

Influence of Climate Change on Natural Degreening of Lemons (*Citrus limon* L. Burm. f)

M. Erena¹, J. M. Brotons², A. Conesa³, F. J. Manera⁴, R. Castaner^{4*}, and I. Porras⁵

ABSTRACT

The influence of the minimum air temperatures on the lemon fruits color change from green to yellow was studied in three climatic change scenarios. With the drop in temperature in early autumn, chlorophylls in the lemon fruits break down and they naturally take on their characteristic yellow colour. In this work, based on three climate models, in which the temperature change is predicted until 2100, the effect of climate change on natural degreening of lemons fruits was analyzed. According to these models, due to the rise in air temperature, the start of color development would be delayed by one week to two months. But, in none of these cases would the fruits reach their characteristic colour on the tree, therefore, it would be necessary to use degreening chambers to achieve the commercial coloration, implying an increase in production costs.

Keywords: Color development, Hunter *L, a, b* scale, Minimum temperatures, Rind color.

INTRODUCTION

Direct observation of lemon trees in the field shows that the change in color of lemon fruits in late summer does not occur abruptly, but gradually as night time temperatures decrease. Of the colorimetric coordinates, “*a*” is the one that best correlates with temperature. Manera *et al.* (2012a) correlated the air temperature with the loss of green color of the peel of lemon and the development of yellow color, for lemon varieties Eureka, Lisbon and Fino 49. It has been determined that the process of color change of the fruit on the tree begins when the average minimum temperature falls below 15°C, or if two days have a minimum temperature of 10.5°C. In addition, Manera *et*

al. (2012a) found that the green color of the fruit disappeared when the temperature fell to 6°C.

Fruits for consumption frequently require artificial degreening in special chambers, since their internal maturity does not always correspond to external colour (Casas *et al.*, 1988). Legally, lemons can only be sold with a minimum of 20% juice (European Community 2001a, b) and harvesting begins when the fruit reach a calibre of 58 mm (García-Lidón *et al.*, 2003), at which time they are still green although consumers want fruit that are yellow in color. If the growers wait for this color to develop on the trees, up to two months may be necessary before the temperatures drop sufficiently (Brotons *et al.*, 2013; Manera *et*

¹ Department of Natural Resources, Murcian Institute of Agriculture and Food Research and Development (IMIDA, Estacion Sericicola, Calle Mayor s/n. 30150, La Alberca, Murcia, Spain.

² Department of Economic and Financial Studies, Miguel Hernandez University, 03202. Elche. Alicante Spain.

³ Department of Vegetable Production and Microbiology, Miguel Hernandez University, Ctra de Beniel, km 3.2. 03312 Orihuela. Alicante, Spain.

⁴ Department of Physics and Architecture of Computers, Miguel Hernández University, Ctra de Beniel, km 3.2. 03312 Orihuela. Alicante, Spain.

* Corresponding author; e-mail: r.castaner@umh.es

⁵ Department of Citriculture, Murcian Institute of Agriculture and Food Research and Development (IMIDA), Estación Sericícola, Calle Mayor s/n. 30150, La Alberca, Murcia, Spain.



al., 2012a, b), which may result in substantial reduction in profit.

Some of the effects of climate change on agriculture are known as well as being the focus in research projects (Kumar *et al.*, 2016). Many of these effects and the practical measures that can be taken to prevent or mitigate their adverse negative impact on the ability to feed the world's population are discussed in Rosenzweig *et al.* (1998).

The method most often used to make climate predictions and, in particular, the impact of increased CO₂ concentration on crops (Aien *et al.*, 2014) is the use of computer models that attempt to simulate possible future atmospheric conditions. These models are intended to forecast future temperatures, precipitation, humidity, solar radiation rates, wind speed, and a range of parameters that can affect crops (Gordo *et al.*, 2010). The models have limited validity, both temporally and spatially, and depend greatly on the adopted assumption of CO₂ emission, which is related to the expected growth (economic, social, and industrial) forecasted for a given region. These forecasts are called climate scenarios of emission. A review of the forecasts of several models concerning the effects of CO₂ on crops is done by Tubiello *et al.* (2002a). In the review, two types of climate models were applied to maize, potato, and citrus (Tubiello *et al.*, 2012b). For the latter, the citrus cultivation model (Navel and Valencia oranges) was used (Mechlia *et al.*, 1989). Recently, the IPCC (Intergovernmental Panel on Climate Change) published its 5th report and advice on appropriate policies (Stocker *et al.*, 2013) and identified significant consequences for the economy and life styles.

