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Effects of preharvest abscission agent application on postharvest quality of destemmed Autumn King and Sheegene-12 table grape berries

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ABSTRACT

Table grapes have high production costs partly due to laborious picking and packing practices. Mechanized harvest is not yet feasible for whole table grape clusters, but it might be suitable for "fresh cut" (destemmed) table grapes if mechanical damage could be minimized. Preharvest application of methyl jasmonate (MeJA) and 1-aminocyclopropane-1-caboxylic acid (ACC) activate the abscission zone of some grape varieties, improving harvestability and reducing harvest wounds, but effects on postharvest quality of destemmed berries are unknown. Sheegene-12 and Autumn King table grapes treated with 3 mM MeJA and 500 to 750 ppm ACC were destemmed and berry condition evaluated at harvest, and after two and four weeks of postharvest storage. Treatments improved harvestability and reduced destemming wounds of both varieties and generally improved the quality of Sheegene-12 berries at harvest, and after postharvest storage. However, treated Autumn King berries became darker, and more yellow-colored in storage, which is undesirable.

KEYWORDS: 1-aminocyclopropane-1-carboxylic acid, fresh cut, jasmonic acid, mechanization, methyl jasmonate

INTRODUCTION

Table grape production costs are high, largely due to picking and packing labor (Fidelibus *et al.*, 2018). Consequently, U.S. growers must develop automated, semi-automated, or mechanized harvest methods (Charlton *et al.*, 2025). Because table grape berries are generally sold on whole clusters, with no tolerance for mechanical damage (Fidelibus *et al.*, 2022), harvest automation could require robots with sophisticated perception and manipulation systems that are still under development (Coll-Ribes *et al.*, 2023). However, "fresh cut" berries sold in packages of destemmed ready-to-eat berries (Crisosto *et al.*, 2020) could possibly be harvested with less sophisticated machines that shake the vines to dislodge individual berries. However, the detached berries need to remain in excellent condition, with minimal stem-end damage which typically occurs when a berry is detached from a cluster (Fidelibus *et al.*, 2007; Fidelibus *et al.*, 2022).

Preharvest application of certain plant hormones, termed abscission agents, could facilitate mechanical harvest and help minimize stem-end tearing by reducing fruit detachment force (FDF) and stimulating the development of protective layers, dry scars on the stem-end of berries (Fidelibus *et al.*, 2007; Fidelibus *et al.*, 2022; Fidelibus *et al.*, 2024). Abscission agents that contain ethylene-promoting PGRs, such as ethephon or 1-aminocyclopropane-1-carboxylic acid (ACC), and jasmonates, including methyl jasmonate (MeJA) or jasmonic acid (JA), are particularly effective (Uzquiza *et al.*, 2014; Fidelibus *et al.*, 2022; Fidelibus *et al.*, 2024). Abscission agents may cause preharvest berry abscission, so berries should be shaken from vines within three or four days after treatment (DAT) to minimize yield loss (Fidelibus *et al.*, 2022; Gonzáles-Herranz *et al.*, 2009; Uzquiza *et al.*, 2014).

Abscission agent effectiveness varies among grape varieties (Fidelibus *et al.*, 2007). A preliminary trial suggested that abscission agents were effective on Sheegene-12, a mid-season red grape marketed as "Krissy™" or "Summer Bliss™", and Autumn King, a late-season white grape (Fidelibus, unpublished). Therefore, those varieties were selected as candidates for a postharvest study. Sheegene-12 berries treated preharvest with abscission agents, harvested as whole clusters, and destemmed after three weeks in postharvest storage, remained in good condition after destemming (Fidelibus *et al.*, 2024), but the effects of abscission agents on the postharvest quality of berries that were destemmed at harvest, and then stored, has not been determined for any grape variety.

