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Effects of Different Levels of Boron on Fruit Cracking and Quality of Sweet Cherry

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ABSTRACT

Sweet Cherries (*Prunus avium L.*) are a highly nutritious fruit, beneficial for health due to their antioxidants (anthocyanins) and melatonin. However, fruit cracking is a serious physiological problem that causes economic losses. Boron deficiency is considered an important cause of cherry fruit cracking because it reduces skin strength and structural integrity. The objective of this study was to evaluate the effects of different levels of boron (Boron Plus 5% w/v) on reducing fruit cracking and improving fruit quality. The experiment was conducted in 2024 in a cherry orchard located in Malang Village, Khak-e-Jabar District, Kabul Province, using an RCBD Design with five treatments and four replications. The treatments were as follows: T1 – Control; T2 – 2 mL L^{-1}; T3 – 3 mL L^{-1}; T4 – 4 mL L^{-1}; and T5 – 5 mL L^{-1} boron foliar application. The results, analyzed using LSD at 5% significance level, indicated that boron application significantly reduced the percentage and severity of fruit cracking while improving fruit quality. Across all ripening stages, the lowest fruit cracking and the highest proportion of healthy fruits were observed in T5, whereas the control showed the poorest results. Sensory evaluation also ranked T5 as the best treatment. In summary, foliar application of boron at 5 mL L^{-1} application of boron during three critical developmental stages effectively minimized fruit cracking and improved fruit performance. Its use is recommended under similar climatic conditions. Future research should focus on the combined use of boron with calcium and zinc, as well as comparative studies among different cherry cultivars.

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INTRODUCTION

Sweet cherry (*Prunus avium L.*) is an important temperate fruit whose quality determines consumer satisfaction and market value (Samadi & Shirzad, 2018; Santos et al., 2025). It is believed to be native to Europe and southern Asia (Vignati et al., 2022). Commercial sweet cherry cultivation in Afghanistan is still developing and is concentrated mainly in several temperate regions of the country such as Badakhshan, Takhar, Kunduz, and Herat, primarily in home gardens and small orchards, in total, 28 cultivars exist (22 sweet and 6 sour), with foreign cultivars introduced from Italy and the Sarthe harvest season begins in early June. The current cultivated area is approximately 2,000 hectares, with an estimated annual production of 50–100 metric tons, most of which is consumed domestically, although there is good export potential (Mohtasebzada & Esumi, 2019; Samadi & Shirzad, 2018). The primary origin of cherries is reported to be around the Black and Caspian Seas, from which they later spread to other parts of the world. The exact historical date of cherry cultivation is not clearly recorded, suggesting that its cultivation may have existed before documented history (Samadi & Shirzad, 2018).

Sweet cherries are valued for their high nutritional content and abundance of health-promoting antioxidant compounds, they help reduce inflammation, support heart health, slow the aging process, improve sleep, and relieve joint pain (Vitale et al., 2017). Cherries are a natural source of beneficial bioactive compounds and essential nutrients for the human body, including N, P, K, Ca, Mg, S, B, Fe, Zn, Mn, and Cu (Santos et al., 2024).

Environmental conditions including temperature, solar radiation, humidity, wind, and precipitation play a decisive role in cherry development, maturation, and productivity(Santos et al., 2024). Excessively high temperatures and heavy rainfall reduce fruit quality and increase fruit cracking (Santos et al., 2025). Climate change has affected fruit yield and quality, leading to nutrient deficiencies and increased fruit cracking. Therefore, precise nutrition and balanced fertilization are essential for good yield and quality (Santos et al., 2024).

Fruit cracking in sweet cherries is a major problem for growers, rain covers are the most effective protection method, but cracking can still occur in some cultivars even under covers(Suran et al., 2019). A major cause of fruit cracking in sweet cherries is boron deficiency. Boron is essential for cell wall formation, and its deficiency leads to fruit cracking and reduced fruit quality (Álvarez-Herrera et al., 2025). Cherry fruit cracking is caused by excessive water uptake, skin tension, and microcracks. Water enters the cells, weakening them and causing the skin to rupture in a zipper-like pattern (Knoche, 2019). Cracking is a major physiological defect that lowers market quality, shortens storage life, and predisposes fruits to pathogen infection, resulting in significant losses in the fresh produce market (La Spada et al., 2024).

