# Pheno-physiological responses of grapevine cultivars vary under the influence of growing season temperature – a study from Pothwar region of Pakistan

R. Rafique[1], T. Ahmad[1], M.A. Khan[1,a], M. Ahmed[2] and A. Atak[3,b]

[1]Department of Horticulture, PMAS Arid Agriculture University Rawalpindi, Pakistan; [2]Department of Agronomy, PMAS Arid Agriculture University Rawalpindi, Pakistan; [3]Department of Horticulture, Bursa Uludağ University Bursa, Turkey.

*Abstract*

**Grapevines are an environmentally sensitive crop, their phenology and physiological responses are driven under the influence of different climatic factors. Among different climatic variables, growing season temperature (GST) is considered as a key driver of phenology and physiological activities. Rising air temperature due to climate change has posed a serious challenge for sustainable grape production. The grape cultivation has spread to non-traditional viticulture zones such as Pothwar region of Pakistan where lack of knowledge on comprehensive understanding of grapevine cultivars is a key challenge. The objective of the present research was to explore the effect of variable growing season temperature on the timings of key developmental stages and associated vine physiological activities in Pothwar – a new emerging viticulture zone of Pakistan. Four commercial table grape cultivars, 'Pelette', 'Sugraone', 'King's Ruby' and 'NARC Black', were selected for the pheno-physiological monitoring at two study sites in Pothwar region of Pakistan. Data were recorded for key growth stages; budburst, 5 leaf, bloom, berry set, vearison and harvest for the 2019 and 2020 vintages. The results indicated that all developmental stages were attained earlier with less photosynthetic activity (up to 31%) and WUE (up to 29%) for the hotter site Chakwal than Islamabad. The length of growth period, budburst to harvest was longer (up to 21 days) for the relatively colder vintage of 2020 with higher photosynthetic activity (up to 12%) and WUE (up to 13%) than for 2019. Grapevine cultivars showed a distinct variability (up to 19 days) for the ripening time with earlier ripening for 'Perlette', whereas higher photosynthetic activity (up to 30%) was recorded for 'Sugraone'. The results of the present study contribute to an improved pheno-physiological understanding for devising adaptation strategies for climate smart and sustainable viticulture industry.**

**Keywords:** table grapes, phenology, photosynthesis, WUE, climatic variability

## INTRODUCTION

Understanding grapevine phenology and physiology is necessary to evaluate the regional suitability for good quality grapes production. Different grapevine cultivars have striking differences in their phenology and physiological activities and these differences are important to select cultivars, with more production and competitiveness of viticulture production under varying climatic conditions (Parker et al., 2013; Koyama et al., 2020; Rafique et al., 2020). The identification of plant physiological responses at key developmental stages such budburst, blooming, setting, veraison, grape maturity is necessary for enhancing the productivity of this high value crop.

Grapevines are highly sensitive to environmental variability and a higher seasonal temperature coupled with dry conditions modifies phenology, physiological activity and fruit quality (Anjum et al., 2020; Rafique et al., 2021, 2023c). Photosynthetic processes in plants

[a]E-mail: drazam1980@uaar.edu.pk
[b]E-mail: arifatak@uludag.edu.tr

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are affected by temperature above 35°C, however, summer air temperature across many viticulture zones exceeds 40°C, which has deleterious effects on grapevine particularly at berry ripening, thus it lowers fruit yield and economic profitability of vineyard (Salvucci and Crafts-Brandner, 2004; Liu et al., 2012; Carvalho et al., 2015). It is critical to quantify grapevine genotypes based on their phenology, physiological activity such as water use efficiency and photosynthetic activity as a useful tool to select genotypes with adaptive traits under varying pedo-climatic conditions.

Pothwar Plateau is an important rain-fed region of Pakistan, having an area of 1.82 million ha with huge agricultural, economic, and cultural value. It has a distinct climatic conditions with air temperature variations from 0 to 40°C (https://de.climate-data.org/). Rapid emergence of table grapes in this region has altered traditional rain-fed agriculture and helped in poverty elevation in rural areas. Economic return from one-acre vineyard is 347,000 rupees as compared to wheat, lentil and groundnut, moong bean and *Brassica* where net profitability is 25,525, 12,667, 106,000, 54,000-72,000, 29,391 rupees acre$^{-1}$, respectively (Khalid, August 20, 2022, pers. commun.). Variable growing season environmental conditions particularly of temperature affect vine growth and physiological responses. Climate models have predicted a temperature rise of up to 4.5°C by the end of century for this region (Gutiérrez et al., 2021). These environmental trends may change the viticulture outlook and cultivars currently grown in Pothwar region. Therefore, the present study was designed to explore the effect of seasonal temperature on pheno-physiological responses for four table grape cultivars in the Pothwar region of Pakistan.

