Inception, progression, and compositional consequences of the sugar accumulation disorder (SAD)

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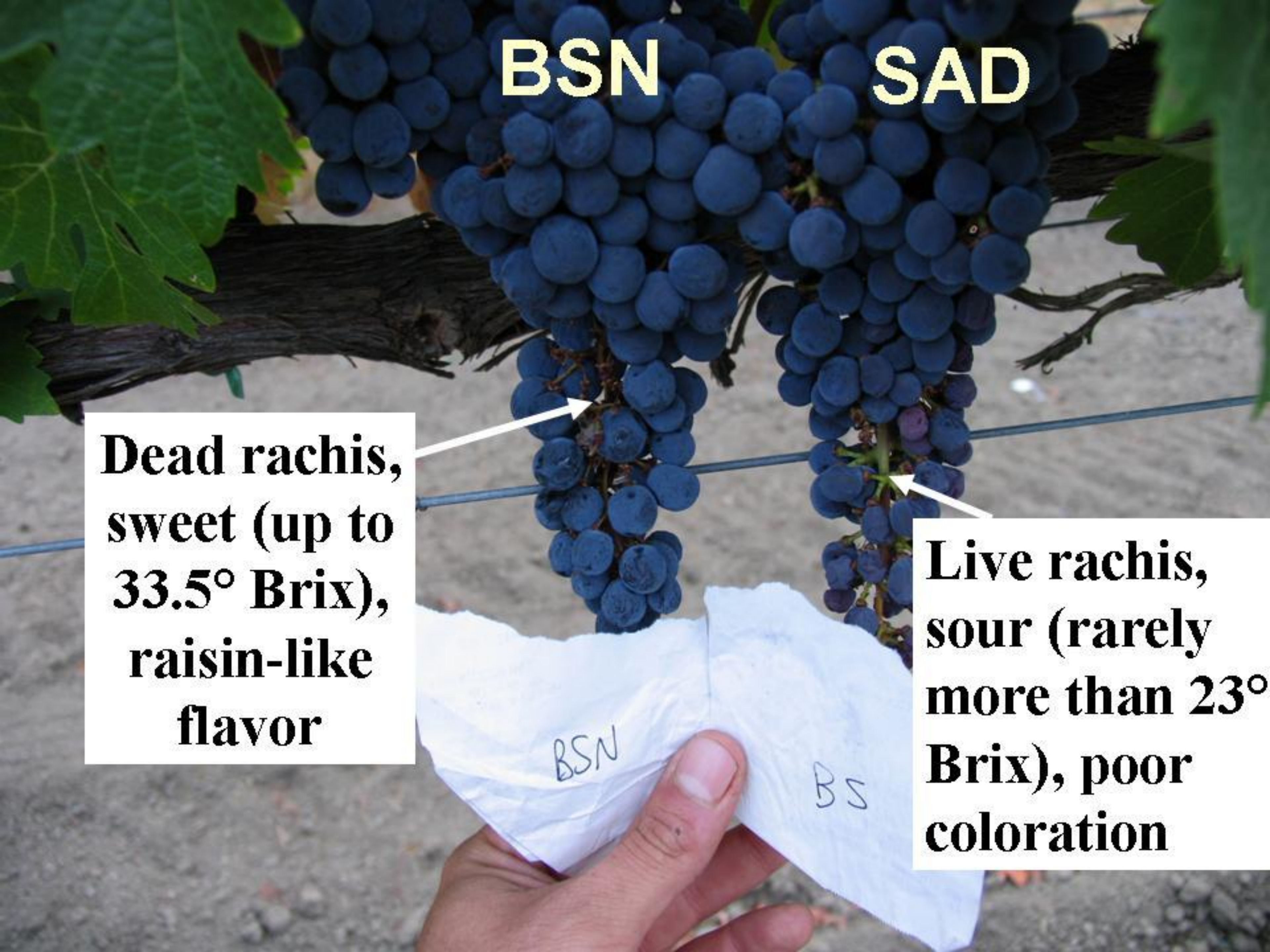
Sugar Accumulation Disorder (SAD)
a.k.a. ‘Berry shrivel’

- Impeded sugar accumulation
- Healthy appearing rachis
- Poor color development (in red varieties)
- Premature berry desiccation


BSN
SAD
BSN
BS


BSN
SAD
Dead rachis, sweet (up to 33.5° Brix), raisin-like flavor
Live rachis, sour (rarely more than 23° Brix), poor coloration
BSN
BS


SAD
BSN

Cabernet Sauvignon and Sauvignon blanc clusters displaying symptoms of SAD.

SAD

Grapes displaying SAD have been seen:

- Throughout California
- In Oregon and Eastern Washington
- In Europe (Austria)

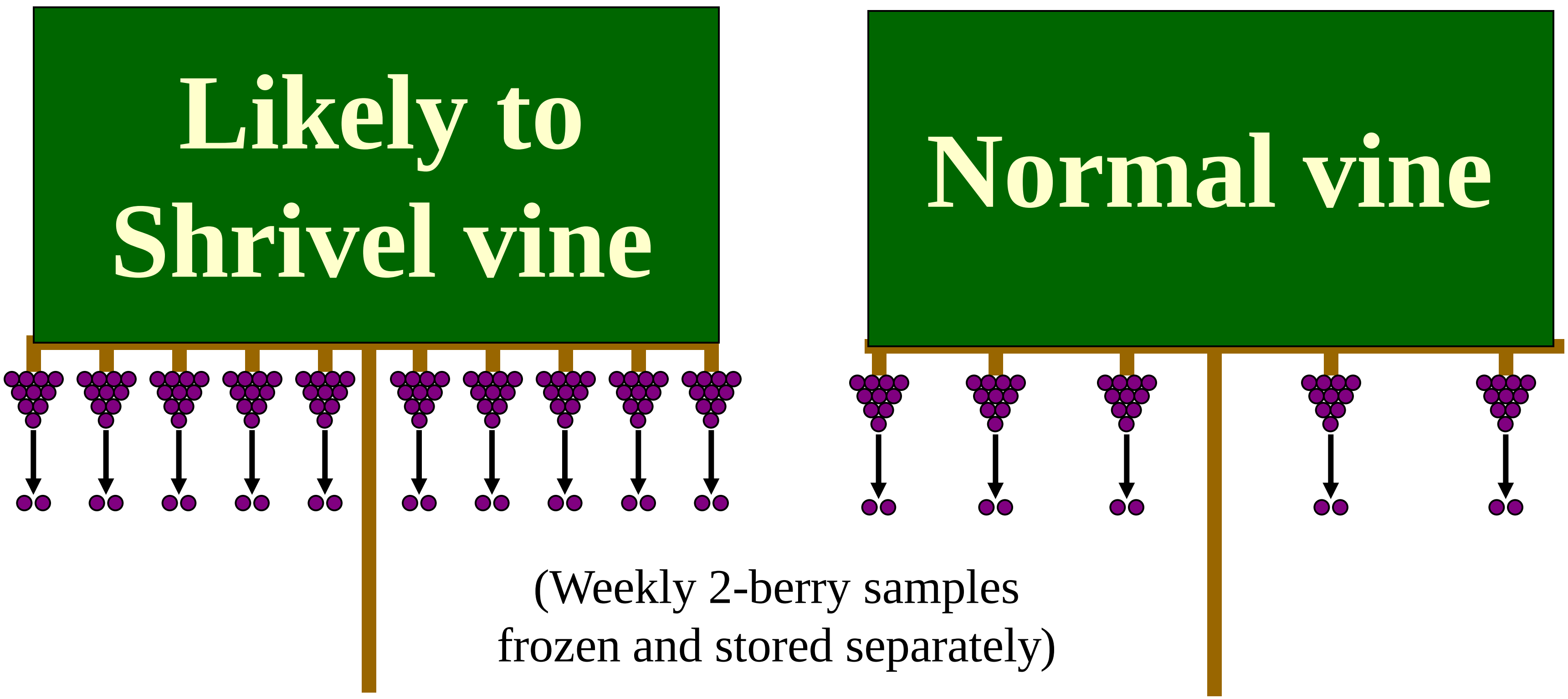
Sample	Sample Date	condition	Berry weight (g) ± SD	Brix ± SD	pH ± SD
Round Pond (Rutherford) Cabernet S.	8/14/07	SAD	0.84 ± 0.09	11.2 ± 0.3	3.1 ± 0.07
		Control	1.08 ± 0.04	17.4 ± 0.6	3.3 ± 0.04
Juliana (Napa) Sauv. Blanc	8/23/07	SAD	0.8 ± 0.03	15 ± 1.3	3.1 ± 0.04
		Control	1.2 ± 0.04	26.2 ± 1.2	3.6 ± 0.06
Chimney Rock (Napa) Sauv. Blanc	8/27/07	SAD	1.34 ± 0.15	13.2 ± 2.1	3.3 ± 0.07
		Control	1.7 ± 0.08	25.8 ± 0.9	3.6 ± 0.09
Oakville Exp. V. (Napa) Cabernet S.	9/24/07	SAD	1.00 ± 0.1	19.3 ± 0.9	3.3 ± 0.1
		Control	1.11 ± 0.03	23.2 ± 3.2	3.4 ± 0.1
Jordan (Sonoma) Cabernet S.	10/7/07	SAD	0.73 ± 0.1	15.5 ± 2.0	3.2 ± .06
		Control	1.06 ± 0.01	22.8 ± .8	3.5 ± .03
Chimney Rock (Napa) Cabernet (mature)	10/16/07	SAD	0.82 ± 0.008	13.8 ± 1.4	3.4 ± .1
		Control	1.04 ± 0.05	22.4 ± 1.0	3.7 ± .05
Chimney Rock (Napa) Cabernet (young)	10/23/07	SAD	0.77 ± 0.03	15.6 ± 1.4	3.4 ± .07
		Control	0.89 ± 0.07	22.2 ± .9	3.5 ± .03
SAD Average			**0.9 a**	**14.8 a**	**3.26 a**
Control Average			**1.15 b**	**22.9 b**	**3.51 b**

Our work originated at the
Oakville Experimental Vineyard

With Cabernet Sauvignon vines that had consistently shown berry shrivel symptoms over several seasons

Some clusters showed shrivel and others did not.

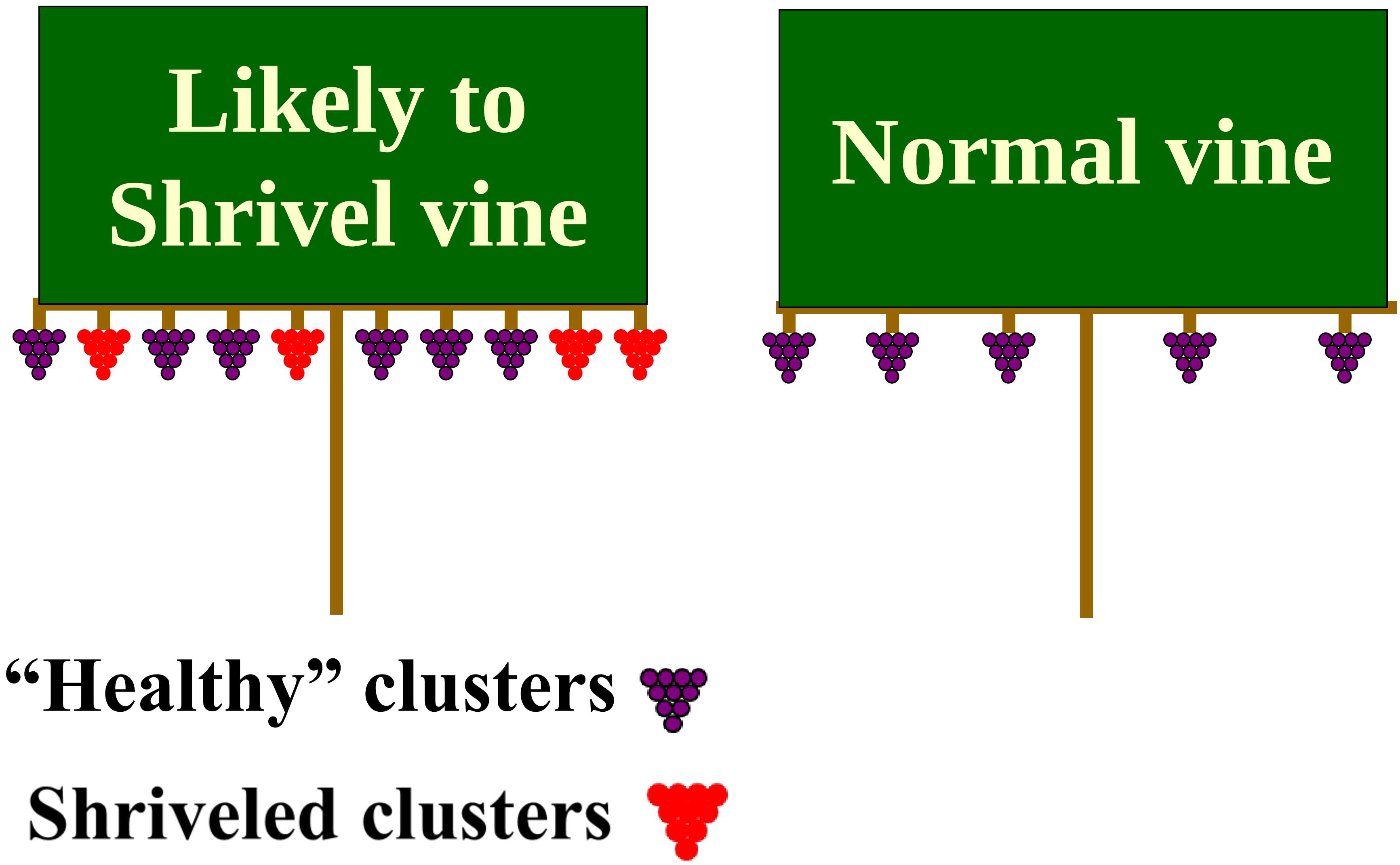
Sampling protocol: pre-symptom expression