Cherry is an important commercial fruit suited to Afghanistan’s climate. However, fruit cracking is a serious physiological problem that causes economic losses, one key factor contributing to this issue is boron deficiency, which weakens the fruit's skin. Improving yield and quality requires proper nutrition, especially boron and calcium, adequate boron nutrition enhances fruit resistance to cracking, minimizes production losses, and strengthens plant tolerance to environmental stress, determining the correct boron level is essential for better yield and fruit quality, supporting the development of high-quality cherry production, This study aims to evaluate the effects of boron on fruit quality and resistance, and to provide practical recommendations for growers to optimize cherry production, We formulated the following research question:

1. How does boron affect fruit quality and resistance, and how can it be used to provide practical recommendations for optimizing cherry production?

METHODS AND MATERIALS

A randomized complete block experimental arrangement was employed to evaluate the treatment effects under field conditions with five treatments and four replications in a Bing cherry orchard.

The experiment included five treatments: T1 – Control, T2 – 2 mL L^{-1} boron, T3 – 3 mL L^{-1} boron, T4 – 4 mL L^{-1} boron, and T5 – 5 mL L^{-1} boron. Foliar boron treatments were administered during three key phenological stages of crop development: full bloom, fruit pea stage, and 1.5 weeks before harvest.

Sample

In this study, 125 ten-year-old sweet cherries (Bing cultivar) trees were selected. The experiment consisted of five treatments with four replications. For fruit assessment, three to five branches were randomly selected from each replication, and fruits were harvested manually. Organoleptic evaluation was conducted using ten semi-trained evaluators.

Data Collection Method

Data were collected through field observations and sensory evaluation. Fruit cracking parameters, including the number of healthy and cracked fruits and the severity of cracking, were recorded after harvest. Fruit quality attributes such as appearance, color, texture, taste, and overall acceptability were assessed using a 5-point hedonic rating scale, where:

- 1 = Dislike Extremely
- 2 = Dislike Moderately
- 3 = Neither Like nor Dislike
- 4 = Like Moderately
- 5 = Like Extremely

Data Collection Procedure

Foliar boron applications were performed at full bloom, followed by a second spray at the pea-fruit stage and a final spray approximately 10–11 days before fruit ripening.

Irrigation was applied every 10 days, and the final irrigation was stopped 10 days before harvest. At harvest, three to five branches from each replication were randomly selected. Fruits were harvested manually, and the numbers of healthy and cracked fruits were counted. Cracking severity and fruit quality characteristics were then evaluated.

Experimental Site Description

The experimental site was located in Malang Village, Khak-e-Jabar District, Kabul Province, Afghanistan, at 34°21′14″ N and 69°24′32″ E, with an elevation of 1,985 m above sea level. The soil type was sandy loam with a pH of 6.5.

Kabul has a continental climate characterized by hot, dry summers and cold, snowy winters. Temperatures generally range from −4°C to 34°C. rarely falling below -10°C or exceeding 37°C. (Kabul Climate, Weather by Month, Average Temperature (Afghanistan) - Weather Spark, 2024).

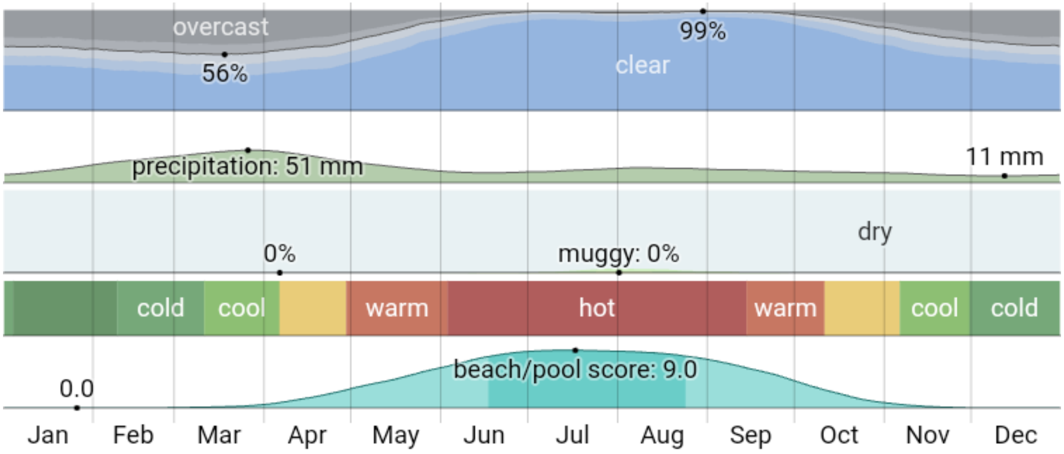

Figure 1: *Weather conditions of Kabul city and surrounding areas during the year 2024*