Composition, size, colour, texture, and soundness are important table grape quality characteristics (Crisosto *et al.*, 2020). Abscission agents generally have little effect on grape composition, probably because they are applied a few days before harvest (Clore & Fay, 1970; El-Zeftawi, 1982; Fidelibus *et al.*, 2007, Fidelibus *et al.*, 2024; Ferrara *et al.*, 2016, Rizzuti *et al.*, 2015). However, ethephon on Crimson Seedless made the berries slightly darker (Ferrara *et al.*, 2016), and increased their flavonoid, terpenoid, and tartaric acid content (Rizzuti *et al.*, 2015). Similar treatments on Thompson Seedless caused the berries to become darker, and more yellow-colored (Ferrara *et al.*, 2016), an undesirable effect that was probably due to the accumulation of phenolic compounds (García-Pastor *et al.*, 2019; Ranjbaran *et al.*, 2022) and the upregulation of polyphenol oxidase (PPO) (Ranjbaran *et al.*, 2022). Fidelibus *et al.* (2024) found that abscission agents did not affect size, Brix, or firmness of Sheegene-12. Off odor could be a concern, as JA and its metabolites, including MeJA, have a potent floral aroma (Acree *et al.*, 1985) that is atypical of grape berries. The most common effect of abscission agents on grape berries is less mechanical damage from destemming, and the development of a protective layer on the stem-end of the fruit, both of which might improve appearance, and help facilitate sanitation and reduce rot, thus helping to preserve postharvest quality (Fidelibus *et al.*, 2024). The objectives of this study were to determine how abscission agent application affected the condition of table grapes from Sheegene-12, a mid-season red-colored table grape, and Autumn King, a late-season white-(green) colored table grape immediately after harvest/destemming, and again after two and four weeks postharvest storage, and to determine if volatile MeJA could be detected in containers of berries at harvest, or after two weeks of postharvest storage.

MATERIALS AND METHODS

1. Treatment applications, sample preparation, and storage conditions

On 15 September 2023, clusters of Sheegene-12 table grape vines in a commercial vineyard in Fresno County, California, were sprayed to runoff with a solution of 3 mM MeJA, 750 ppm ACC (both from Valent BioSciences, Libertyville, Ill., USA), and 0.25 % *(v/v)* Latron-B1956 spreader-sticker (Loveland Industries Inc., Greeley, CO, USA) or unsprayed. Sprayed and unsprayed vines were arranged in a randomized complete-block design, replicated four times. Each treatment replicate consisted of two or three adjacent vines, depending on crop load, to ensure there would be approximately 18 kg of destemmed berries at harvest. Spray solution was applied to the fruiting zone with a backpack mist blower (Solo 450, Solo, Newport News, VA, USA). Untreated vines were shielded from overspray with plastic sheets. Berries were harvested on 19 September 2023. Berries on treated vines are loosely attached and prone to dropping during picking and handling (González-Herranz *et al.*, 2009), so treated vines were shaken by hand to detach the loosest berries onto 1-mil polyethylene sheets suspended beneath the vines. Berries that fell onto the sheets were collected and weighed, and the remaining clusters of grape berries were harvested with shears and transported to the University of California Kearney Agricultural Research and Extension Center (KAREC). At KAREC, clusters from treated vines were shaken again individually, and the berries that shook off were weighed. Any berries that remained attached after shaking were destemmed by hand and weighed. Then the berries in each class were combined by treatment replicate, omitting

any rotten or crushed berries. The proportion of fruit in each class (shaken from vines, shaken from clusters, picked by hand, rotten, or crushed) were determined by weight ratio. Berries from untreated berries could not be shaken off the vines or from individual clusters, so whole clusters were cut from the vines with shears and taken to KAREC where they were destemmed by hand, discarding any rotten berries. No statistical comparisons were made between treated and control berries with respect to the percent which could be shaken off the vines or clusters.

Subsamples consisting of 25 berries were collected from each treatment replicate for fruit quality measurements, and the remaining destemmed berries were split into two 8.62-kg lots. Each lot was stored in a ventilated plastic stacking container with a perforated plastic liner (Crisosto *et al.*, 2020). One of the two containers from each treatment replicate was randomly assigned to a two-week storage period, and the other to a four-week storage period. The containers were stored in a commercial postharvest facility at 0 °C and 95 % RH, with sulfur dioxide fumigation (Crisosto *et al.*, 2020). After two and four weeks of storage, one container from each treatment replicate was evaluated. At each evaluation, the containers were reweighed, and weight loss determined. Afterwards, all the berries in each container were poured onto a table and physically divided into four parts. Four 25-berry subsamples were randomly collected from each part and used for fruit quality measurements. Extra berries were discarded. Treatments were retested on Sheegene-12 in 2024, following similar protocols except that the rate of ACC was reduced from 750 ppm to 500 ppm. Treatments were applied on 22 August 2024, and the berries were harvested on 26 August 2024. Autumn King table berries were sprayed on 20 September 2024 and picked on 24 September 2024.

