bud dormancy. Models (1) and (2) are functions, which use mean temperature or daylength as an explanatory variable. Model (3) uses both mean temperature and daylength as explanatory variables, and is obtained by multiplying (1) by (2). Model (4) is also a function which uses both temperature and daylength, but is represented by the sum of (1) and (2), with temperature and daylength contributing to bud dormancy independently. From these functions, the most suitable model with the smallest standard error was selected so as to minimize the residual sum of squares of predicted and actual values. The Akaike's Information Criterion (AIC) was used for the evaluation of the models in considering the parameter numbers.

Furthermore, RDF was simulated with the most suitable models in the southwestern islands of Japan such as Yakushima (N 30° 2′) and Okinawa (N 26° 13′). For Yakushima, the meteorological data for the period 1999 to 2000 were collected and used from Japan's Auto Meteorological Data Station (AMeDAS), and for Okinawa, the AMeDAS data from 1998 to 1999 were used for the simulation.

Results

Daylength decreased from the start of the experiment, with a minimum value (9.97 h.) on December 22, 1999 (Fig. 1). Thereafter, it increased with a maximum value (12.12 h.) recorded on the final day of the experiment (March 24, 2000). Average daylength throughout the experiment was 10.86 h. The fluctuations of the daily mean temperature were basically synchronized with

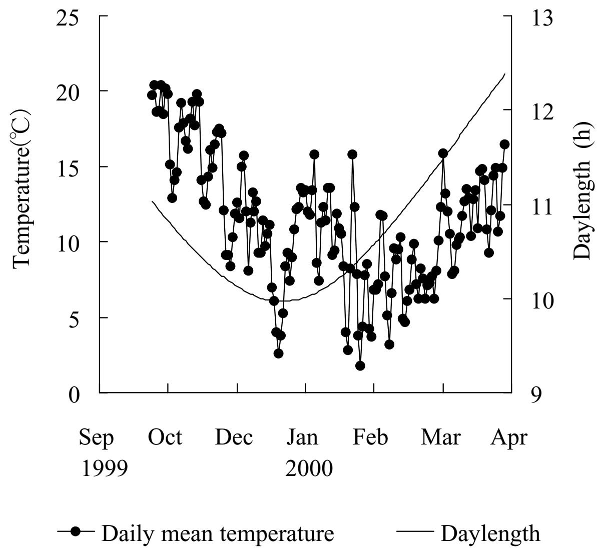

Fig. 1. Fluctuations of daily mean temperature and daylength in winter

those of the daylength. However, the lowest temperature (1.8°C) was recorded at 36 days after the shortest day (January 27, 2000), and the highest temperature (20.4°C) was recorded on October 26 and 29, 1999. The average value of the daily mean air temperature was 11.2°C.

The degree of bud dormancy remained low from the middle to the end of November, 1999, but increased sharply from early to mid-December, with a maximum value of RDF (10) on December 16, 1999 and January 10, 2000 (Fig. 2). The RDF values remained steady at a high level in January, and gradually decreased after early February, with flushing (RDF = 0) occurring on March 16.

The bud dormancy model was first developed from the relationship between the changes in the meteorological data (Fig. 1) and RDF (Fig. 2). However, the results were not satisfactory. The meteorological data were, thus, revised by calculating the moving average of both values, i.e. daily mean air temperature and daylength, and reanalyzing. That is, the moving averages of the data sets of daily mean air temperature (or daylength) for several days were calculated and used for the dormancy model. In the results, the moving average value of the daily mean air temperature for 5 days showed the highest negative correlation with RDF (Fig. 3) with an r^2 value of –0.41. These average values were, thus, used for the bud dormancy model.

Model (4) which uses both temperature and daylength as explanatory variables showed the lowest values of standard error (1.71) and Akaike's Information Criterion (AIC =124.06) among the 4 models evaluated (Table 1). The standard errors for (1) and (2) showed similar values. Model (4) showed the most similar changes in the RDF values in relation to the actual data among the models (Fig. 4). Notably, the estimated values corresponded well to minor fluctuations which occurred over several days, for example, a slight decrease at the end of January or a slight increase in the middle of February, although slight discrepancies were observed during the

