PGTF INT/NT/22/K01 “Rethinking climate change mitigation strategies by improving phenological adaptability and tolerance to abiotic stresses in temperate crops”

Narrative Report: The PGTF INT/NT/22/K01 project had three main axes on which work was carried out throughout the 2024 period. Firstly, an executive summary is presented. Then, the main results and products obtained in each axis, including publications are detailed.

Executive summary

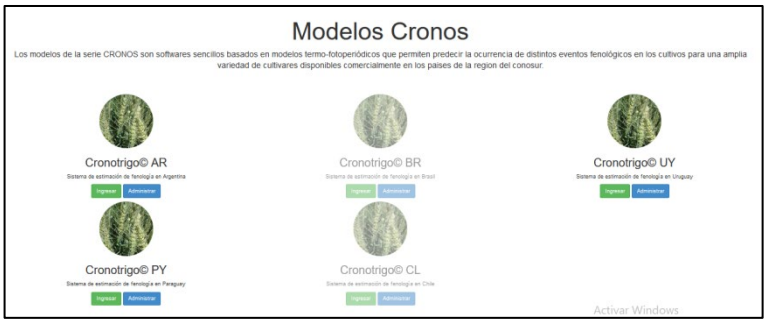
The project was aimed to (1) design a simple quantitative model of phenology prediction for temperate cereals and rapeseed, (2) to evaluate the effect of combined abiotic stresses (e.g. high temperature and waterlogging) in winter crops (wheat, barley, and rapeseed), and (3) actively disseminate the results of the project among farmers, agricultural technicians, and the scientific community. All objectives were successfully achieved during 2024, through field experiments, data analysis, participation in technical meetings, and the publication of scientific articles. The most outstanding achievements of the project include: (i) the expansion of the CRONOS models for wheat (CRONOTRIGO http://cronotrigo.agro.uba.ar/) and barley (CRONOCEBADA http://cronocebada.agro.uba.a) and the development of the new CRONOS model for canola (CRONOCANOLA http://cronocanola.agro.uba.ar/), available free of charge, allowing the users establish the best sowing date for each particular genotype of each crop specie quantifying the risk of environmental stress for the main temperate productive areas of the Southern Cone, (ii) the establishment of a new plant growth chamber that expands the facilities for the study of stress in crops, and (iii) the organization of scientific and technical meetings involving students, advisors, scientist, farmers and technicians, and the publication of 17 papers. In conclusion, the project contributed to strengthening winter farming systems in the Southern Cone and expanding ties between research groups from Argentina, Chile and Uruguay.

Axis 1: Phenological Models for Wheat, Barley and Rapeseed

In this modelling area, work has been done on the three crops mentioned, which are the main winter crops in the Southern Cone region and throughout the world. Phenological prediction models called CRONOS have been designed within the framework of this project. The CRONOTRIGO (for wheat), CRONOCEBADA (for barley) and CRONOCANOLA (for rapeseed/canola and carinata) models have been completed and are available to users free of charge upon user registration.

The CRONOTRIGO model is available in Argentina, Uruguay and Paraguay with a wide range of cultivars not only for baking wheat but also for noodle wheat (commonly known as durum wheat). The domain where it can be accessed is http://cronotrigo.agro.uba.ar (See Figure 1).

The CRONOCEBADA model, which operates on the domain http://cronocebada.agro.uba.ar/, includes the main malting barley cultivars used in the Southern Cone region and is available for the same three countries that have been detailed in the CRONOTRIGO model.