2. Fruit quality measurements

Similar fruit quality measurements were made at harvest, and after two or four weeks of postharvest storage, except that 25 berries per sample were measured at harvest, whereas 100 berries per treatment replicate were sampled thereafter. For Sheegene-12, color index of red grapes (CIRG; Carreño *et al.*, 1995) was calculated from lightness, chroma, and hue data (CIRG = ((180°-hue°)/(lightness + chroma))) from a chroma meter (CR-400, Konica-Minolta Sensing Americas, Ramsey, NJ, USA). Fruit firmness was determined with a fruit firmness tester (FirmTech 2, BioWorks, Inc., Cleveland) which compresses the berries to determine a force-deformation value (Luby *et al.*, 2022). The stem-end of each berry was observed and scored as "dry" or "wet", depending on whether an intact protective layer was present. An additional observation "no defects" was also noted after four weeks of storage. This observation was added because some berries were observed to have multiple defects, and it was otherwise not clear what percentage of berries had no defects. A berry was considered to have no defects if it was free of cracks, had a dry stem scar, no rot, and an all-around acceptable appearance. The number of cracked or rotten berries was recorded, and all the non-rotten sampled berries were crushed and soluble solids determined with a refractometer. The remaining berries from each container were then destroyed.

In 2024, storage conditions, inspection times, and data collected were mostly the same as in 2023, except in 2024, there were three field replicates of each treatment, and firmness was not measured instrumentally, but the number of obviously "soft" berries was recorded. The number of berries with peeled skins were also recorded. The 2024 Autumn King study followed the same experimental protocols as Sheegene-12, except the proportion of berries shaken *versus* picked were not recorded, and color was expressed as lightness, chroma, and hue, rather than CIRG.

3. Volatile analysis

Twenty grape berries were randomly collected for each of the treatment replicates of Sheegene-12 and Autumn King in 2024. The berries from each replication were placed into individual 473 mL canning jars and weighed in preparation for volatile analysis. Each jar was then sealed with a canning lid and thymol (0.0401 µg/ml) added through a PTFE/rubber septa into the jar to act as an internal standard. Each jar was then preincubated at 20 °C for 30 min, followed by insertion and deployment of a 2-cm solid phase microextraction (SPME) 50/30 µm DVB/CAR/PDMS StableFlex fiber (Sigma-Aldrich, St. Louis, MO). The SPME fiber was exposed to the headspace for 30 min at 20 °C. The fiber was removed from the jar and volatile compounds were then desorbed for 2 min into an Agilent 7890/5975N GCMS system (Agilent, Santa Clara, CA) using hot splitless injection at 240 °C. Helium was used as the carrier gas at a constant flow rate of 1 mL/min. The initial oven temperature was 32 °C, held for 5 min, ramped up to 220 °C at 25 °C/min, and held for 5 min. A 30 m × 0.25 mm id × 0.25 µm film thickness Stabilwax® GC column (Restek, Bellefonte, PA) was used to separate the volatiles. The MS transfer line and ion source temperatures were 240 and 230 °C, respectively. Ionization voltage was 70 eV, mass range (*m/z* 35 to 300), electron multiplier voltage (Autotune + 200 V), and scan rate at 50 scans/s. Selective ion monitoring mode was used with a dwell time of 50 ms with the ions monitored being *m/z* 83, 135 and 150. Methyl jasmonate was identified by a match with a mass spectral library, comparison to an authentic standard, and retention index match. Values were expressed in ug/kg. One measurement was performed on each field replicate.

4. Data analysis

Stem-end condition, berry cracking, and rotten berry data were expressed as percentage data, and arcsin transformed for statistical analyses (Ott, 1993), though untransformed treatment means are shown for ease of interpretation. Data were analysed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, USA), testing for abscission agent effects at each observation time (harvest, two weeks storage, and four weeks storage). Significant differences ($p < 0.05$) between berries from treated and control vines, within observation times, are noted by letters.

