# EFFETTI DEL CAMBIAMENTO CLIMATICO SULLA FENOLOGIA DEL FRUMENTO IN ITALIA: UN CASO STUDIO

## *CLIMATE CHANGE EFFECTS ON WHEAT PHENOLOGY IN ITALY: A CASE STUDY*

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**Abstract**
Successful bread wheat (*T. aestivum*) cropping in Italy is strongly menaced by climate change (CC): variations in temperature affect plants' phenology, being temperature the major driving force of plants' development. Hence, we assessed the effect of CC on bread wheat phenological development, through a case study in the Emilia-Romagna region (North of Italy), where temperatures have steadily increased since the 1950s. Bread wheat phenological development has been compared in two 15-years periods before and after the breakpoint in the increasing trend of mean annual air temperature in the area, i.e. 1952-1966 (past-period), and 2007-2021 (present-period). The climatic characterization confirmed that the two 15-year periods showed different climatic characteristics. A significant shortening of the chronological time necessary to reach the phenological phases of booting, heading, beginning of anthesis, and full ripening (BBCH stages 40-49, 50-59, 61 and 89 respectively) from sowing date was observed for the present-period compared to the past-period. The average wheat life cycle length in the past-period was 244 ± 6 days, in the present period it was, in average, 223 ± 22 days. The precise definition of CC impact on wheat phenological development represent an important tool for modeling applications, aimed at identifying climate smart agriculture strategies, useful for mitigating the impact of rising temperatures on yield and grain quality, such as the change in cropping calendar, the development of new cultivars with improved duration of critical phenological phases, optimization of management practices.

**Parole chiave:**
Scala BBCH, Gradi Giorno, Emilia-Romagna
**Keywords:**
BBCH scale, Growing Degree Days, Emilia-Romagna

### Introduction

Bread wheat (*Triticum aestivum*) cropping is a fundamental sector of Italian agriculture, with a harvested area of approximately 0.5 Mha, and a production of 2.7 Mtonnes, of which 0.14 Mha and 0.9 Mtonnes in the Emilia-Romagna region (ISTAT). In this region, with a sub-humid climate (average regional annual air temperature equal to 12.8 °C and mean annual precipitation amount of 924 mm - Antolini et al. 2017), climate change (CC) effects have become evident. Specifically, an increasing trend in mean maximum and minimum air temperatures has been observed, accompanied by an increase in heat waves and a reduction in frost days (Tomozeiu et al. 2006). Since temperature is known to be the major driving force of plants' phenological development (Chuine and Régnière 2017), it is essential to address CC impacts on bread wheat phenology in the region. In fact, CC has greatly shifted the timing of major phenological events, producing deep impacts on agricultural management and crops performances (Piao et al., 2019), affecting for example vegetation activity, carbon uptake, water and energy exchanges in the agro-ecosystems (Richardson et al. 2013; Piao et al. 2017; Dusenge et al., 2019). So, phenological observations are extremely important for modeling purposes, as they allow to foresee the manifestation of key phases during crop cycle, essential to guide agricultural management. Aim of this study was to assess the effect of CC on bread wheat phenological development in Italy, through a case study in the Emilia-Romagna region.

### Materials and methods

Phenological and meteorological data were analyzed in the experimental farm of the University of Bologna in Cadriano (BO, Lat 44°32'58''N, 11°21'15''E), a representative site of the climate of the Emilia-Romagna region. To evaluate CC effects on wheat phenology, two 15-years periods have been compared: the growing seasons 1951/1952 – 1965/1966 (past-period), and the growing seasons going from 2006/2007 to 2020/2021 (present-period). These two periods refer respectively to a pre and a post CC time for the area considered, since they fall respectively before and after the identified break point in the increasing trend of mean annual air temperature in the area (Matzneller et al., 2010). Phenological data for the past-period on four wheat varieties, i.e. San Giorgio, San Pastore, Mara, and Fortunato, were obtained from bibliography evaluating the performances of these varieties in long-lasting agronomic surveys (Quagliotti 1957; Antoniani 1960; Antoniani 1971). The same phenological data were obtained for the present-period from the phenological bulletin, weekly released by the Department of Agricultural and Food Sciences (DISTAL), based on survey of the wheat cultivar Mieti at the agrophenological station in Cadriano. Phenology data are

encoded using the BBCH scale. The station is run following the methods stated in the Phenagri project (Pasquini et al., 2006). The link between temperature and phenology is expressed in Growing Degree Days (GDDs), calculated starting from air temperature.

