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Postharvest Hot Water-Dip Optimization for Accelerated Khalal to Tamar Transition of Aseel Dates

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ABSTRACT

High tannin astringency limits the commercial utility of Khalal-stage Aseel dates, while traditional sun-drying to the palatable Tamar stage is highly vulnerable to monsoon-induced spoilage. To overcome this climate-biochemical bottleneck, this study optimized postharvest hot-water-dip parameters as a rapid thermal curing strategy. This intervention successfully accelerated the Khalal-to-Tamar transition, mitigating weather risks while preserving superior physicochemical and organoleptic quality. Uniform Khalal fruits were subjected to two sequential hot-water-dip experiments: different temperatures (35, 70, 90 and 100°C for 5 min) and different dipping durations at 70°C (1, 3, 5, 7 and 9 min). Treated fruits were surface-dried and sun-cured for 2-3 days until a Tamar-like stage, followed by assessment of physical attributes, moisture, total soluble solids (TSS), pH, titratable acidity (TA), TSS:TA ratio, ripening percentage and sensory quality. Increasing temperature and dipping duration accelerated ripening and dehydration. At 5 min, ripening increased from 42.0% at 35°C to 92.0% at 100°C, while moisture decreased from 30.77% to 19.37% and TSS increased from 29.07 to 34.03 °Brix. However, the best sensory quality occurred at 70°C for 5 min, with the highest overall acceptability score (4.57) despite slightly lower ripening than at 100°C. HWD duration optimization at 70°C showed a similar pattern: 9 min produced the highest ripening (93.0%) but reduced overall acceptability (3.20), whereas 5 min gave high ripening (88.0%) with the highest overall acceptability (4.67). The findings indicate that 70°C for 5 min is the most balanced HWD condition for Aseel dates because it combines strong ripening induction, Tamar-like moisture reduction and superior sensory retention. The treatment offers a simple, low-cost postharvest option for reducing losses from premature Khalal harvesting in monsoon-affected date-growing regions.

KEYWORDS: Aseel date; accelerated ripening; hot water dip; Khalal; Tamar; postharvest processing; sensory quality

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is an important horticultural crop in arid and semi-arid regions, where its ability to produce energy-rich fruit under high temperature and water-limited conditions supports rural livelihoods and food security (Abul-Soad *et al.*, 2017). Pakistan is one of the significant date-producing countries and Khairpur in Sindh is one of the significant production belts for commercial cultivars. Aseel has a specific economic value among local cultivars due to its semi-dry characteristic, consumer acceptance, processing suitability, and storability (Jatoi *et al.*, 2009; Markhand *et al.*, 2010; Abul-Soad *et al.*, 2015). Date cultivation as a key fruit crop continues to be adopted in many countries to improve their food security, particularly due to increased international interest in dates (Subhash *et al.*, 2024). Fruit size, shape, color, texture (chewiness), cleanliness, and freedom from defects and decay-causing pathogens are some of the quality features of dates (Brizmohun *et al.*, 2023).

One of the major constraints on Aseel date production is the synchrony of ripening and monsoon rains. In the local situation, growers frequently

harvest fruit at the Khalal stage before the rain to prevent fruit cracking and microbial spoilage and loss, to prepare boiled dried dates, commonly known as Chuhhara in Pakistan (Jatoi, 2025). Aseel fruits at the Khalal stage are physiologically mature but with high moisture content, firm flesh, and comparatively low soluble solids content, and are less desirable for fresh consumption. The natural progression from Khalal to Rutab and Tamar is related to water loss, sugar concentration, reduction in acidity, softening of the tissues and improvement in the sensory quality (Zaid & de Wet, 2002; Kader & Hussein, 2009). However, when this natural process is halted by early harvest, postharvest ripening technologies are required.

Hot-water dipping is a relatively simple physical treatment that may change the behavior of ripening and curing fruits without the presence of chemical residues (Li *et al.*, 2023). Hot-water dipping (HWD) can raise tissue permeability, speed up water loss, initiate biochemical changes characteristic of ripening, and enhance the uniformity of drying after thermal dipping. Previously, it has been demonstrated that heat treatment can affect the texture, moisture loss, and quality of date fruits (Baloch *et al.*, 2003;

Awad, 2007). However, temperature and exposure time need to be carefully optimized, as excessive heat will result in surface damage, excessive shrinkage, undesirable softening and sensory loss.