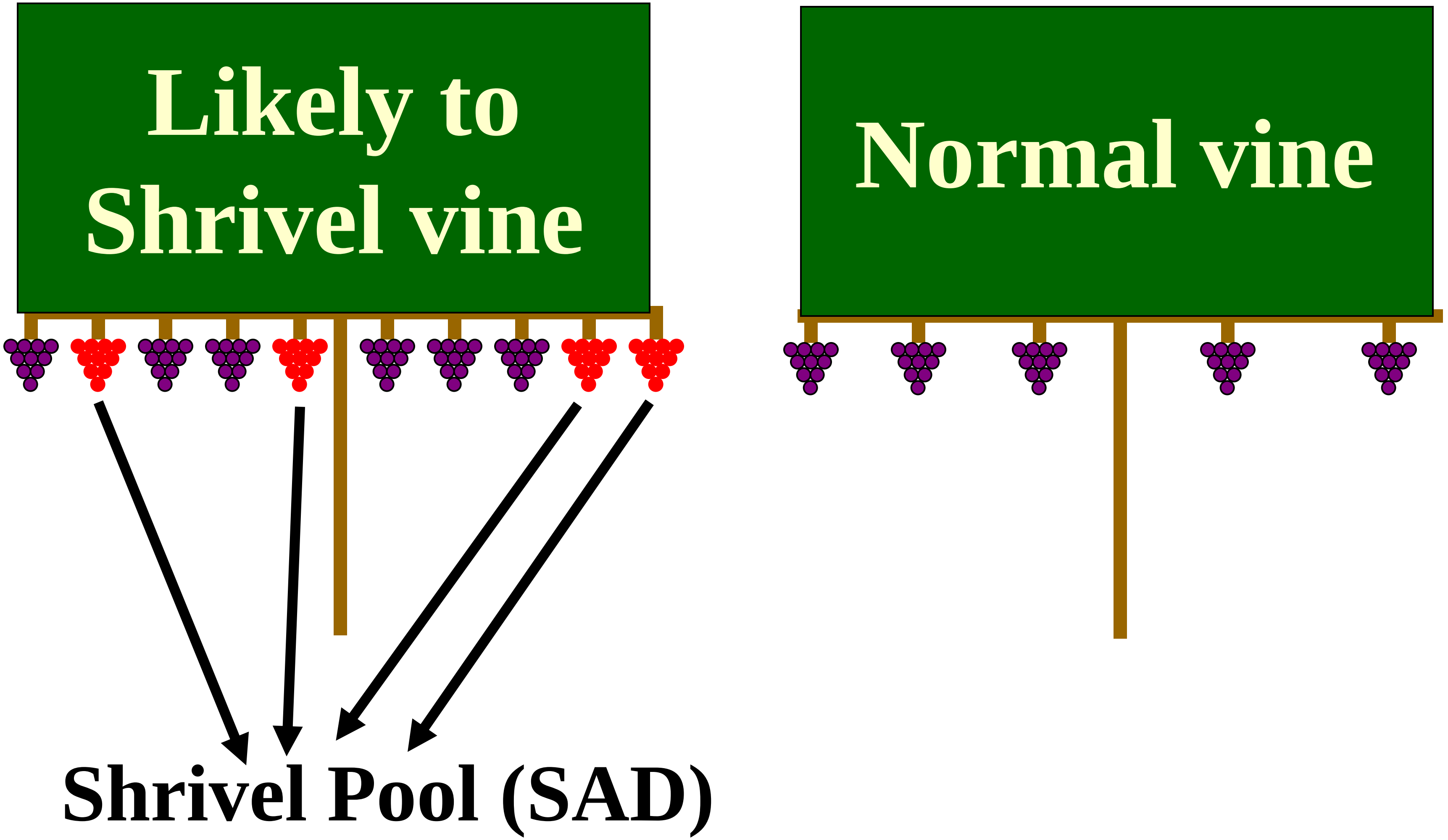
Ten clusters tagged for composition/firmness

