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Balancing humidity and temperature for extended shelf-life and nutrient retention in watermelon

Nur Azlin, R.[1*], Nurul Khdijah, R.[1], Farah Aqila, H.[1], Hasmin Hakim, H.[2], Masniza, S.[2], Zainun, M. S.[2], Teoh, C. C.[2] and Suhana, S.[3]

[1]*Horticulture Research Centre, MARDI Headquarters, 43400, Serdang, Selangor, Malaysia*
[2]*Engineering Research Centre, MARDI Headquarters, 43400, Serdang, Selangor, Malaysia*
[3]*Socio-Economy, Market Intelligence and Agribusiness Research Centre, MARDI Headquarters, 43400, Serdang, Selangor, Malaysia*

Abstract

Watermelon registered the highest total exports with 43.1 thousand tonnes, 33.7% of local production. A preliminary survey estimated the postharvest loss for watermelon in Malaysia at 33%, with losses at the collection centre accumulating at the highest rate (56%). This high loss needs to be addressed to reduce the postharvest losses in the agriculture sector. A study on storage temperature and relative humidity (RH) to reduce losses of watermelon was conducted for four weeks. Treatments included storage at temperature of 10 °C with 85 – 95% RH and 60 – 70% RH. Storage at ambient temperature (25 °C) with RH 60 – 70% was set as a control. Representative samples from each treatment were removed weekly for visual appearance and physicochemical quality. Watermelon stored at the ambient temperature of 25 °C scored good until four weeks. Fruits stored at a cold temperature of 10 °C with 60 – 70% RH scored acceptable at week-4, while fruits stored at the same temperature with 85 – 95% RH were infected with mould and scored as poor. Fruits stored at lower relative humidity reported a high percentage of weight loss. In conclusion, storage at low relative humidity (60 – 70%) at 25 °C, helps slow down the fungal infection and extends the shelf life of watermelon up to four weeks.

Keywords: *postharvest, postharvest loss, fungal infection, value chain, temperature*

Introduction

Watermelon (*Citrullus lanatus*) is classified under the family Cucurbitaceae and it varies in size and shape, commonly round and oblong. Watermelon is a rich source of bioactive compounds, for example, carotenoids (lycopene and β-carotene), phenolics, flavonoids, amino acids (L-arginine and L-citrulline) and vitamins (A and C) (Sabeetha et al. 2017; Ridwan et al. 2018; Noh et al. 2020) that are valuable to human health (Martínez-Sánchez et al. 2017).

Watermelons were grown in Malaysia in the early 1950s and under the National Agro-Food Policy (NAP) 1.0 and 2.0, watermelon was categorised as one of the main fruits for food security commodities. Watermelon ranks fifth in Malaysian fruit production after coconut, durian, banana and pineapple. According to the production report, Peninsular Malaysia planted watermelons on 4.8% (9,248 ha) of its total fruit production areas in 2022 (Department of Agriculture Malaysia 2023). The main regions are Kelantan (35.5%), Pahang (22%) and Johor (13%). The production of watermelon in 2022 was 129,433 mt, an increase of 1.25% from the previous year (127,835 mt). In 2021, watermelon emerged as the top export, accounting for 43.1 thousand tonnes, or 33.7% of the total local production (Department of Statistics Malaysia 2022). Its export value has increased significantly at 6.2%, from 60 thousand mt (2018) to 64 thousand mt (2019). Watermelon's per capita consumption was reported at 2.6 kg/year in 2021 and the average price was RM3.07/kg. As the second largest Self-Sufficient Level (SSL) value (140%) in 2022 after papaya, it is suggested that local production is adequate to meet domestic needs and is available for the export market.