A cultivar-specific thermal protocol is required for Aseel dates due to variability in ripening behavior related to fruit texture, stage of maturity, moisture content and local curing conditions. Therefore, the current study aimed to investigate the best temperature and immersion time for HWD to accelerate the ripening of the Khalal stage Aseel dates to the Tamar stage of ripeness without altering the physicochemical properties and organoleptic attributes.

MATERIALS AND METHODS

Plant material and experimental site: The fresh fruits of Aseel were picked at the Khalal stage of maturity from commercial date orchards of Khairpur district, Sindh, Pakistan. The Khalal stage was chosen, as it is generally the stage harvested prematurely in the region to prevent losses due to the monsoon season. Fruits were selected manually to ensure uniformity and freedom from disease, along with similar color and size, and fruits showing cracks, bruising, insect damage and visible disease symptoms were discarded. The fruits were transported to the laboratory of the Department of Botany and Date Palm Research Institute, Shah Abdul Latif University, Khairpur, for postharvest treatment and analysis.

Experimental design: The HWD experiments were conducted as two related experiments under a completely randomized design with three replicates per treatment two kilograms of dates in each treatment were used. The first experiment evaluated the effect of dipping temperature using four thermal levels: 35, 70, 90 and 100°C for 5 min. The second experiment evaluated exposure duration at the selected intermediate temperature of 70°C using five dipping times: 1, 3, 5, 7 and 9 min. Each treatment lot contained uniform Khalal-stage fruits, and the same post-treatment curing and analytical procedures were followed for all treatments. However, three untreated replicates were maintained as controls.

Hot water-dip treatment and curing: Fruits for the HWD time duration experiment were dipped at 70°C for 1, 3, 5, 7 or 9 min, with complete immersion, to ensure uniform heat exposure. After treatment, the fruits were taken from the hot water bath. Draining and surface drying came right after. The fruits were then spread out in one layer. Sun drying went on for two or three days to reach the cured stage like tamar. Analytical measurements came next to evaluate the physicochemical characteristics. This happened at the tamar-like stage.

Physical analysis: The digital balance was used to measure the weight of the fruit. Length and width of

the fruits were taken with a digital vernier caliper. Pulp weight and seed weight were obtained separately after manually removing the seeds from the fruits. The pulp-to-seed ratio was calculated as an index of the edible portion of the fruit using the following formula: **Pulp-to-seed ratio = Pulp weight (g) / Seed weight (g)**. A higher pulp-to-seed ratio indicates a greater proportion of edible pulp relative to seed mass.

Chemical analysis: Moisture content was calculated using the oven drying method at 105°C until a constant moisture weight was obtained and the results were expressed as percentage moisture. A refractometer was used to determine total soluble solids (TSS), which is expressed in °Brix. A calibrated digital pH meter was used for measuring the pH of pulp extract. Titratable acidity was determined by titrating the fruit extract with standardized 0.1 M NaOH to the end-point and reported as percentage acidity. TSS:TA ratio was used as a measure of the sweetness-acidity ratio and maturity advancement.

Ripening percentage and sensory evaluation: Ripening percentage was determined after curing by counting the fruits that reached a Tamar-like maturing state and dividing by the number of fruits in each replicate. Sensory evaluation was done by a five-point hedonic scale, with 1 indicating dislike extremely and 5 indicating like extremely. Coded samples of fruits were assessed by a panel of 10 date-palm experts for appearance, texture, taste and acceptability. Water was provided between samples for palate cleansing.

Statistical analysis: The data obtained were analyzed using XLSTAT software. Data are reported as mean $\pm$ SD ($n = 3$). The treatment effects were assessed by analysis of variance, and means were separated by Tukey's HSD test at $P \leq 0.05$. Means within a column with different letters differ significantly.