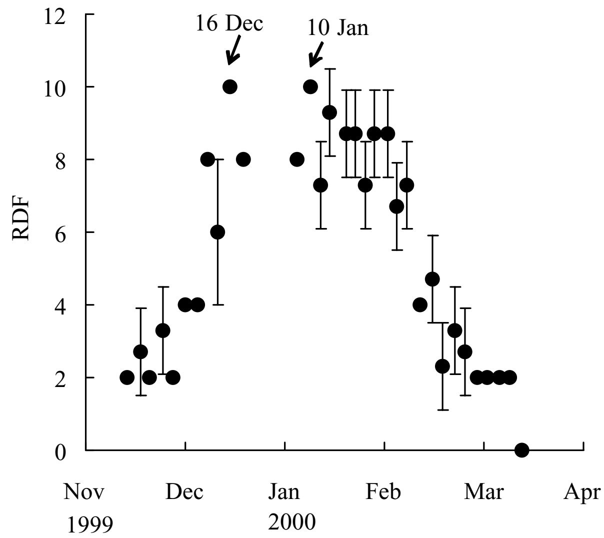

Fig. 2. Changes in the degree of bud dormancy in winter

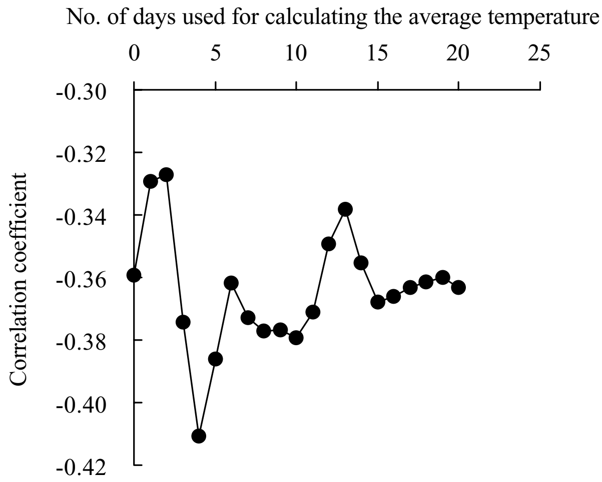

Fig. 3. Correlation coefficient between number of days used for calculating the average temperature and RDF

Table 1. Models for predicting the degree of bud dormancy, including functions, parameters a, b, c, standard error between estimated and actual values, and AIC[a)]

Functions	Parameters a	Parameters b	Parameters c	S.E.	AIC[a)]
(1) –a(T–b)	0.3308	27.9	–	2.49	142.22
(2) –a(D–b)	3.322	12.19	–	2.43	141.01
(3) a(T–b)(D–c)	0.4034	21.4	11.74	1.73	124.58
(4) –aT–bD+c	0.5525	5.280	66.41	1.71	124.06

Mean temperature (T:°C) and daylength (D:h) were the moving averages for the 5 days preceding the day of examination (including the day of examination).

a): Akaike's Information Criterion.

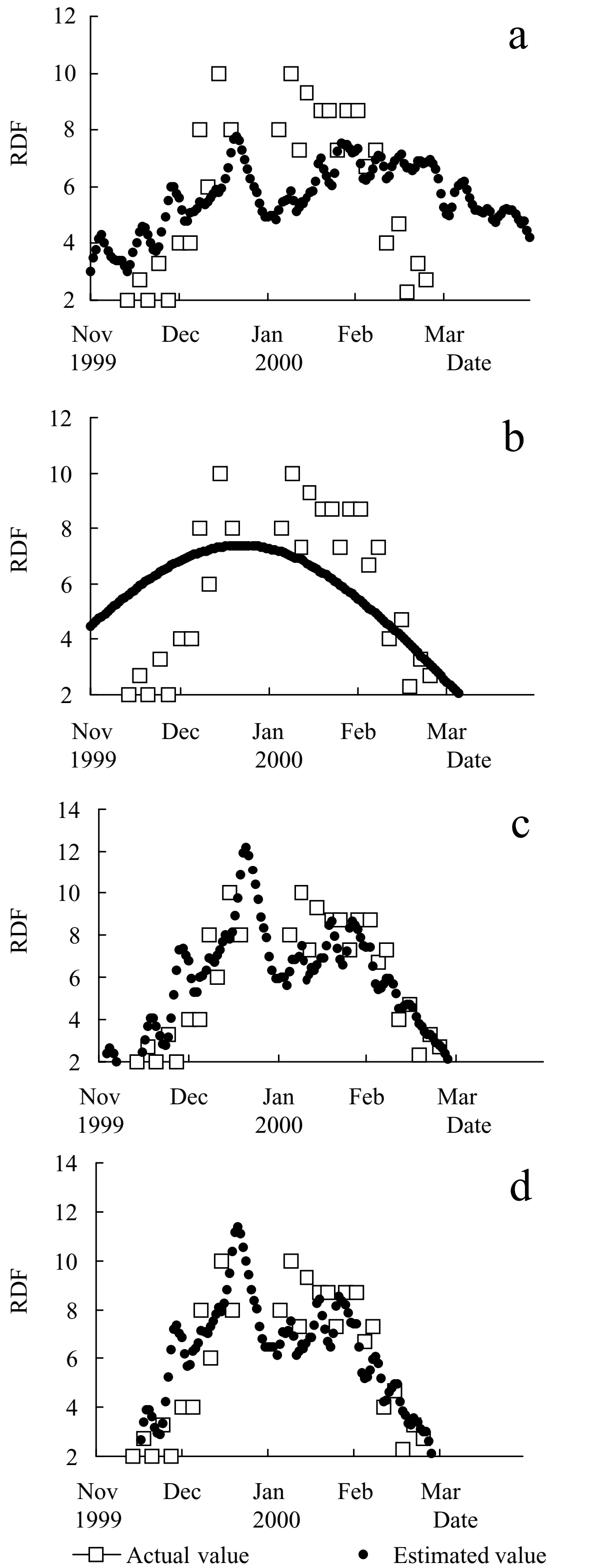

Fig. 4. Differences between estimated and actual values of degree of bud dormancy among the models
a: Model (1), **b**: Model (2), **c**: Model (3), **d**: Model (4) in Table 1.