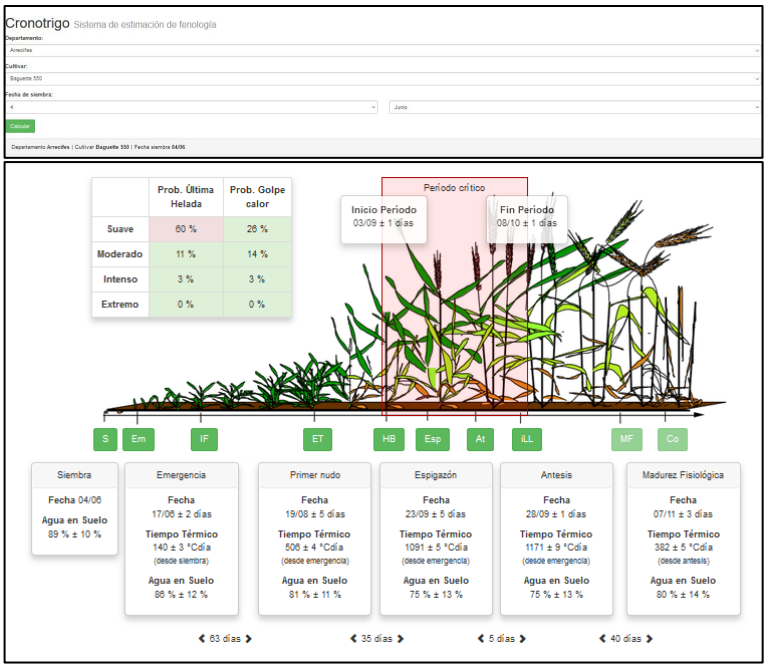


Figure 1. Examples of information output from the CRONOTRIGO model http://cronotrigo.agro.uba.ar

The CRONOCANOLA model was uploaded to the domain http://cronocanola.agro.uba.ar/. This model covers not only rapeseed-canola cultivars but has also incorporated *Brassica carinata*, that has been in full expansion in Argentina and Uruguay, Paraguay and Chile. Carinata is an oilseed crop used to produce biofuel for aviation, and it has surpassed canola in acreage in Argentina. In the case of Uruguay, the most important cruciferous plant has been and continues to be rapeseed-canola. The same is true in Chile, where rapeseed is used as a product for feeding in the fish industry, in addition to the extraction of oil. The CRONOCANOLA model is the most recent of the CRONOS models and the algorithms are being revised since it will be updated with the experiments that have been recently carried out at FAUBA in Argentina and FAGRO-UdelaR in Uruguay (see field experiments in Figure 2).

Figure 2. View of field trials testing genotypes at the School of Agriculture at the University of Buenos Aires FAUBA (Argentina), and at the Faculty of Agronomy at the Universidad de la República FAGRO (Uruguay).

The project funds made it possible to acquire materials for field experiments, laboratory supplies, and technical work to carry out the field experiments and data analysis.
In summary, within the framework of the Perez Guerrero project, new CRONOS models have been developed (for canola and carinata crops) and updated (for wheat and barley). All the models are free and open access, after a simple registration. CRONOS models are used by

more than 45,000 users since its launch, including farmers, agronomists, advisors, technicians, and students of agricultural sciences. During 2024 at least 1500 new users were registered in the CRONOS but the all the CRONO´s models continue being actively used by most of the registered users. The models are in Spanish, as the users are mostly from countries of the South Cone.

Currently, the same working group that forms the Perez Guerrero project is developing a phenological prediction model based on genomic characterization so that it can be used by plant breeders to predict the phenology of new materials to be crossed through a combination of parents. This work derived in a scientific publication accepted with minor revision in Plant Physiology Journal (see details in Axis 3). The name of the model to be developed is CRONGENWHEAT and this model can be universally used for farmers and mostly by plant breeders, and thereby can be used in both languages Spanish and English.

As future perspectives, CRONOS models are planned to be extended not only to other countries in the Southern Cone region, but the algorithms are also being developed in collaboration with the University of Lleida in Spain in order to extend the construction and use of these models to the European continent, starting with Spain.

Axis 2: Productivity loss functions according to the level of abiotic stress

The second axis of the project was aimed to evaluate, by field experiments, the effect of combined abiotic stresses at different stages of the phenological cycle on productivity of winter crops (wheat, barley and canola).