The Coupled Model Intercomparison Project Phase 5 (CMIP5), which combines the efforts of 25 research centres with regard to climate modelling, has recently defined a series of four Representative Concentration Pathways (RCPs). These define the climatic conditions during the 21st century in terms of the concentration of greenhouse gases in the atmosphere, their increase or decrease, climate dynamics, and certain demographic, economic, and social conditions. The four

RCPs (RCP2.6, RCP4.5, RCP6 and RCP8.5) are named according to the elevation of the radiative forcing that they predict for 2100, compared to pre-industrial times in 1765: +2.6, +4.5, +6.0 and +8.5 W m⁻², respectively.

The RCPs are consistent with the range of concentration of greenhouse gases (CO₂ equivalents) predicted for 2100: 1370, 850, 650 and 490 ppm for RCP8.5, RCP6.0, RCP4.5 and RCP2.6, respectively (Moss *et al.*, 2010).

There are studies that deal with the effect of climate on citrus fruit, in particular lemon. Some of these focus on the dependence of the flowering season on temperature (Fitchett *et al.*, 2014) and others on the water stress caused by climate change; for example, the flowering of the lemon variety Fino is more intense after a period of drought (Ávila *et al.*, 2012).

As climate change involves increased temperatures in both the short- and long-term, the objective of this study was to estimate how climate change will influence the natural degreening of lemons, using climate models predicting the influence of temperature increase during autumn.

MATERIALS AND METHODS

Plant Materials and Experimental Conditions

The lemon cultivars used in this work were Fino 49, Eureka Frost, and Lisbon Frost (autumn-winter varieties) grafted on *Citrus macrophylla* rootstock. The lemon trees were planted in April 1983 on a plot of the Murcian Institute of Agricultural Research and Development (IMIDA), at La Alberca (Murcia). The planting density was 6×6 m, with a drip irrigation system having five drippers per tree, which provided a flow of 4 L h⁻¹. The average temperature at this site is 18.7°C, the average rainfall is 321 mm yr⁻¹ and the soil is permeable and calcareous (17.1% total calcium carbonate). All the trees were healthy and in full production.

The rind color was measured with illuminant C, which represents daylight

(MacDougall, 2002), and the observer angle standard CIE-2° was determined with a Minolta CR-300 reflection colorimeter (Ramsey, NJ, USA), performing three readings in the peel of the equatorial zone of each fruit. At each reading, the colorimetric coordinates “*L*”, “*a*” and “*b*” were measured in the HunterLab colour space (Hunter, 1967). The colorimetric “*a*” coordinate corresponds to the green-red axis, where negative values relate to green and positive values to orange and red (-60 green, +60 red) and between blue and yellow (negative -60 and positive +60 “*b*” values point towards blueness and yellowness, respectively). (MacDougall, 2002; Hutchings, 1994)

At the beginning of each trial, 10 fruits per tree were selected randomly. Five were labelled on the north-facing side and five on the south-facing side, on the inside of each of the four trees tested for each of the three varieties. On the equator of each fruit, the color was measured with the colorimeter, taking three measurements per fruit and calculating the average, during the period from September to February, with a frequency of 1 to 2 weeks, resulting in approximately 13 measurements per season. The study was conducted over six seasons (2008 to 2013).

Temperatures and Climate Models

The temperature data used in the study were recorded on the experimental farm, using a weather station (MU62, La Alberca, Murcia) as part of the IMIDA agro-meteorological network, which covers the major growing areas of the Region of Murcia (SIAM, 2016). The minimum temperatures refer to the daily minimum, and the daily average was calculated using the temperature measured each hour.

