Sugars in grapes: intra- and inter-cluster variability

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Abstract. The study, conducted in 2023 on Chardonnay, Pinot Noir, Trebbiano Toscano, and Sangiovese, investigated sugar concentration variability within and between clusters during ripening. The objectives were: (i) to assess intra-cluster sugar variability among individual berries, including the effect of berry exposure, and (ii) to compare the technological ripening of basal and upper clusters on the same shoot to support thinning decisions. Within each variety, marked differences were observed between the richest and poorest berries, ranging from 12 °Brix in Sangiovese to 16 °Brix in Trebbiano Toscano. No significant differences emerged between the external and internal portions of clusters. Similarly, no significant inter-cluster differences were found between basal and upper clusters in terms of sugar content, organic acids, or pH. As ripening progressed, sugar accumulation tended toward greater homogeneity, while very high sugar levels (>25 °Brix) were mainly associated with berry dehydration. Trebbiano Toscano and Sangiovese showed heavier basal clusters compared to upper ones, suggesting that thinning should preferentially remove upper clusters to avoid yield and sugar losses. Conversely, to limit sugar accumulation and potential alcohol content, removal of basal clusters is recommended.

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1 Introduction

During the ripening, grapes undergo a complex progression, from the accumulation of sugars, organic acids, and aromatic substances to the breakdown of phenolic compounds. Sugar loading, defined as the accumulation of sugars, primarily glucose, and fructose, in grape berries from veraison onwards, is a dynamic process thatrequires careful monitoring to optimize grape harvesting strategies. Technological maturity, defined by the balance between fermentable sugars and organic acids, is crucial in assessing when to harvest. The accumulation of sugars is a marker of grape ripeness and fermentation potential, while organic acids contribute to the wine's structure and freshness. Harvesting grapes either too early or too late can result in undesirable outcomes, such as insufficient or excessive sugar levels, underdeveloped flavours, and phenolic polymerization, all of which compromise the overall quality of the wine. The influx of sugar into the berry is mainly facilitated by the hydrolysis of sucrose, coming from leaf chloroplasts.Itis formed through photosynthesis, and its transport into berry cells—a process largely dependent on phloem function and the vine's physiological condition [6, 7]. Recent research has highlighted the importance of sugar loading not only as a marker of grape ripening but also as a predictor of grape and wine quality. Studies have shown that different profiles of sugar loading, such as rapid, slow, or plateau phase, can influence the style of the resulting wine, ranging from fresh-green to aromatic profiles to mature, full-bodied wines [1, 8].Moreover, the kinetics of sugar accumulation provide insights into the physiological responses of the vine to environmental factors such as water stress and high temperature, which are critical in defining the terroir and its influence on grape development and ripening [4, 3]. Understanding the patterns of sugar loading concerning environmental conditions enables viticulturists to fine-tune their vineyard management practices. Additionally, balancing growth and fructification, to stabilize vine yields and grape quality, can be achieved by adjusting the crop levels through grape thinning treatments [2]. This involves removing some grape clusters during the growing season to reduce the vine's fruit load and redistribute water and nutrients on the remaining clusters, thereby improving their ripeness and composition [5]. The aim of this trial was: 1) to analyse sugar accumulation in all berries of the cluster (intra-variability) working on 4 grapevine cultivars with different ripening periods and taking into consideration the outer (facing the inter-row) and inner (facing inside the canopy) portions of the cluster as well as the relative portions (upper, middle, basal portions of the cluster and wings, when present); 2) to identify any differences, under the same conditions, between the two clusters on the same shoot in four grape cultivars (inter-variability), as there is limited clarity regarding the best choice of the cluster to be discarded when cluster thinning is required.

2 Materials and methods

The experiment was conducted in 2023, involving two different locations and four commercial vineyards located near Perugia (Umbria region, central Italy). Four grape varieties were chosen for the study: Chardonnay and Pinot Noir (near Magione town, 44°42' N, 12°57' E, elevation 272 m a.s.l.) and TrebbianoToscano and Sangiovese (near Deruta town 42° 57' N 12° 24' E, elevation 405 m a.s.l.). These varieties were selected based on the following criteria:
1. Berry color: red (Pinot noir and Sangiovese), white (Chardonnay and Trebbiano Toscano);
2. Ripening period: early (Pinot noir and Chardonnay), late (Sangiovese and Trebbiano Toscano);
3. Cluster size was classified as large (Trebbiano Toscano and Sangiovese) or small (Pinot noir and Chardonnay).

