

1 **Optimizing Thermal Treatments and Packaging to Enhance Oleaster**  
2 **Shelf Life and Quality**

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4 **ABSTRACT**

5 This study aimed to extend the shelf life of oleaster (*Elaeagnus angustifolia*), which faces  
6 postharvest challenges such as weight loss, texture changes, and sensory degradation. The  
7 effects of heat (45, 55, and 65°C for 15, 30, and 60 minutes) and cold treatments (-18°C for  
8 30, 60, and 90 minutes) combined with different packaging atmospheres (normal air, vacuum,  
9 and nitrogen) were evaluated in terms of physicochemical and sensory attributes during  
10 storage. Samples were stored for 10 months, and parameters such as weight loss, moisture  
11 content, firmness, color indices (a\*, b\*, L\*), and sensory attributes were measured. Using  
12 response surface methodology, numerical optimization was applied to estimate conditions  
13 associated with improved quality retention under each packaging atmosphere. The model-  
14 based optimization suggested that heat treatment at 45°C for 15 minutes (normal  
15 atmosphere), 45°C for 25 minutes (vacuum), and 45°C for 29 minutes (nitrogen), as well as  
16 cold treatment at -18°C for 90 minutes combined with nitrogen packaging, could be favorable  
17 in terms of selected quality indicators. In a second phase, samples prepared under the  
18 predicted optimal conditions were stored for 6 months under warehouse conditions. The  
19 validation results indicated that nitrogen-packaged, heat-treated samples generally exhibited  
20 lower firmness and higher sensory acceptance compared with untreated controls, whereas  
21 vacuum-packaged samples showed lower appearance scores. Overall, the findings indicated  
22 that the combined application of mild thermal pre-treatment (45°C for 29 minutes) and  
23 modified atmosphere packaging (70% Nitrogen) had the potential to improve the storage  
24 performance of oleaster. Further studies are required to confirm these effects under  
25 commercial conditions.

26 **Keywords:** Packaging, Russian olive, Silverberry, Storage, Thermal pretreatment.

27  
28 **INTRODUCTION**

29 *Elaeagnus angustifolia* L., commonly known as oleaster, silverberry, Russian olive,  
30 or wild olive, belongs to the *Elaeagnaceae* family. This deciduous tree is widely  
31 distributed in several countries, including Pakistan, India, Afghanistan, China, and Iran

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32 (Ahmad *et al.*, 2006). Oleaster fruit is a rich source of bioactive phytochemicals such as  
33 flavonoids, carotenoids, terpenes, phenyl esters, vitamins, essential fatty acids,  
34 phospholipids, glycolipids, beta-sitosterol, and minerals like potassium, magnesium,  
35 sodium, iron, calcium, zinc, and copper (Pirbodaghi *et al.*, 2023). The whole fruit of  
36 oleaster contains 13.5% moisture, 6.75% protein, 1.49% fat, and 2.26% ash and provides  
37 an energy value of 4208 calories per gram (Darvishzadehboroojeni, 2021). Most research  
38 on oleaster has focused on its medicinal and therapeutic properties. Limited studies have  
39 investigated the chemical and physical properties of oleaster, including its lipid and  
40 phytochemical composition, phenolic compounds, soluble sugars, antioxidant properties,  
41 and nutritional value (Zor *et al.*, 2025; Al Jubouri and Gharnah, 2024; Ghannadiasl *et al.*,  
42 2020; Babakhanzade Sajirani *et al.*, 2017). Bioactive peptides present in oleaster are  
43 considered one factor responsible for its health-promoting and medicinal effects  
44 (Sarabandi *et al.*, 2024). Very few studies have been conducted on the processing and  
45 utilization of oleaster powder in food products. However, no work has been done so far  
46 about the packaging and storage of oleaster.

47 Abbaszadeh *et al.* (2012), in a study on the drying of oleaster, showed that increasing  
48 the temperature increased moisture content and energy consumption, while increasing the  
49 air flow rate reduced these factors. Khayyat *et al.* (2018) recommended that temperatures  
50 below 60°C are more suitable for drying. Boudraa *et al.* (2020) introduced microwave  
51 drying at 450 watts as the best method for drying oleaster. Sarvarian *et al.* (2022)  
52 increased the shelf life of orange juice by using oleaster as an antioxidant. Azarpazhooh  
53 and Mokhtarian (2007) also introduced polyethylene packaging at 4°C as the best storage  
54 condition for jujube fruit. Modified Atmosphere Packaging (MAP) extends the shelf life  
55 and preserves the quality of fruits and vegetables by controlling the gaseous environment  
56 through the use of appropriate packaging films. However, its effectiveness depends on  
57 proper temperature and humidity management (Rai *et al.*, 2022). Modified atmosphere  
58 packaging, particularly nitrogen-based systems, has been shown to reduce oxidative  
59 degradation and moisture loss in dried and semi-dried fruits (Wilson *et al.*, 2017; Wu *et*  
60 *al.*, 2022).