## MATERIAL AND METHODS

### Plant material

Two main grape growing districts (Islamabad and Chakwal) of Pothwar were selected for pheno-physiological observations. Healthy fruit bearing vines of four commercial table grape cultivars ('Perlette', 'Sugraone', 'King's Ruby' and 'NARC Black') with an age of about 6 years were selected at Barani Agricultural Research Institute (BARI) Chakwal and Raja Yasir Farms (RYF) Islamabad. The vines were trained on vertical positioning, (I system) with a row spacing of 3.0-m, whereas vine spacing was 2.4 m. Both vineyards were managed through standard viticulture techniques as suggested by Rafique et al. (2023b).

### Pheno-physiological data recording

Phenological data for key stages, i.e., budburst, 5 leaf, bloom, berry set, veraison and harvest were recorded at almost three times a week to determine the exact timings of growth stage. Harvest timings were determined based on physiological maturity when 50% of the berries reached 16-18 °Brix. Phenological data were recorded on nine randomly selected vines for each cultivar. Physiological data were recorded from 5$^{th}$ distil leaf, fully exposed to sun light at different branch positions in canopy. Measurements were recorded at key growth stages (Figure 1) on a sunny day between 10.00 am to 12.00 at noon.




Figure 1. Key phenological stages of tables grape cultivar 'NARC Black'.

Photosynthetic activity (µmol m$^{-2}$ s$^{-1}$), and water use efficiency (WUE) µmol mmol$^{-1}$ were recorded through portable photosynthesis system-3. Experiments were laid out in a

factorial arrangement (locations, vintages, cultivars and developmental stages) with three replications of three vines each. The data were expressed as mean along with standard error, whereas mean physiological responses for locations, years, cultivars and growth stages were analyzed by applying analysis of variance (ANOVA) techniques at a 5% probability level using software Statisticx 8.1.

## RESULTS AND DISCUSSION

Growing season temperature variability existed between vintages and locations with Islamabad having a relatively lower mean temperature (1.2°C) compared to Chakwal. The active growing season (March to July) mean temperature for 2020 was lower (by 0.9°C) for district Chakwal and (by 1.2°C) for Islamabad compared to 2019 (Figures 2 and 3). These trends make Chakwal a relatively hotter location and 2019 a relatively warm year.

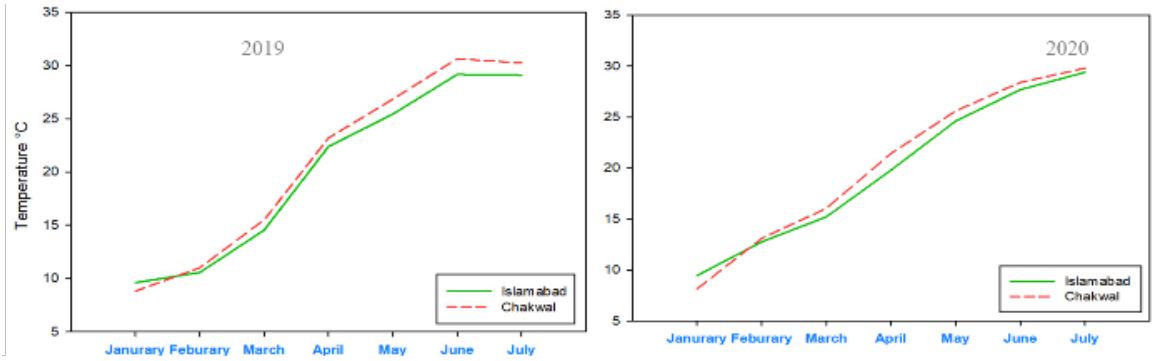



Figure 2. Mean monthly temperature trends for at Islamabad and Chakwal.

