Kor. J. Hort. Sci. Technol. 30(6):650-656, 2012 DOI http://dx.doi.org/10.7235/hort.2012.12108

Yield and Nutritional Quality of Several Non-heading Chinese Cabbage (*Brassica rapa* var. *chinensis*) Cultivars with Different Growing Period and Its Modelling

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Abstract. The aims of the experiment, conducted over three years in the Central Europe field conditions, were (1) to investigate the effect of growing period (plantings in the middle and at the end of August: 1st and 2nd term, respectively) on yield and chemical composition of the non-heading Chinese cabbage (*Brassica rapa* var. *chinensis*) cultivars 'Taisai', 'Pak Choy White', and 'Green Fortune', and (2) to develop regression models to evaluate the changes in crop yields as a function of weather conditions. A highest marketable yield was obtained from 'Taisai' (65.71 and 77.20 $t \cdot ha^{-1}$), especially in the 2nd term of production. Low yield, observed for 'Pak Choy White' was due to its premature bolting. Almost 39% (1st term) and 70% (2nd term) of plants of this cultivar formed inflorescence shoots before harvest. The highest dry matter level was observed in the leaf petioles of 'Taisai', while 'Green Fortune' was the most abundant of carotenoids and L-ascorbic acid. The content of soluble sugars was the lowest for 'Pak Choy White'. In a phase of harvest maturity, more of the analyzed constituents were gathered by plants from earlier plantings, and differences were as follows: 4.7% (dry matter), 26.3% (carotenoids) and 22.1% (L-ascorbic acid), in comparison to 2nd term of production. Significant increase of soluble sugars level was observed for plants from later harvest. The regression model for marketable yield of Chinese cabbage cultivar 'Taisai' as a function of maximum air temperature can predict the yield with accuracy 68%. The models for yield or bolting of 'Pak Choy White', based on extreme air temperatures and sunshine duration, were more precise (98%). It should be pointed out that Taisai could be recommended for later growing period in Central Europe conditions with regard to maximum yield potential. 'Green Fortune' was notable for its uniform yielding. To obtained plants of higher nutritional value, earlier time of cultivation should be suggested. Described models can be successfully applied for an approximate simulation of Chinese cabbage yielding.

***Additional key words*:** bolting, nutrient content, pak-choi, regression models, yield

Introduction

Non-heading type of Chinese cabbage (*Brassica rapa* var. *chinensis*) originated in China (Hanson et al., 2009; Ran, 1984). This crop, still little known in European countries, is increasingly favoured by producers and consumers with regard to short vegetation period, easy cultivation, unique flavour, number of useful health benefits and attractive appearance. However, only a few non-heading Chinese cabbage cultivars are sale on the European market, some of them are easy-bolted (Kalisz, 2004; Reghin et al., 2002; Siomos, 1999). Forming of flower stalks by plants significantly decreases marketable yield of many vegetable crop species (Ran, 1984; Staugaitis and Starkutė, 1999; Wurr et al., 1996). One of the main objectives of the crop production is obtaining the highest yield of the best commercial quality. Many factors can affect the yield of vegetable crops, especially weather conditions (Hoogenboom, 2000). Species introduced to the field cultivation in new regions, have to be evaluated for the response to local climatic factors. One of the methods to check this response is to differentiate of sowing or planting dates. It is necessary to develop a detailed schedule of crop production in order to maximize the yields. Such studies have been already performed for a number of vegetable species, including those from Brassicaceae family introduced in Poland (Cebula and Kalisz, 1997; Kalisz, 2010; Kałużewicz et al., 2009; Kobryń, 2001; Korus, 2010; Mirecki, 2006; Siomos, 1999). The yield of non-heading Chinese cabbage is closely associated with the premature formation of flower stalks. The impact of growing time may be significant in

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※ Received 4 June 2012; Revised 13 September 2012; Accepted 15 September 2012.

this regard (Kalisz, 2010; Pokluda, 2008; Staugaitis and Starkutė, 1999). It is very important to assess also yield quality, mainly the content of bioactive components in the plants. Both term of cultivation (Acikgoz and Altintas, 2011; Kalisz, 2010; Kobryń, 2001; Siomos, 1999) and cultivar (Artemyeva and Solovyeva, 2006; Hanson et al., 2009; Pokluda, 2008) affects biological value of vegetables.

