Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

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Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

1. **Introduction**
   - Climate change
   - Effects of climate change
     - Direct
     - Indirect
   - Why Grapevine? Why Tempranillo grapevines?
   - Effects of climate change in Mediterranean area.
   - Aim

2. **Materials and Methods**
   - Climate change scenarios simulation
     - Temperature Gradient Greenhouses (TGG)
   - Experimental design
   - Parameters:
     - Phenology
     - Yield
     - Berry Must Quality (Technological and Phenolic Maturity)

3. **Results and discussion**
   - Phenology-Yield-Berry Quality

4. **Conclusions**
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

Climate Change

• An effect of human activities
• Major ecological, social and economic problem of the planet.

• Effects:
  • Increasing temperature (1.4 to 5.8°C)
  • Widespread melting of snows and ice
  • Rising global sea levels
  • Decreasing rainfall
  • Changing species distribution
  • Plant vulnerability and mortality
  • Affecting crops, etc.

• Associated directly and indirectly to:
  ➢ Elevated CO₂
  ➢ Temperature increase
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Evolution of the atmospheric CO$_2$ concentration in the last 50 years.

Evolution of the atmospheric CO$_2$ concentration and temperature during the last 400,000 years (Ice cores, Antartica).

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Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

**Direct Effects of Elevated CO$_2$**

**In the short time period:** Increasing photosynthesis and growth.

**In the long time period:** Decline of photosynthesis → Acclimation

\[
\text{Effect of acclimation} = \frac{A_{CO_2} \text{ (plants grown at elevated CO}_2\text{ and measured in elevated CO}_2\text{)}}{A_{CO_2} \text{ (plants grown at ambient CO}_2\text{ and measured in elevated CO}_2)}
\]

Bunce et al., 2000

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400 ppm 700 ppm [CO$_2$] Time
Indirect Effects of Elevated CO$_2$

- Increasing of:
  - Temperature
  - Plant Metabolism
  - Plant Growth

- In the cold areas, the temperature can be close to optimum temperature of growth.

- In the warm areas, temperature increase can exceed the optimum temperature and affect physiological processes.

- Changing the duration of seasons.
- Changing phenology.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

Why grapevines?

Grapevine is an economically important crop worldwide that occupies the largest area of cultivated hectares.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

Importance of Red and White Tempranillo grapevines

• Red Tempranillo is one of most commonly grown varieties in the vineyards of many growing areas of Spain, Mexico, New Zealand, South America, South Africa, Australia, Turkey and Canada.

• Therefore it is more widespread in many areas of the planet, so the conclusions that can be obtained from the study will be of great impact on viticulture.

• White Tempranillo is a natural mutant emerged from the red variety, that was found on vines in a vineyard Red Tempranillo Rioja in 1988.

• White wine obtained from the processing of these grapes has been a great interest to the region of La Rioja, Spain.

(Pictures from Juana Martínez, del ICVV, Logroño)
Effects of Climate Change in Mediterranean Area

- In the Mediterranean area, crop yield and quality changes are occurring due to climate change, associated to atmospheric CO₂ concentration increases, enhanced temperatures and scarce water availability (Tubiello et al., 2000).

- Previously, we reported, within the three above mentioned factors, a drastic reduction of vegetative growth under drought conditions in fruit-bearing cuttings of two grapevine (Vitis vinifera L.) cultivars (Red and White Tempranillo)(Kizildeniz et al., 2015).

- Therefore, climate change scenarios and the plant responses is a matter that deserves further investigation.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

Aim

Assess the effect of climate change factors (elevated CO$_2$, high temperature and drought) on grapevines (Red and White Tempranillo) phenology, yield and berry must quality
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Temperature Gradient Greenhouses (TGG)

- Ambient T and Ambient T+ 4°C
- CO₂ Control (400 and 700 mmol mol⁻¹)
- Control of water availability (cyclic drought and full irrigation)
- Illumination (natural intensity and photoperiod)
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

Experimental Design

First experiment in 2013
Second experiment (repetition) in 2014
Third experiment (repetition) in 2015
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

**Phenology-Yield-Berry Quality**

**Phenology:**
Elapsed time from fruit-set to maturity in days, monitoring both the period from fruit-set to veraison and from veraison to maturity.