RESULTS AND DISCUSSION

1. Harvestability

In 2023, 64 % of the grapes from treated vines were destemmed by shaking, with approximately half shaken directly from the vines and the other half shaken from individual clusters (Table 1). The remainder required manual detachment or were unpicked due to rot (Table 1). Similarly, in 2024, 60 % of the Sheegene-12 grapes treated with 3 mM MeJA + 500 ppm ACC were destemmed by shaking, with 34 % of the grapes shaken from vines, 26 % from individual clusters, and the remainder requiring manual destemming (Table 1). Untreated grapes of both varieties required manual destemming, and the proportion of fruit that was shaken from clusters was not determined for Autum King. The results confirm previous research (Fidelibus *et al.*, 2024), that suggested abscission agents could improve harvestability and reduce destemming wounds. Adjustments to vine training/trellising, and the use of an appropriate harvest machine might further improve harvestability and reduce mechanical damage, as observed with table olives (Jimenez-Jimenez *et al.*, 2015).

2. Fruit quality

In 2023, abscission agents did not affect berry weight or color of Sheegene-12, at harvest or after postharvest storage, although berry weight decreased, and CIRG increased after two weeks of storage, regardless of treatment (Table 2). Treated berries had slightly less soluble solids after both storage periods, and slightly higher firmness after two weeks, but not after four weeks (Table 2). The most obvious and notable effects of abscission agents were a substantial reduction in the percentage of berries with wet stem scars or

TABLE 1. The percentage of grapes shaken from treated vines, harvested clusters, not removed, or rotten, Sheegene-12, Parlier, CA, USA.

Year	Shaken from vine (%)	Shaken from picked clusters (%)	Not removed by shaking (%)	Rotten (%)
2023	32	32	22	14
2024	34	26	40	1

Data are the average of four field replicates in 2023, and three field replicates in 2024.

TABLE 2. Effect of abscission agent treatments on berry quality of Sheegene-12 table grapes at harvest, and after postharvest storage. Grapevines were treated on 15 September 2023, and harvested on 19 September 2023.

Observation date	Weight	Colour	Firmness	Soluble solids	Berry condition (%)				
Treatment	(g)	CIRG[y]	(g/mm^{-1})	Brix	Wet scar	Dry scar	Cracked	Rot	No defects
Harvest									
Control	11[z]	3.42	440.7	20.2	74 a	26 b	1	ND[x]	ND
3 mM MeJA + 750 ppm ACC	11	3.45	483.8	20.0	1 b	99 a	3	ND	ND
Two weeks storage									
Control	10.2	3.62	300 b	20.4 a	70 a	30 b	77 a	3	ND
3 mM MeJA + 750 ppm ACC	10.4	3.55	327 a	19.7 b	0 b	100 a	5 b	2	ND
Four weeks storage									
Control	10.5	3.68	290	20.4 a	89 a	10 b	46 a	18 b	6 b
3 mM MeJA + 750 ppm ACC	10.2	3.68	302	19.7 b	6 b	94 a	11 b	31 a	47 a

[z] Data are means of each treatment and storage period. Means followed by a different letter, within columns and storage periods, are significantly different. ND,

[y] CIRG is the colour index of red grapes which was calculated from lightness, chroma, and hue data (CIRG = ((180°-hue°)/(lightness + chroma))).

[x] ND, no data.

cracks, and a greatly increased percentage of berries with dry stem scars (Table 2). After two weeks storage, treated berries were firmer than non-treated berries, with dry stem scars and without cracks (Table 2), although the treated berries had slightly lower soluble solids. Rot increased during storage (Table 2), and after four weeks, the treated berries had much more decay than untreated berries but treated berries were more likely to be free of defects, mostly because they sustained less mechanical damage (Table 2).

In 2024, Sheegene-12 berries from treated grapevines were heavier at harvest and after postharvest storage than berries from non-treated vines (Table 3), although soluble solids were not affected. Treated berries had higher CIRG than untreated berries throughout the storage period. As in 2023, the treated berries were much less likely to have harvest wounds, including cracks, wet stem scars, or peeled skin, than controls, although treated berries had a higher incidence of rot after four weeks of storage (Table 3). Even so, treated berries were less frequently soft (after four weeks storage), and were overall more likely to be without defects, at harvest, and after postharvest storage (Table 3).