Climate information from the database AEMET (Spanish Meteorological Agency) available on its website (AEMET, 2016) was used for this work. The AEMET data used for comparisons have been obtained from the Fifth Assessment Report (AR5) of the IPCC. In the present work, models based on

statistical regionalization performed by the synoptic analogues method were used. Specifically, for the Region of Murcia, there are different predictions given by distinct models of regionalization, of which 14 models use RCP8.5, five use RCP6.0, and 13 use RCP4.5.

According to the forecast models consulted (AEMET, 2016), an increase in the day mean temperatures is expected to occur in the next few years. The forecasts of rising temperatures for the autumn season, regionalized for the Region of Murcia, are summarized in Figure 1.

The temperature predictions given by different models are much more sensitive to the RCP used than to the differences in the characteristics of each model. Therefore, three models were used, each one in a different RCP. Of the models in RCP8.5, the one chosen gave more-unfavourable predictions (higher temperature rise). This was the model HadGEM2-CC_RCP8.5 developed by the Met Office Hadley Center for Climate Science and Services (UK) (Collins *et al.*, 2011). A model that gave more-favourable predictions (RCP4.5) was also used (inmcm4_RCP4.5) from the Russian Academy of Sciences (Volodin *et al.*, 2010), which couples atmospheric and oceanic models as well as interactive calculations of the carbon and methane cycles. The last model RCP6.0 that provides some intermediate predictions was used. This is the model BCC_CSM1.1.m_RCP6.0 of the Beijing Climate Centre Climate System Model version 1.1 (BCC_CSM1.1), with moderate resolution (Wu, 2012).

Based on lemons color changes in the autumn in the region of Murcia, in the years 2008 to 2013, a climate projection to the year 2100 was carried out. The purpose was to estimate how the degreening of lemon fruits will evolve over this period, considering the aforementioned climate models and revealing its impact on the cultivation of lemons in the Levante (south-eastern) region of Spain.

The relation between coordinate *a* and temperatures will be fitted in a better way

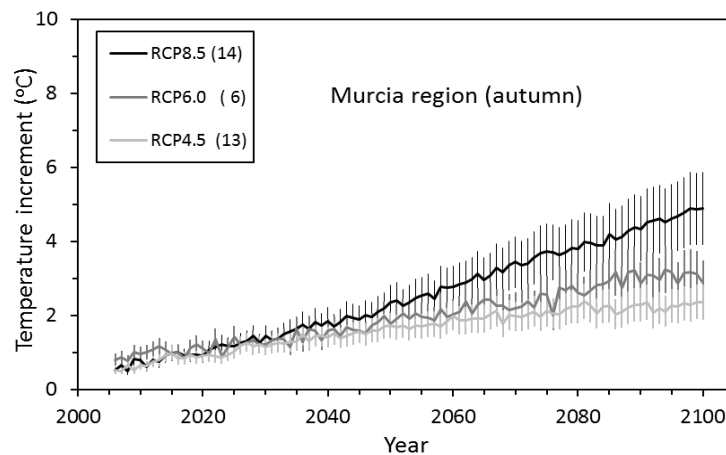


Figure 1. Forecasts of the increase in autumn minimum temperatures in the region of Murcia (Source: AEMET, 2016).

using a sigmoidal function like the following:

$$a = \frac{-b}{1 + \exp\left(-\frac{(t-c)}{d}\right)} \quad (1)$$

Where, a is the value of the coordinate “ a ”, t is the average minimum temperature over the 14 days prior to the measurement of the fruit color in °C. The parameters to estimate are b , c , and d : b refers to the high of the function, c is related to the range where the function has the maximum slope, and d refers to the slope of the function.