Watermelons' postharvest quality and shelf life are essential to industry players, as shelf-life indicates the profits lost due to food. Watermelons are susceptible to several postharvest disorders, for example, ethylene

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Authors' full names: Nur Azlin Razali, Nurul Khdijah Rosly, Farah Aqila Hamzah, Hasmin Hakim Hasbullah, Masniza Sairi, Zainun Mohd Shafie, Teoh Chin Chuang and Suhana Safari
Corresponding author: nurazlin@mardi.gov.my

damage, mechanical injury and chilling injury. Changes in appearance, diseases, fruit firmness, weight, colour, quality and sensory attributes are responsible for the end of shelf-life. During its postharvest life, the rind may sustain damage from a number of common fungal infections, including fusarium, black rot, stem end rot and anthracnose (Ho et al. 2017). The most prevalent bacterial illness that results in rind degradation is soft rot. Losses happen throughout the supply chain, especially during production and logistics. The watermelon supply chain involves one or two-tier supply chain, which comprises movement from producers, wholesalers, retailers and final users. Delivering food to consumers by reducing losses in fields, transport, storage, retailing and processing should be the priority. Each operation and handling stage leads to certain losses, which in turn reduces the availability of food (Dos Santos 2020). A preliminary survey was conducted to estimate the percentage of postharvest losses along the supply chain. The total postharvest loss for watermelon in Malaysia was 33%, with losses at the collection centre accumulating the highest rate (56%) (Safari et al. 2022) (*Figure 1*).

This high loss needs to be addressed, as it will affect the farmers' income and increase food waste in the agriculture sector. In mobilising efforts towards food security issues, proper postharvest techniques developed should be considered to reduce the postharvest losses, especially in the collection centre and distribution stages. Ahmad and Siddiqui (2015) suggest that storing watermelon at an optimal temperature of 10 – 15 °C and relative humidity of 90% can extend its storage life to 14 – 21 days. To overcome the postharvest losses of watermelon during storage, a study on storage temperature and relative humidity (RH) was conducted to slow down fungal infection and extend the shelf life of watermelon.

Materials and method

Sample preparation of watermelons

Watermelons (345 F1 Hybrid) harvested in commercial maturity stage used in this study were obtained from a farm in Perak, Malaysia and transferred to the Postharvest Laboratory, MARDI, the day after harvesting. Fruits were sorted out for defects and sound fruits were chosen for treatment. After the sanitation process (dipping in sodium hypochlorite (200 ppm) for 30 seconds), fruits were air-dried for 30 minutes and were packed in clean corrugated fibreboard (CFB) boxes, two fruits for each box. The fruits were stored in three controlled temperature rooms, treatment 1 (25 °C, RH 60 – 70%), treatment 2 (10 °C, RH 85 – 95%) and treatment 3 (10 °C, RH 60 – 70%), for up to 5 weeks to simulate the storage temperature for transit and transportation. Each fruit represents one replicate, with four replicates/treatment.

Fruit quality assessment

Representative samples from each treatment were removed weekly for visual appearance and physicochemical quality. Visual appearance and quality parameters were compared to those stored at an ambient temperature of 25 °C, RH 60 – 70% (control). On each evaluation day, the individual fruit's visual appearance was subjectively scored for fungal infection, stem-end rot, overall appearance and acceptability rating.

To determine the changes in quality, samples were analysed for postharvest parameters such as weight loss, endocarp colour, exocarp and mesocarp firmness and compositional characteristics (total soluble solids (TSS), total titratable acidity (TTA), ascorbic acid content (AAC), juice content and moisture content). The weight loss percentage was obtained by measuring the difference in weight before and after storage. The watermelon firmness was determined at three different places on the fruit after removing the thin exocarp and measured using a texture analyser (TA.xt.Plus, Stable Micro Systems) fitted with a flat stainless-steel cylindrical probe (P2N) that travelled 10 mm of the depth of the cut surface of the sample with a penetration speed of 5 mm/s. Values were expressed as Newton (N). Endocarp's surface colour was measured by using a reflectance colourimeter (Minolta Chroma Meter, Model CR400, Osaka, Japan), obtaining CIE L*, a*, and b* values; the a* and b* values were converted into hue angle (h*) and chroma value (C*) as described by McGuire (1992).