Negative effects of increased temperature were observed in wheat and rapeseed, when they occur at reproductive stages after flowering. Seed yield penalization was more severe in Buenos Aires (Argentina), with 35% of reduction respect control without heat stress for wheat, and 10% of seed yield reduction for rapeseed, compared to no reduction in Valdivia (Chile). Interestingly, a high plasticity of rapeseed seed weight was observed in Valdivia which partially compensated for the loss of seed number. By contrast, such compensation was not observed in Buenos Aires. In addition to heat stress, the combination with low irradiance stress caused synergistic effects on seed yield. The results highlight the climatic impact of high temperature in mid latitude areas which could move agriculture to higher latitude areas. Also, the results indicate physiological characteristics of seed plasticity, useful to explore in breeding programs aimed at obtaining resilient crops capable of facing climatic change.

The occurrence of waterlogging events throughout the crop cycle in winter crops affected seed yield and end-use quality. In the framework of the project, climatic data from southern South America was analyzed to anticipate how climate change and variability will affect future food availability. Also, results from waterlogging treatments applied to wheat, barley, and canola (in Argentina), and barley, camelina and lupine (in Uruguay) were compared to evaluate tolerance among new cultivars, and design management strategies to avoid yield penalizations. Waterlogging occurring immediately before flowering, combined with high vapor pressure deficit (VPD) conditions caused by high temperatures, significantly increased yield losses per plant compared to temperate control conditions. Rising VPD during waterlogging reduced relative yield at rates of -0.84 kPa^{-1} in wheat and -1.52 kPa^{-1} in barley. These findings suggest that waterlogging in low-latitude regions or under later sowing dates, where the likelihood of increased VPD is higher, intensify its negative impact on yield. The impact of climatic variability on cropping systems in the southern South Cone was also addressed in the context of agriculture intensification and efficient use of resources. The results show the relevance of winter crops in crop rotation, key to the agricultural sustainability of the region.

The project funds made it possible to acquire the materials (panels, lights, cold system) to build a large plant growth chamber at the FAUBA (Buenos Aires), which expands the capacity to apply stress treatments to crops. Also, experiments at field were installed in locations sprayed in Santa Fe (Rosario, Venado Tuerto) and Buenos Aires (Chivilcoy, América) provinces in Argentina, and visited periodically.

Axis 3: Publications and technical meetings associated with the project

The third axis of the project is the extension of the results to farmers, agronomists, technicians, decision makers, and the scientific community. The main results have been published in 17 papers and book chapter. Technical publications were also made in national journals, and preliminary results were shared in symposium and congress. Also, the members of the project were actively engaged in a wide range of field activities aligned with the objectives of the project. Among these activities, some of them are highlighted for their significance as the field days were organized in Chivilcoy (Argentina) and Paysandú (Uruguay) in 2024 as part of the results dissemination activities of the present project and the 14th IBGS (International Barley Genetic Symposium) organized in Rosario Argentina that included a Field day. Around 80 and 150 attendees gathered at each events of Chivilcoy and Paysandú, respectively. Both field days were a gold opportunity to join and share the results of the project. The attendants at the Field day of the 14th IBGS were ca. 170 mostly scientists from different part of world.

The field day in Chivilcoy was on October 17, 2024 in the technology exchange site and experimental field of Plexagro company. Farmers, technicians, and researchers visited demonstrative plots with cultivars of wheat, barley and rapeseed (Figure 3). The event was posted in social media:
https://www.instagram.com/p/DAJETqtOIzU/
https://www.instagram.com/reel/DAZKvVHyjR2/
https://www.instagram.com/reel/DBbYSP9JUHZ/