RESULTS AND DISCUSSION

Relationship between the Minimum Temperatures and Coordinate “ a ”

As demonstrated in previous work (Manera *et al.*, 2012a), the increase of coordinate a indicates the beginning of degreening (decrease of negative values) and this occurs when the daily minimum temperature drops below 10.5°C, for at least two days. Han *et al.* (2012) studied the effect of global warming on the characteristics of the fruit of the 'Niiitaka' pear fruit (*Pyrus pyrifolia*

Nakai). They found that, regarding the skin colour of the fruit, the Hunter L and b values did not differ significantly between treatments, while the Hunter a^* value was higher for the treatments involving a higher temperature and CO₂ concentration. Our data agree with this study as Figure 2 shows the evolution of both variables a and temperatures in 2008, their behaviour being very similar in other years. The value of coordinate a is the average of the three cultivars for each date.

There is a clear relationship between a decrease in the temperature and the increase in the value of coordinate a (i.e. degreening) of the lemon peel (Figure 2). The initial green color of the lemon peel corresponds to values of coordinate a of -15 and the fruit gradually lose their green color (negative values) through the autumn as the already-existing yellow - masked by the green of the chlorophylls – becomes apparent during the fruit ripening.

In another study of climate change effects, changes in the texture, flavour and skin color in apple varieties 'Fuji' and 'Tsugaru' were found, which may be due to earlier flowering and higher temperatures during the ripening period as a result of recent global warming (Sugiura *et al.*, 2013).

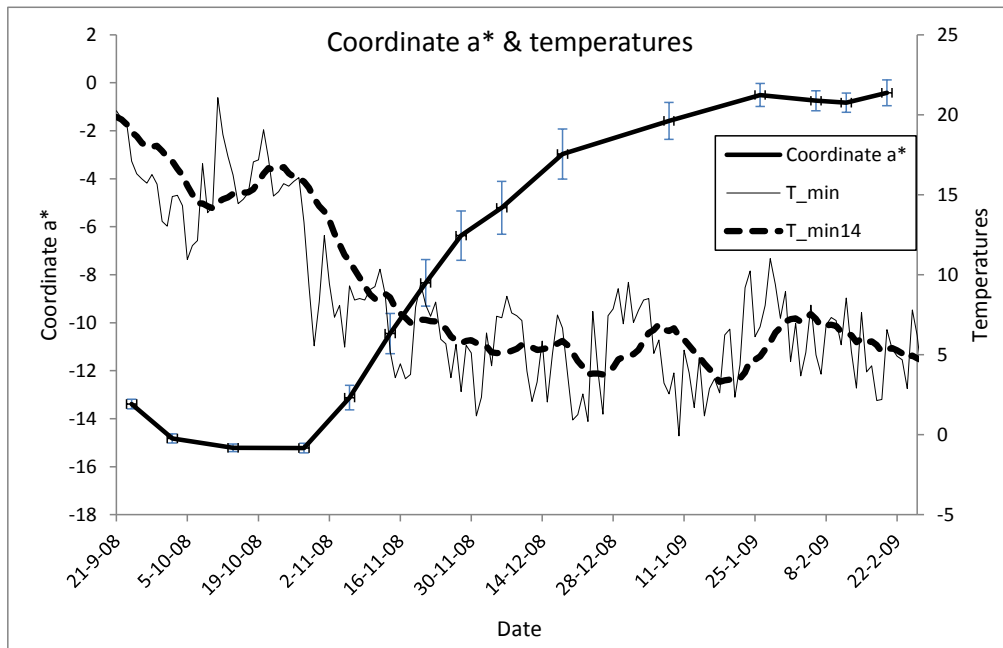


Figure 2. Evolution of the colorimetric coordinate a in the lemon peel, minimum daily temperatures and average minimum temperatures during the 14 days prior to collection of data.

In our study, the analysis was done by comparing the average values of the temperatures of the 14 days prior to the measurement of the color of the fruit - since they show less variability than the daily values - with the variation of the coordinate a .