- For GDDs calculation, daily temperature data were provided by DISTAL agrometeorological station mechanical series that goes from January 1st 1952 to the present, representing a continuous and uniform historical series, measured near the plots where the phenological data for both periods were collected (Ventura et al. 2002; Matzneller et al. 2010). The same weather data for the last quarter of 1951, were kindly provided by ARPAE Emilia-Romagna, and refer to the Bologna IdroGrafico station. Other than mean air temperature, precipitation data from the same time series were analyzed using the Bagnouls and Gaussen (B&G) climate Index (Bagnouls and Gaussen 1957), in order to climatically characterized the two considered 15-years period. As the definition of B&G climatic index states, when the twice-monthly precipitation curve lies below the monthly average temperature curve, the so-called aridity period is identified
- For each variety in each agronomic season, the chronological time, expressed as Days after Sowing (DAS), and the Cumulative Growing Degree Days (CGDDs) necessary to reach several BBCH stages were calculated using the Single Triangle method (Snyder et al. 1999), with a base temperature of 0 °C (Steduto et al. 2012). In particular, stages 40-49 (booting), 50-59 (heading), 61 (beginning of anthesis) and 89 (full ripening) were analyzed.
- Statistical analysis was performed using R. To be sure that any differences among the varieties for the achievement of BBCH stages, in terms of chronological time from sowing (DAS), were not due to a different precocity, the corresponding CGDDs for each variety in the 15 years were subjected to statistical comparison. Non-parametric Kruskal - Wallis test was used, since data were homoscedastic, but did not met normal distribution (verified by Levene and Shapiro-Wilk test, respectively). To statistically verify the significance of the difference between past-period and present-period in terms of DAS, the average values of the 4 varieties of past-period over the 15 years, were compared with the values of Mieti, using Wilcoxon Rank Sum test, since data did not satisfy normal distribution (verified by Shapiro-Wilk test).

**Results**

The B&G diagrams of past-period and present-period are presented in figure 1. Diagrams represent 15 years averaged data, obtained starting from the daily weather data of the aforementioned mechanical time series. Present-period showed an evident aridity period, concentrated between the months of June and August, absent in the past-period, highlighting the different climatic characteristics of the two considered periods.

CGDDs values necessary to achieve BBCH stages 40-49, 50-59, 61 and 89 in 15 agronomic seasons were calculated using the Single Triangle method for 5 varieties: S. Pastore, Mara, Fortunato and S. Giorgio for the period 1951/52 - 1965/66, Mieti for the period 2006/07 - 2020/21. The Kruskal – Wallis test was applied to the data. The test did not show any statistically significant difference for stages 40-49, 50-59, 61 and 89 ($P > 0.05$). All the five varieties considered, therefore showed, starting from the booting phase, the same requirements in terms of thermal thresholds for reaching the phenophases, until the end of their cycle, as shown in Figure 2A. The past-period data is expressed as the average of the 4 varieties.

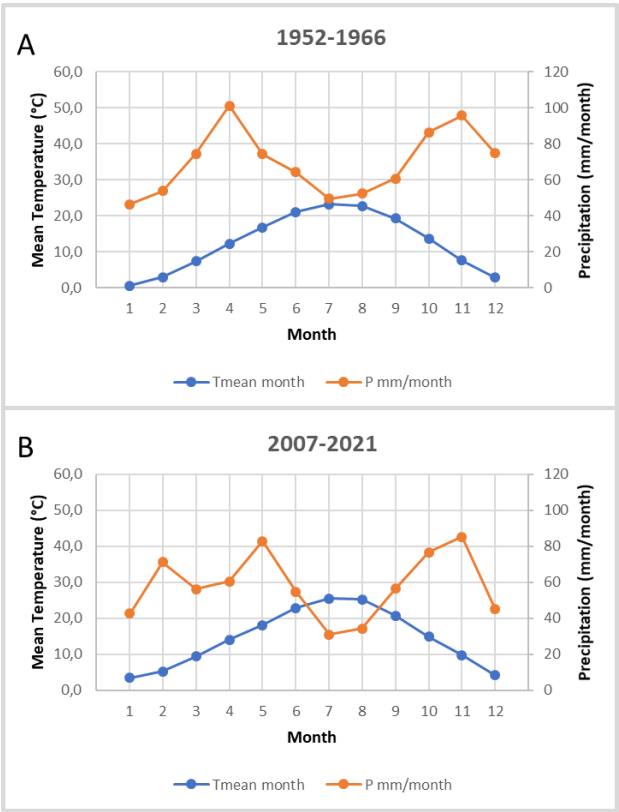


*Fig. 1 Diagramma di Bagnouls e Gaussen per i due periodi a confronto. Quando la curva delle precipitazioni si trova al di sotto della curva della temperatura media mensile, si identifica il cosiddetto periodo di aridità*