Figure 3. Field day in Ayarza, near Chivilcoy (Argentina) on October 17, 2024

The field day in Paysandú was on October 22, 2024 in the facilities of Experimental Station Mario A Cassinoni (EEMAC) of the Faculty of Agriculture at the Universidad de la República, Uruguay. Technicians, farmers and researchers from Uruguay and Argentina met at the EEMAC to exchange knowledge and experience in winter crops. They referred to wheat, barley, lupine, pea, and camelina and the impact that abiotic stress has on these crops, from drought to heat waves. The event was posted in the press and social media:
https://www.instagram.com/eemac_agronomia/reel/DBeOgKWxeHo/
https://portal.fagro.edu.uy/seminario-sobre-cultivos-de-invierno-una-oportunidad-para-discutir-y-contrastar-experiencias/
https://www.eltelegrafo.com/2024/10/jornada-sobre-cultivos-de-invierno-en-eemac-permitio-interesante-intercambio-sobre-los-datos-presentados/

Figure 4. Field day at the EEMAC in Paysandú (Uruguay) on October 22, 2024.

In September, Dr. Miralles FAUBA-CONICET together with the University of Agrarian Sciences of Rosario (UNR) organized the 14th International Barley Genetics Symposium (IBGS) at the Rosario Santa Fe Stock Exchange between October 28 and 31, 2024 (See https://ibgs14.agro.uba.ar/). The IBGS has been carried out since 1963, initially held in the Netherlands in Wageningen, and since then it has been held uninterruptedly until the present, being the first time it is held in South America and was held at the Rosario Argentina Stock Exchange. The objective of the IBGS since its creation is to show the latest advances in the different topics associated with barley cultivation, not only from a genetic point of view but also from the biotic and abiotic restrictions that barley cultivation presents and the strategies to increase productivity by making efficient use of inputs. The symposium promotes the exchange of knowledge between researchers from all over the world and is an ideal setting for generating collaboration networks between different working groups for the training of excellent human resources and for generating synergy and efficiency in future research. The 14th IBGS was attended by nearly 200 researchers and postgraduate students from all over the world (Denmark, UK, USA, Spain, Sweden, Germany, Uruguay, Argentina, Finland, Latvia, Estonia, Spain, Italy, etc.) (See Figure 5).

Figure 5: 14th International Barley Genetic Symposium carried out in Rosario City and the Field Day at Zavalla University of Rosario, Sta Fe Argentina.

Published papers in scientific journals and book chapter

1) Alvarez S, Ernst O (2024) Impact of cropping systems on soil quality. **European Journal of Agronomy** 158:127197. https://doi.org/10.1016/j.eja.2024.127197

2) Arata AF, Lázaro L, Tranquilli GE, Arrigoni AC, Dinolfo MI, Rondanini DP (2024) Manipulation of the post-flowering source/sink ratio differentially affects protein composition and gluten quality in contrasting bread wheat genotypes. **Journal of Cereal Science** 117: 103900. https://doi.org/10.1016/j.jcs.2024.103900

3) Bustamante–Silveira M, Siri–Prieto G, Mazzilli SR, Carrasco-Letelier L (2024). Carbon footprint of four bioethanol cropping systems in a temperate region. **Biofuels** 15: 1029–1039. https://doi.org/10.1080/17597269.2024.2327154

4) Fernández-Long ME, Alvarez Prado S, Miralles DJ (2025) Climatic constraints behind spatial and temporal variability of wheat yields in the Pampa region of Argentina. **Agricultural Systems** (in press) https://doi.org/10.1016/j.agsy.2024.104217

5) Fischer AR, Gonzalez FG, Miralles DJ (2024) Breeding for increased grains/m2 in wheat crops through targeting critical period duration: a review. **Field Crops Research** 316: 109497. https://doi.org/10.1016/j.fcr.2024.109497

6) Giménez VD, RA Serrago Abeledo LG, Ciampitti IA, Miralles DJ (2024) Comparative analysis of wheat and barley yield performance across temperate environments. **Field Crops Research** 315: 109339 https://doi.org/10.1016/j.fcr.2024.109339

7) Giménez VD, Ciancio N, Abeledo LG, Miralles DJ (2024) Genetic progress of malting barley potential grain yield between 1982 and 2019 in Argentina. **Field Crops Research** 315: 109435. https://doi.org/10.1016/j.fcr.2024.109435

