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Prediction of berry cracking in Thompson Seedless grape

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ABSTRACT

To evolve a prediction model of berry cracking in grapes based on its relationship with environmental factors, the percentage of berry cracking was recorded in 25 vineyards of Thompson Seedless in India. Data on growing degree days from fruit pruning, average relative humidity, cumulative rainfall, average soil moisture tension, average maximum temperature, and average wind speed, all during the preceding three days of cracking were recorded from the automatic weather station and the soil moisture sensors installed in the affected 25 as well as an equal number of unaffected vineyards. Growing degree days, average relative humidity, and cumulative rainfall had a positive relationship with cracking while the soil moisture tension, maximum temperature, and wind speed had the negative. The maximum threshold level for degree days was 1415, while the minimum for soil moisture tension was 31.2 kPa. Relative humidity of 74.1 per cent and cumulative rainfall of 20.5 mm accounted respectively for 41 and 67.5 per cent berry cracking. Maximum temperature of 26.6°C and wind speed of 9.8 km/hr accounted respectively for 41.4 and 45.4 per cent variation in berry cracking. The multiple regression function Y = -104.55 + 0.1723X1 + 0.0826X2 + 4.1161X3 + 0.4813X4 - 4.5706X5 - 8.0401 X 6 was found to determine berry cracking by 92.4 percent. A non-significant difference of 2.2 per cent was observed between the observed and predicted cracking in the validation of the model in the 2024 fruiting season. Observed and predicted per cent berry cracking in individual vineyards are presented graphically.

Key word: Berry cracking, environmental factors, prediction model, validation

INTRODUCTION

Grape is a commercially important crop in India. The area under grapes was estimated at 155.3 thousand ha with an annual production of 3262.4 thousand MT, of which 263.1 thousand MT of table grapes valued at 305.66 million US$ were exported (APEDA, 1). The predominant variety is Thompson Seedless grown in Maharashtra state. In recent years, considerable crop losses have been experienced due to berry cracking. Berry cracking is an eco-physiological disorder associated with rains during the ripening of *vinifera* varieties of grapes. Decomposition of cracked berries can produce ethyl acetate and acetic acid, which are undesirable constituents in the wine must (Corison *et al*., 3). The physiological basis of berry cracking is the buildup of turgor pressure in the berry caused by a greater rate of water inflow than transpiration. The rate at which pressure builds inside the berry and berry skin flexibility to tolerate the pressure determines the degree of cracking (Lang and During, 8). Accumulated sugars at fruit maturity encourage absorption of enough water to crack the skin on receiving environmental conditions consisting high soil moisture and cool, humid days with little wind (Considine and Kriedmann, 4). Direct water uptake through the skin was observed by Lang and Thorpe (9). Yet another contributory factor for berry cracking is the limitation of its skin to expand (Considine and Knox, 5) and a rapid decrease in berry skin extensibility was observed two to three weeks before harvest by Matthews *et al.* (10). The cell wall becomes thin due to increased enzyme activity, mainly of pectin methyl esterase during ripening (Deytieux-Belleau *et al.* (6). Water uptake by the fruit from the root system can also build up internal turgor pressure of the fruit (Kertesz and Nebel, 7; Considine & Kriedeman, 4; Yamamoto *et al*., 13). However, the relationship between degree days from pruning, rainfall, atmospheric humidity, air temperature, and wind speed with berry cracking is not established. Such relationships were established to evolve a prediction model of berry cracking and the critical levels of these weather parameters.

MATERIALS AND METHODS

A survey was conducted to collect data on berry cracking on March 10, 2023, after three days of consecutive rains on 25 Thompson Seedless vineyards around Nashik district of Maharashtra, India. Agri-hawk technologies' weather station 'Kairo' (Certified by the Indian Meteorological Department) and soil moisture sensor 'Nero' were installed in all the vineyards surveyed. The percentage of berry cracking was derived from the number of cracked berries out of the total berries in 15 bunches for each

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sample. Degree days (X1) were computed from the date of pruning. Cracking is visible only after three days. Hence, the mean data during the preceding three days of cracking were computed on percent of relative humidity (X2), Cumulative rainfall in mm (X3), soil moisture tension at 30 cm depth in kPa (X4), Maximum temperature in degree Celsius (X5) and wind speed in km/h (X6). Similar data were collected on 25 vineyards in which berry cracking was not noticed on the 10^{th} of March 2023. Similar data were collected from 23 vineyards showing berry cracking after rains in January 2024 around Sangli and Solapur, districts, Maharashtra to validate the prediction function evolved in 2023.