Chardonnay and Pinot Noir samples were collected at harvestfrom a vineyard with vines trained to a VSP (Vertical Shoot Positioning) system and pruned according to the Guyot method(2.5 × 0.8 m, inter- and intra-row distances, 5.000 vines/hectare)leaving one cane with 12 buds per vine.TrebbianoToscano and Sangiovese samples were collected from a vineyard VSP system trained and spur-pruned (2.5 × 1 m, inter- and intra-row distances, 4.000 vines/hectare)leaving five spurs with a total of 10 buds per vine. For each variety, the analysis focused on the sugar content (expressed in °Brix) of all berries from three clusters sampled from opposite sides of the same row. Sampling for early-ripening varieties, Chardonnay and Pinot Noir, was carried outon August 23, while Sangiovese sampling took place on September 19 and TrebbianoToscano on September 28.Sampling dates were determined according to the ripening stage of the grapes and thus coincided with commercial harvest maturity. At harvest, six representative bunches per variety were collected from three vines. From each vine, one bunch was taken from the side most exposed to sunlight and one from the opposite side.Once collected, the clusters were placed in flat plastic containers, with the internal and external halves marked with tape to distinguish the unexposed and exposed portions. After collection, all clusters were photographed in the lab from both sides (external and internal). For each berry from both halves, a sample of juice was extracted using a syringe with a needle to determine the sugar content (°Brix) using a temperature-compensating refractometer (RX-5000; Atago Ltd., Tokyo, Japan). The °Brix of all berries were initially recorded and then organized by side of the bunch (exposed and non-exposed) and by the four portions: A (upper, near the peduncle), B (middle), C (basal), and ALA (wing, if present). Average values were calculated for each portion of the bunch on both sides, as well as for the entire bunch, and subsequently compared.

In the second study, sampling was carried out at harvest simultaneously in the same four vineyards used in the first trial. In all grape varieties, 10 shoots were randomly selected from 10 vines, each bearing two clusters (Figure 1). At harvest, the fresh weight (g) of

each cluster, divided in basal and upper according to their position along the shoot, was recorded as well as the weight of 200 berries (g) for each cultivar and cluster position. The berries were crushed and the juice was recovered to measurethe sugar content (°Brix), and titratable acidity using a Titrex Universal Potentiometric Titrator (Steroglass, Perugia, Italy), by raising pH to 8.2with 0.1 N NaOH (expressed in g L^{-1} of tartaric acid). Finally, the pH was determined using a PHM82 standard pH-meter (Radiometer, Copenhagen, Denmark). Data were subjected to analysis of variance and differences between average values were determined using the Student-Newman-Keuls (SNK) test at the 5% level (SigmaStat software package; Systat Software, Inc., San Jose, CA, USA).

3 Results

3.1 Intra-cluster variability

At harvest, in all grape varieties examined, the difference in sugar accumulation between the richest and poorest berry was high, with a minimum of 12 °Brix in Sangiovese and a maximum of 16 °Brix in TrebbianoToscano (Figure 1).
In none of the four grape varieties studied was there any significant variation in the cluster portion (Table 1).

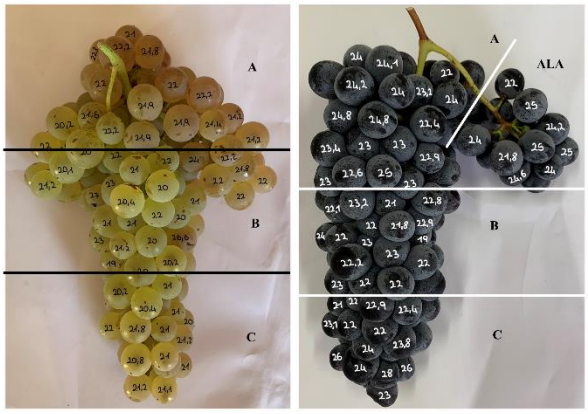


Fig.1. Sugarscontent (°Brix) for each berry in theTrebbianoToscano (left) and Sangiovese (right) clusters. A= upper portion of the cluster (closest to the petiole), B= middle portion of the clusterand C=, basalportion of the cluster.

In all cultivars examined, the comparison of °Brix content between berries on the outer side of the clusters (sun exposure) and those on the inner side of the same clusters (shaded exposure) did not show any differences (Table 2).