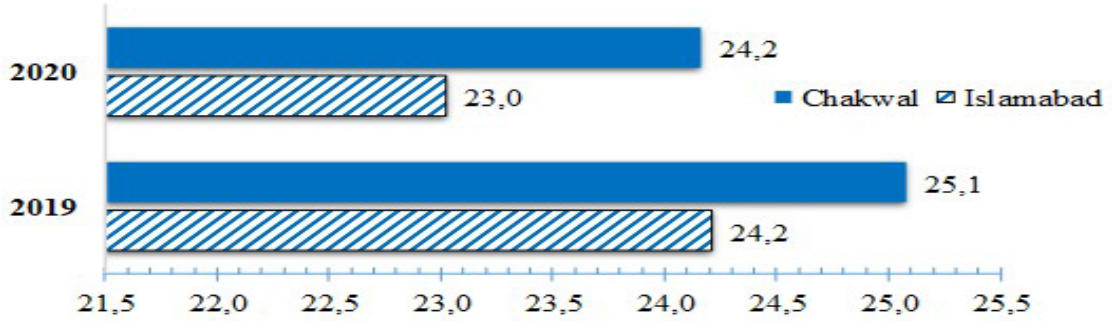



Figure 3. Active growing season temperature (March-July) at Islamabad and Chakwal.

Table 1. Timings of key developmental stages of table grape cultivars at Islamabad and Chakwal for the 2019 vintage.

| Developmental stage | King ‘s Ruby | | Perlette | | NARC Black | | Sugraone | |
|---|---|---|---|---|---|---|---|---|
| | Islamabad | Chakwal | Islamabad | Chakwal | Islamabad | Chakwal | Islamabad | Chakwal |
| Bud burst | 85±0.48 | 82±0.24 | 80±0.31 | 76±0.54 | 87±0.42 | 84±0.24 | 83±0.24 | 79±0.48 |
| 10 cm shoot | 92±0.42 | 88±0.24 | 90±0.18 | 85±0.51 | 95±0.18 | 91±0.18 | 90±0.42 | 85±0.36 |
| Full bloom | 120±0.48 | 114±0.73 | 116±0.51 | 110±0.47 | 111±0.48 | 105±0.33 | 120±0.51 | 114±0.63 |
| Berry set | 126±0.55 | 118±0.65 | 120±0.09 | 114±0.48 | 117±0.36 | 110±0.48 | 125±0.54 | 117±0.36 |
| Veraison | 166±0.73 | 159±0.87 | 160±0.96 | 151±0.09 | 175±0.65 | 165±0.48 | 163±0.54 | 155±0.54 |
| Harvest | 187±0.79 | 178±0.73 | 181±1.10 | 171±0.87 | 199±0.91 | 189±0.98 | 192±0.54 | 184±0.71 |

Means of phenological onset timings (DOY) in table grape cultivars along with standard error.

Table 2. Timings of key developmental stages of table grape cultivars at Islamabad and Chakwal for the 2020 vintage.

| Phenological stage | King ‘s Ruby | | Perlette | | NARC Black | | Sugraone | |
|---|---|---|---|---|---|---|---|---|
| | Islamabad | Chakwal | Islamabad | Chakwal | Islamabad | Chakwal | Islamabad | Chakwal |
| Bud burst | 72±0.31 | 67±0.48 | 63±0.27 | 60±0.54 | 76±0.31 | 71±0.73 | 65±0.09 | 62±0.32 |
| 10 cm shoot | 82±0.42 | 78±0.24 | 77±0.31 | 73±0.18 | 87±0.31 | 82±0.54 | 79±0.36 | 74±0.73 |
| Full bloom | 118±0.31 | 113±0.54 | 113±0.24 | 109±0.40 | 108±0.31 | 105±0.33 | 120±0.51 | 114±0.63 |
| Berry set | 124±0.40 | 117±0.51 | 119±0.48 | 114±0.31 | 114±0.33 | 110±0.18 | 125±0.36 | 118±0.71 |
| Veraison | 169±0.65 | 162±0.87 | 161±0.57 | 155±0.48 | 178±0.64 | 168±0.48 | 166±0.54 | 158±0.57 |
| Harvest | 190±0.68 | 182±0.63 | 183±0.63 | 175±1.13 | 202±1.02 | 193±1.1 | 194±0.65 | 188±0.71 |

Means of phenological onset timings (DOY) in table grape cultivars along with standard error.

Table 3. Photosynthetic activity and water use efficiency of four grapevine cultivars at Islamabad and Chakwal for key developmental stages.