Five clusters tagged for composition/firmness

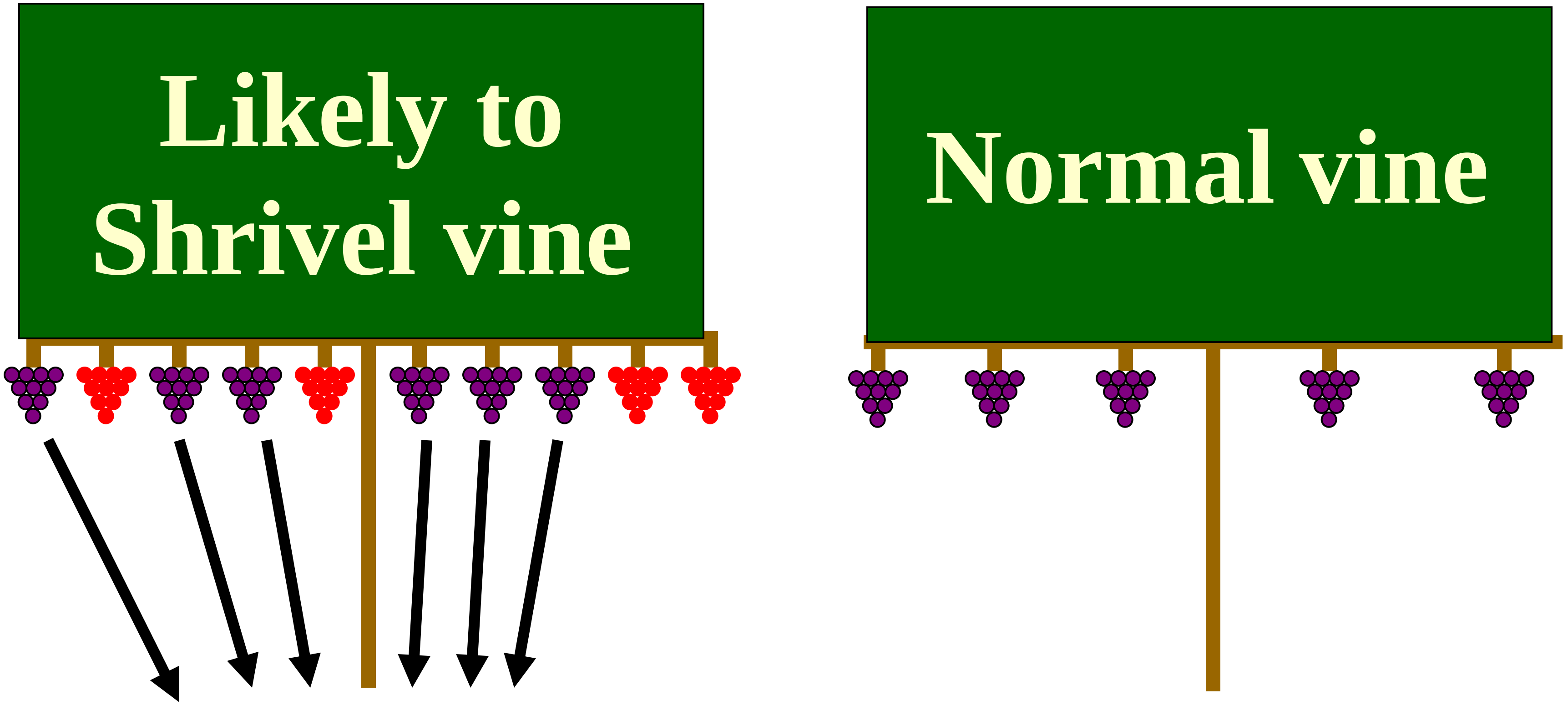
Symptom expression



Pooling 2-berry samples within/between vines

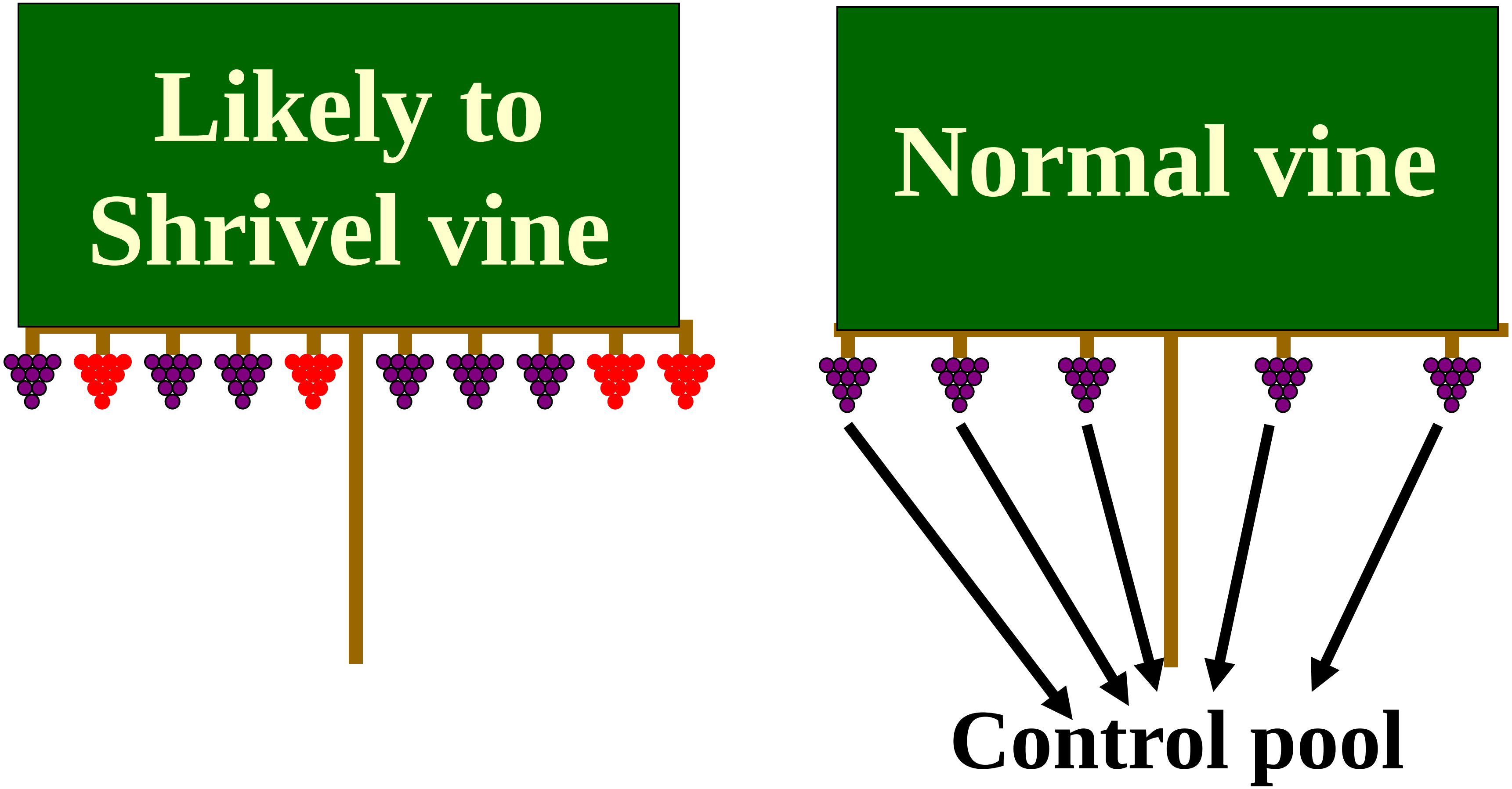


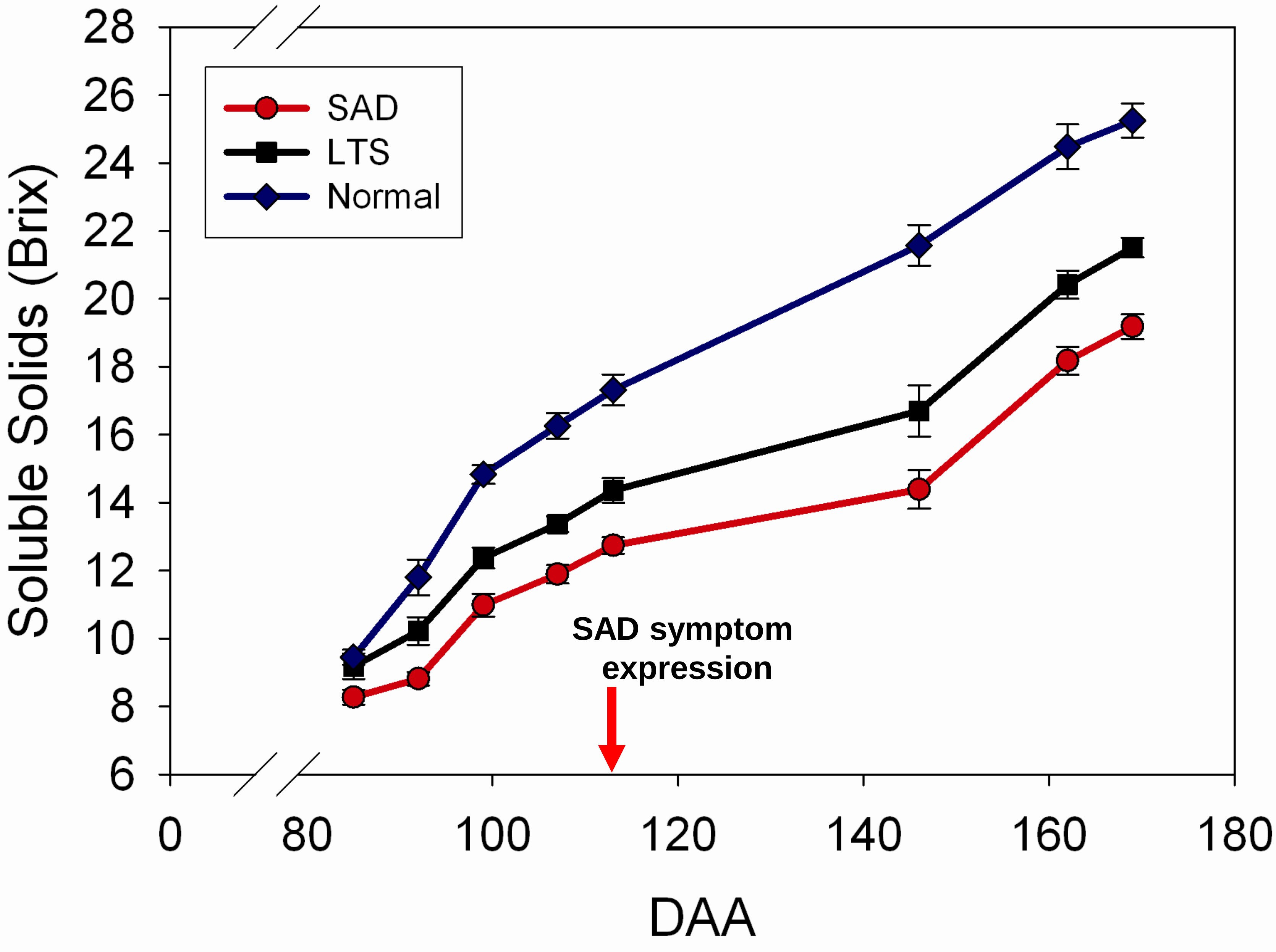
Pooling 2-berry samples within/between vines