Samples for the chemical analysis were blended using a kitchen blender. The pH and TTA value were measured using an automatic titrator (905 Titrando, Metrohom AG, USA) and total titratable acidity was

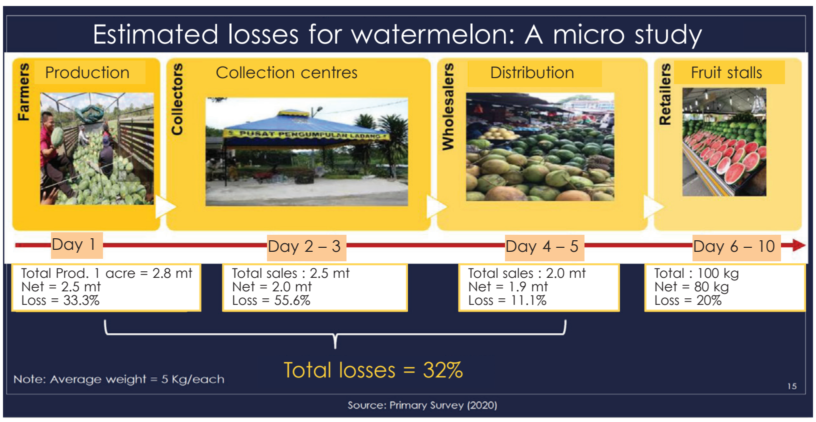

Figure 1. Estimated losses for watermelon in Malaysia (Safari et al. 2022)

measured by titrating the known volume of homogenate solution with 0.1 N NaOH to an endpoint of pH 8.1. The total soluble solids (TSS) were determined by a digital refractometer (ATAGO RX-5000, ATAGO, Japan). Ascorbic acid content was determined by titration with 2,6-dichlorophenolindophenol until a faint pink colour persisted. The juice content (%) was determined by weighing 100 g of the sample (initial). The sample was squeezed using a hand squeezer, the sample juice obtained was collected into a beaker, and the weight of the sample was recorded. The juice percentage was calculated using Equation 1 below:

$$\text{Juice content (\%)} = \frac{\text{Weight sample juice (g)}}{\text{Weight sample initial (g)}} \times 100 \quad (1)$$

The moisture content (%) was determined by weighing 10 g of sample (initial) and after three days in the oven (60 °C). The percentage was calculated using Equation 2 below:

$$\text{Moisture content (\%)} = \frac{\text{Weight sample initial (g)} - \text{Weight sample final (g)}}{\text{Weight sample initial(g)}} \times 100 \quad (2)$$

Statistical analysis

Statistical analyses of the treatment responses were conducted using Analysis of Variance (ANOVA) and the Duncan Multiple Range Test (DMRT). A 95% confidence interval was used for all calculations (p ≤0.05). SAS statistical software version 9.4 was used to perform statistical analyses. *Tables* and *figures* present the main effects.

Results and discussion

Fungal infection, stem-end rot and overall acceptability

Quality attributes such as appearance and overall acceptability contribute to a consumer's desire to purchase the fruit. The general appearance of the watermelon fruits was scored every week for four weeks (*Table 1*). Results showed that watermelon samples stored at the ambient temperature of 25 °C scored good on overall acceptability ratings until four weeks of storage. However, samples at 10 °C with high RH (85 – 95%) reported fungal infection as early as two weeks of storage. A previous study showed that postharvest deterioration of watermelon is linked to the activities of pathogenic fungi (*A. flavus, Streptomyces* spp. and *F. oxysporum*) (Odelade and Oluwole 2020). When disease affects fruit, they are rendered unmarketable and prone to decay, resulting in losses during distribution, shipment, transit and at consumer premises. For overall acceptability, fruits stored at a cold temperature of 10 °C with 60 – 70% RH scored acceptable until week 4 of storage (*Figure 2*). In comparison, fruit stored at a cold temperature of 10 °C with 85 – 95% RH was infected with fungus and thus scored poor (*Figure 3*). Lesions are formed at the blossom end, stem end or side of the fruit, extending over much of the surface. High moisture content in fruits significantly contributes to postharvest deterioration if not correctly stored. Storage condition is the main factor for the extension of watermelon quality, while other factors such as agrochemicals, rainfall, poor soil drainage, insect attacks, inappropriate harvest, transport and packaging could contribute to postharvest rot of watermelon. As the storage life was up to four weeks in fruits stored at 25 °C and 10 °C with 60 – 70% RH (*Table 1*), therefore, the quality data were collected and presented at the end of week four of the study for all treatments.