RESULTS

Baseline maturity differences between Khalal and Tamar fruits: The comparison between the Khalal and Tamar stages showed a significant decrease in fruit mass, pulp mass and moisture content, and an increase in soluble-solids-to-acidity balance (TSS:TA) during ripening of Aseel dates (Table 1). The weight of the fruit reduced from 11.29 g (at Khalal) to 8.90 g (at Tamar) and the weight of the pulp reduced from 10.24 to 7.85 g. Regarding moisture content, it decreased from 61.45% at Khalal to 21.07% at Tamar, which is consistent with dehydration as the most significant change associated with maturity. TSS increased from 27.18 to 33.14 °Brix, titratable acidity declined from 0.44% to 0.30%, and soluble-solids-to-acidity balance (TSS:TA) increased from 61.77 to 110.47. These maturity parameters were used to determine if HWD-treated fruits had a 'Tamar-like' chemical profile.

Table 1. Physicochemical baseline parameters of Aseel date fruits during Khalal and Tamar stages.

Parameter	Khalal stage	Tamar stage	P-value
Fruit weight (g)	11.29 ± 0.03 a	8.90 ± 0.06 b	<0.001
Fruit length (cm)	3.48 ± 0.04 a	3.14 ± 0.04 b	<0.001
Fruit width (cm)	2.33 ± 0.02 a	1.73 ± 0.03 b	<0.001
Pulp weight (g)	10.24 ± 0.03 a	7.85 ± 0.06 b	<0.001
Pulp:seed ratio	9.79 ± 0.04 a	7.53 ± 0.04 b	<0.001
Moisture (%)	61.45 ± 0.92 a	21.07 ± 0.74 b	<0.001
pH	5.79 ± 0.04 b	6.64 ± 0.03 a	<0.001
TSS (°Brix)	27.18 ± 0.18 b	33.14 ± 0.29 a	<0.001
Titratable acidity (%)	0.44 ± 0.02 a	0.30 ± 0.01 b	<0.001
TSS:TA ratio	61.77 ± 3.26 b	110.47 ± 4.92 a	<0.001

Values are mean ± SD (n = 3). Different letters within a row indicate significant differences between maturity stages at P ≤ 0.05.

Effect of HWD temperature on physical attributes:

Hot water dip temperature resulted in a gradual decrease in fruit weight, fruit size, pulp weight and pulp:seed ratio. Fruit weight declined from 9.55 g at 35°C to 8.25 g at 100°C, while pulp weight decreased from 8.45 to 7.09 g (Table 2). The fruit length and

width also decreased with the increasing temperature of treatment. Seed weight was almost the same among all treatments, suggesting that the seed weight variation resulted primarily from pulp dehydration and shrinkage, not due to the seed itself. This was further verified by a decrease in pulp:seed ratio from 8.10:1 to 6.75:1 as the temperature increased

Table 2. Effect of hot-water-dip temperature for 5 min on physical properties of Aseel dates after curing.

Treatment	Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	Pulp weight (g)	Seed weight (g)	Pulp: seed ratio
HWD 35°C - 5 min	9.55 ± 0.07 a	3.22 ± 0.01 a	1.80 ± 0.01 a	8.45 ± 0.05 a	1.04 ± 0.02 a	8.10 ± 0.07 a
HWD 70°C - 5 min	8.90 ± 0.02 b	3.14 ± 0.01 b	1.73 ± 0.01 b	7.85 ± 0.02 b	1.04 ± 0.01 a	7.52 ± 0.06 b
HWD 90°C - 5 min	8.54 ± 0.06 c	3.10 ± 0.01 c	1.70 ± 0.01 c	7.44 ± 0.06 c	1.05 ± 0.00 a	7.09 ± 0.06 c
HWD 100°C - 5 min	8.25 ± 0.05 d	3.05 ± 0.01 d	1.67 ± 0.01 d	7.09 ± 0.04 d	1.05 ± 0.00 a	6.75 ± 0.03 d

Values are mean ± SD (n = 3 replicates). Different letters within a column indicate significant differences at P ≤ 0.05.