Weather-plant interrelations are characterized by relatively high level of complexity. It is difficult research task to determine precisely the impact of weather on the crop yield. The development of regression models used for yield prediction, which are based on meteorological conditions, may be helpful in this regard (Dufault et al., 2009; Francescangeli et al., 2004). Several environmental factors are introduced to the models as the initial variables. A maximum simplification of the regression equations is looking for by stepwise regression analysis, finally leaving the parameters which most significantly affect the plant growth and yielding (Weng et al., 1999). A simple structure of the models makes easier its application in large- or small-scale horticultural production (Hoogenboom, 2000). Different meteorological data can be included in these empirical models (Wurr et al., 2002). The common weather variables such as air temperature, precipitation, solar radiation or sunshine duration are often used as key components of the basic regression models. Such type of data was applied by Dufault et al. (2009) to simulate the yield of romaine lettuce, by Kalisz (2010) for heading Chinese cabbage and by Lin et al. (1995) for non-heading Chinese cabbage. Appropriate control of sowing or planting dates of the crops allows gathering sufficient data for modeling during one or a few years of cultivation.

The objective of this study was to verify the impact of growing period and the cultivar on yield and nutritional value of Chinese cabbage plants. In this paper, simple regression models were also developed to describe the yield of chosen cultivars of Chinese cabbage, including premature bolting of the plants. An additional objective of this study was to determine which weather components had the greatest impact on the estimated yield parameters of tested cultivars.

Materials and Methods

Experimental Design

The Chinese cabbage (*Brassica rapa* var. *chinensis*), referred to also as pak-choi, has been produced from transplants prepared in the greenhouses of the University of Agriculture in Krakow, Poland, in the black 96-cells trays (volume of a single cell was 53 cm^3), filled with peat substrate. The experiments were conducted in the years 2003-2005, as 2-factors set. Two terms of production for the summer-autumn harvest were taken into consideration (factor I). The seeds were sown in the third ten days of July and early August. Transplant production time was approximately of 3-4 weeks. Transplants were planted out in the field of the Vegetable Experimental Station in Krakow in the middle and at the end of August (1^{st} and 2^{nd} growing period, respectively). Chinese cabbage cultivars: Taisai, Pak Choy White and Green Fortune F_1 (Takii & Co., Ltd.) were used in the experiment (factor II). Taisai belongs to a group of cultivars forming very high rosettes with white leaf petioles, Pak Choy White has similar colouration of petioles, but the sizes of rosettes are much lower. Green Fortune F_1 is characterized by the lowest size of rosettes and light-green petioles. Morphological differentiation of tested Chinese cabbage cultivars was shown in Fig. 1.

Yield Trials

The plants were planted out in a field with spacing of 40 × 25 cm. A single plot to harvest comprised of 24 plants and it had an area of 2.4 m^2. The plots were surrounded by shelterbelts. During the vegetation of Chinese cabbage in the field, the standard cultivation procedures were performed (weeding, irrigation, or fertilization), with use of adapted recommendations for heading Chinese cabbage. Harvest was performed only once for tested growing periods, specifying

Fig. 1. *Brassica rapa* var. *chinensis* cultivars: ‘Taisai’, ‘Pak Choy White’, and ‘Green Fortune’ (from left).

the mass of rosettes and their number. Mature rosettes, with no mechanical damages or damages caused by diseases and pests were included among marketable yield. Deformed, under sized rosettes and with visible damages were classified as non-marketable yield. Plants with inflorescence shoots were classified separately. Structure of total yield was calculated on the basis of number of plants in mentioned groups. The harvest took place in mid-September (1^{st} growing term) and in the first ten days of October (2^{nd} growing term), after 4.5 weeks and 6.5 weeks from planting, respectively.

Weather Condition Measurements

During the field experiment, the weather conditions were recorded. The air temperature, at 1-hour interval, was measured by automatic sensors HOBO Pro RH/Temp. (Onset Comp. Corp., USA), placed on the plots, 30 cm above ground. On the base of the recorded data the mean, maximum and minimum daily temperatures were measured. The data on sunshine duration, defined as number of hours in which the solar radiation falling on a plane, was derived from the station of the Institute of Meteorology and Water Management in Krakow-Balice, located 3 km from the Vegetable Experimental Station.