Statistical analysis tools Tableau (2) and the Data Analysis package of Microsoft Excel were used for statistical analyses of the data collected. Correlations were worked out to assess the relationship of the selected environmental factors with berry cracking. The significance of the difference in the means of each factor in affected and unaffected vineyards was also tested by 't-stat' derived from Student's t-test for two samples assuming unequal variances. The critical value of each factor was determined by the vertex (X-optimum) value derived from its quadratic relationship with berry cracking. Multiple regression analysis was performed to determine the function that accounts for the maximum variation in berry cracking.

The best prediction function was validated during the 2023-24 fruiting season. Berry cracking was assessed in the 2024 fruiting season in 23 affected vineyards, three days after rain occurring after veraison, as it was done in the 2023 fruiting season. The significance of the difference in the means of percentages of observed and predicted cracking was tested by Student's t-test. The predicted and observed cracking were plotted for comparison and validation of the model.

RESULTS AND DISCUSSION

Berry cracking is an eco-physiological disorder associated with rain during ripening. The crux of berry cracking is turgor pressure. According to Considine and Kriedmann (4), sufficient sugar content in the mature berry is essential to absorb enough water to build up the critical turgor when other environmental conditions are favourable for berry cracking. Growing degree days (GDD) from fruit pruning were significantly more in affected vineyards when compared to unaffected vineyards. Similar trend was observed for the average relative humidity and cumulative rainfall. Contrarily, the average maximum temperature and wind speed concerning affected vineyards were comparatively less. Soil moisture tension in the two groups of vineyards did not differ significantly (Table 1).

Among the environmental factors considered for developing a statistical model to predict the incidence and intensity of berry cracking, growing degree days (GDD) from pruning and cumulative rainfall (CR) in the preceding three days to the day of appearance of cracking were only correlated with cracking (Table 2).

Berry cracking was minimal (18.4%) at 1400 growing degree days. The rate of increase in berry

Table 2. Correlation of environmental factors with berry cracking

	Y	X1	X2	X3	X4	X5	X6
Y	1						
X1	0.861**	1					
X2	0.236	0.079	1				
X3	0.555**	0.427	0.598	1			
X4	-0.186	0.018	-0.105	0.042	1		
X5	0.148	0.139	-0.434	-0.412	-0.191	1	
X6	-0.281	-0.008	-0.154	0.057	0.806	0.039	1

Table 1. Significance of the difference in the means of factors of berry cracking in Thompson Seedless grape.

Factor	Cracking (a)	No cracking (b)	Difference (a-b)	Calculated 't'	Significance
Degree days from fruit pruning (°C)	1541	1456	85	4.629	**
Average humidity (%)	73.7	69.6	4.1	2.95	**
Cumulative rainfall (mm)	8.6	4.9	3.7	3.737	**
Average soil moisture tension (kPa)	13.5	19.8	-6.3	1.861	NS
Average T-max (°C)	30.1	31.2	-1.1	2.154	*
Average wind speed (km/h)	4.27	5.12	-0.85	2.248	*

*Significant at 5% probability (>2.011),**Significant at 1% probability (>2.684)
NS: Non significant.

cracking per unit increase in degree days increased with increasing degree days above 1400. The critical level of degree days was 1415 (Table 3) above which cracking increased progressively. (Fig.1). GDD had a greater influence than CR on berry cracking as evidenced by their respective correlation coefficient of 0.861 and 0.555. Total soluble solids (TSS) content in grape berries increases with advancing time from pruning. A strong relation was recorded between the degree days and TSS content of berries (Winkler *et al*. 12). The significance of GDD lies in the fact that irrespective of the prevailing temperatures in different locations the GDD remains the same for a given level of TSS. In locations with higher temperatures, a given degree of soluble salts accrues faster. Thus, it scores over the days from pruning. Because of this, GDD can be taken as a synonym for TSS content. The percentage of cracked berries increased steadily with increased GDD (Fig.1) above the threshold level of 1415 Celsius GDD (Table 3). The amount of water absorbed by a berry through endosmosis depends on its TSS (solute) content leading to the cell turgidity. Thus, the rate at which pressure builds inside the berry determines the degree of cracking (Lang and During, 8). Hence it can be inferred that the TSS content of berries below 1415 GDD is not adequate to absorb enough water to build up the required turgor