61 From a postharvest perspective, oleaster fruit is highly susceptible to quality  
62 deterioration during storage due to moisture loss, texture hardening, color changes, and  
63 insect infestation, which severely limit its marketability and storage life. These limitations  
64 are exacerbated by the lack of temperature control, high permeability of traditional

65 packaging materials, and uncontrolled gas exchange during storage. Conventional storage  
66 practices, particularly in rural production areas, often rely on permeable plastic bags and  
67 ambient warehouses, offering minimal control over gas composition and water vapor  
68 transfer. In recent years, modified atmosphere packaging (MAP) has been recognized as  
69 an effective strategy to suppress physiological degradation, reduce oxidative reactions,  
70 and extend shelf life in dried and semi-dried fruits. However, despite the growing  
71 importance of oleaster as a functional and economic crop, studies addressing the  
72 combined effects of pre-treatments and packaging atmospheres on its postharvest quality  
73 are still lacking. Therefore, the objective of this study was to evaluate the effects of  
74 thermal and cold pre-treatments combined with different packaging atmospheres (normal  
75 air, vacuum, and nitrogen) on the physicochemical, sensory, and storage stability of  
76 oleaster fruit, and to identify optimal postharvest conditions for extending shelf life using  
77 response surface methodology and numerical optimization.

78

## 79 MATERIALS AND METHODS

### 80 Sample Preparation and Treatments

81 This project was conducted in two phases. In the first phase, the 'Khormaei' cultivar of  
82 oleaster, which is the primary export cultivar and common in the region (Shahroud, Iran),  
83 was purchased from a local orchardist in Golestan, Shahroud, and transferred to the laboratory  
84 for sorting. The oleasters were then heated in a fan-equipped oven (model Froilabco, France)  
85 at three temperatures of 45, 55, and 65°C for 15, 37, and 60 minutes. Some samples were also  
86 placed in a home freezer at sub-zero temperature (-18°C) for 30, 60, and 90 minutes.  
87 Afterward, using a vacuum packaging machine (Boxer42, Netherlands), the samples were  
88 packaged in laminated polyamide-polyethylene bags (0.1 mm thickness) purchased from  
89 Vosoughi Packaging Company (Mashhad, Iran) under normal, vacuum (approximately 99%  
90 vacuum level), and nitrogen atmospheres (with an initial nitrogen concentration of about  
91 70%). They were then stored at ambient temperature for 10 months. After this period, various  
92 tests were conducted to assess product quality, including weight changes, moisture content  
93 (Iranian National Standard No. 6257), color changes (using ImageJ software), tissue firmness  
94 (using a manual penetrometer, model FT011), and sensory properties including taste, texture,  
95 color, and appearance (using a five-point hedonic scale), as well as insect activity (presence  
96 of insect traces in the packaging). At this stage, the results obtained from each packaging  
97 method (normal, vacuum, and nitrogen) and various pre-treatments were analyzed separately,

98 and the optimal conditions for heat pre-treatment related to each packaging method were  
99 determined. In the second phase, oleaster samples of each type of packaging (normal,  
100 vacuum, and nitrogen) under the obtained optimal conditions were subjected to heat or cold  
101 treatments and stored at ambient temperature for 6 months. In this phase, LDPE packaging  
102 was used exclusively as a conventional storage control to represent routine postharvest  
103 handling practices for oleaster and to enable direct comparison with the optimized treatments.  
104 After analyzing the results of the experiments in this stage, the best method and packaging  
105 conditions for storing oleasters were identified.

106

### 107 Measurement of Weight Loss

108 To determine the weight loss, samples were weighed after packaging, at the beginning  
109 of storage, and again after 10 months. The weight loss was calculated using Equation 1.  
110  $w_1$  and  $w_2$  are sample weights at the beginning and end of storage (Ziaolhagh, 1999).

$$111 \text{ Weight loss (\%)} = \frac{w_1 - w_2}{w_1} \times 100 \quad (1)$$

112

### 113 Moisture Content Determination

114 To measure moisture content, an oven at 105°C was used. Approximately 5 grams of  
115 sample (in triplicate) were placed in the oven, and after the weight became constant, the  
116 moisture percentage was calculated (Equation 2). The average of the three replicates was  
117 reported as the mean moisture percentage (Ziaolhagh, 2021).  $m_1$  and  $m_2$  are sample  
118 weights at the beginning and end of storage.

$$119 \text{ Moisture (\%)} = \frac{m_1 - m_2}{m_1} \times 100 \quad (2)$$

120

### 121 Firmness Measurement

122 A manual penetrometer (model FT011), calibrated in kilograms, was used to  
123 determine the firmness of each sample. First, a portion of the thin oleaster peel was  
124 removed, and then the probe of the device was inserted into the oleaster tissue up to the  
125 mark on it (approximately 5 mm), and the amount of force applied (in kilograms) was  
126 read at the mark. For each sample, tissue firmness was measured at three points on three  
127 oleasters, and the average of the 9 replicates was reported as an indicator of firmness  
128 (Hosseini *et al.*, 2023).