The cold season lasts for approximately three months, from mid-December to mid-March, during which the average daily maximum temperature remains below 12°C. In Kabul, January is the coldest month, with an average minimum temperature of -4°C and a maximum of 7°C.

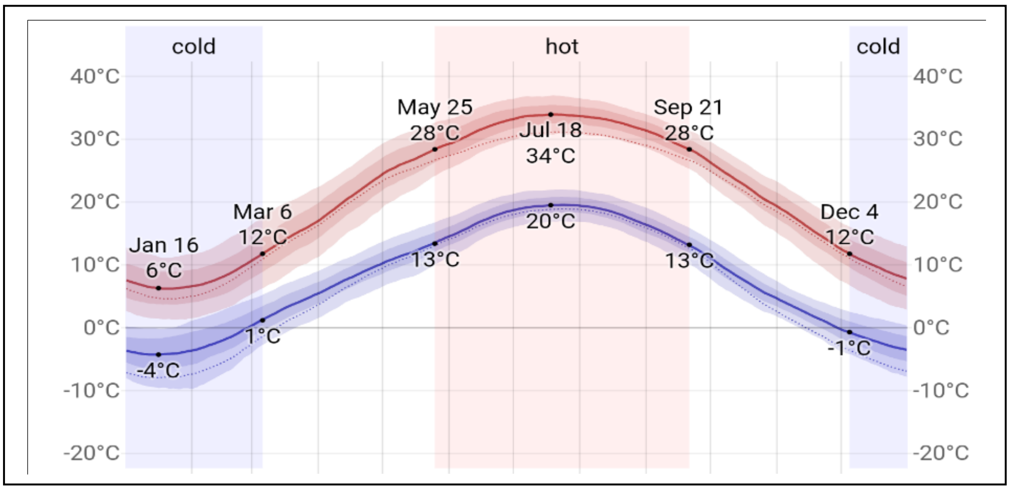

Figure 2*: Average temperature in Kabul Province during the year 2024 The annual rainfall was 312 mm (Kabul Climate, 2024)*

Data Analysis

The collected data were subjected to Analysis of Variance (ANOVA) using the STAR statistical software package. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% level of significance ($P \leq 0.05$).

Validity and Reliability

To ensure the validity of the study, all treatments were applied uniformly under the same orchard conditions, and standard experimental procedures were followed throughout the study period. The RCBD design helped minimize environmental variation among experimental units.

Reliability was enhanced through four replications, random selection of branches for sampling, and the use of ten semi-trained evaluators for sensory assessment. Consistent data collection methods and standardized evaluation criteria were applied across all treatments to ensure accurate and reliable results.

FINDINGS AND DISCUSSION

The parameters recorded in this study and their results are presented in order below. It should be noted that the experiment included the number of cracked and healthy fruits, the length of cracks per fruit, and fruit quality parameters such as appearance, color, texture, taste, and overall acceptability.

Effect of Boron on the Number of Cracked and Healthy Fruits

The application of different boron levels significantly affected fruit cracking and the proportion of healthy fruits in sweet cherries at 50%, 75%, and 100% fruit maturity, according to LSD at 5% probability. At 50% maturity, the control treatment showed the highest percentage of cracked fruits (9.12%) and the lowest percentage of healthy fruits (90.88%). In contrast, boron application progressively reduced the incidence of fruit cracking.

The best results were observed in the 5 mL L^{-1} boron treatment (T5), where only 1.24% of fruits were cracked, and 98.76% remained healthy. This was followed by the 4 mL L^{-1} treatment (T4), with 2.73% cracked fruits and 97.27% healthy fruits. No significant difference was observed between the 2 and 3 mL L^{-1} treatments (T2 and T3), although both significantly reduced fruit cracking compared to the control.