Table 1. Effect of different storage treatments on fungal infection, stem-end rot and overall acceptability rating (score 1 – 5) for watermelon during 4 weeks of storage at different storage temperatures and RH

Week	Treatments	Fungal infection	Stem-end rot	Overall acceptability rating
0	25 °C (RH 60 – 70%)	-	-	5.0a
	10 °C (RH 85 – 95%)	-	-	5.0a
	10 °C (RH 60 – 70%)	-	-	5.0a
1	25 °C (RH 60 – 70%)	-	-	5.0a
	10 °C (RH 85 – 95%)	-	-	4.5a
	10 °C (RH 60 – 70%)	-	-	5.0a
2	25 °C (RH 60-70%)	-	-	4.5a
	10 °C (RH 85 – 95%)	+	+	4.0a
	10 °C (RH 60 – 70%)	-	-	4.0a
3	25 °C (RH 60 – 70%)	-	-	4.8a
	10 °C (RH 85 – 95%)	+	+	3.3b
	10 °C (RH 60 – 70%)	-	+	4.3ab
4	25 °C (RH 60 – 70%)	-	-	4.3a
	10 °C (RH 85 – 95%)	++	+	2.5b
	10 °C (RH 60 – 70%)	+	+	3.3ab

Abbreviations: Score of symptoms based on each fruit (n = 4): negative = no trace; + = slightly affected; + + = moderately affected; Overall acceptability ratings: 5 = Excellent, 4 = Good, 3 = Acceptable, 2 = Poor, 1 = Very poor

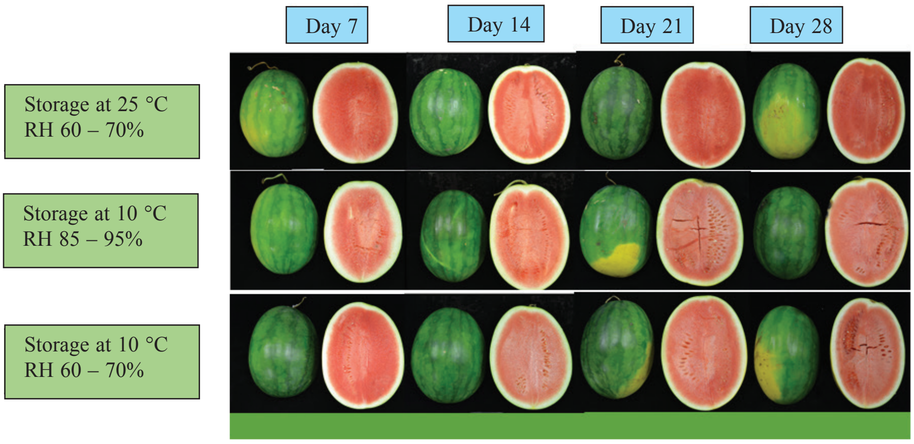

Figure 2. Appearance of watermelon in different storage conditions at 7, 14, 21 and 28 days

Endocarp colour, weight loss, total soluble solids (TSS), total titratable acidity (TTA), ascorbic acid content (AAC), juice and moisture percentage, exocarp and mesocarp firmness

According to the analysis, the watermelon endocarp primarily maintained its red colour during the four weeks of storage, with only minor variations in L* and h° (*Table 2*). L values* ranged from 41.1 (Week 0) to 49.1 (Week 2), with significant changes over time ($p \leq 0.01$), indicating lightening of the endocarp as storage progressed. Chroma (C)* and hue angle (h°) also changed significantly, reflecting shifts in pigmentation and maturity. The watermelon endocarp stored at 25 °C (RH 60 – 70%) reported a significantly higher chroma value compared with watermelon stored in cold storage. Colour degradation over time is typical in stored watermelon due to chlorophyll and carotenoid breakdown (Ilahy et al. 2019).

Weight loss refers to the loss of water content in fruit (Ktenioudaki et al. 2021). A ripe watermelon's water content makes up 93% of its net weight (Md Saad et al. 2020). Low relative humidity conditions, either at room temperature or in cold storage, displayed the highest weight loss percentage during four weeks of storage (*Figure 4*). Highest weight loss (2.8%) occurred at 25 °C, significantly higher than at 10 °C (1.6 – 2.7%), demonstrating that refrigeration reduces moisture loss. A significant factor in weight loss is the gradient difference in vapour pressure between the surrounding area and fruit tissue (Khaliq et al. 2016).