Laboratory Analyses

The leaf petioles of non-heading Chinese cabbage in a phase of harvest maturity were collected for laboratory analyses. The dry matter content was determined by drying sample at 92-95°C until constant weight was obtained, measured with the use of Sartorius A120S (Germany). The total soluble sugars were determined by anthrone method (Yemm and Willis, 1954). For this analysis, plant material was mixed with 80% ethanol. After addition of anthrone reagent, samples were placed for 30 min in a water bath (100°C), cooled down to room temperature and the absorbance was measured at 625 nm using Helios Beta spectrophotometer (Thermo Fisher Scientific Inc., USA). L-ascorbic acid was measured by Tillmans method (Krełowska-Kułas, 1993). Plant material (50 g) was mixed with 200 mL CH_3COOH, and after 30 min extract was titrated with the reagent 2,6-dichlorophenolindophenol (Tillman's reagent). Carotenoid content was determined by the modified Lichtenthaler and Wellburn (1983) method after acetone extraction, at 470 nm, with Helios Beta spectrophotometer (Thermo Fisher Scientific Inc., USA).

Statistical Analyses

Results were repeatable in three years of the experiment, so for a synthetic description the data were averaged over years. Differences between means were evaluated with ANOVA, using STATISTICA program (StatSoft Inc., USA), and the Tukey's test was used to determine homogeneous groups at $p < 0.05$. It was also attempted to create a simplified regression model to predict the marketable yield (expressed in $t \cdot ha^{-1}$) of Chinese cabbage plants and the number of inflorescences shoots (1000 plants/ha) based on average values of weather parameters in two periods of production. Multiple regression analysis was performed for cultivars 'Taisai' and 'Pak Choy White', using a stepwise backward elimination method. The primary independent variable in the model for prediction of marketable yield and number of plants with inflorescences shoots, the mean daily air temperature was assumed (T_{mean}) with extreme values (T_{max} - maximal, T_{min} - minimal) and sunshine duration (Sun_d) prevailing during the last three weeks of plant growth in the field. The base equation for all models was: $y = B_0 + B_1 \cdot T_{mean} + B_2 \cdot T_{max} + B_3 \cdot T_{min} + B_4 \cdot Sun_d$, where B_0 is the intercept (constant), and B_{1-4} is the regression coefficients (slope). Simplified regression equations were developed, multiple correlation coefficients (R), coefficients of determination (R^2) and also standard errors of estimation (SE_e) were determined, assessing obtained models with a significance level of $p < 0.05$.

Results and Discussion

The mean values of weather parameters for the different

Table 1. Mean values of temperature and sunshine duration in particular growing periods (data from 3 weeks before harvest).

Year	Growing period	Temperature (°C)			Sunshine duration (hours)
		mean	max	min	
2003	1^{st} term	15.1	22.6	8.3	7.8
	2^{st} term	10.4	16.7	4.3	4.0
2004	1^{st} term	15.0	23.6	7.3	8.0
	2^{st} term	10.0	16.8	5.0	3.9
2005	1^{st} term	17.1	26.8	9.6	7.9
	2^{st} term	11.8	20.0	5.8	5.5

dates of production and years of experiment, over the last three weeks of plant growth before harvest, were presented in Table 1. In the 2nd growing period, plants experienced cooler weather and far less sunshine. During this period, air temperature was lower by about 4.7-5.3°C (mean temperature), 5.9-6.8°C (maximum) and 2.3-4.0°C (minimum) in comparison to the earlier production. Higher sunshine duration was observed in the 1st term of growing, and the differences amounted to 2.4-4.1 hours, depending on the year of experiment.