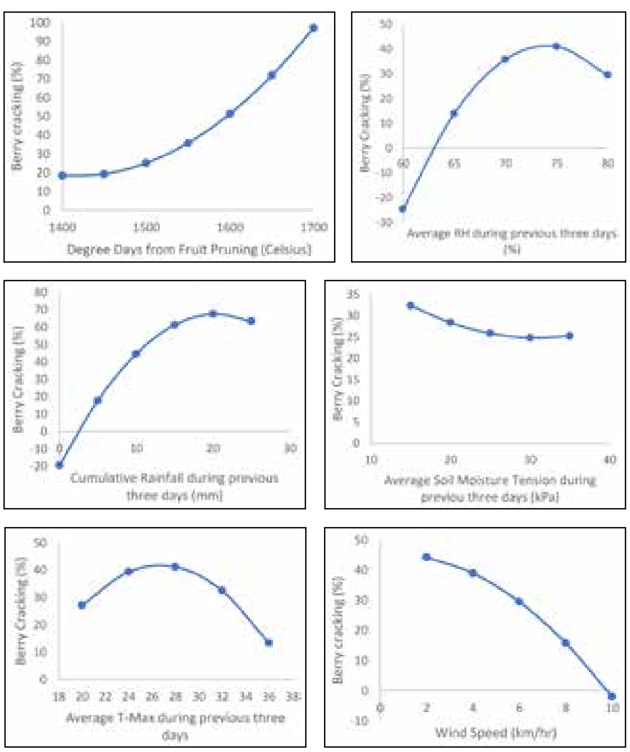

Fig. 1. Relationship of environmental factors with berry cracking.

Table 3. Relationship of × parameters with berry cracking.

Parameter	Regression equation	R^2	X- Opt
X1	$Y= 1971.4 - 2.76X1 + 0.001X1^2$	0.773	1415
X2	$Y= -1789.6 + 49.45X2 - 0.334X2^2$	0.092	74.1
X3	$Y= -19.47 + 8.465X3 - 0.206X3^2$	0.309	20.5
X4	$Y= 53.03 - 1.82X4 + 0.029X4^2$	0.081	31.2
X5	$Y= -191.15 + 17.45X5 - 0.327X5^2$	0.023	26.6
X6	$Y= 45.41 + 0.466X6 - 0.5213X6^2$	0.081	0.446

pressure to inflict cracking. It can also be inferred that any amount of rain before the accumulation of 1415 GDD after pruning cannot cause rotting. The highest percentage of berry cracking was recorded at 1700 GDD, which corresponds to the advanced stage of ripening. As the berry stage progress towards the harvest, the cell wall thickness affects by enzymatic activity (predominantly by pectin methyl esterase) leading to thinning of cell wall and sub epidermal cell layers (Meynhardt, 11; (Deytieux-Belleau *et al*., 6).

Rainfall during berry ripening is a significant cause of berry cracking. If no rain berries do not crack at any stage of ripening. Cumulative rainfall during the preceding three days of the appearance of berry cracking is relevant for predicting its occurrence. No berry cracking was observed at <3 mm rainfall and it increased progressively up to 20.5 mm (Table 3) resulting in 67.5 percent cracking (Fig.1), indicating no adequate turgor pressure development at <3 mm rainfall to cause berry cracking. If the water flow into the berry is only from the berry surface, cumulative rainfall of 20.5 mm distributed over three days may have more effect than occurring in one day, because whatever amount of rainwater falls on the berry, it remains on the berry as a film due to the surface tension of water. If such film forms repeatedly at intervals of varying duration in 72 h the water inflow into the berry is more as compared to a single event of 20.5 mm rain. When such heavy rainfall occurs in one spell or two at a short interval in a day, the effect of 20.5 mm of rain can be attributed to the combined effect of water entering the berries through its surface and also roots.

Relative humidity was significantly higher, but maximum temperature and wind speed were less in vineyards where berry cracking occurred as compared to those in the unaffected vineyards. Increased relative humidity as a result of rainfall reduces the evaporation of water from the berry surface. Contrarily higher atmospheric temperature and wind speed enhance it. Longer retention of water on the berry surface increases the inflow of water into the berry and increases the turgor pressure. Faster evaporation of water from

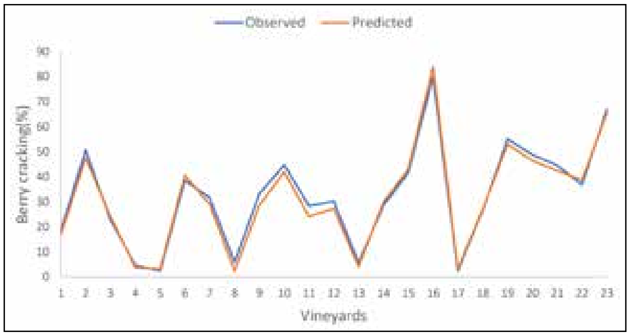

Fig. 2. Comparison of observed and predicted berry cracking.

the berry surface increases the transpiration through berry skin thereby reducing the turgor pressure. Berry cracking was nil at the average RH of 63 per cent (Fig.1). It increased progressively with increasing RH up to 74.1%, (Table 3).