The effect of storage temperature and RH on total soluble solids of watermelon was contrary to ascorbic acid content and moisture. The decrease in the TSS content after four weeks of storage was more for room temperature storage in comparison to cold storage. The significant loss suggests a decrease in total sugars and may be attributed to the enhanced respiration rate of the fruits during storage (Mishra et al. 2014). Similar results have been reported by Pelayo et al. (2003). The decrease of soluble solids eventually reduced fruit juice sweetness. Jerry and Bright's (2019) discovery that soluble solids are retained longer in low-temperature storage corroborated the current work. This study showed that temperature can influence fruit sugar concentration, leading to a decrease in total soluble solids.

Ascorbic acid, a predominant form of vitamin C, is known to be highly unstable. Storage temperatures affect watermelon quality by decreasing its ascorbic acid content. Fruits stored at ambient temperatures were found to have lower ascorbic acid content than those stored at cold temperatures (*Figure 5*). In one study reported by Auwal Ibrahim (2016) on fruit juices (including watermelon), vitamin C content decreased by approximately 75.5% after 4 weeks at room temperature and by around 47.2% under refrigeration. A study by Mohamad Salin (2022) also found that during nine days of storage, watermelon juice had notable alterations in its physical and chemical appearance and a reduction in its overall phytochemical content. Fruit's moisture content changes during storage, potentially impacting its quality. The present study demonstrated an increased moisture content (%) of watermelon at room temperature with a decrease in cold storage (*Table 2*). The results of this study showed that storage temperature and humidity influenced the moisture content as reported by Ayomide et al. (2019). An increase in moisture content reflects the permeability of moisture transfer from the surrounding environment into the fruit cells (Jalali et al. 2019). Other physical and biochemical properties (L*, H°, TTA and juice content) were not affected by storage conditions.

The exocarp and mesocarp firmness decreased when water activity was reduced as a result of water loss from the extended storage duration. This study reported no significant changes occurred in the watermelon's exocarp and mesocarp firmness over the sampling times, indicating moderate textural stability during the 4-week period. However, there was a slight firmness decrease in watermelon stored at high relative humidity, which was 85 – 95% of the relative humidity. Loss of firmness during storage is widely reported for watermelon and related cucurbits and is commonly attributed to enzymatic breakdown of cell wall polysaccharides at higher temperatures and advanced storage durations (Anees et al. 2021; Zhang et al. 2022).

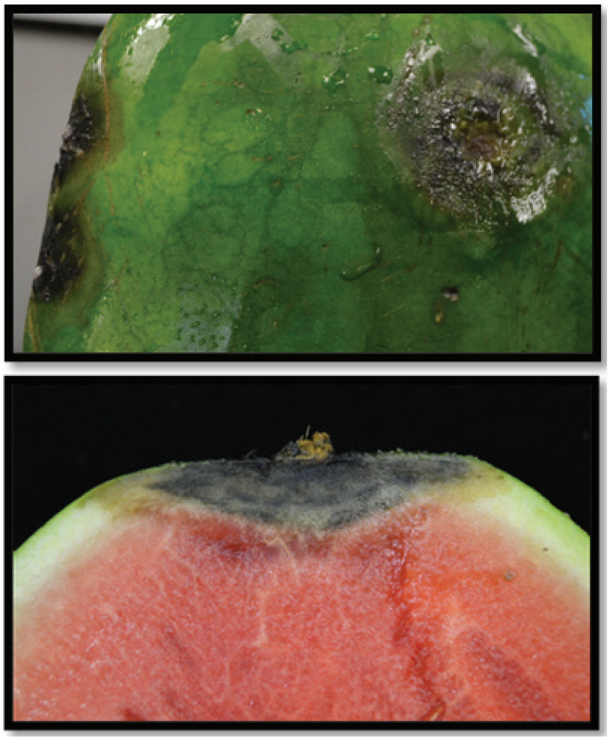

Figure 3. Fungal infection on the surface and stem-end rot in watermelon

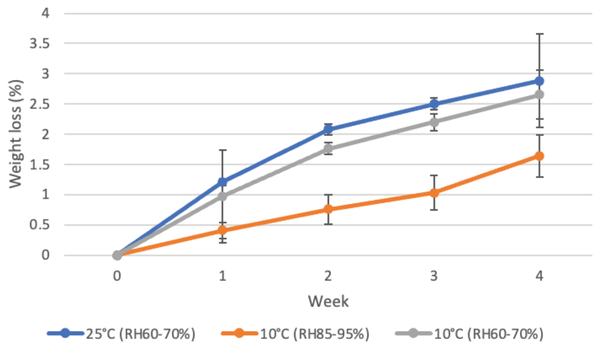

Figure 4. Weight loss percentage of watermelon in different storage temperature and RH during 4 weeks storage