*Fig. 1 Bagnouls and Gaussen diagram for the two periods under comparison. When the twice-monthly precipitation curve lies below the monthly average temperature curve, the so-called aridity period is identified*

To verify if wheat life cycle has significantly shortened compared to the past, especially the generative period going from flowering to ripening, DAS between the average values of the four varieties of past-period and the values of the present variety Mieti in 15 growing seasons, were compared. As regards BBCH stages 40-49, 50-59, 61 and 89, Wilcoxon Rank Sum test was applied, and a significant shortening of the chronological time necessary to reach the aforementioned phenophases from sowing date was observed for the present-period ($P < 0.05$). The average life

cycle length in the past-period was 244 ± 6 days, compared to the average 223 ± 22 days in the present-period. Figure 2B shows DAS necessary to reach 40-49, 50-59, 61 and 89 BBCH stage in past-period (mean of 4 varieties) and present-period (Mieti).

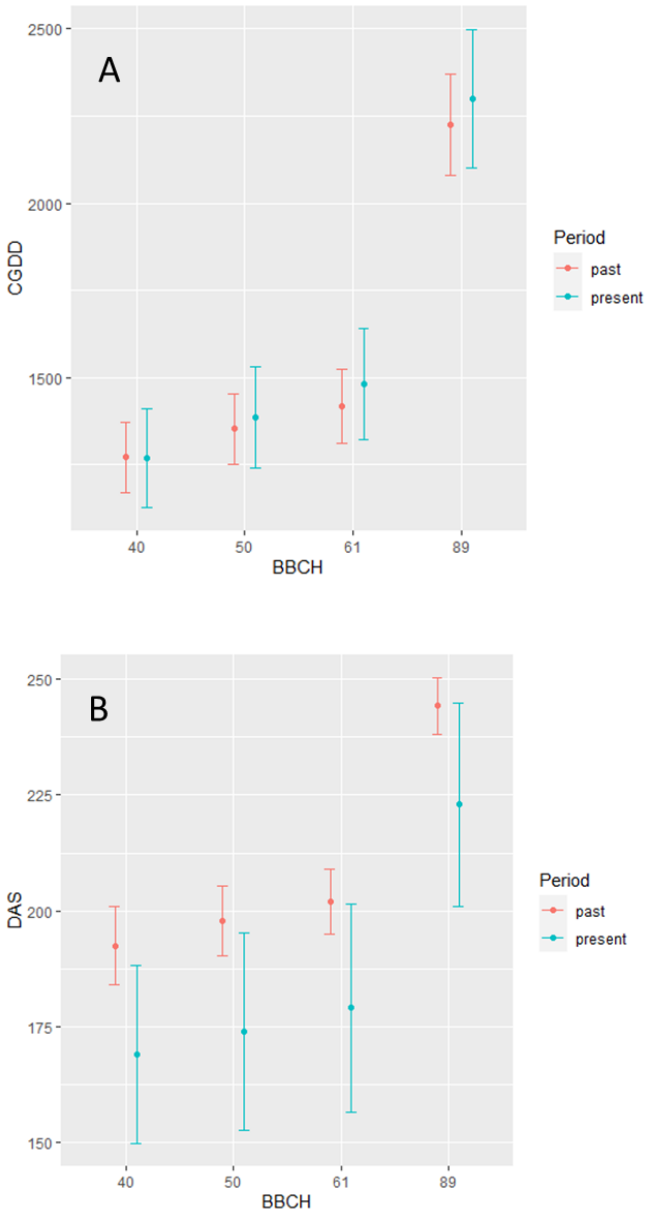


*Fig. 2A – Gradi giorno cumulati (CGDD) necessari per raggiungere le fasi BBCH selezionate. 2B - DAS necessari per raggiungere le fasi BBCH 40-49, 50-59, 61 e 89 nel passato (media di 4 varietà) e nel presente (Mieti). I punti rappresentano la media di 15 stagioni agronomiche, le barre superiore e inferiore rappresentano una deviazione standard)*