Although soil moisture tension did not influence berry cracking significantly, it varied inversely.. Less soil moisture tension level below 31.2 kPa was associated with increasing berry cracking reaching to 37.8 per cent at 10 kPa. Maximum temperatures above 26.6°C were associated with reduced berry cracking reaching nil at 38°C. Increasing wind speed was associated with reduced berry cracking, which was nil at 9.8 km/h. The highest berry cracking of 45.5 percent was associated with 0 km/hr (Fig. 1).

Multiple regression analyses indicated that the function $Y= -104.55 +0.1723X1 +0.0826X2 +4.1161X3 +0.4813X4 -4.5706X5 -8.0401X6$ was the best with the highest and satisfactory determination coefficient of 0.924. Hence this model was identified for prediction and validation (Table 4).

The mean percentage of predicted berry cracking was 31.6 percent as against the observed cracking of 32.5. However, the deviation of predicted cracking from the observed varied from 0.5 to 4.6 per cent in

Table 4. Validation of the prediction model.

Vineyard	X1	X2	X3	X4	X5	X6	Yo	Yp	Deviation (±)
1	1416	68.6	16.6	3.3	34.8	4.7	18.3	16.7	1.6
2	1562	67.7	12	4.7	31	3.8	50.7	47.6	3.1
3	1368	71.2	10.8	1.6	28.3	3.5	22.8	24.1	1.3
4	1433	72.1	11.2	2.7	38.4	1.9	4.6	3.8	0.8
5	1380	75.3	11.6	5.3	37.5	1.6	2.4	3.2	0.8
6	1423	72.9	10.8	5	27.9	2.9	38.5	40.5	2.0
7	1496	74.1	8.6	4.7	31.2	2.9	31.6	29.0	2.6
8	1426	73.9	10.8	7	36.9	3.3	5.8	2.3	3.5
9	1481	79.3	12.4	5	33.9	3.1	33.2	28.6	4.6
10	1499	78.6	14.7	5.3	32.5	3.8	44.7	41.9	2.8
11	1397	76	12.7	3.3	33.3	2.3	28.4	24.2	4.2
12	1433	77.1	12.2	4.7	31.1	3.7	30.2	27.3	2.9
13	1432	72.3	7.2	10.3	32.2	3.8	5.6	4.0	1.6
14	1350	77.8	17.7	3.8	34.1	2.7	28.5	30.0	1.5
15	1388	70.1	20	3.5	32.5	3.9	41.6	43.0	1.4
16	1457	79.3	20.6	0	29.8	2.2	79.8	83.9	4.1
17	1424	83.3	15.2	9.7	38.9	3.7	2.4	3.2	0.8
18	1435	87.4	13.6	5.7	33.2	3.4	26.6	27.1	0.5
19	1478	78.5	16.7	4.7	31.6	3.5	55.1	53.0	2.1
20	1565	76.2	14.8	3.9	34.2	3.7	48.8	46.4	2.4
21	1503	78.8	13.7	11.7	32.4	3.4	44.6	42.5	2.1
22	1482	77.4	14.3	5.3	33.4	3.1	36.8	38.7	1.9
23	1318	77.1	23	3	31.5	1.8	66.8	65.3	1.5
Average	1443.3	75.87	13.97	5.21	33.07	3.16	32.51	31.57	2.18

Yo = Observed percent berry cracking; Yp = Predicted percent berry cracking individual vineyards, with an average deviation of 2.2 percent, which was not significant as assessed by the Student's t-test. t-stat being 0.154 as against the t-critical of 2.18. A comparison of the percentage of observed cracking and predicted cracking is presented in (Fig. 2)

AUTHORS' CONTRIBUTION

Conceptualization of research (SDS, S); Designing of the experiments (SDS, S); Contribution of experimental materials (SR); Execution of field/ lab experiments and data collection (R, SR); Analysis of data and interpretation (S, SDS); Preparation of the manuscript (SDS, R).

DECLARATION

The authors declare that they do not have any conflict of interest.

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