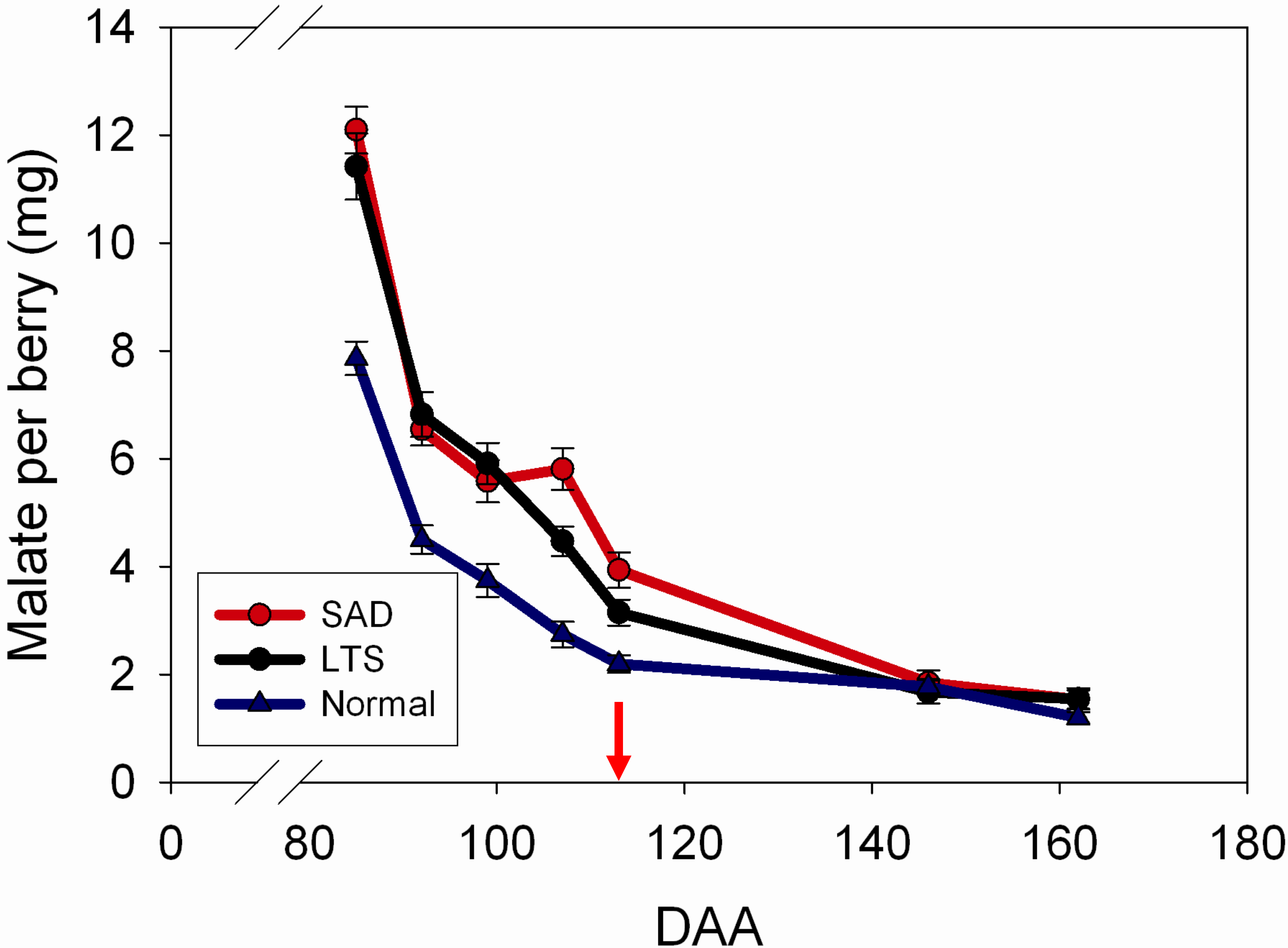
“Likely to shrivel” (LTS) pool

Pooling 2-berry samples within/between vines

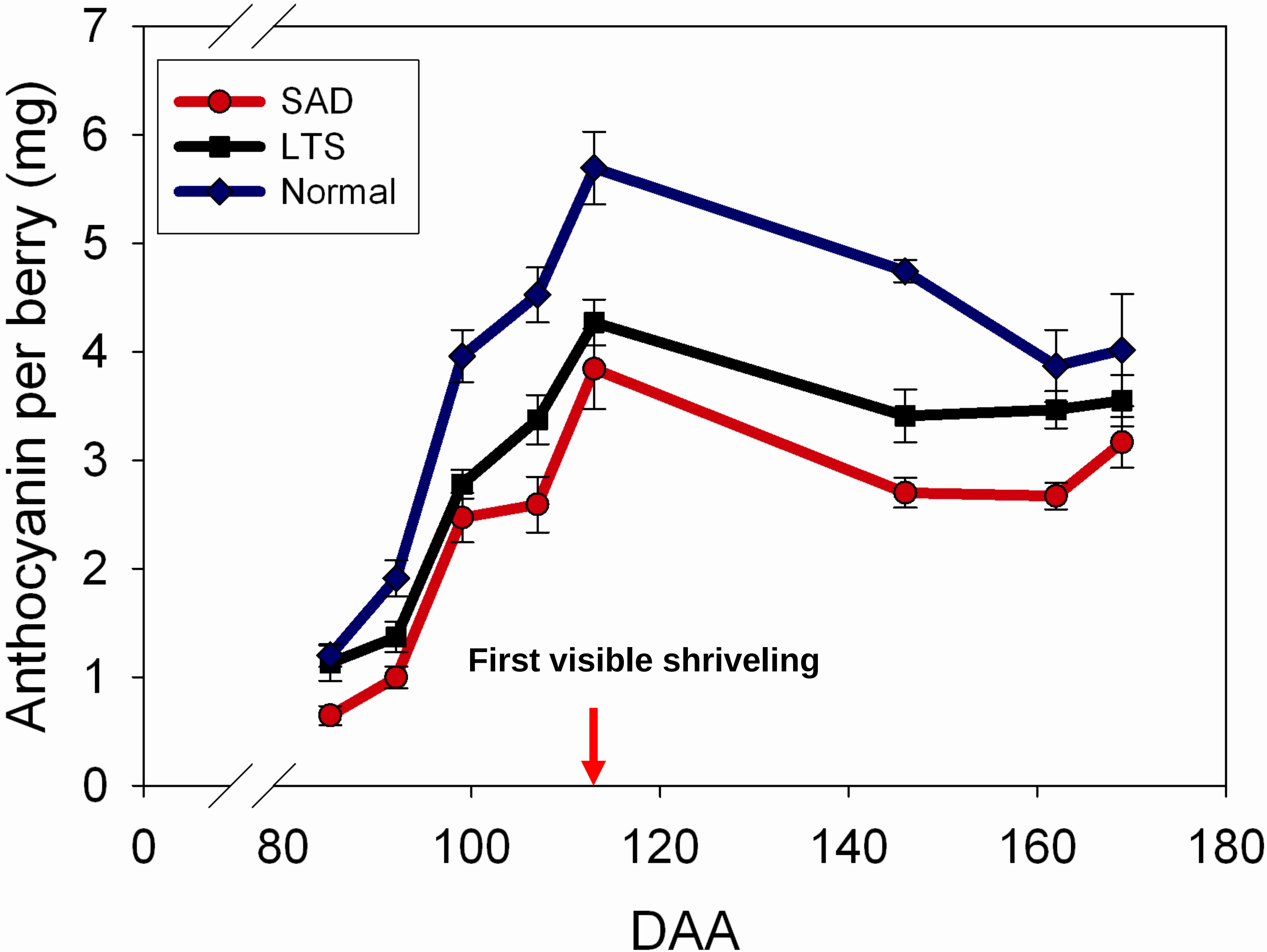




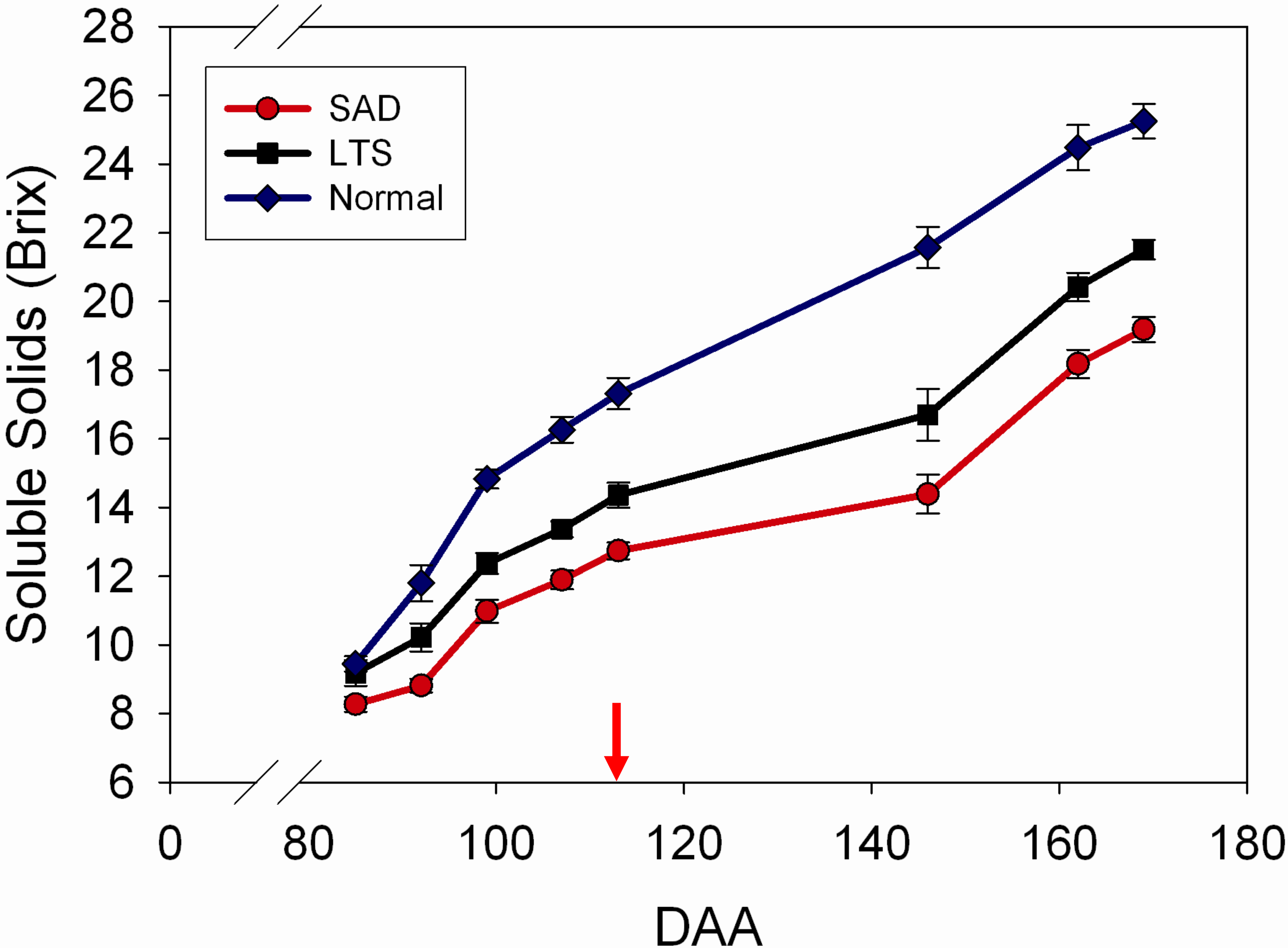
Krasnow et al. 2009 AJEV



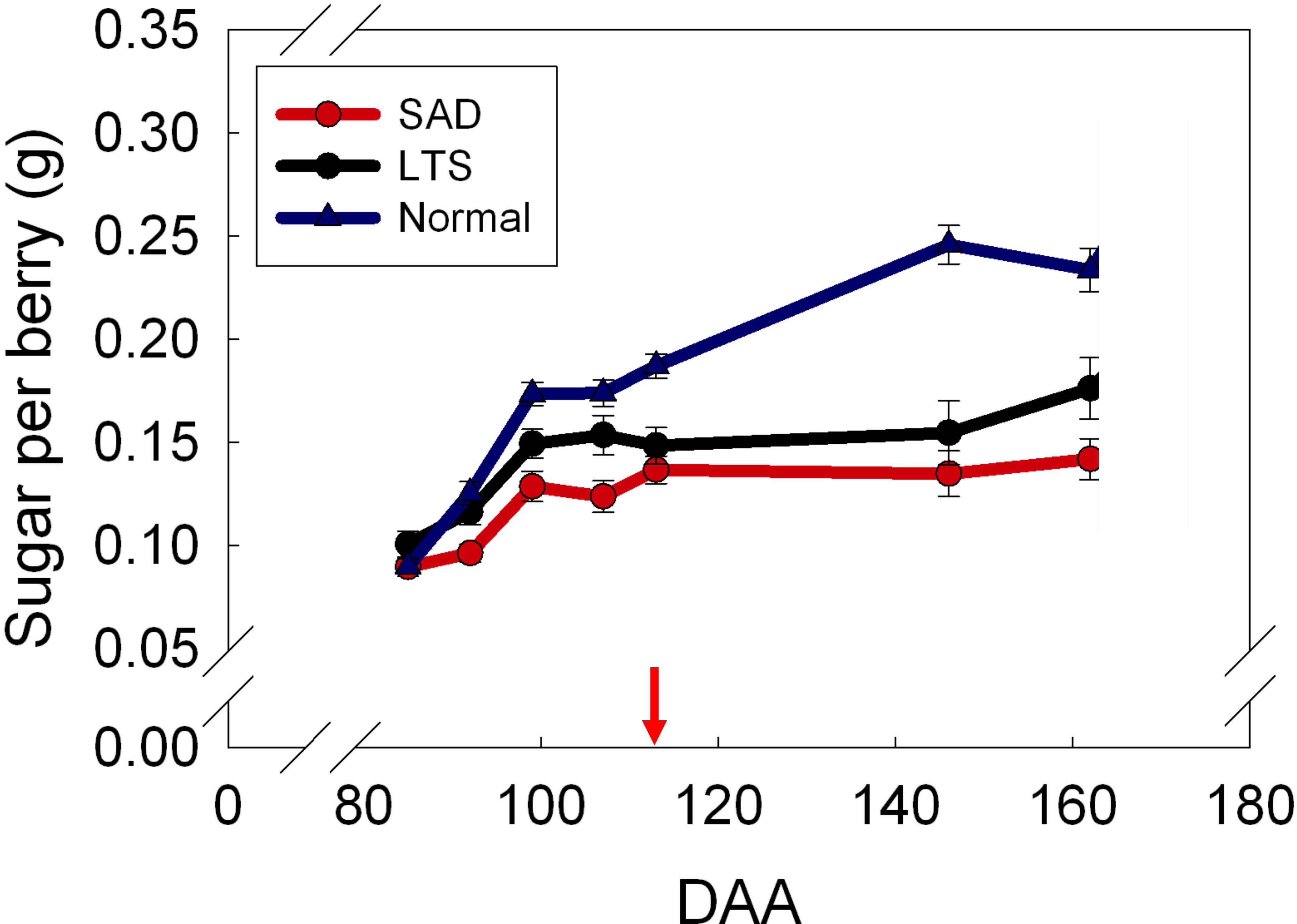
Malate per berry (mg)
14
12
10
8
6
4
2
0
SAD
LTS
Normal
0
80
100
120
140
160
180
DAA



Anthocyanin per berry (mg)
SAD
LTS
Normal
First visible shriveling
DAA
0
1
2
3
4
5
6
7
0
80
100
120
140
160
180



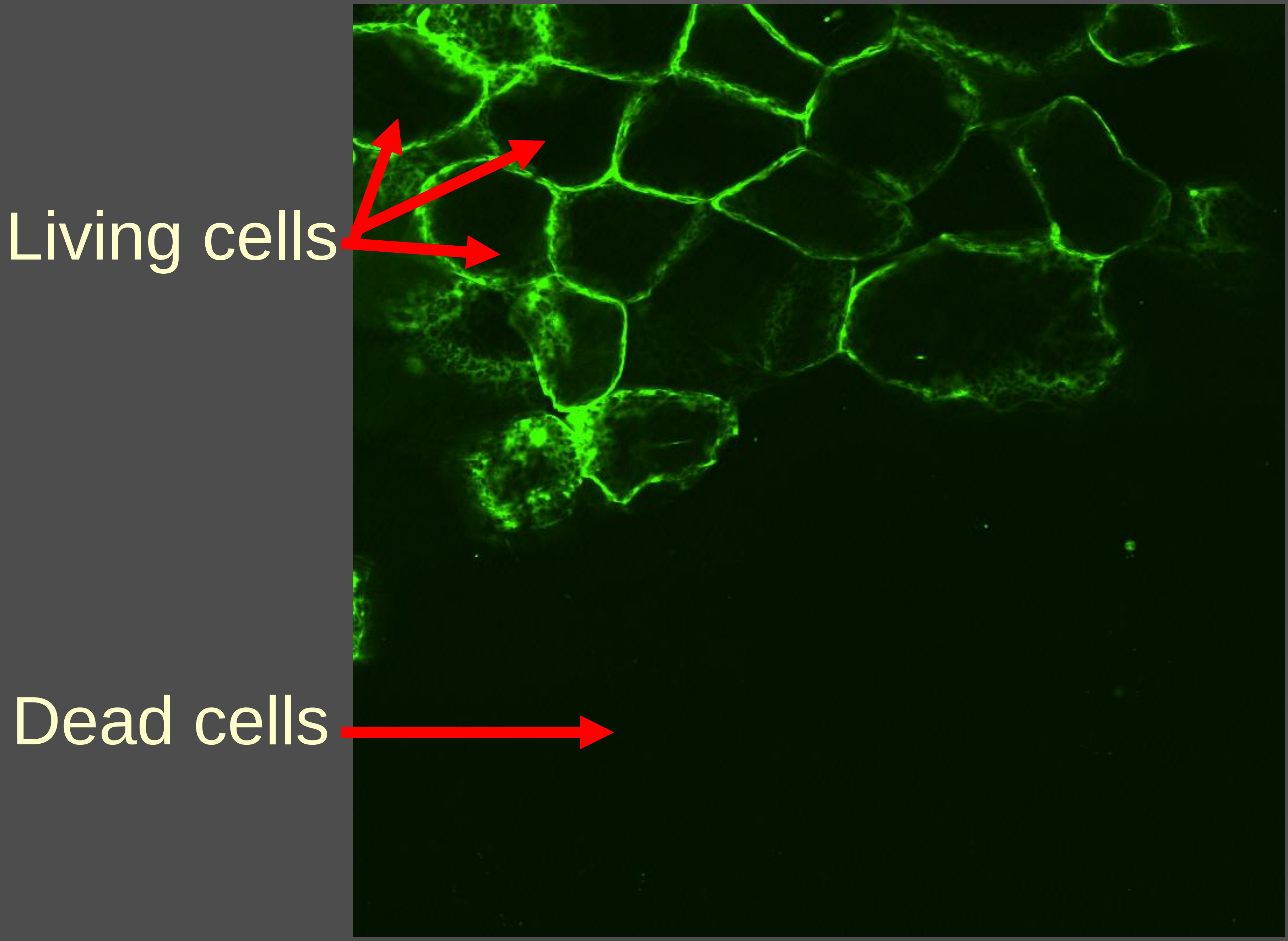
Soluble Solids (Brix)
28
26
24
22
20
18
16
14
12
10
8
6
SAD
LTS
Normal
0
80
100
120
140
160
180
DAA