**Yield:**
Bunch fresh weight in maturity stage (21-23°Brix).

**Berry quality:**
Technological and phenolic maturity parameters were evaluated in maturity stage.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

**Grapevine phenology**

**Fruit-set to Veraison**

58 days

69 days

55 days

Elevated CO₂ and temperature tented to shorten fruit-set to veraison phenological period (although many changes were not significant).
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

<table>
<thead>
<tr>
<th>Year</th>
<th>Variety</th>
<th>Days from fruit-set to maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Red Tempranillo</td>
<td>93 days</td>
</tr>
<tr>
<td>2014</td>
<td>Red Tempranillo</td>
<td>95 days</td>
</tr>
<tr>
<td>2015</td>
<td>Red Tempranillo</td>
<td>81 days</td>
</tr>
<tr>
<td></td>
<td>White Tempranillo</td>
<td>111 days</td>
</tr>
<tr>
<td></td>
<td>White Tempranillo</td>
<td>99 days</td>
</tr>
</tbody>
</table>

Red Tempranillo had consistently shorter phenology than the White one.

\[ P_{(CO_2)} < 0.0001, \quad P_{(T)} < 0.0001, \quad P_{(WA)} = 0.025, \quad P_{(Variety)} < 0.0001, \quad P_{(Year)} < 0.0001, \quad P_{(CO_2 \times Variety)} = 0.021, \quad P_{(WA \times T)} = 0.0001, \quad P_{(WA \times CO_2)} = 0.002, \quad P_{(T \times Year)} = 0.002, \quad P_{(WA \times Year)} < 0.0001, \quad P_{(Variety \times Year)} = 0.005 \]
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Grapevine phenology

**Veraison to Maturity**

Red Tempranillo had shorter veraison to maturity phenological period than White Tempranillo.

Red Tempranillo had shorter veraison to maturity phenological period than White Tempranillo.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

### Results and Discussion

#### Individual and Interacting Effects in Phenology

Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality. ANOVA results show that temperature and CO₂ had influences in almost all phenological phases. Phenology depended on variety and year. Year factor had influence almost in all parameters. Water availability did not have so huge influence alone. However, it had influence with T and CO₂ after veraison.

<table>
<thead>
<tr>
<th>ANOVA P value</th>
<th>Factors</th>
<th>Fruit set to veraison</th>
<th>Veraison to maturity</th>
<th>Fruit set to maturity</th>
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</thead>
<tbody>
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<td><strong>Individual Effects</strong></td>
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<td>&lt;0.0001 ***</td>
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<tr>
<td></td>
<td><strong>P (CO₂)</strong></td>
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<td>0.011</td>
<td>&lt;0.0001 ***</td>
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<td>&lt;0.0001 ***</td>
<td>&lt;0.0001 ***</td>
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<tr>
<td><strong>Interacting Effects</strong></td>
<td><strong>P (Variety x T)</strong></td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
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<tr>
<td></td>
<td><strong>P (Variety x CO₂)</strong></td>
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<td>0.007</td>
<td>0.021</td>
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<tr>
<td></td>
<td><strong>P (Variety x WA)</strong></td>
<td>0.032 *</td>
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<td>ns</td>
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<tr>
<td></td>
<td><strong>P (Variety x Year)</strong></td>
<td>ns</td>
<td>&lt;0.0001 ***</td>
<td>0.005</td>
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<tr>
<td></td>
<td><strong>P (T x CO₂)</strong></td>
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<td>ns</td>
</tr>
<tr>
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<tr>
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<td><strong>P (T x Year)</strong></td>
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<td>0.0001 ***</td>
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</tr>
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<tr>
<td></td>
<td><strong>P (CO₂ x Year)</strong></td>
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<td>0.033</td>
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<td><strong>P (WA x Year)</strong></td>
<td>&lt;0.0001 ***</td>
<td>0.001</td>
<td>&lt;0.0001 ***</td>
</tr>
</tbody>
</table>
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Yield was impacted by drought and year, specially in 2015 due to July heat shocks with a 60% reduction.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

What occurs during the evolution of berry in the quality parameters?

- Sugar and pH
- Acid (Tartaric and Malic acids)
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Temperature and drought increased must pH.

By the contrary, elevated CO2 decreased pH.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Technological Maturity
Total Soluble Sugars (TSS-°Brix)

TSS were increased by both: only elevated CO₂(***) and elevated CO₂ - drought interaction (**).
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Malic Acid
Technological Maturity

Malic acid decreased significantly by temperature increase (***) and less significantly by elevated CO₂ (*).
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Tartaric Acid
Technological Maturity

Tartaric acid increased significantly by elevated CO$_2$ and less significantly by elevated temperature.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Acidity decreased significantly by elevated temperature and drought, having White Tempranillo less acidity than Red one.