Effect of HWD temperature on chemical attributes, ripening and sensory quality:

The chemical maturity development was strongly promoted by a high HWD temperature. Moisture decreased from 30.77% at 35°C to 19.37% at 100°C, while TSS increased from 29.07 to 34.03 °Brix. The titratable acidity decreased from 0.38% to 0.27%, while the pH value increased with the increase in temperature. Thus, at higher thermal intensity, the TSS:TA ratio rose from 76.54:1 to 124.55:1, which shows a more pronounced shift in sweetness-acidity at higher thermal intensity. The samples treated at 70°C produced a chemical profile close to natural Tamar

fruit, with 21.13% moisture, 33.13 °Brix TSS and a TSS:TA ratio of 109.26 (Table 3).

Ripening percentage also increased sharply with temperature, rising from 42.0% at 35°C to 87.0% at 70°C, 89.0% at 90°C and 92.0% at 100°C. But there was no linear response to sensory quality (Figure. 1). The highest overall acceptability was recorded at 70°C for 5 min (4.57), whereas 100°C for 5 min, despite producing the highest ripening percentage, had the lowest overall acceptability (2.70). Excessive heat shortened maturity indices, yet hurt eating quality, likely due to excessive softening, shrinkage, surface damage, or loss of flavor

Table 3. Effect of hot-water-dip temperature for 5 min on chemical attributes, sensory quality and ripening percentage of Aseel dates after curing.

Treatment	Moisture (%)	TSS (°Brix)	pH	TA (%)	TSS:TA	Appearance	Texture	Taste
HWD 35°C - 5 min	30.77 ± 0.65 a	29.07 ± 0.25 c	6.10 ± 0.02 d	0.38 ± 0.01 a	76.54 ± 2.67 d	3.60 ± 0.10 b	3.40 ± 0.10 b	3.50 ± 0.10 b
HWD 70°C - 5 min	21.13 ± 0.42 b	33.13 ± 0.15 b	6.61 ± 0.02 c	0.30 ± 0.01 b	109.26 ± 2.46 c	4.63 ± 0.06 a	4.47 ± 0.06 a	4.57 ± 0.06 a
HWD 90°C - 5 min	20.13 ± 0.31 b	33.53 ± 0.15 b	6.67 ± 0.02 b	0.29 ± 0.01 b	117.02 ± 2.90 b	3.30 ± 0.10 c	3.10 ± 0.10 c	3.40 ± 0.10 b
HWD 100°C - 5 min	19.37 ± 0.25 c	34.03 ± 0.15 a	6.76 ± 0.02 a	0.27 ± 0.01 c	124.55 ± 3.04 a	2.70 ± 0.10 d	2.60 ± 0.10 d	2.90 ± 0.10 c

Values are mean ± SD (n = 3). Different letters within a column indicate significant differences at P ≤ 0.05. TA = titratable acidity.

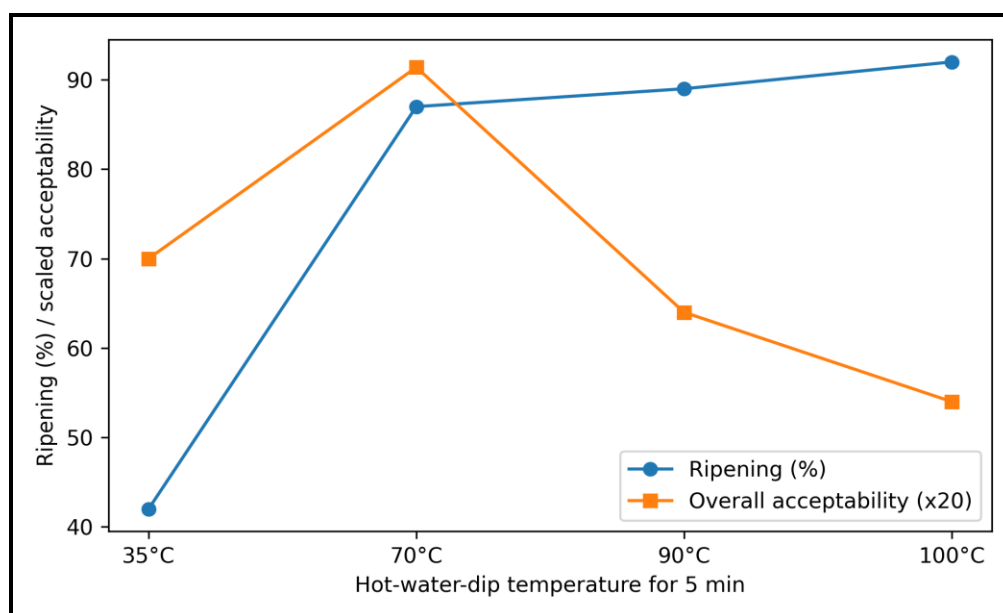


Figure. 1. Response of ripening percentage and overall acceptability to HWD temperature.