Preharvest treatment with JA and ACC increased CIRG in postharvest storage in a previous study (Fidelibus *et al.*, 2024). Ruiz-Garcia *et al.* (2012) also reported that a preharvest application of MeJA increased anthocyanin content of berries and wine, and Flores *et al.* (2015) found that a postharvest application of MeJA increased anthocyanin content of 'Redglobe' grapes after five and seven days of storage. Thus, jasmonate applications with or without ACC appear to consistently stimulate anthocyanin biosynthesis and improve berry color, on vines and in storage. It is unclear why treated berries had the highest rot incidence, since protective layers generally help prevent pathogens from entering abscised organs (Li & Su, 2024). Some berries may have necrotized due to the treatments, imparting a poor appearance that was scored as rot, and berries shaken from the vines could have sustained punctures, abrasions, or other types of mechanical damage that facilitated rot. Additional work is needed to better understand the effect of abscission agents on berry necrosis and rot during storage. Despite the higher incidence of "rotten" berries after four weeks of storage, treatment greatly increased the percentage of berries having no defects. Moreover, four weeks is two to four times the storage duration tested in some previous postharvest studies on destemmed grape berries (Kou *et al.*, 2007; Shiri *et al.*, 2011). Overall, treatment improved postharvest quality of Sheegene-12, as berry weight, firmness, and color were either not affected, or improved by the treatments, confirming previous results on Sheegene-12 on berries that were treated with abscission agents preharvest, but destemmed after postharvest storage (Fidelibus *et al.*, 2024).

Untreated Autumn King berries were heavier and softer than treated berries at harvest, but after two weeks of storage, the treated berries were the heaviest and softest (Table 4).

TABLE 3. Effect of abscission agent treatments on berry quality of Sheegene-12 table grapes at harvest, and after postharvest storage. Grapevines were treated on 22 August 2024, and harvested on 26 August 2024.

Observation date	Weight	Colour	Soluble solids	Berry condition (% affected)						
Treatment	(g)	CIRG[y]	(%)	Soft	Rotten	Cracked	Peeled skin	Wet scar	Dry scar	No defects
Harvest										
Control	6.74 b[z]	3.09	-	0.33	0.33	29.7 a	8	47.0 a	3.0 b	2.0 b
3 mM MeJA + 500 ppm ACC	8.63 a	3.55	-	3.83	0.17	5.83 b	3	7.7 b	43.2 a	28.2 a
Two weeks storage										
Control	7.39 a	3.20 b	19.2	7	0.33	13.5 a	14.2 a	20.1 a	1.4 b	0.5 b
3 mM MeJA + 500 ppm ACC	9.08 a	3.71 a	19.2	8	0.58	3.2 b	1.1 b	3.4 b	21.4 a	20.5 a
Four weeks storage										
Control	7.49 b	1.99 b	19.1	11.25 a	1.17 b	18.83 a	21.1 a	24.7 a	0.33 b	0 b
3 mM MeJA + 5,000 ppm ACC	8.96 a	2.23 a	19.0	3.42 b	3.33 a	4.58 b	0.58 b	0.2 b	24.83 a	17.5 a

[z] Data are means of each treatment and storage period. Means followed by a different letter, within columns and storage periods, are significantly different.

[y] CIRG is the colour index of red grapes which was calculated from lightness, chroma, and hue data (CIRG = ((180°-hue°)/(lightness + chroma))).

TABLE 4. Effect of abscission agent treatments on berry quality of Autumn King table grapes at harvest, and after postharvest storage. Grapevines were treated on 20 September 2024 and harvested on 24 September 2024.

Observation date	Weight	Soft	Soluble solids	Berry condition (%)				Colour		
Treatment	(g)	(%)	Brix	Wet scar	Dry scar	Cracked	No defects	Lightness	Chroma	Hue
Harvest										
Control	7.97 a[z]	56 a	17.4	97 b	3 a	0	1 b	41.9	21.3 a	96.6 a
3 mM MeJA + 750 ppm ACC	6.97 b	13 b	17.2	39 a	61 b	4	70 a	40.1	20.3 b	91.0 b
Two weeks storage										
Control	7.71 b	43 b	17.9	95 a	5 b	1	1	44.00 a	14.47	110.3 a
3 mM MeJA + 750 ppm ACC	8.14 a	70 a	17.9	48 b	52 a	0	4	40.78 b	14.18	107.3 b
Four weeks storage										
Control	9.15	53	17.4	83 a	17 a	4	1 b	50.32 a	20.12	108.8 a
3 mM MeJA + 750 ppm ACC	8.52	67	17.1	62 b	38 b	8	8 a	46.82 b	19.89	106.8 b

[z] Data are means of each treatment and storage period. Means followed by a different letter, within columns and storage periods, are significantly different.