The findings indicate that boron supplied through foliar spraying can substantially reduce the occurrence of fruit cracking in sweet cherry, Previous studies support this finding, highlighting boron as an essential micronutrient involved in several key plant functions, such as maintaining cell wall structure, reinforcing the cell wall through borate–pectin complex formation, enhancing mechanical strength of fruit skin and mesocarp tissues, and regulating carbohydrate transport and water balance—all crucial for fruit quality and skin resistance (Álvarez-Herrera et al., 2025; Matsunaga & Ishii, 2022).

Other research has shown that nutrients such as boron, zinc, calcium, copper, molybdenum, manganese, and potassium participate in physiological processes during fruit development, and their deficiencies can lead to fruit cracking. Boron and copper enhance growth in surface tissues by stimulating enzymatic activity, a process that may not occur naturally in nutrient-deficient soils, in addition, boron facilitates carbohydrate movement within the plant and contributes to proper cell wall development(Sheik & Manjula, 2012).

These findings indicate that nutrient elements are essential for plant growth and metabolism, and that foliar application enables rapid uptake of small amounts of minerals, thereby enhancing physiological processes. Not only boron, but other micronutrients such as calcium, potassium, and others also improve fruit yield and quality, enhance storage, and reduce fruit drop when applied as foliar sprays (Bons & Sharma, 2023).

Similarly, at 75% and 100% fruit maturity, the percentages of cracked and healthy fruits followed the same trend as at 50% maturity. The highest fruit cracking occurred in the control treatment, while the lowest cracking was observed in the 5 mL L^{-1} boron treatment (T5). The summarized results are presented in Table 1.

***Table 1.** Fruit cracking parameters at different fruit maturity stages*

Treatment	Number of Cracked Fruits (%)			Number of Healthy Fruits (%)		
	50% fruit maturity	75% fruit maturity	100% fruit maturity	50% fruit maturity	75% fruit maturity	100% fruit maturity
1. Control	9.12[a]	10.53[a]	12.30[a]	90.88[d]	89.47[d]	87.70[d]
2. Boron 2 mL L^{-1}	4.95[b]	5.57[b]	6.53[b]	95.05[c]	94.13[c]	93.47[c]
3. Boron 3 mL L^{-1}	4.19[b]	5.14[b]	6.21[b]	95.81[c]	94.86[c]	93.79[c]
4. Boron 4 mL L^{-1}	2.73[c]	3.27[c]	3.89[c]	97.27[b]	96.73[b]	96.11[b]
5. Boron 5 mL L^{-1}	1.24[d]	1.36[d]	2.02[d]	98.76[a]	98.64[a]	97.98[a]
F-Test	*	*	*	*	*	*
LSD @ 5%	1.1050	1.2737	1.6264	1.1050	1. 2737	1.6264
CV (%)	16.14	15.80	17.06	0.7506	0.8724	1.13

Treatments sharing the same letter are not significantly different from each other; * indicates a statistically significant difference at the 5% level.

Fruit Cracking Shape and Crack Length

According to the results, boron application had no significant effect on fruit cracking shape or crack length at 50% fruit maturity (LSD at 5%), with all treatments showing similar crack lengths, ranging from approximately 12.75 to 13.38 mm. However, at 75% and 100% fruit maturity, boron application had a significant effect (F-Test = *). At these stages, the control treatment exhibited the longest crack lengths (16.31 mm at 75% maturity and 22.56 mm at 100% maturity), whereas higher boron levels significantly reduced crack lengths. The shortest crack lengths were observed in the 5 mL L^{-1} boron treatment (T5), measuring 14.19 mm and 3.106 mm, respectively.

These results indicate that foliar boron application, particularly at higher doses, not only reduces the percentage of cracked fruits but also decreases the severity and length of cracks, especially during the later stages of fruit ripening. Similar studies have shown that boron, when combined with other micronutrients, effectively reduces fruit cracking because it strengthens the cell wall structure(Haleema et al., 2024; Zhang et al., 2024). Boron is thus a suitable micronutrient for achieving high quality and yield, provided it is applied in appropriate amounts, as excessive levels may have negative effects (Hapuarachchi et al., 2022). These results are presented in Table 2.