The effects of cultivar and growing period were significant for almost all the estimated Chinese cabbage yield parameters (Table 2 and Fig. 2). The yields (total, marketable) were highest for Taisai. Rosette weight was also the largest for this cultivar, however, no significant difference between 'Taisai' and 'Pak Choy White' was noted. The best total yield structure was noted for Taisai plants. Percent of marketable rosettes exceeded 90%. 'Green Fortune' have also a high share of marketable yield in total one. In the previous work of Kalisz (2004), Taisai yielded at the highest level among tested cultivars. Non-heading Chinese cabbage cultivars investigated by Hanson et al. (2009), Ran (1984), and Žutić et al. (2000) also showed significant differences in yield potential. This pointed out importance of genetic factor in yield performance. In the present experiment, large differences among tested cultivars were observed especially for marketable yield. The notable yield loss of 'Pak Choy White' was due to its premature bolting. It exceeded 60%, on average, as compared to Taisai, where flower stalks were not observed. This indicates smaller suitability of 'Pak Choy White' for large-scale production. Susceptibility of some Chinese cabbage cultivars for premature bolting was presented in earlier research work of Kalisz (2004). Differences in bolting of non-heading Chinese cabbage cultivars have been also described by several other authors (Hill, 1991; Ran, 1984; Reghin et al., 2002). Cultivation period had no significant effect on the marketable yield, but there were significant interactions between cultivar and growing period regarding this parameter. Taisai gave much greater yield when planting date was delayed. In opposite, 'Pak Choy White' cultivated for later harvest developed almost twice more

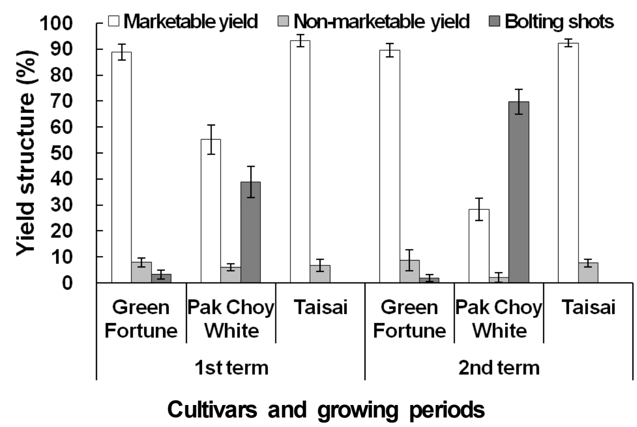

Fig. 2. Structure of total yield of non-heading Chinese cabbage based on the plant number in defined groups; error bars represent the standard deviation of four replicates.

Table 2. Effect of growing period and cultivar on yield (total, marketable) and weight (marketable rosettes, bolted ones) of non-heading Chinese cabbage.

Growing period	Cultivar	Total yield ($t \cdot ha^{-1}$)	Marketable yield ($t \cdot ha^{-1}$)	Marketable rosette weight (kg)	Mass of bolted plants ($t \cdot ha^{-1}$)
1st term	Taisai	68.77 c	65.71 d	0.720 ab	0.00 a
	Pak Choy White	56.17 a	34.11 b	0.599 a	20.06 b
	Green Fortune	58.49 ab	53.89 c	0.623 a	1.44 a
2st term	Taisai	80.54 d	77.20 e	0.842 b	0.00 a
	Pak Choy White	67.03 bc	21.90 a	0.799 b	44.57 c
	Green Fortune	58.90 ab	55.36 c	0.622 a	0.60 a
Mean for growing period					
1st term		61.14 A	51.24 A	0.647 A	7.17 A
2st term		68.82 B	51.49 A	0.754 B	15.06 B
Mean for cultivar					
Taisai		74.66 B	71.46 C	0.781 B	0.00 A
Pak Choy White		61.60 A	28.00 A	0.699 AB	32.32 B
Green Fortune		58.70 A	54.63 B	0.623 A	1.02 A

Mean values within a column, followed by different capital letters for main effects and lower case letter for interaction effects, are significantly different at $p < 0.05$ according to Tukey's HSD test.

bolting shoots than in the earlier production (38.8% plants with inflorescence shoots in the 1st term, and in the later one - 69.7%). This was a reason of significantly lowest yield of the Pak Choy White rosettes suitable for the trade. According to Siomos (1999), temperature and genotype are the predominant factors effecting bolting. In the present experiment, not favourable temperatures during field vegetation in the 2nd term of production clearly enhanced bolting of 'Pak Choy White'. There was no significant effect of growing period on yield and rosette weight of Green Fortune. Although more bolting plants of this cultivar were noted in the earlier production period, calculated differences were statistically insignificant. In many vegetables from the Brassicaceae family diversification of planting dates significantly affect the yield and its quality. The influence of this factor on the yield of several vegetables was observed in Central Europe conditions inter alia by Kałużewicz et al. (2009) for broccoli, Kalisz (2010) or Staugaitis and Starkutè (1999) for heading Chinese cabbage, Cebula and Kalisz (1997) for cauliflower, Kobryń (2001) for non-heading Chinese cabbage, and by Korus (2010) for kale. In present experiment conditions Taisai responded better to later growing period, while 'Pak Choy White' - much worse. The yield of 'Green Fortune' plants was stable across growing periods and it was not influenced by environmental factors.