Effect of HWD duration at 70°C on physical attributes: The physical attributes declined as the dipping time was extended at 70°C. The fruit weight decreased from 9.24 g after 1 min to 8.35 g after 9 min, and the pulp weight decreased from 8.20 to 7.19 g. The fruit length and width also decreased slightly. The seed weight did not change again, which also

demonstrates that the treatment-induced weight changes are primarily attributable to the dehydration and shrinkage of the pulp (Table 4). As curing progressed, the moving average ratio of pulp to seed decreased from 7.88 after 1 minute to 6.85 after 9 minutes, indicating increased severity of curing with longer heat exposure

Table 4. Effect of hot-water-dip duration at 70°C on physical attributes of Aseel dates after curing.

Treatment	Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	Pulp weight (g)	Seed weight (g)	Pulp: seed Ratio
HWD 70°C - 1 min	9.24 ± 0.06 a	3.18 ± 0.01 a	1.77 ± 0.01 a	8.20 ± 0.05 a	1.04 ± 0.01 a	7.88 ± 0.03 a
HWD 70°C - 3 min	8.98 ± 0.02 b	3.15 ± 0.01 b	1.74 ± 0.01 b	7.92 ± 0.03 b	1.04 ± 0.00 a	7.62 ± 0.02 b
HWD 70°C - 5 min	8.90 ± 0.02 b	3.14 ± 0.01 b	1.73 ± 0.01 b	7.85 ± 0.02 b	1.04 ± 0.01 a	7.52 ± 0.06 b
HWD 70°C - 7 min	8.62 ± 0.04 c	3.11 ± 0.01 c	1.70 ± 0.01 c	7.52 ± 0.04 c	1.05 ± 0.00 a	7.16 ± 0.03 c
HWD 70°C - 9 min	8.35 ± 0.03 d	3.07 ± 0.01 d	1.68 ± 0.01 d	7.19 ± 0.04 d	1.05 ± 0.00 a	6.85 ± 0.03 d

Values are mean ± SD (n = 3). Different letters within a column indicate significant differences at $P \leq 0.05$.

Effect of HWD duration at 70°C on chemical attributes, ripening and sensory quality: Chemical maturity indicators were strongly affected by dipping time at 70°C. Moisture decreased from 26.73% at 1 min to 19.57% at 9 min, while TSS increased from 31.07 to 33.93 °Brix. Titratable acidity decreased to 0.28, while pH increased from 6.32 to 6.74. With increasing treatment duration, the TSS:TA ratio increased from 90.51 to 122.69 (Table 5), indicating a greater predominance of sweetness relative to acidity and a progression toward a developing Tamar-like flavor profile.

The ripening percentage rose from 62.0% (1 min) to 93.0% (9 min). Sensory quality, however, again showed a clear optimum intermediate exposure (Figure. 2). The 5 min treatment had the highest appearance score (4.73), texture (4.57), taste (4.67), and overall acceptability score (4.67), and also had a high ripening percentage of 88.0%. Conversely, higher ripening percentages, but lower sensory scores were obtained with 7- and 9-min treatments, giving reduced overall acceptability of 3.87 and 3.20, respectively. The results indicate that the 70°C, 5 min combination is the most balanced duration-temperature combination.

Table 5. Effect of hot-water-dip duration at 70°C on chemical attributes, sensory quality and ripening percentage of Aseel dates after curing.