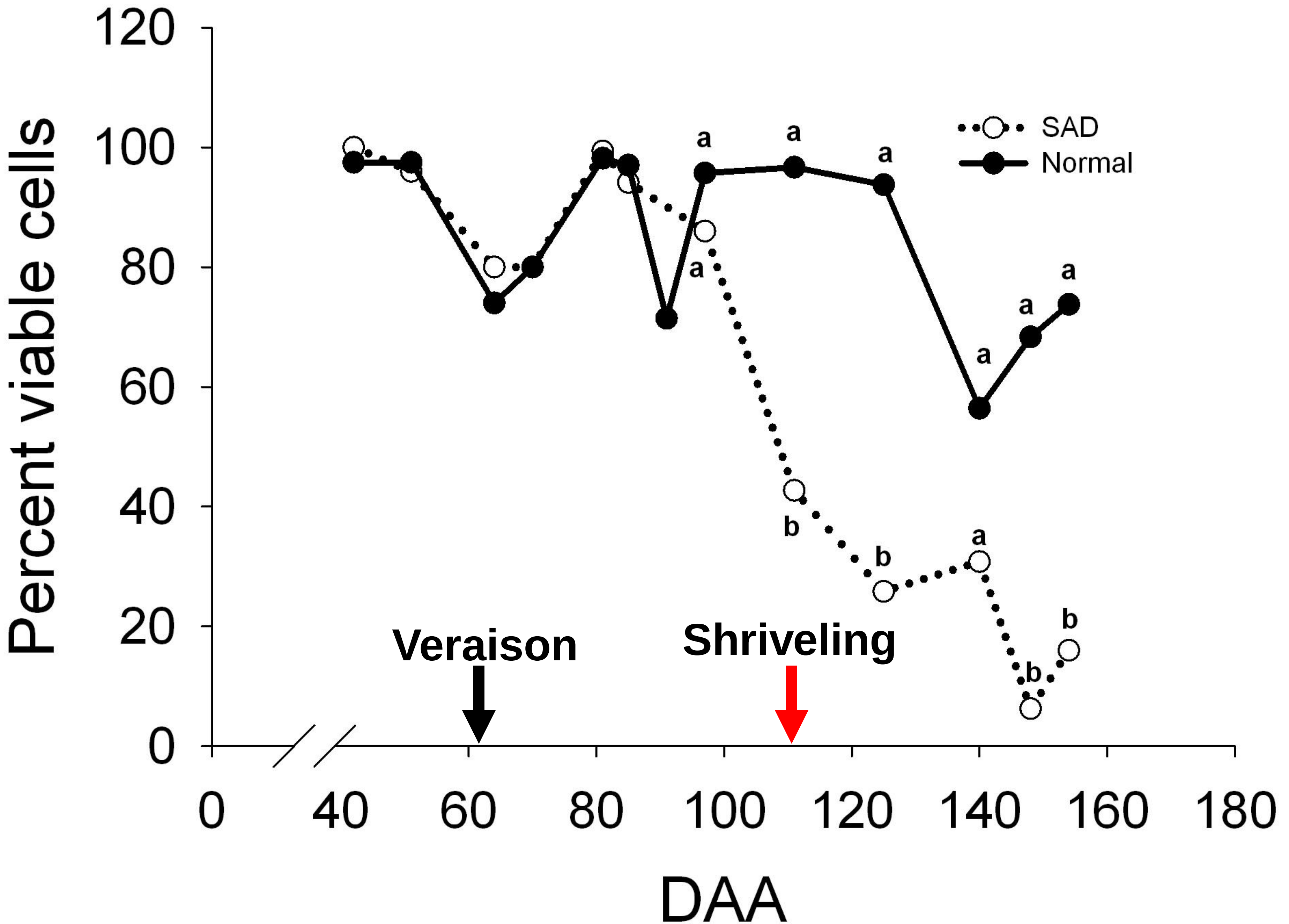


Sugar per berry (g)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
SAD
LTS
Normal
0
80
100
120
140
160
180
DAA

Fluorescein Diacetate cell viability staining in fruit – Ken Shackel

- Allows differentiation of living versus dead cells


Living cells
Dead cells



Percent viable cells
120
100
80
60
40
20
0
0
40
60
80
100
120
140
160
180
DAA
SAD
Normal
Veraison
Shriveling
a
a
a
a
a
a
a
a
b
b
a
b
b

SAD symptom development

- SAD fruit has lower Brix, pH, and anthocyanin concentration than control fruit

SAD clusters stop accumulating sugars weeks before visible symptoms

- Cells die as symptoms become visible

- Vine phenomenon - nonsymptomatic clusters on SAD vines develop similarly to SAD clusters

Is shrivel [SAD] the result of impaired phloem transport?

Stopping sugar import by girdling the cluster should mimic SAD

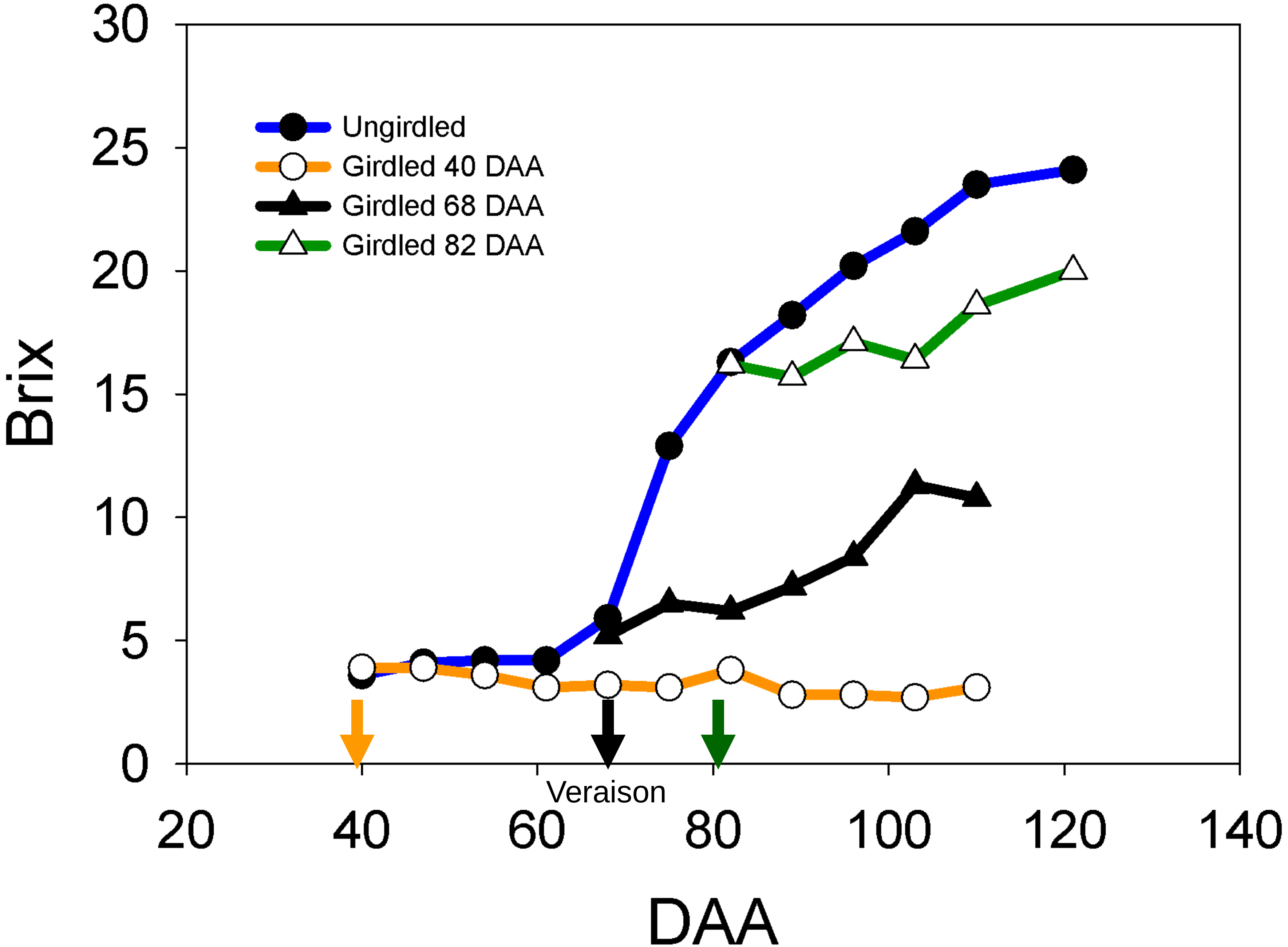
Girdling experiments to mimic SAD

Girdling was done with a knife above and below the peduncle to stop sugar transport to the berries.