The most consistent treatment effects were a reduction in the percentage of berries with wet scars, an increase in the percentage of berries with dry scars, and an increase in the percentage of berries with no defects, especially at harvest (Table 4). However, treatment effects on defects were insignificant at the two-week storage inspection, and modest at the four-week inspection period (Table 4). Treatment negatively affected Autumn King berry color, particularly after storage (Table 4), contributing to the steep decline in the percentage of treated berries without defects. Treated berries had a lower hue angle (were more yellow-colored) than controls at harvest and after postharvest storage and were also darker (had lower lightness) than untreated control fruit after storage, rendering them less visually appealing (Fidelibus, personal observation).

Similarly, ethephon used as an abscission agent on Thompson Seedless, a white-(green) variety, also caused the grapes to become darker, and more yellow-colored (Ferrara *et al.*, 2016). Methyl jasmonate stimulated accumulation of phenolic compounds in grape berry skin (García-Pastor *et al.*, 2019; Ranjbaran *et al.*, 2022) and upregulated PPO (Ranjbaran *et al.*, 2022), suggesting that phenol accumulation and oxidation could explain the undesirable treatment effects on Autumn King berry color. Crisosto *et al.* (2020) reported that rough handling during harvest, packaging, or transport can induce skin browning, which is most evident on white-colored berries. Thus, browning may be due to abscission agents, harvesting/destemming methods, or both. Additional research is needed to determine the root cause(s) of browning and whether changes in the treatment or harvest methods might help reduce it.

3. Volatile analysis

Methyl jasmonate was detected in the headspace of jars containing treated and non-treated Sheegene-12 at harvest, and after two weeks storage (Table 5). At harvest, the amount of MeJA was similar for control and MeJA treatment. The amount of MeJA detected diminished during storage, especially for the control grapes, such that the headspace of jars with control grapes had significantly less MeJA than the headspace of jars with MeJA-treated berries (Table 5). Compared to Sheegene-12, there was much less MeJA detected in the headspace of jars filled with treated and untreated Autumn King berries but, at harvest, the difference between treated and untreated berries was more pronounced and the difference was highly significant (Table 5). However, after two weeks of storage, MeJA was not detected (Table 5). Odor is a concern because MeJA has a noticeable jasmine fragrance, which is undesirable on table grape berries. The volatile MeJA concentration was relatively low for both varieties, possibly below the level of detection at harvest (Acree *et al.*, 1985) and decreased during storage.

TABLE 5. Concentration of methyl jasmonate (MeJA) in the headspace of jars containing the berries of two varieties of grapes either not sprayed (Control) or sprayed with MeJA + ACC and measured at either zero weeks or two weeks of storage.

Variety[a]	Treatments	
Storage time (wks)		
Sheegene-12	Control[b]	MeJA + ACC
0	1.47 ± 1.03	2.07 ± 1.19
2	0.70 ± 0.12	1.65 ± 0.28
Autumn King	Control[b]	MeJA + ACC
0	0.13 ± 0.03	1.12 ± 0.19
2	ND[c]	ND

[a] Storage conducted at 1 °C.
[b] Concentration ± SE.
[c] Not detectable.

CONCLUSION

In conclusion, after a preharvest application of MeJA with ACC, > 60 % of Sheegene-12 and Autumn King table grape berries could be shaken from the clusters. Abscission agents reduced harvest wounds and improved the appearance of destemmed Sheegene-12 berries at harvest and after postharvest storage, but diminished the appearance of Autumn King berries which became darker and more yellow coloured. Overall, the results suggest that abscission agents could be used to enable mechanical harvest of destemmed table grape berries, but more research is needed to determine if some of the unwanted side effects, including berry necrosis and browning, could be minimized.

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