The correlation between a and $t_{min_{14}}$ is shown in the following equation, which represents the curve of Figure 3.

$$a = \frac{-15.23}{1 + \exp\left(-\frac{(t-9.75)}{1.20}\right)} \quad (2)$$

Where, a is the value of the coordinate color a and t is the average minimum temperature over the 14 days prior to the measurement of the fruit colour (Figure 3). This correlation shows that minimum values are near -15.23, the change in color is produced at a temperature of 9.75°C and 1.20 is just a measure of the slope of the function.

As can be seen, 94% of the increase in the coordinate a (degreening) can be explained by the temperature variation of the 14 days prior to the measurement. Therefore, this

temperature value is a good data to use in the model for predicting degreening.

Starting Point for Degreening

The minimum daily temperatures for the season 2099/100 were estimated according to models Inmcm4 RCP4.5, bcc-csm1-1-m RCP6.0, and HadGEM2-CC RCP8.5 and were compared with the temperatures of the last season (2014/2015) at the experimental site at La Alberca, Murcia (SIAM, 2016). In all cases, the moving 14-day average was obtained.

Figure 4 shows the temperatures for the 2014/15 season and the forecast for the 2099/2100 season, regarding the minimum daily temperatures and average temperatures over 14 days.

In Figure 4, the three climate models predict temperature rises with respect to the curve of the 2014-2015 season (Figure 4). Therefore, the initiation of the degreening process would be delayed and it would take a few more days for a 14-day average temperature of 10.5°C to be reached. In particular, the model HadGEM2-

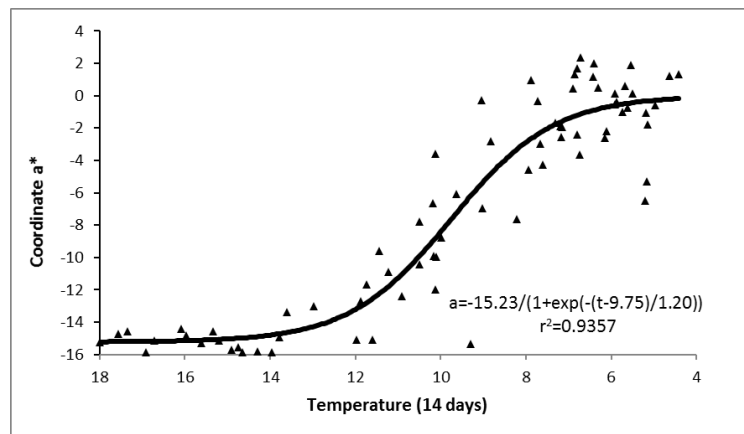


Figure 3. Relationship between the colorimetric coordinate a and the average minimum temperature of the 14 previous days in the seasons 2008-2013.

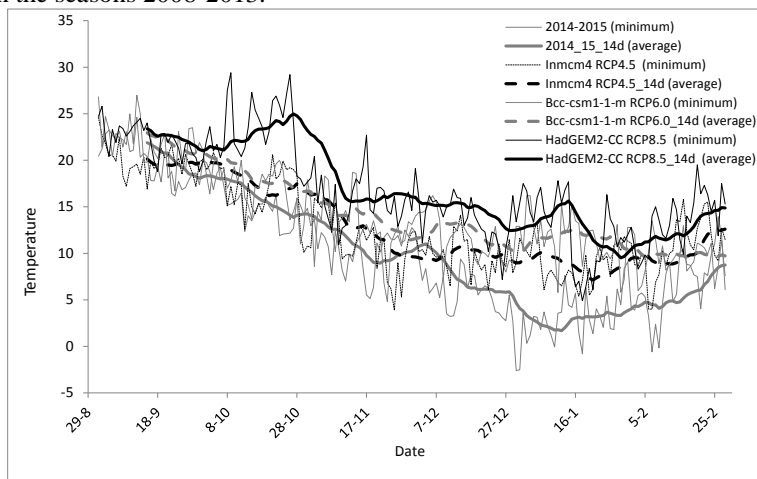


Figure 4. Temperatures recorded in the 2014/2015 season and the forecast for the 2099/2100 season for the minimum daily temperatures and the average temperatures over 14 days (models HadGEM2-CC_RCP8.5, BCCCSM-1-m RCP6.0 and inmcm4_RCP4.5).