8) Jardon MR, Alvarez Pardo S, Vanzetti L, Gonzalez FG, Perez-Gianmaro M, Gomez D, Serrago RA, Dubcovsky J, Fernandez Long ME, Miralles DJ (2025). Gene-based model to predict heading date in wheat based on allelic characterization and environmental drivers. **Journal of Experimental Botany** 2023/312222ms (accepted minor revision)

9) Martre, P., Dueri, S., Guarin, J.R. et al. (2024) Global needs for nitrogen fertilizer to improve wheat yield under climate change. **Nature Plants** 10, 1081–1090. https://doi.org/10.1038/s41477-024-01739-3

10) Mori Alvez C, Ernst Benech O, González Barrios P, Perdomo Varela C (2024) Wheat productivity and nitrogen use efficiency in no-till systems: a comparative analysis of crop-pasture and continuous cropping rotations in Uruguay. **Frontiers in Sustainable Food Systems** 8:1460734. https://doi.org/10.3389/fsufs.2024.1460734

11) Rivelli GM, Calderini DF, Abeledo LG, Miralles DJ, Rondanini DP (2024) Yield and quality traits of wheat and rapeseed in response to source-sink ratio and heat stress in post-flowering. **European Journal of Agronomy** 152, 127028. https://doi.org/10.1016/j.eja.2023.127028

12) Rodriguez IM, Lacasa J, van Versendaal E, Lemaire G, Belanger G, Jégo G, Sandaña PG, Soratto RP, Djalovic I, Ata-Ul-Karim ST, Reussi Calvo NI, Giletto CM, Zhao B, Ciampitti IA (2024) Revisiting the relationship between nitrogen nutrition index and yield across major species, **European Journal of Agronomy** 154,127079. https://doi.org/10.1016/j.eja.2023.127079

13) Striker GG, Pampana S, Mollard FPO, Da-Silva CJ., Negrao S, Miralles DJ (2025) Waterlogging stress on cereal, legume, and oilseed crops **In. Crop Physiology: Applications for Genetic Improvement and Agronomy, 3er edition**, Editors: D Calderini, D Bustos-Korts, I Ciampitti, V Sadras Publisher: Academic Press Elsevier (in press)

14) Verdejo J, Calderini DF (pre-print under review) Resilience of rapeseed to heat stress during grain filling in a high yielding environment. https://doi.org/10.1101/2024.12.11.628060

15) Verocai M, González-Barrios P, Mazzilli SR (2024) A comparative study of yield components and their trade-off in oilseed crops (*Brassica napus* L. and *Brassica carinata* A. Braun). **European Journal of Agronomy** 161: 127377. https://doi.org/10.1016/j.eja.2024.127377.

16) Vicentin L, Canales J, Calderini DF (2024) The trade-off between grain weight and grain number in wheat is explained by the overlapping of the key phases determining these major yield components. **Frontiers in Plant Sciences** 15:1380429. https://doi.org/10.3389/fpls.2024.1380429

17) Zachow M, H Kunstmann, DJ Miralles, S Asseng (2024). Multi-model ensembles for national wheat yield forecasts in Argentina. **Environmental Research Letters** 19: 084037. https://doi.org/10.1088/1748-9326/ad627c

Publications in technical journals, congress and symposium

18) XXVIII Reunión Científica Grupo Argentino de Bioestadística. Buenos Aires, 8-10 Oct 2024. Rendimiento y estabilidad de híbridos y variedades de colza primaveral en múltiples ambientes. Vigneau F, Rondanini DP, Puhl LE.

19) 1º Simposio Nacional de colza y otras brasicáceas. INTA Paraná, 12 Sept 2024. Crono canola-carinata: software para predecir fenología. Rivelli G, Alvarez Prado S, Rondanini D, Abeledo G, Grispi J, Ibañez C, Crespo A, Miralles D.