Table 3 presents the content of selected chemical constituents in the leaf petioles of Chinese cabbage. The highest amount of dry matter and soluble sugars was found in 'Taisai'. The statistically similar content of soluble sugars was observed in 'Green Fortune'. This cultivar was also characterized by significantly higher levels of carotenoids and L-ascorbic acid as compared to other investigated cultivars. The influence of the period of cultivation on the level of the analysed components was also significant. Plants of the 1st growing period had greater nutritional value with the exception of soluble sugars. The amount of dry matter was higher of 0.16% f.w., carotenoids - 0.05 $mg \cdot 100\ g^{-1}$ f.w., and L-ascorbic acid - 3.43 $mg \cdot 100\ g^{-1}$ f.w., in relation to subsequent growing term. The higher level of soluble sugars (approximately by 8%) was determined in the plants from delayed cultivation. Some interaction effects of experimental factors on chemical compositionof Chinese cabbage was also observed, but no clear dependences can be pointed.

Differences in chemical composition of Chinese cabbage were also observed by Hanson et al. (2009) and Artemyeva and Solovyeva (2006). Influence of genetic factor on the level of chemical compounds in plants is a phenomenon often described in the literature (Singh et al., 2007). The term of plant production in the field conditions has also a significant influence on the content of several bioactive components. Many authors pointed to a different chemical composition of vegetables produced at different times of the year, caused by various environmental and agronomic factors. Such effect was observed for several *Brassica* species like heading Chinese cabbage (Kalisz, 2010; Pokluda, 2008; Staugaitis and Starkutè, 1999), non-heading Chinese cabbage (He et al., 2000), Brussels sprouts (Mirecki, 2006), and also broccoli (Acikgoz, 2011). The results of present experiment confirmed these observations.

Table 3. Chemical composition of non-heading Chinese cabbage leaf petioles.

Growing period	Cultivar	Dry matter (% f.w.)	Soluble sugars (% f.w.)	Carotenoids ($mg \cdot 100\ g^{-1}$ f.w.)	L-ascorbic acid ($mg \cdot 100\ g^{-1}$ f.w.)
1st term	Taisai	3.91 d	0.81 a	0.18 a	20.03 c
	Pak Choy White	3.43 b	0.75 a	0.16 a	16.66 b
	Green Fortune	3.39 b	0.82 ab	0.38 b	20.24 c
2st term	Taisai	3.61 c	0.91 c	0.11 a	16.13 b
	Pak Choy White	3.17 a	0.76 a	0.08 a	11.08 a
	Green Fortune	3.47 b	0.89 bc	0.38 b	19.44 c
Mean for growing period					
1st term		3.58 B	0.79 A	0.24 B	18.98 B
2st term		3.42 A	0.85 B	0.19 A	15.55 A
Mean for cultivar					
Taisai		3.76 C	0.86 B	0.15 A	18.08 B
Pak Choy White		3.30 A	0.76 A	0.12 A	13.87 A
Green Fortune		3.43 B	0.86 B	0.38 B	19.84 C

Mean values within a column, followed by different capital letters for main effects and lower case letter for interaction effects, are significantly different at $p < 0.05$ according to Tukey's HSD test.

Table 4. Statistics for simplified regression models for non-heading Chinese cabbage marketable yield ($t \cdot ha^{-1}$) and bolted plants (1000 $plants \cdot ha^{-1}$) depending on climatic conditions.