CC_RCP8.5 predicts that 10.5°C would not be reached until well into the season.

The forecasts foresee large oscillations in the date of beginning of degreening (10.5°C) (Figure 5) because of the variability of daily temperatures (Figure 4). For this reason, it was decided to take moving averages of the beginning of the greening process. In fact, every point of a line in Figure 5 refers to the average of the previous 10 years.

As can be seen, the inmcm4_RCP4.5 model predicts that the start of degreening would undergo virtually no change (for the coming years it would begin around mid-October, and at the end of the century it would do so at the end of October). In the

case of model HadGEM2-CCRCP8.5, with an average of 10 years, at the end of the century, the beginning of degreening would be delayed until December.

The coordinate a is a function of the coordinate a of the previous day, $a(-1)$, and of the temperature of that day.

$$a = 3.02 + 0.70 \cdot a(-1) - 0.52 \cdot T \min(14) \quad (3)$$

Where, $a(-1)$ is the value of the coordinate a on the previous day and $T \min(14)$ is the average of the minimum temperatures of the previous 14 days predicted according to the different models (in all cases, values were

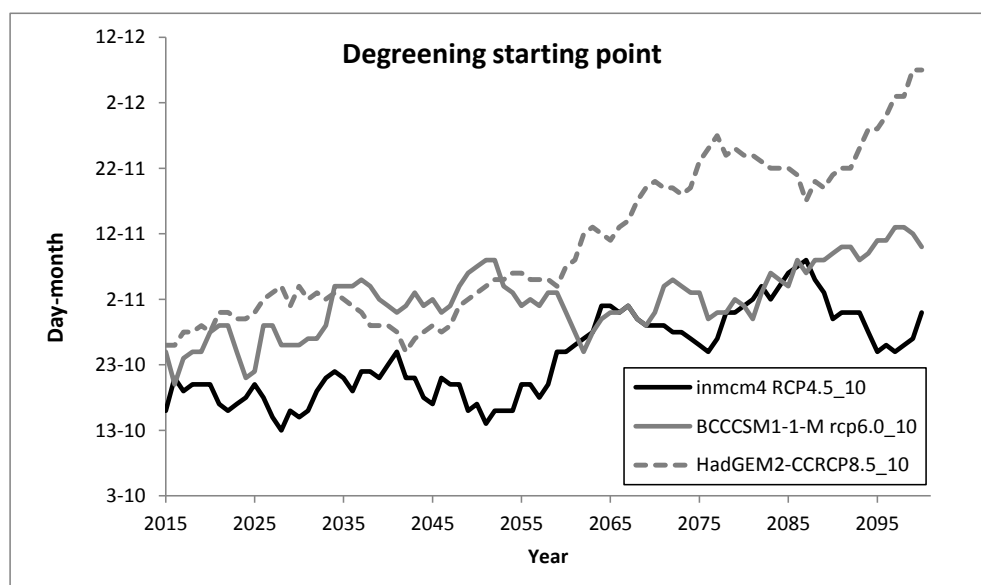


Figure 5. Evolution over time of the start of the process of degreening for models Inmcm4_RCP4.5, BCCCSM1-1-m RCP6.0 and HadGEM2-CCRCP8.5, and the 10-year average for each model.

recorded over 5 years). Since measurements were not done daily, linear interpolation between two consecutive measurements was performed to obtain the value of that coordinate the day before each measurement.

In the area of Murcia, the evolution of degreening according to the climate models is illustrated in Figure 6.

For the Inmcm4_RCP 4.5 model, which gives the most-favourable predictions, the beginning of the degreening process (starting of the increase of a) would not be delayed significantly beyond November 1 over the years. But the final colour of the lemon peel, with maximum values of coordinate a between -4 and -6, would be greenish and not totally yellow, as in 2008 (Figure 6-a).

According to the BCCCSM-1-m RCP6.0 model, which gives predictions more unfavourable than those of the previous model, the start of degreening would be delayed by several weeks compared to the previous model and the degreening would be poorer still in 2099, i.e. coordinate a having a value of -8, indicating that the lemon peel would still be greenish (Figure 6-b).