Table 2: *Crack length of cracked fruits at different fruit maturity stages*

Treatment	Crack Length at 50% Maturity (mm)	Crack Length at 75% Maturity (mm)	Crack Length at 100% Maturity (mm)
1. Control	13.30	16.31 a	22.56 a
2. Boron 2 mL L^{-1}	13.38	14.12 b	19.06 b
3. Boron 3 mL L^{-1}	13.31	14.31 b	18.94 b
4. Boron 4 mL L^{-1}	12.75	14.25 b	15.06 c
5. Boron 5 mL L^{-1}	12.88	14.19 b	14.31 c
F-Test	NS	*	*
LSD @ 5%	–	0.2410	2.1788
CV (%)	–	1.07	5.23

Effect of Boron on the Qualitative Aspects of Cherry Fruits

The qualitative parameters of cherries, including appearance, color, taste, texture, and overall acceptability, were evaluated using an organoleptic test. In this method, scores were assigned numerically, and the evaluators were blind to the treatments. Scores ranged from 1 to 5, with 1 indicating the lowest acceptability and 5 the highest.

The results for fruit appearance showed a significant difference among boron treatments (F-Test = *). The lowest score was recorded in the control (3.10), indicating poor appearance quality, whereas increasing boron levels resulted in higher appearance scores. The highest score was observed in the 5 mL L^{-1} boron treatment (T5) (4.80), followed by 4 mL L^{-1} (T4) with a score of 4.40, both significantly higher than the control. The 3 mL L^{-1} treatment (T3) had an intermediate score (4.05), showing partial overlap with T2 and T4, while 2 mL L^{-1} (T2) recorded a score of 3.80. Overall, these results indicate that higher boron levels significantly improve the appearance of cherry fruits, consistent with previous studies showing that boron is a crucial nutrient for enhancing fruit appearance Table 3. Boron helps maintain fruit firmness, reduce weight loss, improve color, and increase fruit size and weight. Additionally, boron reduces physiological disorders in the fruit, such as cracking, corky spots, internal breakdown, blossom end rot, and skin desiccation, and Boron plays a key role in improving the quality and early development of sweet cherry fruits (Álvarez-Herrera et al., 2025; Singh et al., 2018).

Table 3*. Effect of Boron on the Qualitative Attributes of Cherry Fruits*

Treatment	Appearance	Color	Fruit Texture	Taste	Overall Acceptability
1. Control	3.10 d	4.00	3.00 d	4.25 d	3.10 b
2. Boron 2 mL L^{-1}	3.80 c	4.05	3.90 c	4.40 c d	4.54 a
3. Boron 3 mL L^{-1}	4.05 b,c	4.10	4.15 b	4.25 b,c	4.55 a
4. Boron 4 mL L^{-1}	4.40 a,b	4.10	4.60 b	4.50 a,b	4.50 a
5. Boron 5 mL L^{-1}	4.80 a	4.15	5.00 a	4.50 a	4.60 a
F-Test	*	NS	*	*	*
LSD @ 5%	0.5704	–	0.4751	–	0.5240
CV (%)	15.60	16.70	12.68	14.69	13.57

The evaluation of fruit color showed no significant differences among the boron treatments (F-Test = NS). Although color scores slightly increased with higher boron levels, these changes were not statistically significant. The control treatment scored 4.00, while the highest score (4.15) was observed in the 5 mL L^{-1} boron treatment (T5); however, due to the absence of LSD significance, this difference was not considered meaningful. The coefficient of variation (CV) was 16.70%, indicating some relative variability, but overall, boron application had no significant effect on cherry fruit color Table 3.

The evaluation of fruit texture showed a significant effect of boron treatments (F-Test = *). The control treatment received the lowest score (3.00), indicating weak texture, while increasing boron levels progressively improved fruit texture. The highest score (5.00) was recorded in the 5 mL L^{-1} boron treatment (T5), which was significantly better than all other treatments, followed by 4 mL L^{-1} boron (T4) with a score of 4.60. Overall, boron application plays a critical role in improving cherry fruit texture. Boron plays a vital role in maintaining cell wall stability and strengthening fruit tissues, interacting with cellulose and pectin to form borate–pectin complexes that enhance fruit skin resistance. Appropriate boron application maintains fruit skin firmness and cell structure, and strong cells help prevent fruit cracking and softening under pressure and increased cell volume. Boron increases the levels of sugars, organic acids, and amino acids in sweet cherries, which supports fruit development (Álvarez-Herrera et al., 2025; Michailidis et al., 2023)