Results and Discussion
Grapevine Quality
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Potassium decreased significantly by elevated CO$_2$ (***).

Drought (**), especially in Red Tempranillo, increased potassium.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

### Technological maturity – ANOVA -

<table>
<thead>
<tr>
<th>ANOVA P value</th>
<th>Factors</th>
<th>Brix</th>
<th>pH</th>
<th>Acidity</th>
<th>Tartaric acid</th>
<th>Malic acid</th>
<th>Potassium</th>
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<td>P (T)</td>
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<td>ns</td>
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<td>0.019</td>
<td>&lt;0.0001</td>
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<tr>
<td></td>
<td>P (WA)</td>
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<td>&lt;0.0001</td>
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<td>0.015</td>
<td>0.003</td>
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<tr>
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<td>P (Variety)</td>
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<td>0.042</td>
<td>&lt;0.0001</td>
<td>0.0004</td>
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<td></td>
<td>P (Variety x T)</td>
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<td>P (Variety x WA)</td>
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<td>0.007</td>
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</tr>
</tbody>
</table>

Individual effects have more influence on primary metabolites.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality. Phenolic Maturity

Total Polyphenol Index (TPI)

TPI decreased significantly by elevated temperature and also depends on variety and year.

Results and Discussion
Grapevine Quality - Phenolic Maturity
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

Total Anthocyanins- % Extractable Anthocyanins (EA)- EA Phenolic Maturity

**Results and Discussion**

**Grapevine Quality - Phenolic Maturity**

Total Anthocyanins decreased by drought (**) depending on the year (***) and Temperature, and drought decreased %EA in Red Tempranillo.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

**Tonality Index (Hue) & Color Density Phenolic Maturity**

Results and Discussion

Grapevine Quality - Phenolic Maturity

- Drought increased Tonality index (**) depending on year (***)
- Elevated CO$_2$ (*) and drought (*) increased Color density.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality.

**Phenolic Maturity – ANOVA -**

<table>
<thead>
<tr>
<th>ANOVA $P$ value</th>
<th>Factors</th>
<th>TPI</th>
<th>Total Anthocyanins</th>
<th>Extractable Anthocyanins</th>
<th>% EA</th>
<th>Color density</th>
<th>Tonality Index (Hue)</th>
</tr>
</thead>
<tbody>
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<tr>
<td><strong>Individual effects</strong></td>
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<tr>
<td><strong>Interacting effects</strong></td>
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<tr>
<td>P (WA x Year)</td>
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<td>&lt;0.0001</td>
<td>0.004</td>
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</tr>
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</table>

- Water availability alone and with year factor have more influence on secondary metabolites.
- Generally, secondary metabolites are less influenced than primary metabolites by environmental factors.
Conclusions

Within the three climate change-related factors investigated, drought and temperature (heat shocks) reduced the grapevine production of Red and White Tempranillo.

Regarding the hot topic of climate change effects on plant phenology, this study concludes that grapevine phenology is affected by three climate change related factors: elevated CO$_2$, high temperature and water deficit.

Elevated CO$_2$ and high temperature accelerated the phenology and reduced the number of days to reach a certain phenological stage such as veraison or maturity.

On the contrary, drought slowed down grape development, and increased the number of days to reach veraison and maturity.
Climate change scenarios simulated in temperature gradient greenhouses (TGGs) affect grapevine phenology, yield and berry quality

Conclusions

The period from fruit set to veraison was mainly affected by elevated CO$_2$, while the veraison to maturity period was more impacted by elevated temperature.

Red Tempranillo has a shorter phenological period than White between fruit-set and maturation due to the veraison to maturation period is shorter in Red Tempranillo.

Three year analyses of the berry quality reflect that climate change factors (elevated CO$_2$, elevated temperature and drought) affected in a greater extend the technological maturity parameters (primary metabolism), whereas the phenolic maturity (secondary metabolism) was less impacted.

The response of grape quality (technological and phenolic maturity) to climate change-related factors (elevated CO$_2$, elevated temperature and drought) was highly variable and depended on the year, probably do to the variability of the climate and the interactions among factors defining the climate (temperature, humidity, sunlight etc.).
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Acknowledgements

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