Treatment	Moisture (%)	TSS (°Brix)	pH	TA (%)	TSS:TA	Appearance	Texture	Taste
HWD 70°C - 1 min	26.73 ± 0.55 a	31.07 ± 0.25 d	6.32 ± 0.02 e	0.34 ± 0.01 a	90.51 ± 2.19 d	4.07 ± 0.06 c	3.87 ± 0.06 c	3.97 ± 0.06 c
HWD 70°C - 3 min	23.07 ± 0.31 b	32.50 ± 0.10 c	6.53 ± 0.01 d	0.31 ± 0.01 b	103.75 ± 2.17 c	4.43 ± 0.06 b	4.23 ± 0.06 b	4.37 ± 0.06 b
HWD 70°C - 5 min	21.10 ± 0.30 c	33.20 ± 0.03 a	6.62 ± 0.01 c	0.30 ± 0.01 c	111.94 ± 0.00 a	4.73 ± 0.06 a	4.57 ± 0.06 a	4.67 ± 0.06 a

min	0.36 c		0.10 b		0.01 c		0.01 c		2.23 b		a		0.06 a		0.06 a	
HWD 70°C - 7	20.37	±	33.60	±	6.68	±	0.29	±	117.25	±	4.07	±	0.06	±	3.97	±
min	0.25 c		0.10 a		0.02 b		0.01 c		2.70 a		c		0.06 c		0.06 c	
HWD 70°C - 9	19.57	±	33.93	±	6.74	±	0.28	±	122.69	±	3.40	±	0.10	±	3.30	±
min	0.25 d		0.15 a		0.02 a		0.01 d		3.12 a		d		0.10 d		0.10 d	

Values are mean ± SD (n = 3). Different letters within a column indicate significant differences at $P \leq 0.05$. TA = titratable acidity.

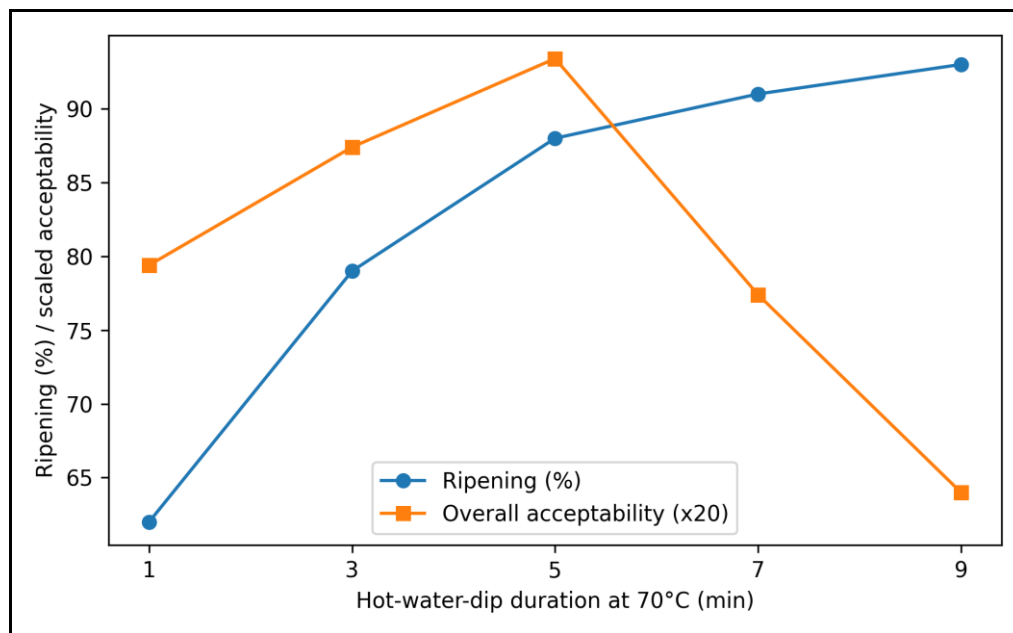


Figure 2. Response of ripening percentage and overall acceptability to HWD duration at 70°C.