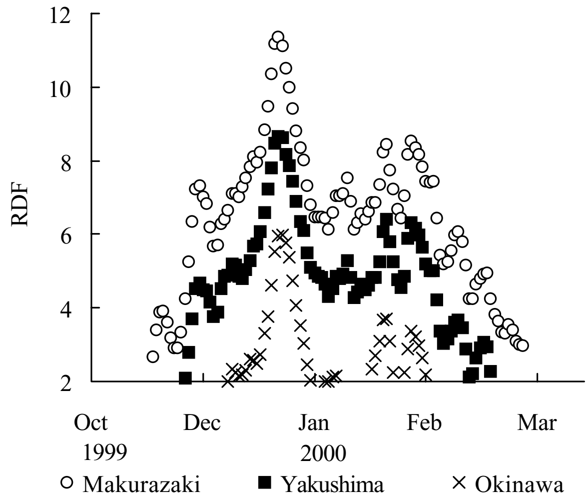

Fig. 5. Prediction of RDF in tea in the southwestern islands of Japan

period from the end of November to early December and at the end of January.

Model (4) was adopted for simulating the conditions in the southwestern islands, as shown in Fig. 5. The changes in the RDF values were similar in the 3 regions. The level of RDF, however, differed, showing the largest value at Makurazaki, followed by Yakushima. The periods during which the RDF value was above 2 differed between Yakushima and Okinawa. In Okinawa, RDF was separated into two periods, the middle to the end of December, and the middle to the end of January.

Discussion

The simulation indicated that the models (Fig. 4-a) enabled to predict the changes in the degree of winter bud dormancy even with minor fluctuations over several days. All the minor fluctuations were simulated by the changes in temperature. On the other hand, according to models (1), (2) and (4) depicted in Table 1, the RDF values were influenced by the daylength, that is, they increased rapidly at the end of November and stopped increasing at approximately the time corresponding to the winter solstice (December 22). After early February, the RDF values decreased steadily until flushing, while the temperature remained low. The daylength in these periods seemed to control a steady discontinuation of autumn bud extension and spring bud flush. On the other hand, 2 to 4.4-day differences were observed between the estimated and actual values of RDF in model (4), for unknown reasons. However, it is considered that the treatment of daily mean air temperature, the correlation between daily mean air temperature and daylength, and other factors were involved. We used moving average values of daily mean air temperature for 5 days for the prediction, only based on the correlation between the number of days used for calculating the average temperature and RDF (Fig. 3). It is possible that the buffer capacity of woody plants like tea is associated with a slow response to temperature. Further studies may enable to elucidate these relationships in terms of woody plant physiology.

We could not estimate the cross relationship of daily mean air temperature to daylength from the results shown in Table 1, because the difference in the standard error between models (3) and (4) was only 0.0168. It is thus necessary to conduct further examinations.

Cold temperature is generally a factor conducive to the breaking of bud dormancy in deciduous trees. Erez[4] and Richardson et al.[17] introduced the concept of the "chill unit" which uses accumulated temperature calculated from recorded low temperatures for the estimation of the breaking of bud dormancy. Although this concept was broadly adopted mainly for deciduous crops such as apple[1], blueberry[16] and grape[24], it remains to be determined whether it can be adopted for an evergreen plant like tea. In this study, we did not construct any models for bud dormancy with the "chill unit" because the concept of "dormancy" was not suitable for tea. Horiuchi[7] defined spontaneous dormancy as the period during which no sprouting is observed under optimal growth conditions for 20 days. When this definition is applied to tea, there was no spontaneous dormancy at the Makurazaki Station of NIVTS, as shown in Fig. 2. Therefore, a new dormancy model must be constructed for tea.

Kume[8], Kuranuki[9] and Nakano et al.[11,12] pointed out that other factors may affect bud dormancy such as nutritional status and rainfall. The evaluation and introduction of these factors would improve bud dormancy modeling.

Hachinohe et al.[5] defined an RDF of 7 as a critical point for sudden flushing in winter. According to this definition, tea grown in Okinawa is always at risk of sudden flushing in winter (Fig. 5). In addition, the period during which RDF was above 2, was separated into two parts in Okinawa (Fig. 5), which clearly explains the present situation in Okinawa. In Okinawa, farmers have delayed the final skiffing from the end of December to the end of January. This situation is not recommendable because a delay in final skiffing might cause a shortening of the developmental period for tea buds, resulting in low tea yields and quality in the first crop. This tendency will become more serious with global warming. Hence, urgent measures must be taken through the execution of these types of experiments.

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