129

130

131 **Color Factors**

132 Color indices were measured by image processing. For this purpose, images with a  
133 resolution of 300 pixels were taken from the samples using a scanner (model ColorPage-  
134 HR7X Slim Genius). Then, the images were opened in ImageJ software version 1.50/1,  
135 and by converting the color space from Red-Green-Blue (RGB) to  $Lab^*$  (LAB) in the  
136 plugins section, the red-green, yellow-blue, and lightness indices were calculated. The  
137 lightness index ( $L^*$ ) represents the brightness of the sample and varies between zero  
138 (black) and 100 (white). The red-green index ( $a^*$ ) indicates the proximity of the sample  
139 color to green and red colors and is in the range between -120 (green) and +120 (red).  
140 The yellow-blue index ( $b^*$ ) also shows the proximity of the sample color to blue and  
141 yellow colors, and its range varies from -120 (blue) to +120 (yellow) (Jafari *et al.*, 2019;  
142 Ziaolhagh *et al.* 2017). The color change relative to the oleaster on the first day ( $\Delta E$ ) was  
143 obtained from Equation 3.

$$144 \Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (3)$$

145 Where  $L_0^*$ ,  $a_0^*$ , and  $b_0^*$  are the color indices at the beginning of storage time.

146

147 **Sensory Evaluation**

148 For the sensory evaluation, the five-point hedonic scale test method was used. In this  
149 test, 15 untrained panelists were selected to evaluate each feature of each sample using a  
150 rating scale from 'very bad' to 'very good' on designated forms. Then, the panelists'  
151 assessments were quantified as numbers 1 to 5 and analyzed.

152

153 **Statistical Design**

154 In the first phase, for variance analysis and determination of the best temperature and  
155 time of pre-treatment in each of the packaging conditions, the response surface  
156 methodology in the form of a central composite experimental design with 5 replicates at  
157 the central point was used with the help of Design-Expert software version 1.7.0.8. The  
158 second-order polynomial regression model (Equation 4) was applied to express the  
159 dependent variables as a function of the independent variables. To determine the best time  
160 for cold pre-treatment under three different packaging conditions, a completely  
161 randomized statistical design (CRD) in the form of a factorial experiment was used with  
162 the help of SPSS software version 19. Samples packaged under different conditions with  
163 no pre-treatment were also examined by the CRD method. The results obtained from the  
164 second phase were also analyzed with the help of CRD in three.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{112} X_1^2 X_2 + \beta_{122} X_1 X_2^2 \quad (4)$$

166

## 167 RESULTS AND DISCUSSION

### 168 Heat Pre-treatment

169 For each packaging atmosphere (air, vacuum, and nitrogen), a full second-order  
170 polynomial model including linear, quadratic, and interaction terms was initially fitted to  
171 the experimental data. Model terms were then evaluated using regression ANOVA, lack-  
172 of-fit tests, and model hierarchy principles. Non-significant terms ( $p > 0.05$ ) that did not  
173 contribute to model adequacy were sequentially removed to obtain the most parsimonious  
174 model with adequate predictive capability. As a result, different reduced model forms  
175 (linear, quadratic, or factorial) were selected for different response variables and  
176 packaging conditions, reflecting the distinct effects of treatment factors under each  
177 atmosphere. Optimization of process conditions was carried out using a numerical method  
178 and Design Expert software version 1.7.0.8. The criteria considered for the optimization  
179 process were that the samples should have the least weight loss and stiffness and the  
180 highest moisture and sensory evaluation score at the lowest temperature and process time.

181

### 182 Packaging in Normal Air Conditions

183 Under normal air packaging conditions, regression ANOVA indicated that among the  
184 tested response variables, only the models developed for weight loss ( $p < 0.05$ ) and  
185 moisture content ( $p < 0.01$ ) were statistically significant. For the remaining responses,  
186 higher-order and interaction terms were not significant ( $p > 0.05$ ), and the corresponding  
187 reduced models did not meet adequacy criteria; therefore, they were not further  
188 considered. The predicted model for weight loss was a linear model with a coefficient of  
189 determination ( $r^2$ ) of 0.47 and a coefficient of variation ( $CV$ ) of 9.74%. The linear model  
190 obtained for moisture content had an  $r^2$  of 0.6 and a  $CV$  of 4.8%. Adequate Precision ( $AP$ )  
191 measures the signal-to-noise ratio. A ratio greater than 4 is desirable. The ratio of 6.246  
192 for the weight loss model and 8.71 for the moisture model indicate adequate signals.  
193 These models can be used to navigate the design space. Table 1 shows the coefficients of  
194 the predicted models based on actual values.

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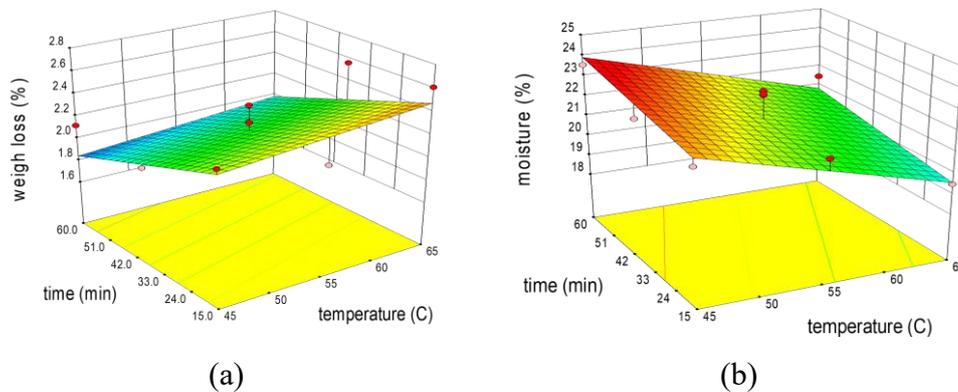
197

198 **Table 1.** The indicates experimental variables (temperature and time of heating) as linear  
 199 ( $x_1$  and  $x_2$ ), quadratic ( $x_1^2$  and  $x_2^2$ ), and interaction ( $x_1x_2$ ) terms of response variables (Weight  
 200 loss, Moisture content, firmness, and Texture score) and coefficients of the predicted  
 201 models.