Predictions of HadGEM2-CCRCP8.5 model, the most unfavourable predictions (higher temperature rise), indicate that, in the

years from 2020 to 2050, the degreening behaviour would be similar to that of the previous model. However, in 2075 and 2099, the start of degreening would be delayed until the second week of December - the lemon peel reaching maximum values of coordinate a of about -9, indicating that the fruits on the tree would still be green in December (Figure 6-c).

These three studied models forecast a gradually increasing delay in the start of degreening, consistent with that shown in Figure 5. In each year, there would be a reduction in breakdown of green color and, in the final years, according to the model providing the least-favourable estimates, the fruits will not turn yellow (values of coordinate a around -10, fruits still green). Therefore, in a climate change scenario, the fruits harvested in November would be green, without having begun the process of degreening, necessitating their placement in a degreening chamber. Harvesting would continue to occur when the fruits on the tree have had a calibre (diameter) of 56 mm and a percentage of juice higher than 20% for their optimal commercialization. The degreening costs over the season would increase because, during the autumn, the

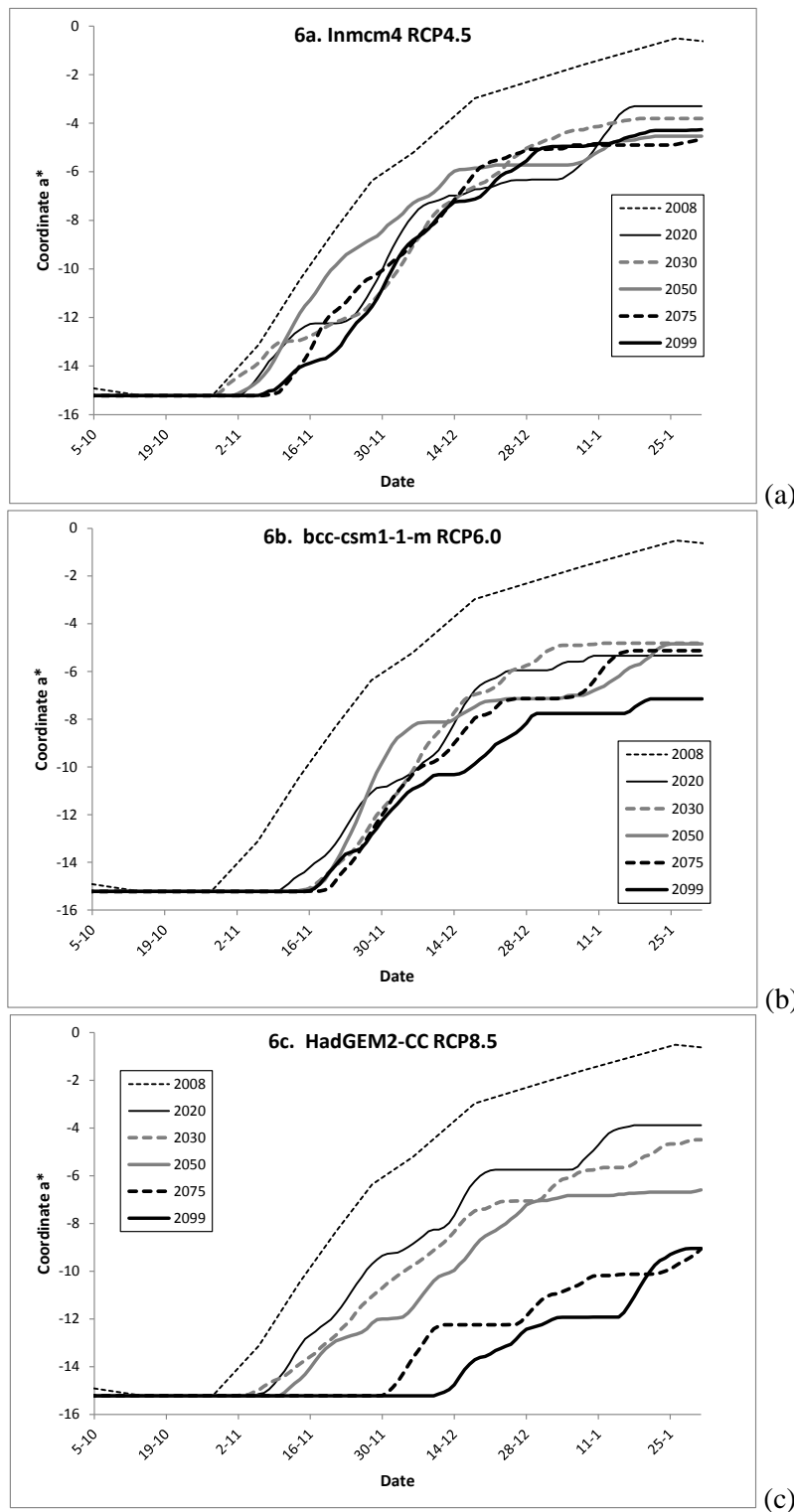


Figure 6. Estimation of the evolution during the autumn and winter of the coordinate a according to the models (a) Inmcm4_RCP4.5; (b) BCCSM-1-m RCP6.0, and (c) HadGEM2-CC RCP8.5, and using the mean values of the proceeding 10 years for different years (2020/2021, 2030/2031, 2050/2051, 2075/2076 and 2099/2100). The comparison with the 2008 season is shown.