DISCUSSION

The present HWD experiments demonstrate that thermal dipping is quite effective in transforming Khalal stage Aseel dates to Tamar stage cured product. The general physiological trend observed in both the temperature and duration experiments was an increase in thermal stress, which decreased fruit weight, pulp weight, fruit size, fruit moisture, and the fruit ripening percentage, while increasing TSS, pH and TSS:TA ratio. These changes resemble the natural process of the transition from Khalal to Tamar fruit, where water loss and sugar concentration are key factors in the quality development of the fruit (Zaid & de Wet, 2002; Kader & Hussein, 2009).

The decrease in fruit and pulp mass under higher temperature or longer exposure is primarily due to loss of water from the mesocarp. This is in line with the near constancy of seed weight in both experiments, which indicates that seeds are structurally mature and less responsive to short-term heat treatment (El-Beltagi *et al.*, 2023). The results demonstrate that too much dehydration is not desirable for curing Aseel dates to the Tamar-like stage. High temperature and extended ripening time enhanced the numerical ripening percentage, but also reduced the sensory quality, thus indicating that the ripening efficiency was not a sufficient criterion for recommending a postharvest treatment (Alsmairat *et al.*, 2022).

For the temperature experiment, fresh date fruits were subjected to hot-water-dip (HWD) treatments at **35, 70, 90, and 100 °C for 5 min**. The required water temperature was established and maintained using a thermostatically controlled water bath. Water temperature was continuously monitored with a calibrated thermometer to ensure that the target temperature remained stable throughout each 5-min treatment period. Fruits were completely immersed in the water during treatment. After dipping, the fruits were removed and allowed to cool to room temperature before subsequent physicochemical analyses. For the duration experiment, fruits were treated at the selected temperature of **70 °C for different exposure periods**, following the same dipping procedure. This caused the TSS:TA ratio to rise significantly, indicating a better sweetness-acidity ratio. The same ripening-related trends of increased TSS and decreased acidity have been observed in date palm maturation and postharvest ripening studies (Rastegar *et al.*, 2012; Kahramanoglu & Usanmaz, 2019).

The key finding obtained indicated that there was a difference between the ripening percentage and the overall sensory acceptability. Ripening was 92.0% at 100°C for 5 min with an overall acceptability of 2.70. Ripening at 70°C for 9 min was 93.0%, with overall acceptability being 3.20. These treatments advanced chemical maturity well, but probably resulted in losses of quality, including too much shrinkage, too much surface firmness, tissue collapse, or uneven

softening or development of heat-related flavors. Such a trade-off is in line with the general thermal treatment optimization principle of maintaining appearance, texture and taste as well as biochemical acceleration (Baloch *et al.*, 2003; Saleem, 2004; Awad, 2007).

The optimum treatment was 70°C for 5 minutes. In the HWD temperature experiment, it produced 87.0% ripening with the highest overall acceptability score among temperatures. In the HWD duration experiment, the same condition resulted in the highest sensory scores and 88.0% ripening across all durations. It contained approximately 21%, a moisture level near the natural Tamar level, and its TSS and TSS:TA values indicated an advanced maturity stage; this treatment is thus a biologically and commercially viable optimum, not just a statistical maximum.

Higher temperatures and longer dipping times resulted in a higher percentage of ripening, but excessive HWD intensity resulted in surface wrinkling, shrinkage, and potential heat injury,

leading to lower sensory acceptability. Similarly, the appearance of the dates differed with HWD level even after treatment, with moderate conditions giving uniform dates which had acceptable appearance, whereas the dates over-exposed to HWD or excessive dipping produced darker color and significant wrinkling and visible shrinkage (Fig. 3A and Fig. 3B).

The results are significant from a postharvest management point of view for conditions in Aseel producing areas, where premature Khalal harvest is adopted to prevent monsoon damage. A short sun curing together with a simple HWD step at 70°C for 5 min may be useful to growers to transform low-quality Khalal fruits into an acceptable Tamar-like product. The treatment is simple, inexpensive, and does not involve any chemical ripening agents and can be applied in small-scale processing, provided temperature control and hygienic handling are maintained. However, scaling must encompass larger batch sizes, variation in fruits and different harvest times.