Packaging conditions	response variables	Predicted model	Coefficients for the prediction models					
			Equation constant	$x_1$	$x_2$	$x_1x_2$	$x_1^2$	$x_2^2$
Air conditions	Weight loss	Linear	2.18	0.007	-0.0108			
	Moisture content	Linear	29.169	-0.154	0.028			
Vacuum conditions	Weight loss	Quadratic	-9.64	0.42	-0.004	-0.00019	-0.0037	0.0002
	firmness	Quadratic	-16.37	0.63	-0.0026	0.000092	-0.0053	-0.00006
	Moisture content	Linear	30.708	-0.16	-0.013			
	Texture score	Linear	5.16	-0.058	0.0037			
N <sub>2</sub> conditions	Weight loss	Factorial	6.45	-0.079	-0.11	0.0017		
	Moisture content	Factorial	37	-0.25	-0.426	0.0071		

202  $x_1$  and  $x_2$  are the temperature and time of heating, respectively.

203 Among the factors studied, only the heating time had a significant effect on the weight  
 204 loss ( $p < 0.05$ ). As illustrated in Fig. 1a, the response surface plot depicts a general trend  
 205 in which higher heating temperatures combined with shorter heating times are associated  
 206 with increased weight loss, whereas lower temperatures and longer heating times tend to  
 207 reduce weight loss. Statistical significance of these effects was evaluated using regression  
 208 ANOVA, as discussed in the text. The lowest and highest weight loss were related to the  
 209 samples heated for 60 and 15 minutes, respectively.



210 **Fig.1** The effect of heating time on the weight loss (a) and heating temperature on  
 211 moisture content (b) of packaged oleaster samples under normal atmospheric conditions  
 212 after 10 months of storage.

213  
 214 The weight loss after the storage time is inversely related to the occurrence of free  
 215 water in the samples. Bagheri *et al.* (2016) also showed that increasing the roasting time  
 216 of peanuts from 10 to 30 minutes decreases free moisture. Therefore, the samples that  
 217 were heated for 15 minutes lost less of their initial free water compared to the samples

218 heated for 60 minutes, and due to having more free water, their weight loss was greater  
219 after the end of the storage time.

220 The effect of heating temperature on the moisture content of the samples after 10  
221 months of storage was significant ( $p < 0.01$ ). Figure 1b illustrates the predicted variation  
222 in moisture content with heating temperature and time, showing a decreasing trend at  
223 higher temperatures. Statistical interpretation of factor effects was based on regression  
224 analysis rather than visual inspection of the response surface. Bagheri *et al.* (2016) and  
225 Kahyaoglu and Kaya (2006) reported that increasing roasting temperature reduces the  
226 immediate moisture content of peanuts and sesame seeds after thermal treatment.  
227 Although these studies were conducted on different products and focused on short-term  
228 moisture changes, they provide mechanistic insight into the effect of heat on free water  
229 removal. In the present study, however, moisture content was evaluated after long-term  
230 storage, where the observed differences are more strongly influenced by the combined  
231 effects of initial moisture reduction, packaging permeability, and moisture migration  
232 during storage. According to the optimization performed by the numerical method using  
233 Design-Expert software, the best sample was obtained using a temperature of 45°C for 15  
234 minutes with a desirability of 0.77. Table 2 shows the predicted response variables for  
235 each optimal treatment.

236

237 **Table 2.** Optimal response variables predicted for optimal conditions for packaging  
238 oleaster under different conditions

Packaging atmosphere	Optimum variables	Weight loss	Moisture content	Firmness	Flavor	Texture	Color	Appearance	a*	b*	L*	Desirability
Air	45°C/15min	2.33	1.26	22.64	2.6	3	2.8	4.9	6.68	30.56	62.83	0.77
Vacuum	45°C/24.6min	1.67	1.28	23.16	2.92	2.62	3.37	2.31	6.86	29.9	59.78	0.72
N <sub>2</sub>	45°C/28.5min	1.95	1.71	22.5	2.89	3.64	3.46	4.5	6.61	30.48	62.97	0.6

239

#### 240 Packaging in Vacuum Conditions

241 For vacuum-packaged samples, the regression analysis showed that quadratic models  
242 for weight loss and firmness, as well as linear models for moisture content and texture  
243 score, were statistically significant ( $p < 0.05$ ). Other potential interactions or higher-order  
244 terms were initially tested but excluded due to lack of statistical significance or  
245 insufficient contribution to model adequacy. The model obtained for weight loss was a  
246 quadratic model (Table 1) with an  $r^2$  of 0.75, an  $AP$  of 6.058, and a  $CV$  of 7.03%.  
247 Regarding weight loss, the effect of the second power of heating temperature ( $x_1^2$ ) was

248 significant ( $p < 0.01$ ). As shown in Fig. 2a, the response surface plot suggests a non-linear  
249 trend in weight loss with respect to heating temperature, with higher values around 55°C.  
250 The increased weight loss might be because the high heat changes the fruit's waxy cuticle  
251 from an ordered (crystalline) to a disordered (amorphous) state. This change in the cuticle  
252 structure then increases the water permeability of the skin, allowing water to escape the  
253 fruit more rapidly, thus leading to greater weight loss (Khayyat *et al.*, 2018). As mentioned  
254 earlier, by increasing the temperature to more than 55°C, the moisture content of the  
255 oleasters decreased, so that during the storage period, not much free water remained for  
256 evaporation and, as a result, weight loss decreased (Bagheri *et al.*, 2016).