fruit would need to be kept for more days in the chamber to reach adequate yellow color. The harvest costs would remain the same, but harvesting would have to be performed carefully to avoid damage to the fruits, which, later in the degreening chamber, would cause spots to appear on the part of the fruit that had been struck. The harvest and storage costs would rise. It would be advisable to search for cultivars that degreen earlier or degreen well in a chamber. Climate change in areas that are not cold (frost-free) would allow expansion of the existing cultivation area of citrus.

CONCLUSIONS

In all the models tested, the start of degreening was delayed by one week to a maximum of almost two months. None of the models predicted that the commercial yellow color of the fruits would be reached on the tree. Currently, lemons on the tree reach their commercial color in mid-December without applying artificial degreening techniques. According to the models tested here, without these artificial treatments, lemon quality will not be desirable. Due to the delay in the start of the natural degreening on the tree and the failure to achieve a yellow color adequate for marketing, the use of degreening chambers in the future will increase, and thus production costs will rise.

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اثر تغییر آب و هوا روی تغییر طبیعی رنگ سبز لیمو (*Citrus limon* L. Burm. f)

م. ارنای، ج. م. بروتونز، ا. کونسا، ف. ج. مانرا، ر. کاستانر، و. ی. پوراس

چکیده

در این پژوهش، اثر درجه حرارت کمینه هوا روی تغییر رنگ میوه لیمو از سبز به زرد در سه سناریو تغییرات آب و هوایی بررسی شد. با کاهش درجه حرارت در اوایل پاییز، کلروفیل درون میوه لیمو شکسته شده و در نتیجه لیموها به طور طبیعی رنگ زرد ویژه به خود را می گیرند. در این بررسی، بر پایه سه مدل آب و هوایی که در آن ها تغییرات درجه حرارت تا سال ۲۱۰۰ پیش بینی شده، اثر تغییرات آب و هوایی روی تغییر طبیعی رنگ سبز لیمو ها تجزیه تحلیل شد. بر پایه این مدل ها، به علت افزایش درجه حرارت هوا، شروع تحول رنگ بین یک هفته تا دو ماه به تاخیر می افتد. ولی، در هیچیک از این موارد، لیمو ها در روی درخت به رنگ (زرد) ویژه خود نخواهند رسید، بنا بر این لازم خواهد بود که برای رسیدن به رنگ تجارتي مطلوب از اتاقک های تغییر رنگ سبز (degreening chambers) استفاده کرد، که معنایش افزایش هزینه تولید است.