*Fig. 2A – Cumulative Growing Degree Days (CGDDs) necessary to reach the selected BBCH stages. 2B - DAS necessary to reach 40-49, 50-59, 61 and 89 BBCH stage in past-period (mean of 4 varieties) and present-period (Mieti). Dots represent the mean of 15 agronomic seasons, upper and lower bars represent one standard deviation.*

**Discussion**

Temperatures have steadily increased since the 1950s in the Emilia-Romagna region (Tomozeiu et al., 2006).

Aim of this case study was to verify whether CC has produced considerable effects on bread wheat phenological development. Phenological data of two 15 growing seasons periods, selected before and after the temperature breakpoint, have been compared, both in terms of CGDDs and DAS necessary to reach BBCH stages 40-49, 50-59, 61, 89. The climatic characterization of the past-period and the present-period, through the Bagnouls - Gaussen diagram, confirmed that the two 15-year periods examined showed different climatic characteristics. As for CGDDs, the thermal threshold necessary to reach phenophases 40-49, 50-59, 61 and 89, showed no differences for any of the varieties involved in this study ($P > 0.05$), assuring that differences between the two periods in chronological time (DAS) for the achievement of the phenological stages from booting forward, were not due to a different precocity of the varieties, but were the effect of the increase in temperatures produced by CC.

Starting from booting, and up to full ripening, a clear and significant ($P < 0.05$) anticipation of wheat life cycle emerged in the present-period, compared to the past-period. On average, 169 ± 19 days vs 193 ± 8 days for booting, 174 ± 21 days vs 198 ± 7 days for heading, 179 ± 22 days vs 202 ± 7 days for beginning of anthesis, and 223 ± 22 days vs 244 ± 6 days for the achievement of stage 89. Furthermore, the high standard deviation in the present period compared to the past period from heading onwards (about three fold), demonstrate the high inter-annual variability linked to CC.

**Conclusions**

In conclusion, this case study quantified CC effects on bread wheat phenology in the Emilia-Romagna region, highlighting a significant shortening of wheat life cycle. The acceleration of wheat life cycle under rising temperatures can have negative consequences on both yield and grain quality, due to the shortening of phenological events, such as vegetative and grain filling period. This reduction in time may affect both photosynthesis and assimilates translocation to the forming grains (Zacharias et al., 2010), also altering carbon balance and evapotranspiration demand (Barnabás et al., 2008; Fatima et al., 2020). This case study allowed first of all to measure how CC influenced the agricultural ecosystems in the Emilia-Romagna region, through the precise quantification of phenological changes for a major crop in the area. Moreover, the precise definition of CC impact on wheat phenological development represent an important tool for modeling applications, aimed at identifying climate smart agriculture strategies, useful for mitigating the impact of rising temperatures on yield and

grain quality, such as the change in cropping calendar (i.e. sowing date), the development of new cultivars with improved duration of critical phenological phases, the optimization of management practices (i.e. fertilizers and irrigation water use efficiency).

**References**


Antolini G., Pavan V., Tomozeiu R., Marletto V.., 2017. Atlante climatico dell'Emilia-Romagna 1961–2015, edizione 2017. ARPAE Emilia-Romagna, Servizio IdroMeteoClima

Antoniani C., 1960. Terzo quadriennio di prove su varieta di frumento nella pianura bolognese.

Antoniani C., 1971. Un ottennio di prove con varietà di frumento tenero nella pianura bolognese. Rivista di Agronomia. Rivista di Agronomia:3-21

Bagnouls F., Gaussen H., 1957. Les climats biologiques et leur classification. In: Annales de géographie. vol 355. JSTOR, pp 193-220

Barnabás B., Järgen K., Fehér A., 2008. The effect of drought and heat stress on reproductive processes in cereals. Plant Cell Environ 31:11–38.