257 The predicted model's  $r^2$ ,  $AP$ , and  $CV$  for the effect of heat treatment on the firmness  
258 of the samples (Table 1) were 0.83, 6.4, and 13.33%, respectively. The results of the  
259 analysis of variance showed that the simple ( $p < 0.01$ ) and second power ( $p < 0.05$ ) effects  
260 of the pre-treatment temperature on the firmness of the samples were significant.

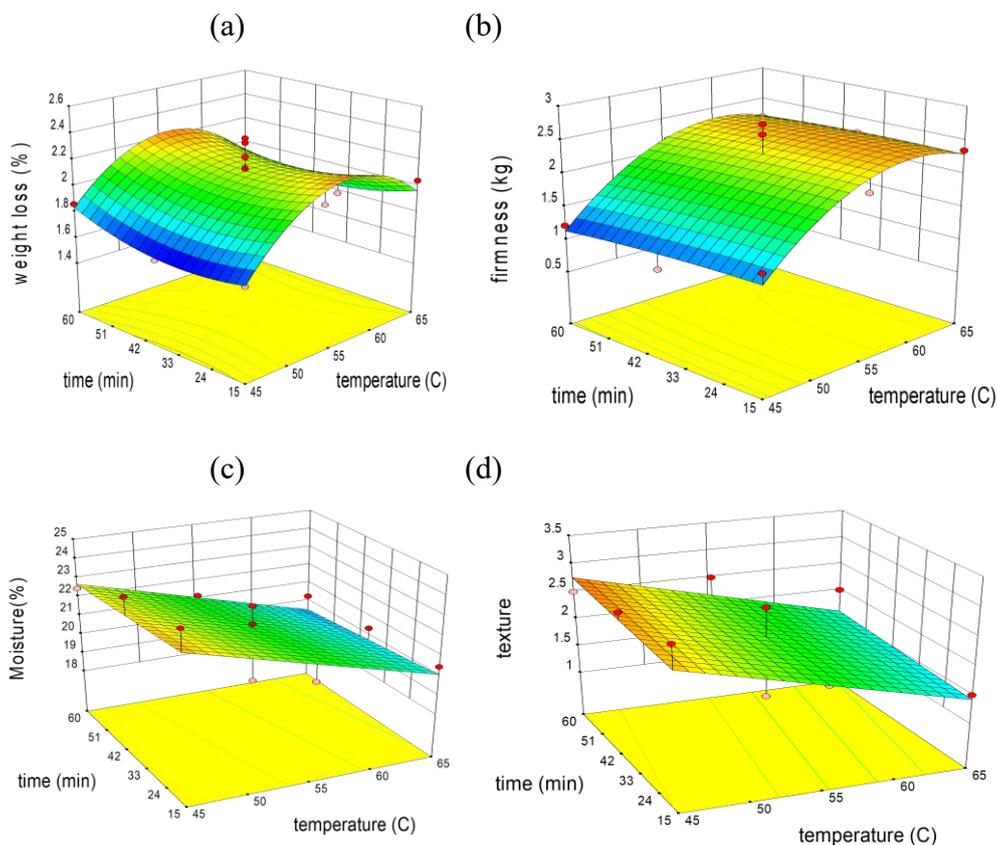
261 Figure 2b presents the predicted response surface for firmness, indicating an  
262 increasing trend with higher heating temperatures. Statistical significance of the  
263 temperature effect was assessed using regression ANOVA rather than inferred from the  
264 graphical representation. Moradinezhad and Dorostkar (2021) reported that vacuum and  
265 passive modified atmosphere packaging significantly maintained the firmness of fresh  
266 jujube fruit during cold storage compared with active MAP treatments. This effect was  
267 attributed to reduced oxygen availability, which lowers ethylene production and  
268 suppresses the activity of cell wall-degrading enzymes. Previous studies have also  
269 demonstrated that low oxygen atmospheres reduce polygalacturonase activity and help  
270 preserve tissue integrity in jujube fruit (Li *et al.*, 2006; Ntsoane *et al.*, 2019).

271 In the present study, the increased firmness observed in oleaster samples packaged  
272 under vacuum conditions can be partly explained by tissue compression resulting from  
273 air removal within the porous structure of the fruit, as well as moisture loss during long-  
274 term storage. Conversely, nitrogen packaging reduced oxidative and physiological  
275 degradation while avoiding excessive tissue compression, leading to more favorable  
276 textural and sensory outcomes. These findings are consistent with reports on structurally  
277 similar fruits and highlight the role of packaging atmosphere in regulating firmness  
278 through both physical and physiological mechanisms.

279 The moisture content was modeled using a linear model (Table 1), with an  $r^2$  of 0.53,  
280 an  $AP$  of 6.68, and a  $CV$  of 5.54. Heating temperature influenced the predicted moisture

281 content, as reflected by the fitted regression model ( $p < 0.01$ ). Figure 2c illustrates the  
 282 descriptive trend of moisture variation with temperature, while statistical evaluation of  
 283 model adequacy was performed using regression analysis. Bhattacharya and Prakash  
 284 (1997) showed that the final moisture content of the chickpeas decreased significantly as  
 285 the roasting temperature increased,

286 The heating temperature also significantly affected the texture sensory score of  
 287 oleaster samples ( $p < 0.05$ ), and the relevant model was a linear model with an  $r^2$ ,  $AP$ , and  
 288  $CV$  of 0.5, 6.13, and 21.62%, respectively (Table 1). Figure 2d illustrates the descriptive  
 289 trend of texture variation with temperature, while statistical evaluation was limited to  
 290 model adequacy. Based on numerical optimization using Design-Expert software, the best  
 291 sample was obtained at 45°C for 24.6 minutes with a desirability of 0.72 (Table 2).