Table 1. Sugars (°Brix) accumulated in grapes as a function of different cluster portions in different varieties. Each number equals the average of the different bunch portions (A = upper; B = middle, C = basal, ALA = wings) from 3 bunches.

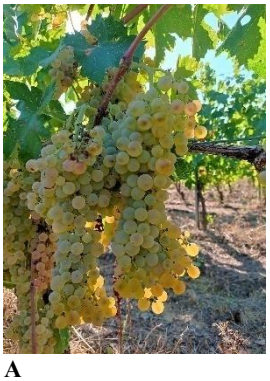
Cultivar	Cluster portio	Mean	Min.	Max.
	n			
		°Brix		
Pinot N.	A	20.5	16.0	30.0
	B	20.3	15.8	28.8
	C	20.9	16.6	30.0
	ALA	20.0	16.2	25.6
Chardonnay	A	23.9	18.4	32.0
	B	23.7	17.0	32.0
	C	23.8	18.8	31.0
Sangiovese	A	23.5	18.2	29.0
	B	22.9	18.0	29.0
	C	23.8	18.0	32.0
	ALA	23.1	20.0	25.2
Trebbiano T.	A	21.1	16.0	31.0
	B	21.4	16.0	32.0
	C	21.1	16.4	32.0
	ALA	22.2	17.0	24.6

Table 2. Sugars (°Brix) accumulated in the berries according to their exposure, outer (O) and inner (I) portions of the cluster, in different grape varieties. Each data represents the average of the inner and outer side from 3 clusters.

Cultivar	Cluster exposure	Mean	Min.	Max.
		°Brix		
Pinot Noir	O	20.8	16.8	30.0
	I	20.0	15.8	30.0
Chardonnay	O	23.8	17.4	32.0
	I	23.8	17.0	32.0
Sangiovese	O	23.1	18.0	30.0
	I	23.7	19.0	32.0
Trebbiano T.	O	21.3	16.0	30.0
	I	21.5	16.0	32.0

3.2 Inter-cluster variability

In all cultivars, no significant differences were found in technological ripening; sugar, titratable acidity (TA), and must pH were similar in both the upper and basal clusters (Figure 2 and Table 3). Sangiovese and TrebbianoToscano showed a significant higher weight of basal clusters compared to the upper clusters (+13% and +23, respectively), consequently, the amount of sugar accumulated was higher, with a notable increase of 11 and 15 g per cluster when comparing the total sugar content in the basal clusters to the upper ones (Table 3).



A

B

Fig.2. Basal and upper clusters of TrebbianoToscano (A) and Sangiovese (B) grape varieties.

Table 3. Upper (U) and basal (B) cluster characteristics ofthe four varieties examined.(PN=Pinot Noir; C= Chardonnay; S= Sangiovese; TT= TrebbianoToascano

Variety	Position	Cluster weight (g)	Berry weight (g)	°Brix	TA (g/L)	pH	Sugars per cluster (g)*
PN.	U	144	1.27	19.8	8.6	2.95	28.5
	B	130	1.23	21.0	8.5	2.95	27.3
C	U	162	1.31	24.2	7.1	3.04	39.3
	B	159	1.25	24.4	7.0	3.02	38.8
S	U	336 b	2.52	21.2	5.6	3.30	71.2
	B	380 a	2.30	21.6	6.0	3.27	82.1
TT	U	356 b	2.14	18.0	5.6	3.23	64.1
	B	439 a	2.36	18.0	5.8	3.21	79.1

4 Conclusions

At harvest time, in all grapevine cultivars examined the sugar accumulation in the berries which constitute the clusters shows a high variability. However, no significant differences emerge according to the cluster portions (upper, middle, basal, and wing) or between portions of the same cluster exposed to full light (outer berries) or in shaded conditions (inner berries). As ripening progresses, sugar accumulation slows down and tends towards homogeneity. High sugar content, greater than 25-26 °Brix is due to berry dehydration phenomena.

No significant differences in technological maturation emerged between upper and basal clusters on the same shootin the four cultivars analyzed.TrebbianoToscano and Sangiovese have basal clusters with higher weight than upper ones, Therefore, unlike Chardonnay and Pinot Noir, cluster thinning operations should focus on removing theupper clusters, otherwise there will be yield and sugar losses. Conversely, if the winegrower aimsto reduce sugaraccumulation and consequently, the alcohol content of the wines, it is advisable to remove the basal bunches.

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