| | | Photosynthetic activity | | | | WUE | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Kings Ruby | Perlette | NARC Black | Sugraone | Kings Ruby | Perlette | NARC Black | Sugraone |
| ISL 2019 | 5 Leaf | 5.1±0.21 | 8.6+0.29 | 4.9+0.13 | 9.6+0.22 | 1.4+0.05 | 1.8+0.06 | 0.9+0.03 | 1.9+0.06 |
| | Bloom | 23.3±0.51 | 31.0+0.30 | 29.5+0.4 | 23.4+0.5 | 4.1+0.10 | 4.8+0.15 | 5.6+0.20 | 4.6+0.13 |
| | Berry set | 24.6±0.21 | 26.1+0.07 | 29.7+0.8 | 28.1+0.1 | 3.7+0.04 | 5.5+0.02 | 4.9+0.10 | 3.4+0.08 |
| | Veraison | 4.1±0.05 | 6.1+0.07 | 3.4+0.03 | 5.6+0.05 | 0.7+0.01 | 1.9+0.02 | 0.6+0.00 | 1.7+0.03 |
| | Harvest | 5.0±0.03 | 7.0+0.04 | 5.8+0.04 | 10.3+0.0 | 1.4+0.01 | 1.4+0.01 | 0.7+0.01 | 1.0+0.01 |
| CKL 2019 | 5 Leaf | 2.7±0.03 | 4.7+0.02 | 3.0+0.03 | 4.3+0.03 | 0.7+0.01 | 1.4+0.01 | 0.9+0.01 | 1.5+0.01 |
| | Bloom | 12.7±0.03 | 16.5+0.74 | 18.7+0.46 | 17.2+0.86 | 2.7+0.06 | 4.0+0.07 | 3.6+0.04 | 2.7+0.02 |
| | Berry set | 15.2±0.25 | 21.4+0.20 | 18.6+0.11 | 14.4+0.49 | 2.6+0.02 | 3.2+0.06 | 3.5+0.04 | 2.3+0.04 |
| | Veraison | 1.2±0.35 | 1.2+0.05 | 0.6+0.61 | 4.4+0.46 | 0.5+0.01 | 0.3+0.00 | 0.5+0.01 | 1.6+0.03 |
| | Harvest | 1.9±0.02 | 0.6+0.02 | -0.9+0.03 | -1.0+0.27 | 0.5+0.01 | 0.1+0.01 | -0.3+0.00 | -0.3+0.00 |
| ISL 2020 | 5 Leaf | 4.2±0.05 | 6.1+0.04 | 4.8+0.03 | 5.3+0.02 | 1.2+0.01 | 1.5+0.01 | 0.9+0.01 | 1.1+0.00 |
| | Bloom | 18.8±0.34 | 22.2+0.24 | 18.5+0.27 | 20.0+0.09 | 3.5+0.03 | 3.9+0.16 | 3.7+0.12 | 3.9+0.18 |
| | Berry set | 19.4±0.10 | 19.4+0.28 | 16.8+0.21 | 24.0+0.15 | 3.4+0.10 | 3.4+0.04 | 3.2+0.05 | 4.2+0.04 |
| | Veraison | 14.8±0.01 | 11.2+0.01 | 16.2+0.02 | 19.1+0.06 | 2.6+0.02 | 2.1+0.03 | 2.6+0.17 | 3.3+0.08 |
| | Harvest | 6.1±0.02 | 2.6+0.02 | 12.0+0.02 | 11.5+0.01 | 2.1+0.02 | 2.2+0.01 | 2.4+0.03 | 2.5+0.07 |
| CKL 2020 | 5 Leaf | 3.3±0.03 | 3.8±02 | 4.3+0.03 | 3.9+0.01 | 0.9+0.01 | 1.1+0.01 | 1.1+0.01 | 0.9+0.01 |
| | Bloom | 17.5±0.53 | 14.8±0.17 | 19.6+0.67 | 18.5+0.19 | 2.9+0.08 | 3.1+0.03 | 3.6+0.11 | 3.2+0.03 |
| | Berry set | 17.0±0.11 | 18.6±0.34 | 19.7+0.74 | 16.0+0.17 | 2.5+0.07 | 2.7+0.22 | 3.2+0.08 | 2.2+0.11 |
| | Veraison | 12.3±0.15 | 9.2±0.08 | 16.7+0.23 | 8.4+0.03 | 2.7+0.02 | 1.6+0.04 | 3.2+0.08 | 1.9+0.02 |
| | Harvest | 7.2±0.11 | 5.2±0.09 | 10.8+0.14 | 7.0+0.04 | 1.9+0.01 | 1.4+0.02 | 2.2+0.02 | 1.8+0.02 |

Means of phenological onset timings (DOY) in table grape cultivars along with standard error.