292 **Fig. 2** The effect of heating temperature on the weight loss (a), firmness (b), moisture  
 293 content (c), and sensory texture (d) of oleasters packaged under vacuum conditions **after**  
 294 **10 months of storage.**

295

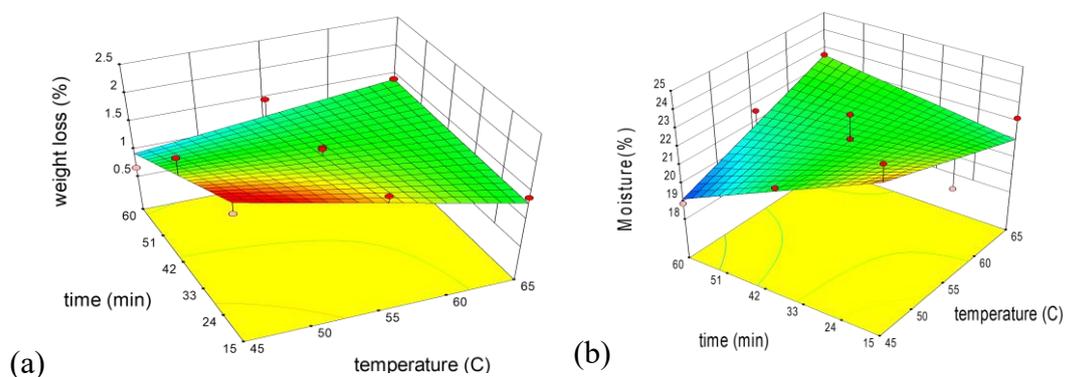
### 296 Packaging in Nitrogen Atmosphere Conditions

297 In nitrogen-packaged samples, factorial models with interaction effects were retained  
 298 for weight loss and moisture content based on regression ANOVA results ( $p < 0.05$ ),  
 299 whereas additional quadratic terms were not significant and were therefore removed

300 during model reduction. The models obtained for weight loss and moisture content were  
 301 factorial models with interaction effects (Table 1), which for weight loss had an  $r^2$ ,  $AP$ ,  
 302 and  $CV$  of 0.76, 11.76, and 14.67%, and for moisture content, 0.59, 8.24, and 4.85%,  
 303 respectively.

304 The effect of heating time and the interaction effect of temperature and heating time  
 305 on the weight loss of samples packaged in a nitrogen atmosphere were significant  
 306 ( $p < 0.01$ ). It is evident from Fig. 3a that the weight loss decreases with increasing heating  
 307 time. The interaction between temperature and heating time significantly influenced  
 308 weight loss. Specifically, weight loss was positively correlated with temperature but  
 309 negatively correlated with heating time. The highest weight loss was at 45°C for 15  
 310 minutes, and the lowest was at 45°C for 60 minutes (Fig. 3b).

311 Statistical analysis revealed a significant interaction effect between temperature and  
 312 time of heating on moisture content ( $p < 0.05$ ). As depicted in Fig. 3c, extending the heating  
 313 time at 45°C from 15 to 60 minutes substantially reduced the moisture content. According  
 314 to the numerical optimization using Design-Expert software, the optimal sample was  
 315 obtained at a temperature of 45°C for 28.47 minutes, with a desirability of 0.6 (Table 2).



316 **Fig. 3** Mutual effect of time and temperature of heating on (a) the weight loss and (b) the  
 317 moisture content of packaged oleaster under nitrogen after 10 months of storage.

318

### 319 Cold Pre-treatment

320 The analysis of variance, conducted using a completely randomized factorial design  
 321 and SPSS19 software, revealed that only the effects associated with weight loss, firmness,  
 322 and moisture content were statistically significant.

323

### 324 Weight Loss

325 The results showed that the effect of packaging conditions and the interaction effect  
 326 of cold pre-treatment time and packaging conditions on the weight loss of the samples

327 were significant ( $p < 0.01$ ). A comparison of the means using Duncan's method showed  
328 that the highest and the lowest weight loss was related to samples packaged under normal  
329 air and those packaged under vacuum or nitrogen, respectively (Fig. 4a). The interaction  
330 between packaging conditions and treatment time significantly influenced weight loss, as  
331 illustrated in Fig. 4e. Under normal air packaging, samples treated for 60 and 90 min  
332 exhibited the highest weight loss. In contrast, under vacuum and nitrogen packaging  
333 conditions, weight loss was markedly lower across treatment times, indicating the  
334 protective effect of reduced oxygen availability and limited gas exchange. Several recent  
335 studies have shown that modified atmosphere packaging, particularly under low oxygen  
336 or nitrogen-rich conditions, can effectively reduce postharvest weight loss and help  
337 maintain textural quality in various fruits. The modification of the gaseous environment  
338 in packaging can retard respiration and moisture loss, thereby contributing to reduced  
339 weight loss and preservation of quality attributes such as firmness in packaged fruit  
340 (Shirvani *et al.*, 2023; Belay *et al.*, 2019).