20) 1º Jornada Ambiental UBA. Buenos Aires, 5 Junio 2024. Eficiencia de uso de recursos y aporte de biomasa del cultivo invernal energético Brassica carinata. Rondanini DP, Rivelli GM, Abeledo LG, Ibañez CM, Rodríguez M, Grispi JA, Miralles DJ.

21) A Todo Trigo 2024, 20 años de liderazgo. Sheraton Hotel, Mar del Plata, 9-10 Mayo 2024. https://www.atodotrigo.com.ar/present2.html

22) 12º Jornada de Intercambio Público-Privada, Córdoba, 2024. ¿Cuáles fueron las estrategias de mejoramiento genético de cebada cervecera en Argentina en los últimos 40 años? Ibañez C, Abeledo LG, Rondanini D, Miralles D (2024) **Revista Nexo Agropecuario** Nº 11 edición especial: 18-25. https://revistas.unc.edu.ar/index.php/nexoagro/article/view/45171

Technical Meetings related to the project

23) Jornada Don Mario Chacabuco 14 Noviembre 2024. Enfrentando los retos en el cultivo para una produccion sostenible: Estrategias de manejo enfocadas en el clima.

24) Jornada a campo Barraca ERRO Cultivos de Invierno, Dolores, Uruguay, 24 Oct 2024. Variabilidad climática y desarrollo de colza. Llenado de granos, desecantes y cosecha de colza.

25) Jornada Técnica organizadas por la Estación Experimental Mario A.Cassinoni (EEMAC) en Paysandú, Uruguay, 22 Octubre 2024. Impacto de los Estrés Abióticos en Cultivos de Invierno: Desde Anegamientos hasta Golpes de Calor.

26) Sitio Intercambio Tecnologico Plexagro Chivilcoy, Pcia BsAs 17/10/24. Pautas para el manejo de Trigo.

27) International Barley Genetic Symposium. Field Day at Zavalla (Santa Fe province, Argentina). Plots of barley genetic progress in Argentina and Uruguay. 30th October, 2024.

Other technical meetings with producers and advisors in which the group has participated

28) Jornada Tecnica de Stoller Expertime. Jornada Tecnica de co creacion con referentes. Iguazú 18-21 Agosto 2024. Misiones.

29) ¿Qué decisiones de manejo tenemos que tener en cuenta en trigo de diferente calidad panadera? 5ta Jornada A Puro Trigo Molinos Carhue, Epecuen, Pcia BsAs 12/6/2024

30) Analisis de Campaña Cultivos de Invierno CREA Monez Cazon, Pehuajo, Pcia BsAs 17/4/24

31) El complejo Triguero en Argentina Asreas de Produccion, rendimiento y calidades. Sociedad Industrial Kuntsmann, Valdivia Chile 11/4/24

32) Analisis de Campaña Grupo GAER Cultivos de Invierno. Gualeguaychu Entre Rios 4/4/24

33) Experiencia y Estrategias de Manejo en Colza. Jornada Actualizacion Tecnica Bunge San Miguel de Tucuman, Tucuman 19/03/24

34) Experiencia y Estrategias de Manejo en Colza. Jornada Actualizacion Tecnica Bunge Victoria Entre Rios 26/03/24

35) 1º Simposio Nacional de colza y otras brasicáceas. INTA, Paraná, 12 Sept 2024. Desafíos del cambio climático y adaptación de las Brassicas.

Concluding remarks

The development of the project was extremely positive. Despite the economic constraints in Argentina and the delay in the design of the funds, the researchers from Argentina, Chile, and Uruguay were able to achieve all the proposed objectives.

The key achievements of the project were: (i) the update and development of the CRONOS models for wheat, barley and rapeseed; (ii) the installation of a plant growth chamber that enhancing the capacity of our research group to study crop stresses under controlled conditions; (iii.1) the successful organization of different field days with farmers and technicians, and (iii.2) the publication of scientific papers in academic journals as well as in congresses and symposiums. In conclusion, the project contributed to strengthening winter farming systems across the Southern Cone and promoted stronger collaboration among research groups from Argentina, Chile and Uruguay.