Cultivar	Parameter	Equation	R	R^2	SE_e	p
Taisai	yield	$y = 118.16-2.22 \cdot T_{max}$	0.822	0.676	6.861	0.045
Pak Choy White	yield	$y = 150.88+18.34 \cdot T_{min}-16.50 \cdot T_{max}+16.47 \cdot Sun_d$	0.988	0.976	4.000	0.036
Pak Choy White	bolters	$y = -86.63-27.69 \cdot T_{min}+22.59 \cdot T_{max}-24.20 \cdot Sun_d$	0.991	0.982	5.504	0.028

R, multiple coefficient of regression; R^2, coefficient of determination; SE_e, standard error of estimation; p, level of significance; T_{min}, minimum temperature; T_{max}, maximum temperature; Sun_d, sunshine duration

Tested cultivars of Chinese cabbage contained less carotenoids and L-ascorbic acid in the 2nd term of production, which was probably caused by limited sunshine duration and lower light intensity. Exposure to sunlight and high temperature enhances carotenoid biosynthesis, increasing its concentrations (Kopsell and Kopsell, 2008). The amount and intensity of light during the growing season have a positive influence on the amount of ascorbic acid (Acikgoz and Altintas, 2011).

Due to the lack of significant differences of 'Green Fortune' marketable yield in different periods of cultivation, only 'Taisai' and 'Pak Choy White' were selected for modelling. The results of stepwise regression analysis are given in Table 4. It is worth noting that in a simplified equation for the marketable yield of 'Taisai', only maximum temperature remained. The fitting of the model stood at the level of 68%, hence it follows that the remaining 32% of the variability of yield was dependent on other factors that were not included in the analysis. This model confirmed that the higher yielding of this cultivar was available at colder weather and maximum temperatures emerging at a moderate level. For 'Pak Choy White', final regression equation took into account extreme temperatures and sunshine duration for both marketable yield and number of plants with inflorescence shoots. 'Pak Choy White' can be described as a cultivar preferring moderate temperature. This cultivar responded to higher maximum and lower minimum temperatures with yield reduction and intensified bolting. The high coefficients of determination, and the relatively low values of standard errors of estimation were noted, indicating a good fit of predicted values to observed ones. In this case the models are wrong by an average of 4 $t \cdot ha^{-1}$ (marketable yield) and about 5000 plants for the rosettes with shoots per 1 hectare.

Lee (1996) presented correlation dependences between yield of two Chinese cabbage (non-heading group) cultivars and air temperature, insolation and rainfall. By multiple regression analysis this author showed that with the raising rainfall the yield of the plants was decreased, while higher solar radiation promoted plant growth and increased the yield. It is interesting that no significant effect of air temperatures was observed in this matter. In turn, Weng et al. (1999), using stepwise regression analysis showed a significant correlation between non-heading Chinese cabbage fresh weight and air temperature and rainfalls, while solar radiation had a much weaker effect in this respect. Fresh weight was strongly and negatively correlated with total rainfalls, while for temperature the relationship was positive. Regression equations published for this species by Lin et al. (1995) described the effect of mean air temperatures and temperature extreme values on the crop yield. Weather-crop models had been also developed for other vegetable crops (Dufault et al., 2009; Fellows et al., 1999; Francescangeli et al., 2004), including *Brassica chinensis* (Kalisz, 2011) and *Brassica pekinensis* (Kalisz, 2010; Wurr et al., 1996; Zhang et al., 2007).

Bolting of vegetables has been of research interest because of the need to understand the mechanism of transition to the generative phase of development. It is also an important aspect of vegetable crops yielding. For heading and non-heading groups of Chinese cabbage, the construction of regression models might be helpful in preventing the reduction of crop yield caused by premature flowering (Kalisz, 2010; Wurr et al., 1996, 2002).

Conclusions

Three cultivars of non-heading Chinese cabbage produced in the field conditions of Central Europe, in two growing periods, were compared in terms of yield and nutritive value. Simplified regression equations for plant yield prediction were developed. Both experimental factors had great influence on estimated parameters of the crop yield and nutrient content. The highest yield was obtained from cultivar Taisai, especially from plantings at the end of August. 'Pak Choy White' should not be recommended for large-scale production due to premature forming of inflorescence stalks, and lowest nutritional value, assessed on the base of dry matter, soluble sugars and L-ascorbic acid content. Comparing the two terms of production, we showed that Chinese cabbage planted in the middle of August contained more dry matter, carotenoids and L-ascorbic acid, while significantly more soluble sugars were found in the plants planted out two weeks later. Predictive models for marketable yield of Taisai involved as independent variable the maximum air temperature, and of 'Pak Choy White' (for marketable yield and number of bolting shoots), extreme temperatures and sunshine duration. Fitting the observed data to predicted ones was in the range of 68% ('Taisai') to 98% ('Pak Choy White').

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