341

#### 342 Firmness

343 The effects of cold treatment time and packaging conditions on the firmness of the  
344 samples were significant ( $p < 0.01$ ). A comparison of the means using Duncan's method  
345 revealed that the highest firmness was associated with samples treated for 30 minutes.  
346 Treatment times of 60 and 90 minutes also resulted in the lowest firmness (Fig. 4c). Also,  
347 the highest firmness was observed in samples packaged under vacuum conditions, and  
348 the lowest firmness was observed in samples packaged under nitrogen conditions (Fig.  
349 4d).

350

#### 351 Moisture Content

352 The results showed that only the effect of cold treatment time on moisture content  
353 was significant ( $p < 0.01$ ). A comparison of the means using Duncan's method showed  
354 that the samples treated for 90 minutes had the highest moisture content (Fig. 4b).

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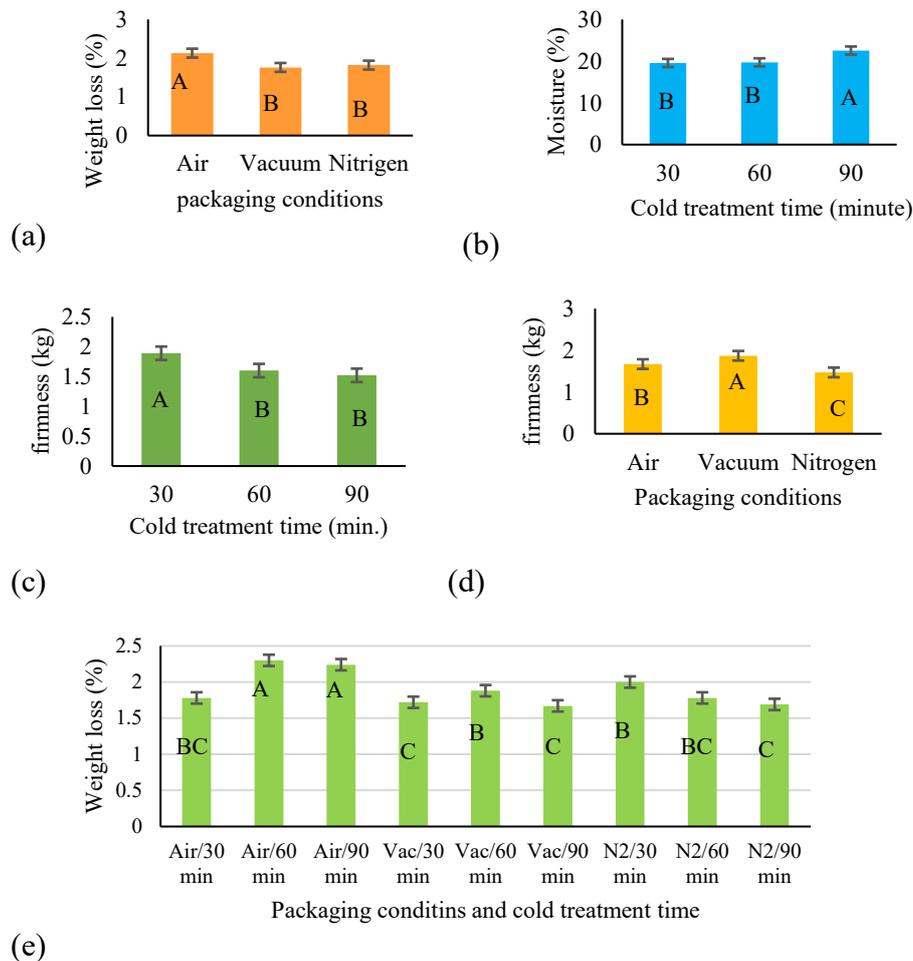
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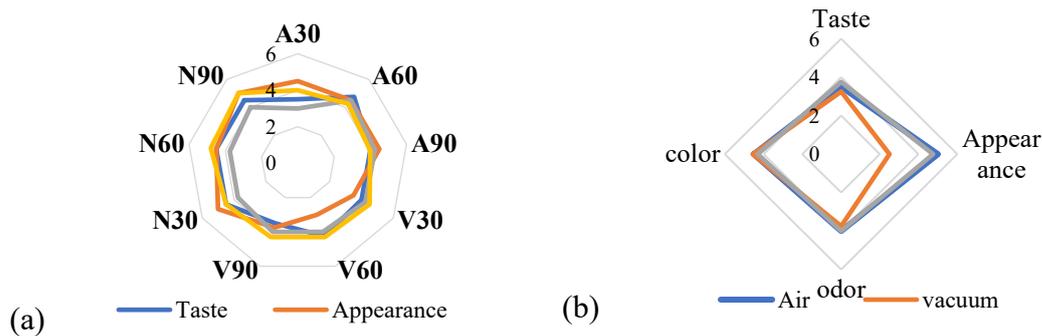


362 **Fig. 4** Effects of packaging conditions on weight loss (a), cold treatment time on moisture  
 363 content (b) and firmness (c), packaging conditions on firmness (d), and mutual effect of  
 364 packaging conditions and cold treatment time (e) on the weight loss of oleaster samples  
 365 (columns with similar letters have no significant effect at the 0.1 level).