**Grapevine phenology under the influence of seasonal temperature**

Phenological stages of grapevine cultivars were attained earlier (up to 10 days) for district Chakwal compared to Islamabad, owing to a higher growing season temperature. Vine developmental stages also varied with seasonal temperature differences between 2019 and 2020 vintages. A higher growing season temperature for February 2020 (up to 2.2°C) compared to 2019 resulted in early budburst (up to 16 days). The accelerated blooming with rapid berry development for the 2019 vintage corresponds to a higher seasonal compared to 2020. However, early bud burst for the 2020 vintage did not cause early ripening, as the phenological progression of grapevine cultivars was driven under the influence of seasonal temperature variability (Tables 1 and 2). Relevant studies also indicate that berry ripening in grapevines is significantly affected by seasonal temperature variability (Rabino et al., 2020; Rafique et al., 2023b). The variability for the harvest time was up to 10 days with earlier ripening for the relatively warmer location Chakwal than for colder Islamabad. The length of growth period from bud burst to harvest, was greater (21 up to days) for the 2020 vintage due to a lower growing season temperature. Grapevine phenological shifts are among the most evident biological signs of the effect of seasonal temperature variability (Rafique et al., 2023b). It is evident from the results that vine phenology and physiological responses are strongly interlinked with growing season temperature. Among cultivars, maturity was attained earlier (up to 10 days) for 'Perlette' compared to the 'NARC Black'. The varying ripening timings for the cultivars help to determine the suitable cultivar for a particular region.

**Variable photosynthetic activity and WUE under the effect of seasonal temperature**

Higher photosynthetic activity (up to 31%) and WUE (29%) were observed at Islamabad compared to Chakwal. For vintages, the colder vintage of 2020 has higher physiological activity particularly for veraison and harvest stages. Similarly, higher WUE (up to 14%) was noticed for the relatively colder site Islamabad, and for the colder vintage of 2020 particularly near ripening (Tables 3 and 4). The lesser photosynthetic activity, and WUE for the hotter vintage and warmer location indicates the negative effects of higher temperature on grapevine physiological processes. Previously, Medrano et al. (2015) and Luo et al. (2011) also observed that high temperature negatively affected vine photosynthesis and WUE.

Table 4. Mean photosynthetic activity and water use efficiency of grapevine cultivars.

| | Photosynthetic activity ($\mu mol\ m^{-2}\ s^{-1}$) | Water use efficiency ($\mu mol\ mmol^{-1}$) |
|---|---|---|
| | Locations | |
| Islamabad | 14.1 A | 2.6 A |
| Chakwal | 9.8 B | 1.9 B |
| | Vintages | |
| 2019 | 11.2 B | 2.1 B |
| 2020 | 12.7 A | 2.4 A |
| | Cultivars | |
| Kings Ruby | 10.8 C | 2.1 C |
| Perlette | 11.8 B | 2.4 A |
| NARC Black | 12.6 A | 2.3 A |
| Sugraone | 12.5 A | 2.3 B |
| | Growth stages | |
| 5 Leaf | 4.9 E | 1.2 E |
| Bloom | 20.1B | 3.7 A |
| Berry Set | 20.6 A | 3.4 B |
| Version | 8.4 C | 1.7 C |
| Harvest | 5.7 D | 1.3 D |

Higher photosynthetic activity (A) was recorded for 'NARC Black' and 'Sugraone', whereas more WUE was recorded for 'Perlette' and 'NARC Black'. Similar genotypic variability for photosynthetic activity and WUE was observed by Greer (2018) and Kamiloğlu et al. (2014). Leaf photosynthetic activity and WUE varied for the key phonological stages, and it was higher from blooming to berry set stage. The lower photosynthetic activity and WUE near ripening particularly for the 2019 vintage corresponds to the elevated temperature above critical limits. The results indicate that blooming to berry set is a critical period for grapevine and any stress at this stage and significantly lower the final yield. Henceforth, a balanced crop management strategy is necessary at key growth stages for increased WUE efficiency along with higher photosynthetic activity which result in higher yield. Therefore, it is crucial to unlock the interaction between the physiological activities, and fruit quality of table grape cultivars through dynamic approaches as suggested by Hopf et al. (2022), Rafique et al. (2023a) and Shah et al. (2021). The results also elucidate that under future warming trends late ripening cultivars might be necessary.

## CONCLUSIONS

The findings of the present research indicate that a relatively lower temperature at Islamabad delayed the phenological timings with increased length of growing season, however, it favored vine photosynthetic activity and WUE. Phenological stages were advanced with shortening of growth season and lesser physiological activity for the hotter vintage of 2019 compared to 2020. Photosynthetic activity and water use efficiency (WUE) peaked during blooming to berry set period thus indicating as a critical growth period for grapevines. It is obvious that higher growing season temperature particularly near ripening negatively affect photosynthesis and leaf water use efficiency, which may reduce the yield potential owing to impaired photosynthetic processes. Variability among grapevine cultivars for pheno-physiological attributes provide an opportunity to adapt viticulture to varying environmental conditions.

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