Chuine I., Régnière J., 2017. Process-based models of phenology for plants and animals. Annual Review of Ecology, Evolution, and Systematics 48:159-182. doi:10.1146/annurev-ecolsys-110316-022706

Djanaguiraman M., Narayanan S., Erdayani E., Prasad P.V., 2020. Effects of high temperature stress during anthesis and grain filling periods on photosynthesis, lipids and grain yield in wheat. BMC Plant Biology 20., 1.:1-12. doi:10.1186/s12870-020-02479-0

Dusenge M.E., Duarte A.G., Way D.A., 2019. Plant carbon metabolism and climate change: elevated CO 2 and temperature impacts on photosynthesis, photorespiration and respiration. New Phytologist 221., 1.:32-49. doi:10.1111/nph.15283

Fatima Z., Ahmed M., Hussain M., Abbas G., Ul-Allah S., Ahmad S. et al.., 2020.. The fingerprints of climate warming on cereal crops phenology and adaptation options. Scientific Reports, 10(1., 1-21.

ISTAT. https://www.istat.it/it/agricoltura?dati doi:10.1016/j.plantsci.2020.110412

Lieth H., 1974. Purposes of a phenology book. In: Phenology and seasonality modeling. Springer, pp 3-19

Matzneller P., Ventura F., Gaspari N., Rossi Pisa P., 2010. Analysis of climatic trends in data from the agrometeorological station of Bologna-Cadriano, Italy., 1952–2007.. Climatic change 100., 3.:717-731. doi:10.1007/s10584-009-9686-z

Pasquini A., Botarelli L., Dal Monte G., Traini S., 2006. Il rilevamento agrofenologico: dall'osservazione in campo alla registrazione dei dati. Ufficio di Ecologia Agraria,

Piao S., Liu Q., Chen A., Janssens I.A., Fu Y., Dai J., Liu L., Lian X., Shen M., Zhu X., 2019. Plant phenology and global climate change: Current progresses and challenges. Global change biology 25., 6.:1922-1940. doi:10.1111/gcb.14619

Piao S., Liu Z., Wang T., Peng S., Ciais P., Huang M., Ahlstrom A., Burkhart J.F., Chevallier F., Janssens I.A., 2017. Weakening temperature control on the interannual variations of spring carbon uptake across northern lands. Nature Climate Change 7., 5.:359-363. doi:10.1038/NCLIMATE3277

Plaut Z., Butow B., Blumenthal C., Wrigley C., 2004. Transport of dry matter into developing wheat kernels and its contribution to grain yield under post-anthesis water deficit and elevated temperature. Field Crops Research 86., 2-3.:185-198. doi:10.1016/j.fcr.2003.08.005

Quagliotti F., 1957. Secondo quadriennio di prove su cultivar di frumento nel piano bolognese. Annali della Sperimentazione Agraria 11., 3-4.:821

Richardson A.D., Keenan T.F., Migliavacca M,. Ryu Y., Sonnentag O., Toomey M., 2013. Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. Agricultural and Forest Meteorology 169:156-173. doi:10.1016/j.agrformet.2012.09.012

Snyder R.L., Spano D., Cesaraccio C., Duce P., 1999. Determining degree-day thresholds from field observations. International Journal of Biometeorology 42., 4.:177-182. doi:10.1007/s004840050102

Steduto P., Hsiao T.C., Fereres E., Raes D., 2012. Crop yield response to water, vol 1028. Food and Agriculture Organization of the United Nations Rome,

Tomozeiu R., Pavan V., Cacciamani C., Amici M., 2006. Observed temperature changes in Emilia-Romagna: mean values and extremes. Climate Research 31., 2-3.:217-225. doi:10.3354/cr031217

van Dongen J.T., Roeb G.W., Dautzenberg M., Froehlich A., Vigeolas H., Minchin P.E., Geigenberger P., 2004. Phloem import and storage metabolism are highly coordinated by the low oxygen concentrations within developing wheat seeds. Plant Physiology 135., 3.:1809-1821. doi:10.1104/pp.104.040980

Ventura F., Rossi Pisa P., Ardizzoni E., 2002. Temperature and precipitation trends in Bologna., Italy. from 1952 to 1999. Atmospheric Research 61., 3.:203-214. doi:10.1016/S0169-8095(01.00135-1

Whitechurch E., Slafer G., Miralles D., 2007. Variability in the duration of stem elongation in wheat genotypes and sensitivity to photoperiod and vernalization. J Agron Crop Sci 193:131–137. doi:10.1111/j.1439-037X.2007.00259.x

Zacharias M., Singh S., Naresh Kumar S., Harit R., Aggarwal P., 2010. Impact of elevated temperature at different phenological stages on the growth and yield of wheat and rice. Ind J Plant Physiol. 15, 350