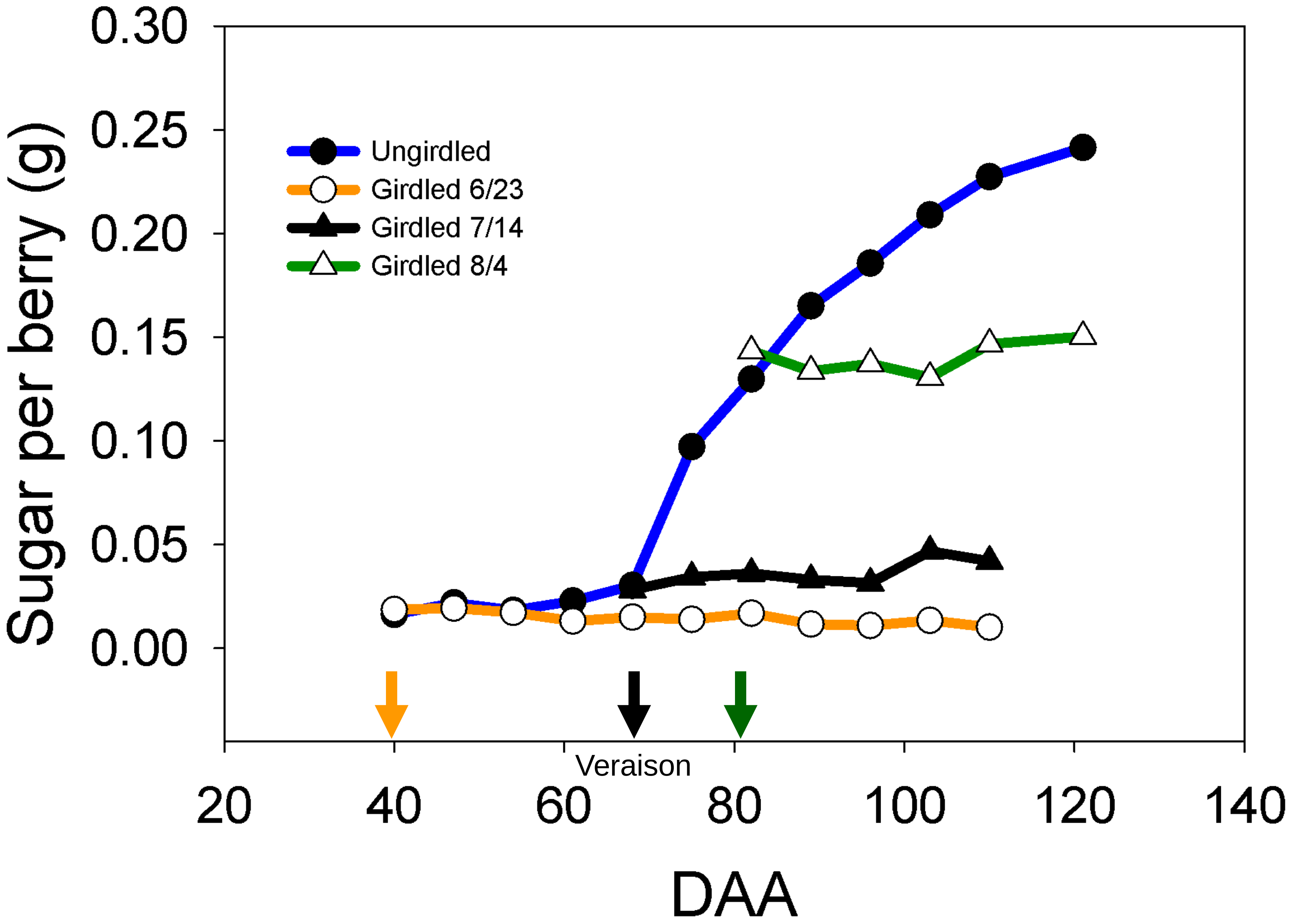
Cabernet Sauvignon

Not girdled

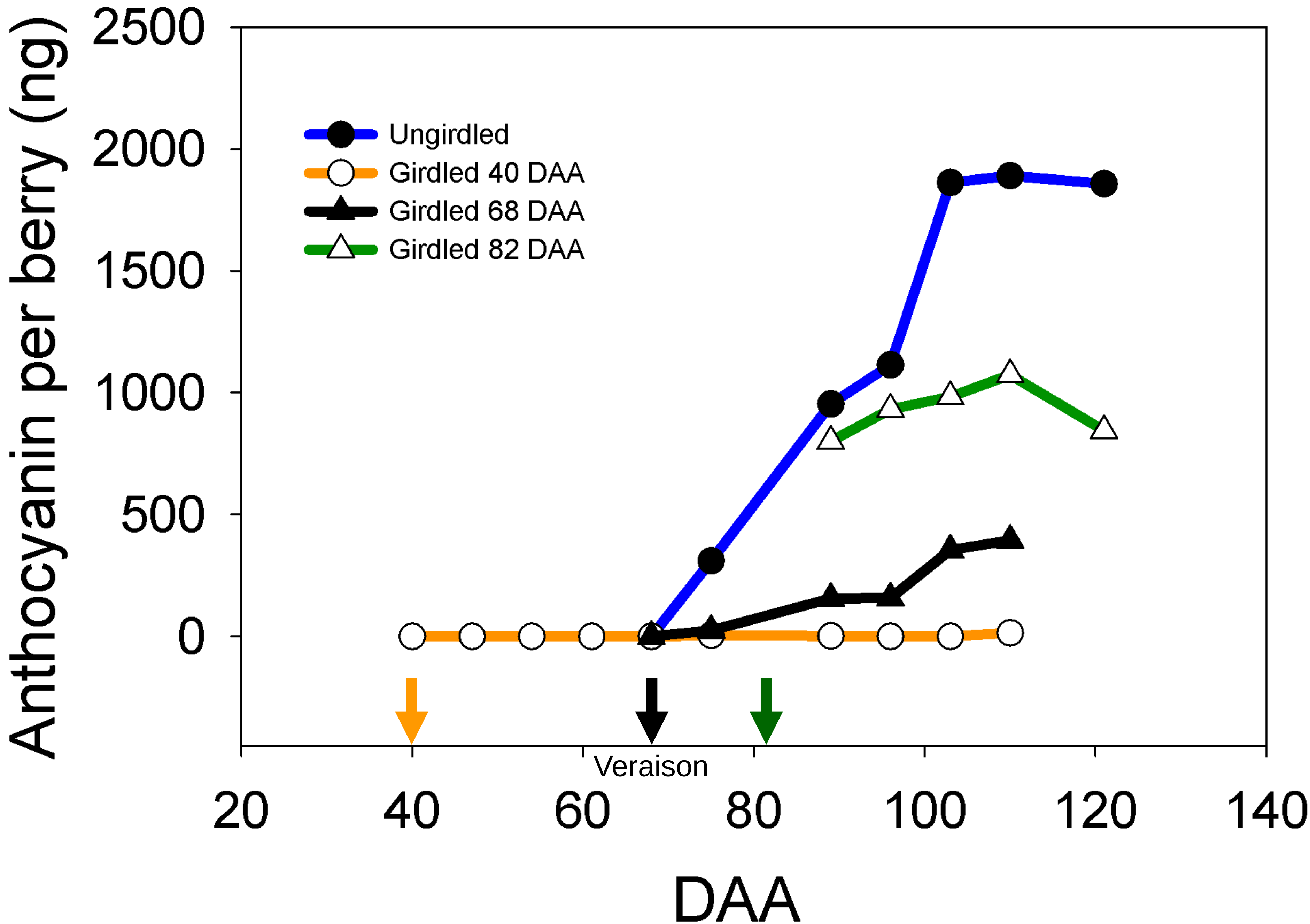
Girdled before veraison. Picture taken 103 DAA (63 DAG)



Ungirdled
Girdled 40 DAA
Girdled 68 DAA
Girdled 82 DAA
Brix
0
5
10
15
20
25
30
Veraison
DAA
20
40
60
80
100
120
140



Sugar per berry (g)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Ungirdled
Girdled 6/23
Girdled 7/14
Girdled 8/4
Veraison
20
40
60
80
100
120
140
DAA



Anthocyanin per berry (ng)
2500
2000
1500
1000
500
0
Ungirdled
Girdled 40 DAA
Girdled 68 DAA
Girdled 82 DAA
Veraison
20
40
60
80
100
120
140
DAA

Yes, girdling mimics SAD with respect to berry growth, sugar accumulation, and color development.

Crop Thinning Experiments

Clusters dropped at set

Greenest clusters dropped at veraison

2007
% SAD

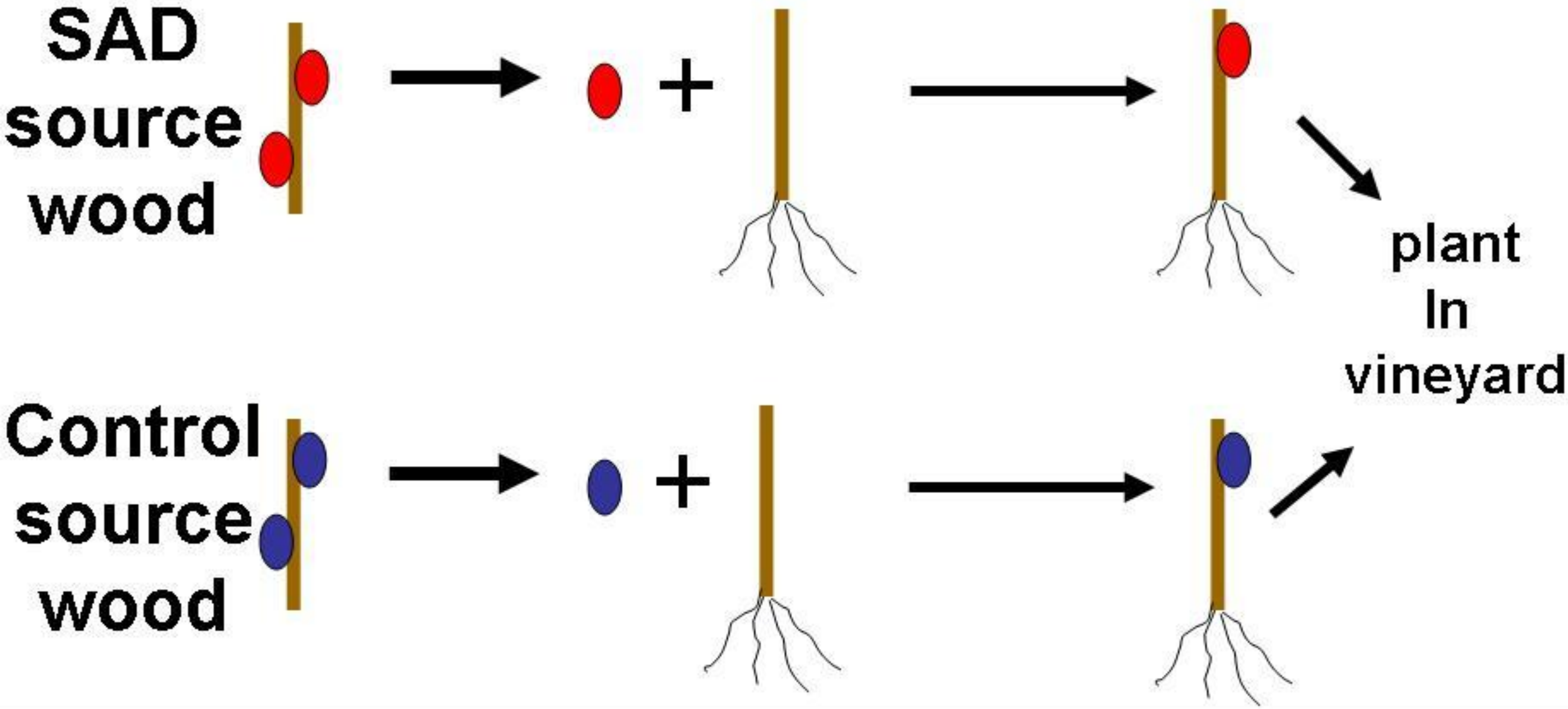
Site	Unthinned	Set thinned	Veraison thinned
Stag’s Leap	1.0 **a**	0 **a**	0.3 **a**
Sonoma	6.3 **a**	0.9 **a**	4.7 **a**
Rutherford River	3.2 **a**	6.5 **a**	6.5 **a**

2008

% SAD --- same lack of thinning effect

Thinning crop has not diminished incidence of SAD symptoms in remaining fruit.

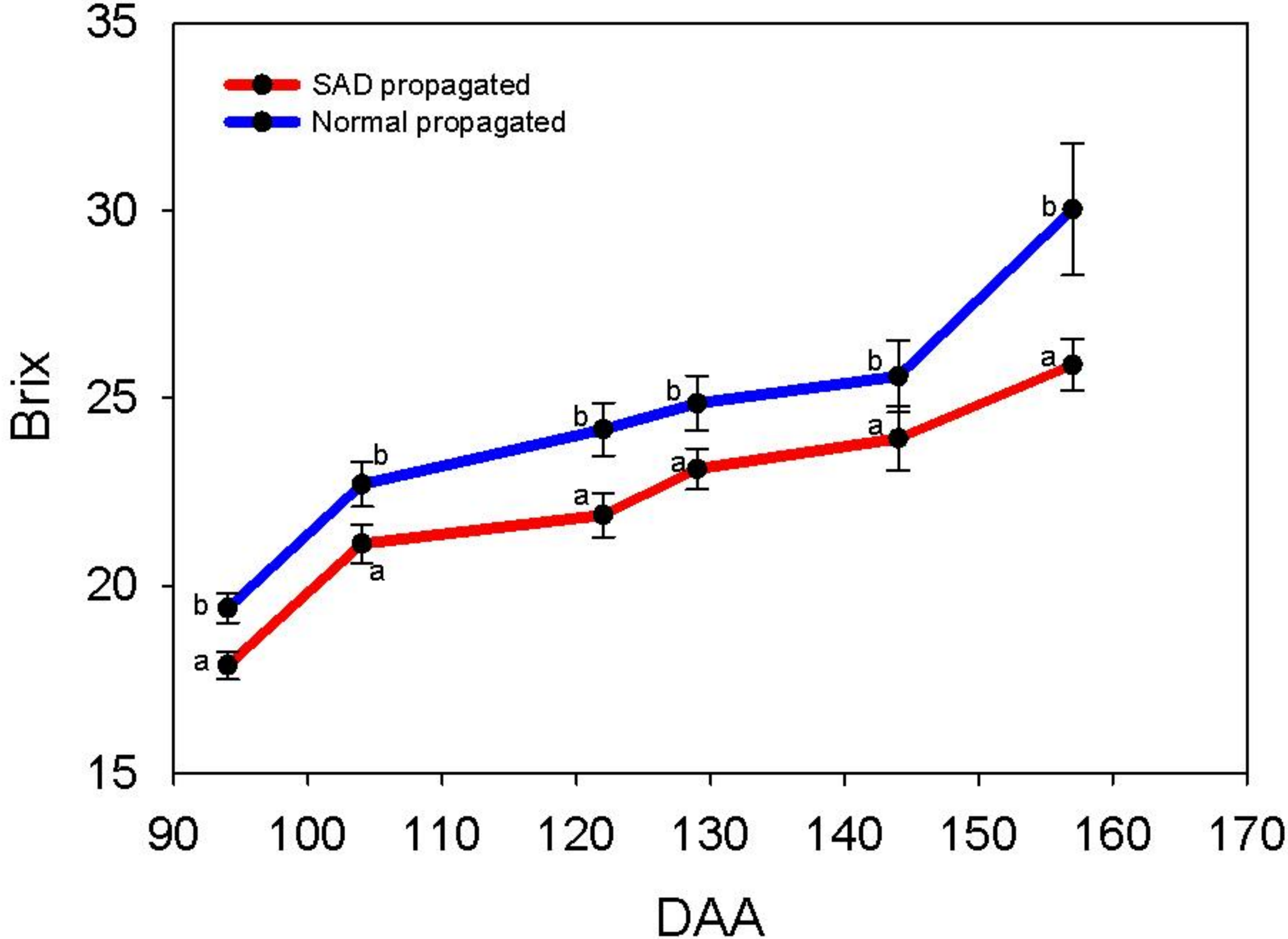
Schematic of SAD propagation experiment



Vineyard plot design

SAD	Cont	SAD	Cont	SAD	Cont	SAD	Cont	SAD	Cont
Cont	SAD	Cont	SAD	Cont	SAD	Cont	SAD	Cont	SAD