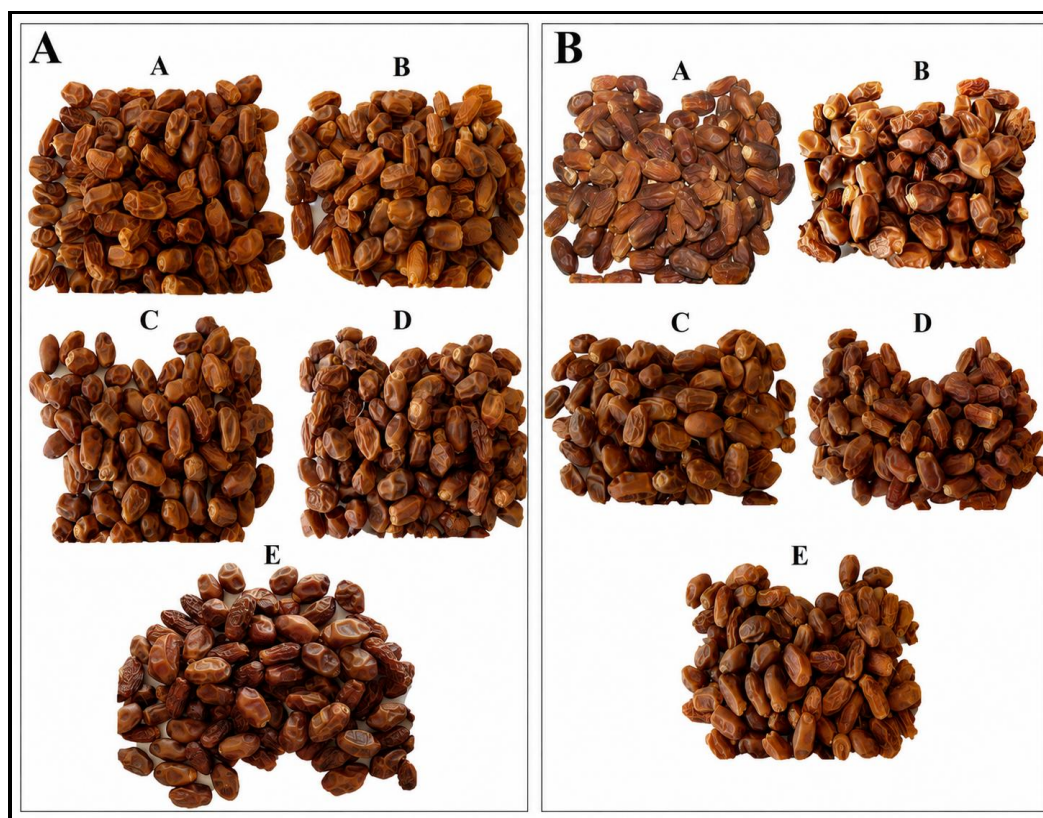


Figure 3. Visual appearance of Aseel date fruits after hot water dip (HWD) treatments used for accelerated ripening. (A) Effect of HWD temperature: A = control, B = HWD at 35°C, C = HWD at 70°C, D = HWD at 90°C, and E = HWD at 100°C. (B) Effect of HWD duration at 70°C on cured Aseel dates: A = 1 min, B = 3 min, C = 5 min, D = 7 min, and E = 9 min.

CONCLUSION

Controlled hot-water dipping significantly accelerated ripening and curing of Khalal-stage Aseel dates. Exposing the HWD at higher temperatures and long durations resulted in greater moisture loss, soluble-solid concentration, reduction in acidity, and

percentage of ripening. The most severe treatments, however, compromised sensory quality, highlighting the need to balance the rate of ripening with sensory quality. In both experiments, 70°C for 5 min provided high ripening along with the highest sensory acceptability, rather than the highest ripening percentage, providing the best balance between

ripening and sensory quality, with moisture and TSS levels comparable to the Tamar stage and the highest overall sensory acceptability. The HWD condition can be recommended as a practical postharvest processing for enhancing the value of premature Aseel dates production in the monsoon region, which should be validated at pilot and commercial level.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

ZP: Methodology, Investigation, Data Curation, and Writing Original Draft. TJ: Conceptualization, Supervision, Validation, and Writing Review & Editing. MAS: Formal Analysis, Visualization, and Writing Review & Editing. All authors reviewed and approved the final version of the manuscript.

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