The evaluation of fruit taste showed a significant difference among boron treatments (F-Test = *). Both the control and 3 mL L^{-1} boron treatment (T3) received the lowest scores (4.25). The 2 mL L^{-1} treatment (T2) showed slightly better taste (4.40). In contrast, the highest taste scores were recorded in the 4 and 5 mL L^{-1} boron treatments (T4 and T5) (4.50), which were significantly superior to the other treatments. These results indicate that higher boron levels positively affect the taste of cherry fruits Table 3. Boron not only improves fruit texture and skin resistance but also enhances taste. Previous studies have shown that foliar boron application in *Muscat grapes* positively affected yield and fruit quality, improving Brix and total boron content, and reducing acidity, thereby enhancing fruit quality and commercial value (Janaki et al., 2004). Additionally, boron assists in the translocation of carbohydrates and sugars, improving sugar content, acid balance, and taste consistency. By maintaining a balanced internal nutrient status, boron also enhances the aroma and flavor of fruit, increasing fruit quality and market appeal. Boron is an important nutrient for fruit quality because it plays a key role in cell wall formation, flower and fruit development, and plant physiological processes. In sweet cherry, boron deficiency disrupts proper fruit formation and leads to reduced yield and lower fruit quality (Álvarez-Herrera et al., 2025; Bonomelli et al., 2025). Another similar study found that boron use not only reduces fruit cracking but also improves yield and TSS (total soluble solids) (Baloda et al., 2023).

The evaluation of overall acceptability indicated a significant difference among boron treatments (F-Test = *). The control treatment received the lowest score (3.10), which was significantly lower than all boron-applied treatments. In contrast, all boron treatments (2, 3, 4, and 5 mL L^{-1}) recorded high, nearly identical scores (4.50–4.60) and were included in the same statistical group. These results demonstrate that boron application significantly improves the overall acceptability of cherry fruits, although no significant differences were observed among the boron levels from 2 to 5 mL L^{-1}. Boron is an essential nutrient for plants, maintaining cell stability and enhancing nutrient uptake. Previous studies in grapes have shown that appropriate boron application improves sugar content, yield, and plant growth, increases juice and soluble sugar content, and reduces starch accumulation (Álvarez-Herrera et al., 2025; Bonomelli et al., 2025; Martello et al., 2025).

Furthermore, boron plays a crucial role in fruit quality, enhancing uniformity of skin color and maintaining consistent color development. It interacts with cell walls and pectin, strengthening the skin and increasing resistance to internal pressure, thereby reducing water uptake and preventing fruit cracking. Boron stabilizes the cell middle lamella, forms borate–pectin complexes, improves skin firmness, reduces softening during storage, and aids in sugar translocation, resulting in sweeter, fresher fruits with improved internal aroma. Consequently, boron application enhances skin firmness and cell strength, extending the storage life of cherry fruits (Álvarez-Herrera et al., 2025; Zhang et al., 2024).

CONCLUSION

Foliar boron treatments markedly decreased cracking incidence while increasing the proportion of marketable and healthy fruits at all maturity stages. The best performance was observed at 5 mL L^{-1}, followed by 4 mL L^{-1}, while the control had the highest cracking. Boron also reduced crack length, especially at later maturity stages, indicating improved fruit resistance. In terms of quality, boron improved appearance, texture, taste, and overall acceptability, but had no significant effect on color, in general, boron supplementation through foliar spraying proved beneficial for enhancing fruit quality and minimizing cracking-related losses in sweet cherry production, future research should focus on the combined use of boron with calcium and zinc and comparative studies among different cherry cultivars

Authors Contributions

Ghulam Rasoul Samadi designed and supervised the research. Matiullah Ahmadzai implemented the field experiment and collected the experimental data. Zabihullah Fiazi managed the data processing and statistical analyses. The manuscript was drafted collaboratively by Zabihullah Fiazi, Ghulam Rasoul Samadi, and Matiullah Ahmadzai, while all authors contributed comments and revisions. All authors read, reviewed, and approved the final manuscript before submission

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Conflict of Interest Statement

The authors affirm that there are no financial, personal, or professional relationships that could have influenced the outcomes of this study.

Data Availability Statement

The datasets generated and analyzed during the current study can be obtained from the corresponding author upon reasonable request and with the approval of the appropriate ethics authority, where applicable.

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