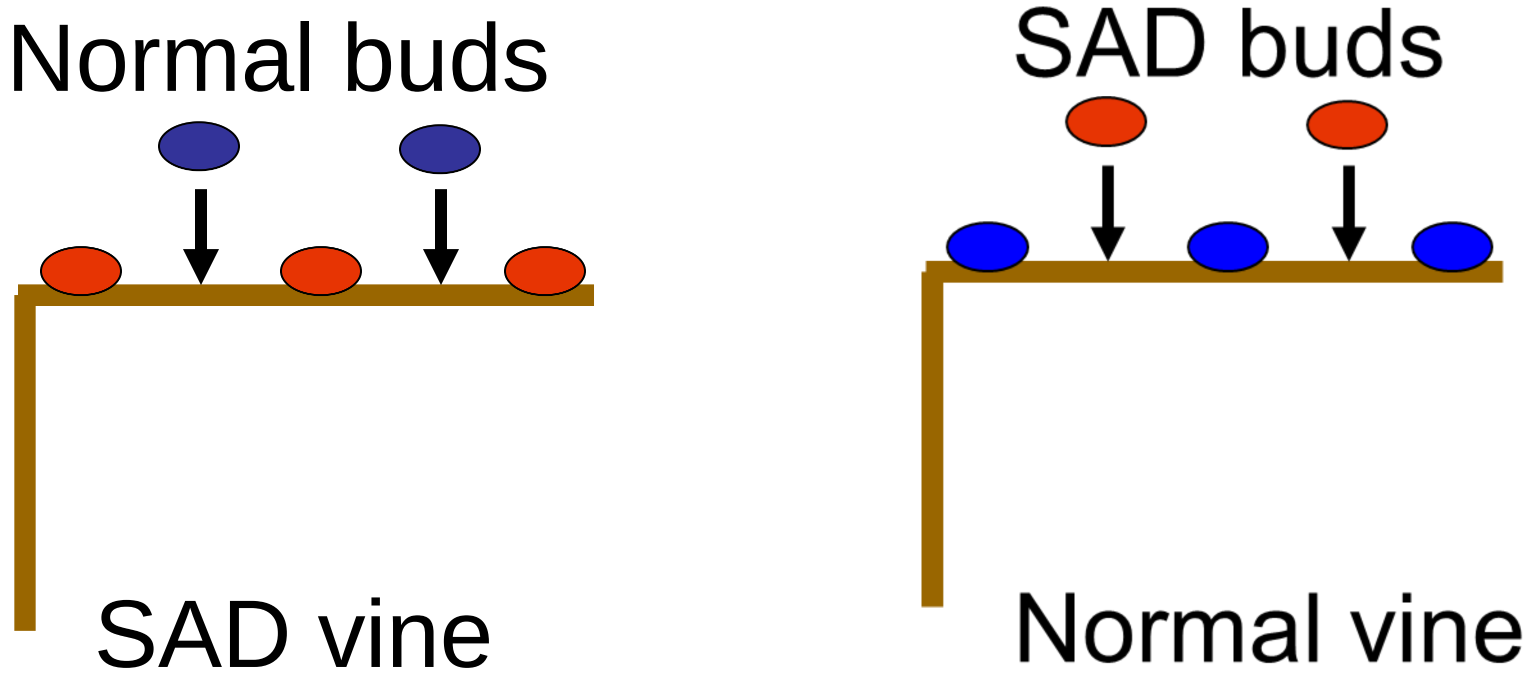
Jason Benz



SAD propagated
Normal propagated
Brix
DAA
35
30
25
20
15
90
100
110
120
130
140
150
160
170
a
b

2007 Budding Experiments

Chip budding from normal to SAD vines and SAD to normal vines



30 vine sets
(15 SAD, 15 healthy)
were planted in:

Oakville (1773 GDD)
Davis (2069 GDD)
Hopland (1937 GDD)
Parlier (2469 GDD)

Normal propagated vine

SAD propagated vine

Normal source

SAD source

2009 Davis vine harvest data

Sample	Harvest weight (g/vine)	Brix
Normal propagated (n=10)	442 **a**	25.7 **a**
SAD propagated (n=11)	372 **a**	17.6 **b**

Similar results at all locations in 2010.

Controls:

Source	Brix
3A	22.0a
4A	21.9a
2A	20.5a

SAD:

Source	Brix
1B	18.8a
3B	17.3 b
5B	15.7 c
2B	15.0 c

Clonal propagation: 3 independent wood sources of control and 4 independent wood sources of SAD, all planted at 4 locations (OEV, UCD, KAC, and Hopland). Due to budget limitations, only the OEV and UCD vines now remain.

The 2003 budding experiments demonstrated that SAD is transmissable

2007 Budding experiments demonstrated that healthy buds grafted onto SAD vines develop SAD fruit and that SAD is able to spread from grafted buds to affect an entire vine;

And - there are consistent clonal differences

SAD and pathogens

The SAD vines at OEV have been tested for the following pathogens by FPS

- Leafroll viuruses
- Fanleaf virus
- Phytoplasmas
- Tomato ringspot virus
- Grapevine vitiviruses
- Arabis mosaic virus
- *Xylella fastidiosa*
- Rootstock stem lesion associated virus
- Grapevine fleck virus
- Rupestris stem pitting associated virus

All tests have yielded negative results, [or both SAD and healthy vines have given positive results]

Conclusions

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Conclusions

- Sugar accumulation stops prematurely
- Anthocyanin accumulation stops about same time as sugar accumulation
- SAD symptoms may arise from impaired phloem flux, like leaf roll virus
- SAD is propagate-able
- SAD at Oakville is a vine phenomenon
- SAD may arise from multiple causes, including a pathogen

Acknowledgements

- Ed Weber and Rhonda Smith
- Jason Benz
- Daniel Robledo - grafting
- Nate Weis
- Derek Cronk
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- Dana Grande and Mark Bailey
- Adib Rowhani
- Valentina Canutti
- Marco LiCalzi
- Sue Ebeler

- AVF and NCVRG

Different types of SAD?

Location	Year	Condition	Juice pH	Brix	Sugar per berry (g)
Oakville	2005	Normal vines	3.71 **a**	25.3 **a**	0.350 **a**
Oakville	2005	LTS clusters	3.63 **a**	22.0 **b**	0.282 **b**
Oakville	2005	SAD clusters	3.61 **a**	19.2 **c**	0.204 **c**
Sonoma	2008	Normal vines	3.45 **a**	24.0 **a**	0.218 **a**
Sonoma	2008	LTS clusters	3.45 **a**	23.0 **a**	0.238 **a**
Sonoma	2008	SAD clusters	3.27 **b**	18.2 **b**	0.127 **b**

Aroma compound profiling – Sue Ebeler

Headspace solid-phase microextraction–gas chromatography–mass spectrometry for profiling free volatile compounds in Cabernet Sauvignon grapes and wines

Table 5
Volatile compounds identified in skins of Cabernet Sauvignon expressed as µg kg^{-1} of grape unless otherwise noted.

Grape compounds	Retention time (min)	Calculated *I* (literature)[a]	H1		H2		H3		H4		H5		H6	
			Mean ± SD	RSD (%)	Mean ± SD	RSD (%)	Mean ± SD	RSD (%)	Mean ± SD	RSD (%)	Mean ± SD	RSD (%)	Mean ± SD	RSD (%)
Hexanal	8.33	1087 (1024)	20.99[b] ± 2.14	10.2	42.82[b] ± 2.84	6.6	32.44[b] ± 1.75	5.4	11.87[b] ± 1.67	14.1	10.11[b] ± 0.72	7.1	6782.56 ± 880.47	13.0
Isovalerone[c,d]	11.72	1178 (1207)	0.37 ± 0.07	7.9	0.68 ± 0.21	30.5	0.55 ± 0.07	13.0	0.63 ± 0.07	11.5	0.65 ± 0.03	3.9	0.49 ± 0.04	7.3
(*Z*)-2-Hexenal[c,d]	12.24	1196 (1207)	190.96 ± 13.46	7.1	227.63 ± 10.44	4.6	172.37 ± 9.30	5.4	144.17 ± 19.70	13.7	129.09 ± 9.42	7.3	100.00 ± 17.48	17.5
4-Methyl-2-heptanone[c,d]	13.02	1213 (1206)	0.17 ± 0.01	5.1	0.39 ± 0.04	10.5	0.33 ± 0.01	2.6	0.31 ± 0.04	14.5	0.30 ± 0.03	10.2	0.25 ± 0.03	12.5
(*E*)-2-Hexenal	13.36	1218 (1212)	140.66 ± 12.98	9.2	182.34 ± 8.90	4.9	113.64 ± 6.82	6.0	60.04 ± 5.96	9.9	46.10 ± 3.84	8.3	17.33 ± 3.36	19.4
3-Octanone[c,d]	14.13	1236 (1251)	<LOD		<LOD		<LOD		<LOD		3.63 ± 0.24	6.7	0.53 ± 0.04	7.9
2-Octanone	17.39	1285 (1283)	<LOQ		<LOQ		<LOQ		<LOQ		<LOQ		<LOQ	
1-Hexanol	21.56	1340 (1345)	745.23 ± 68.91	9.2	1090 ± 39.03	3.6	1194.73 ± 45.03	3.8	1065.02 ± 84.71	7.9	1802.15 ± 218.11	12.1	1251.41 ± 265.97	21.2
(*E*)-3-Hexen-1-ol[d]	21.82	1349 (1367)	0.13 ± 0.07	50.7	0.26 ± 0.03	12.6	0.36 ± 0.02	5.9	0.23 ± 0.06	24.6	0.17 ± 0.06	36.8	0.34 ± 0.06	16.6
Nonanal	22.80	1381 (1392)	3.23 ± 0.70	21.6	2.54 ± 0.89	35.1	1.43 ± 0.60	42.4	0.12 ± 0.01	11.5	<LOD		<LOD	
3-Octanol	23.71	1399 (1394)	<LOD		<LOD		<LOD		<LOD		2.16 ± 0.65	30.2	16.27 ± 3.18	19.6
(*Z*)-2-Hexen-1-ol[d]	24.41	1441 (1411)	12.33 ± 1.33	10.7	7.18 ± 0.21	3.0	8.01 ± 0.27	3.3	13.04 ± 0.81	6.2	4.29 ± 0.33	7.7	0.20 ± 0.03	16.9
1-Octen-3-ol	26.45	1456 (1451)	0.62 ± 0.02	0.3	0.64 ± 0.05	8.3	0.61 ± 0.01	1.7	1.22 ± 0.10	8.3	27.82 ± 1.59	5.7	16.99 ± 1.79	10.6
2-Ethyl-1-hexanol	26.76	1493 (1494)	<LOQ		<LOQ		<LOQ		<LOQ		<LOQ		<LOQ	
Dihydroedulan I[c,d]	27.30	1529 (1506)	0.40 ± 0.07	16.4	0.38 ± 0.10	25.61	0.25 ± 0.02	7.12	0.34 ± 0.02	5.0	0.31 ± 0.05	16.8	0.26 ± 0.07	26.3
(*E*)-2-Nonenal	27.74	1537 (1532)	<LOQ		<LOQ		<LOQ		<LOQ		<LOQ		<LOQ	
β-Linalool	28.22	1554 (1545)	1.25 ± 0.03	2.7	1.28 ± 0.07	5.5	1.30 ± 0.06	4.8	1.38 ± 0.20	14.1	1.26 ± 0.07	5.2	1.13 ± 0.22	19.7
1-Octanol	28.54	1566 (1565)	0.47 ± 0.02	4.3	0.67 ± 0.05	7.5	0.57 ± 0.02	4.1	0.57 ± 0.12	20.4	0.52 ± 0.02	3.8	0.51 ± 0.09	17.1
(*E*,*Z*)-2,6-Nonadienal	28.39	1582 (1576)	0.82 ± 0.03	3.3	0.48 ± 0.06	11.7	0.51 ± 0.03	5.1	0.82 ± 0.12	14.4	0.50 ± 0.05	10.2	0.25 ± 0.08	30.8
1-Nonanol	30.59	1685 (1653)	0.06 ± 0.02	38.8	0.08 ± 0.01	16.0	0.06 ± 0.01	21.6	0.07 ± 0.01	15.6	0.07 ± 0.02	26.1	0.03 ± 0.01	41.8
(*Z*)-3-Nonen-1-ol[c,d]	30.98	1688 (1664)	0.47 ± 0.05	10.9	0.53 ± 0.01	1.3	0.44 ± 0.01	2.9	0.43 ± 0.08	19.0	0.48 ± 0.05	9.7	0.35 ± 0.06	16.0
β-Citronellol[c,d]	32.51	1811 (1744)	0.13 ± 0.01	9.3	0.16 ± 0.04	23.4	0.12 ± 0.02	12.7	0.13 ± 0.02	13.5	0.11 ± 0.01	7.6	0.09 ± 0.03	30.9
β-Damascenone	33.07	1830 (1841)	0.18 ± 0.10	57.3	0.22 ± 0.03	12.5	0.17 ± 0.08	50.0	0.13 ± 0.07	54.0	0.30 ± 0.04	13.2	0.33 ± 0.22	67.0
Nerol	33.35	1875 (1849)	<LOQ		<LOQ		<LOQ		<LOQ		<LOQ		<LOQ	
Geranyl/nerylacetone[c,d]	33.43	1881 (1858)	0.97 ± 0.59	61.2	0.46 ± 0.28	61.2	0.38 ± 0.06	15.2	0.71 ± 0.34	47.4	0.84 ± 0.22	25.7	<LOD	
2-Phenylethanol	34.23	1923 (1939)	4.36 ± 0.33	7.7	5.78 ± 0.62	10.8	4.95 ± 0.22	4.4	5.16 ± 1,19	23.0	4.48 ± 0.20	4.4	5.90 ± 0.30	5.1
β-Ionone	34.60	1955 (1956)	0.33 ± 0.02	5.0	0.33 ± 0.02	6.2	0.33 ± 0.01	4.4	0.34 ± 0.05	14.4	0.32 ± 0.02	5.9	0.27 ± 0.05	19.2

LOQ, Limit of quantitation; LOD, limit of detection.