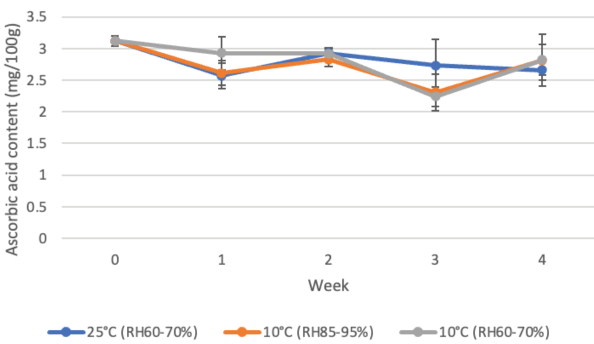

Figure 5. Ascorbic acid content of watermelon in different storage temperature and RH during 4 weeks storage

Table 2. Watermelon exocarp colour, weight loss, compositional parameters, exocarp and mesocarp firmness after 4 weeks of storage at different storage temperatures and during 4 weeks storage

Treatment	Colour			Weight loss (%)	Compositional parameter					Firmness[x]	
	L*	C*	h°		Total soluble solids (%)	Total titratable acidity (%)	Ascorbic acid content (mg/100 g)	Juice content (%)	Moisture (%)	Exocarp (N)	Mesocarp (N)
Treatment											
25 °C (RH 60 – 70%)	42.7a[z]	34.2a	38.8a	2.8a	7.4b	0.1a	2.7a	76.7a	90.9a	93.7a	67.0a
10 °C (RH 85 – 95%)	43.3a	28.7b	39.1a	1.6b	8.2ab	0.1a	2.8b	78.9a	90.6ab	70.4a	51.8a
10 °C (RH 60 – 70%)	43.4a	28.7b	39.4a	2.7a	8.4a	0.1a	2.8b	77.2a	90.0b	92.2a	67.2a
F-significant	ns	*	ns	**	*	ns	ns	ns	*	ns	ns
Storage period											
Week 0	41.1c	31.8ab	35.4c	0.0e	8.2a	0.2a	3.1a	82.4a	90.3a	75.8a	41.8b
Week 1	41.3c	33.0a	35.4c	0.9d	7.4b	0.1b	2.7a	82.1a	90.6a	88.4a	52.9ab
Week 2	49.1a	33.3a	36.8b	1.5c	8.1a	0.1b	2.9a	78.4b	90.3a	88.9a	61.2a
Week3	43.3b	31.8ab	38.7a	1.9b	7.1b	0.1b	2.1a	77.6b	90.9a	80.1a	47.1ab
Week 4	43.1b	30.6b	39.1a	2.4a	8.0a	0.1b	2.4a	77.4b	90.5a	85.4a	62.0a
F-significant	**	*	**	**	**	ns	ns	**	ns	ns	*
Treatment x Storage	*	*	ns	**	ns	ns	ns	ns	ns	ns	ns

[z]Means in each column with the same letter are not significantly different according to Duncan's Multiple Range tests at $p \leq 0.05$.
[y]ns = not statistically different, *, ** = statistically different at $p \leq 0.05$ and $p \leq 0.01$, respectively.
[x]As determined by the bioyield point.

Conclusion

Temperature and humidity play key roles in maintaining watermelon postharvest quality. Store the watermelon at 25 °C in low relative humidity (RH) of 60 – 70% to slow down fungal infection and extend its shelf life to four weeks. The watermelon is practically stored at room temperature unless it needs to be exported by sea shipment, in which case the temperature fluctuates and can increase up to 40 °C. The cold temperature of 10 °C with 60 – 70% RH was effective to prevent fungal infection during shipment. This technique can be used to maintain good quality, reduce losses, expand the domestic and export market.

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Conflicts of interest

The authors declare no conflict of interest

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