[a] Literature sources: http://www.odour.org.uk, http://www.flavornet.org, Ferhat et al. [44], Jennings and Shibamoto [45].

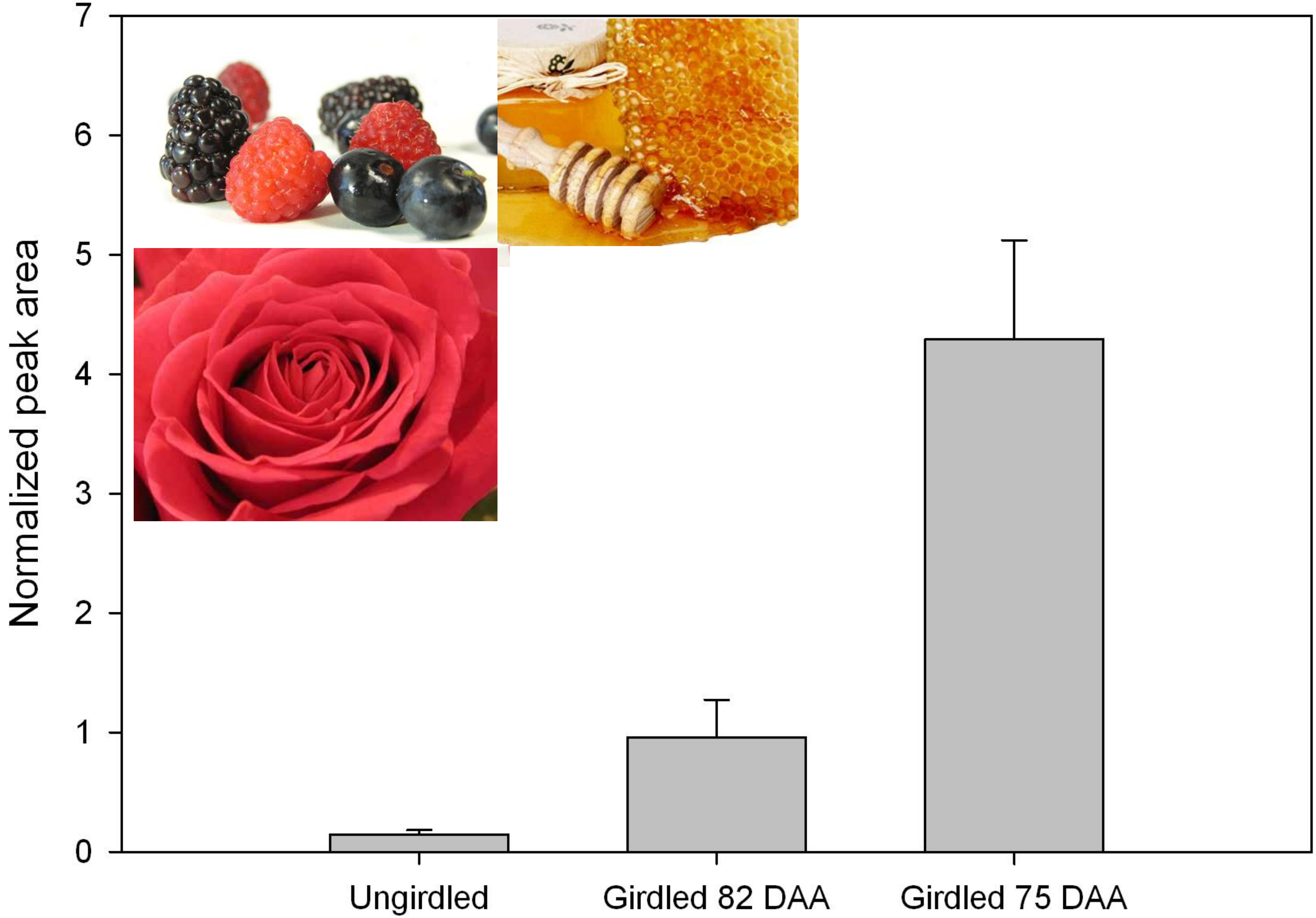
[b] mg kg^{-1} of grape.

[c] Compounds tentatively identified by matching to the NIST MS library spectra and comparison of Kovats' retention indices (*I*) to literature values.

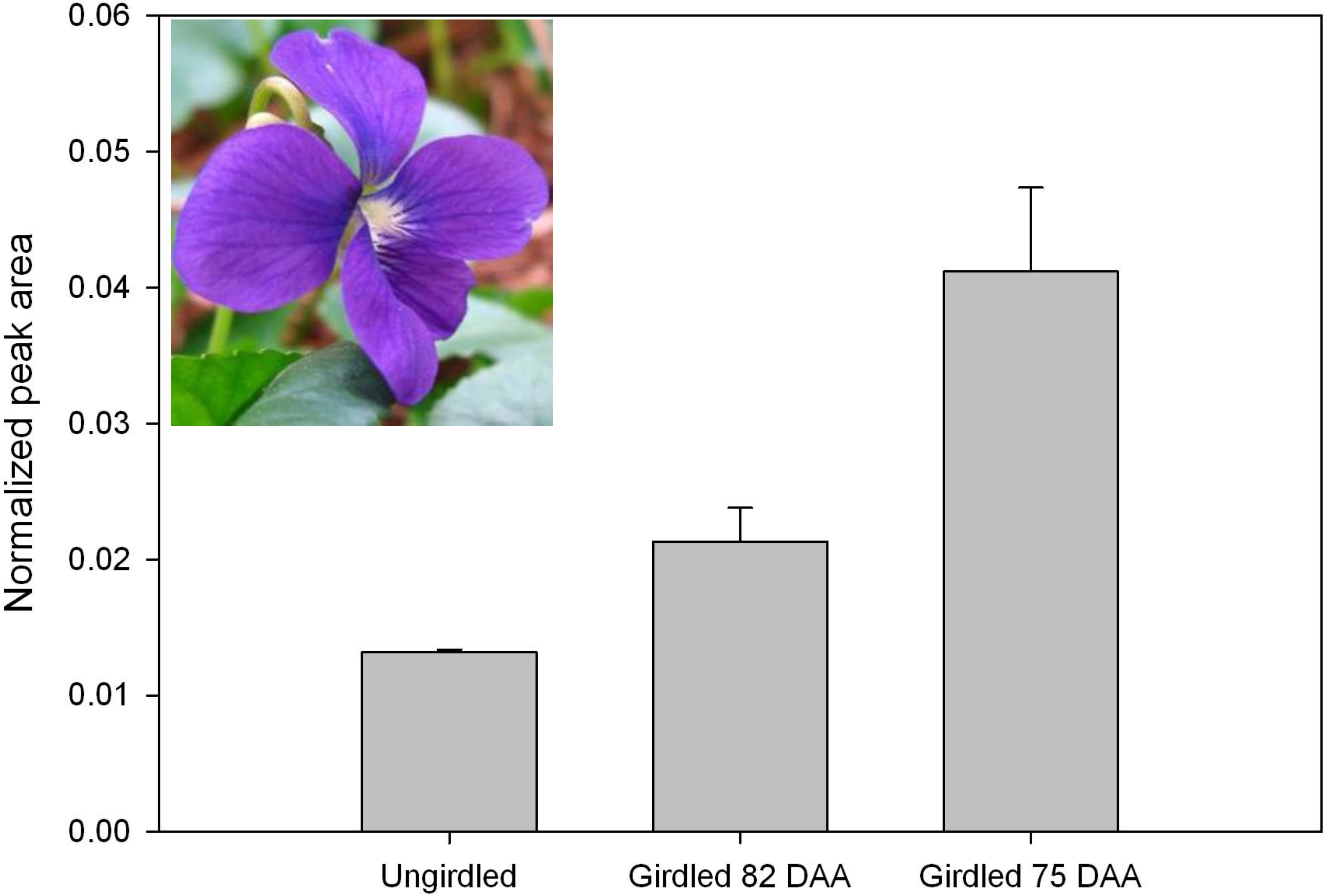
[d] µg equivalents of 2-octanol internal standard per kilogram of grapes.

Canutti et al. 2009

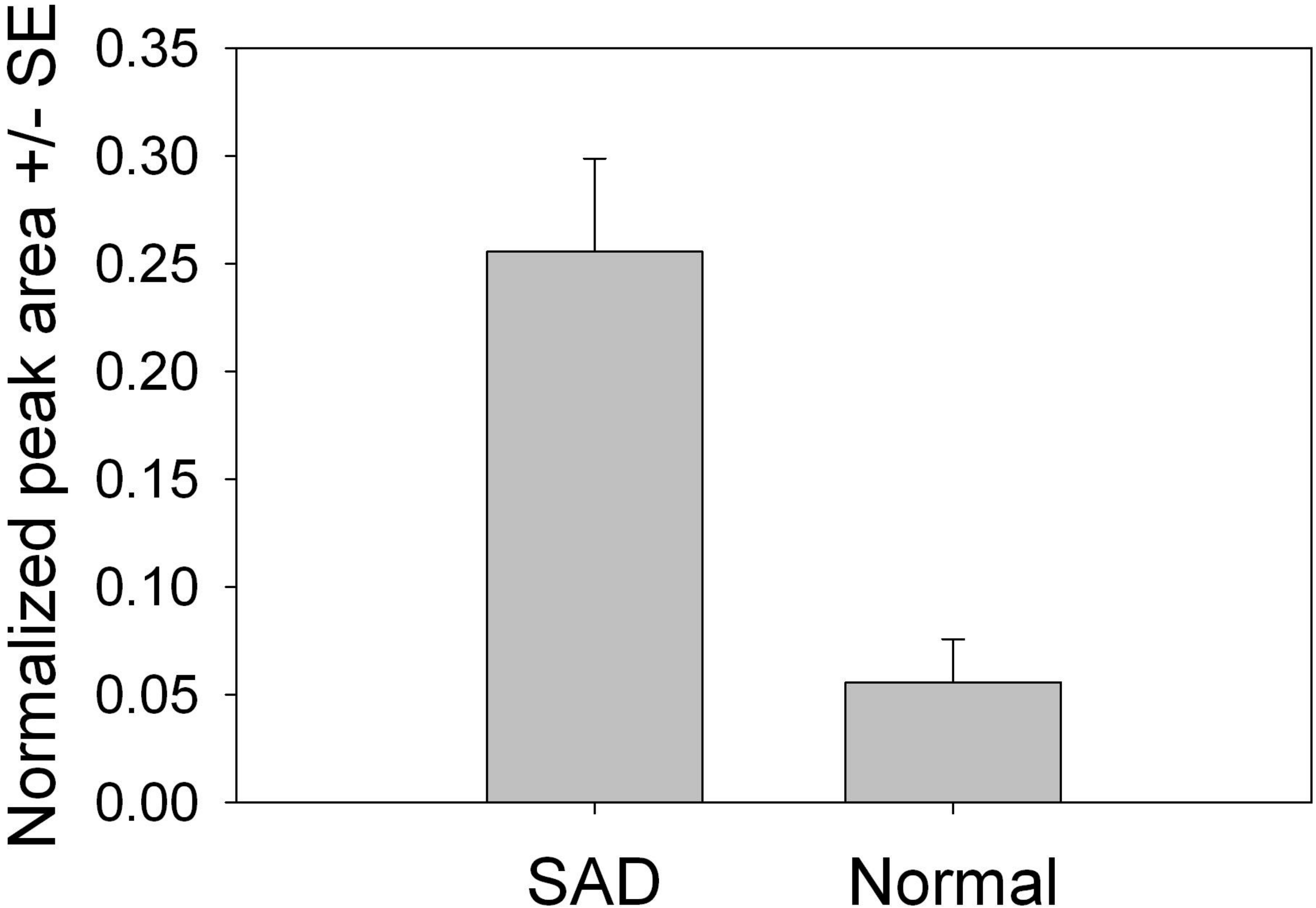
Damascenone content (105 berries) +/- SE



Ionone content (105 berries) +/- SE



β-Damascenone from Napa in 2009



Linalool [and Ionone] are increased in SAD fruit

Sonoma site

Napa site