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### 367 Sensory Properties

368 Packaging conditions had no significant effect on the sensory properties except for the  
 369 appearance score of the samples ( $p < 0.01$ ). As depicted in Fig. 5a, the lowest appearance  
 370 score was given to samples packaged under vacuum. In these conditions, the air between  
 371 the tissues is also partially removed, and the oleasters shrink. For this reason, these samples  
 372 received the lowest score for appearance in the sensory evaluation, but the samples  
 373 packaged under normal air or nitrogen atmosphere conditions received the highest score.



374 **Fig.5** Effect of packaging conditions and cold treatment time (a) and no treatment (b) on  
 375 the sensory properties of oleasters. The letters A, V, and N represent normal air, vacuum,  
 376 and nitrogen packaging, respectively, and the numbers next to them indicate the cold  
 377 treatment time.

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The selection of the optimal cold pre-treatment condition was based on evaluation of statistical analysis and qualitative observations. According to Fig. 4e, three treatments (vacuum packaging at 30 and 90 min and nitrogen packaging at 90 min) exhibited the lowest weight loss among the evaluated cold pre-treatment conditions. Furthermore, as shown in Fig. 4d, the lowest firmness values were observed in samples packaged under nitrogen atmosphere. In addition to these quantitative criteria, visual inspection revealed that samples subjected to vacuum packaging exhibited noticeable compression and deformation within the package, resulting in an undesirable appearance. Considering both the quantitative responses (weight loss and stiffness) and qualitative appearance, nitrogen packaging combined with a 90-min cold pre-treatment was selected as the optimal cold pre-treatment condition.

#### Packaging Conditions without Pre-treatment

The results of the analysis of variance, conducted using a completely randomized design and SPSS 19 software, showed that the effect of packaging conditions was only significant on the appearance of the samples ( $p < 0.01$ ). Additionally, packaging conditions without heat or cold pre-treatment had no significant effect on the other studied properties. As shown in Fig. 5b, packaging under vacuum conditions caused severe shrinkage and deformation of the oleasters, resulting in the lowest score for appearance. Therefore, samples packaged under nitrogen conditions were selected as the optimal sample due to their higher appearance score.

403 **Validation and Determination of the Optimal Method**

404 In the project's second phase, the three optimal samples obtained in the first phase  
405 treatment (Table 2), one sample with cold pre-treatment (90 minutes at -18°C) and one  
406 sample with packaging under nitrogen without any pre-treatment, along with a control  
407 sample (conventional packaging) were prepared and stored in a prevalent warehouse for  
408 6 months. After which, various properties were measured. The results were analyzed  
409 using the CRD and compared by Duncan's method, as implemented in SPSS 19 software.  
410 Finally, a sample was introduced as the best conditions for the packaging and storage of  
411 oleaster. The results of the one-way analysis of variance showed that the effect of different  
412 treatments on the weight loss, firmness, and yellow-blue index (b\*) of the samples was  
413 significant ( $p < 0.05$ ). Sensory evaluations revealed a significant effect of treatments on  
414 the taste and appearance of the samples ( $p < 0.05$ ).

415 Table 4 shows that the T6 treatment (without pre-treatment and traditional packaging in a  
416 prevalent warehouse) had the highest weight loss during the six-month storage period. The  
417 other treatments used showed no significant differences in weight loss. The T6 samples were  
418 packaged in low-density polyethylene (LDPE) bags (prevalent packaging) and stored in a  
419 conventional warehouse without pre-treatment. While LDPE provides some barrier against  
420 water vapor, it was not enough to prevent the samples from gradually drying out over a long  
421 storage period. Additionally, these bags, commonly found in oleaster storage warehouses, are  
422 tied with thread, which also helps remove moisture from the package. However, other samples  
423 were packaged in multi-layer polyethylene-polyamide-polyethylene bags and heat-sealed,  
424 resulting in significantly less weight loss than those packaged using the conventional method.  
425 Azarpazhooch and Mokhtarian (2007) also demonstrated that storing jujube fruit in laminated  
426 polyethylene packages results in the product losing less moisture and, consequently,  
427 experiencing less weight change. Song et al. (1998) investigated methods for storing jujube,  
428 including controlled atmosphere warehouses and polyethylene bags. While they observed no  
429 significant difference in weight loss between controlled atmosphere storage and polyethylene  
430 bag packaging, polyethylene bags significantly reduced weight loss compared to unpackaged  
431 samples.

432 The highest firmness was observed in samples packaged under vacuum (T2) or in a  
433 conventional warehouse (T6), whereas the lowest firmness values were recorded in samples  
434 packaged under nitrogen or normal air (Table 3). Similar trends have been reported for fruits  
435 with comparable structural characteristics. For example, studies on fresh jujube fruit have

436 shown that vacuum and passive modified atmosphere packaging effectively maintained fruit  
 437 firmness during storage compared to other atmospheric conditions. These effects were  
 438 attributed to reduced moisture loss and slower physiological degradation under low-oxygen  
 439 environments. In the present study, vacuum packaging likely affected oleaster firmness  
 440 through mechanisms different from those reported for fleshy fruits such as jujube. Oleaster  
 441 has a relatively porous texture, with air-filled intercellular spaces within the tissue. Under  
 442 vacuum conditions, not only the air surrounding the fruit but also part of the air entrapped  
 443 within the intercellular spaces may be removed, leading to tissue compression and an  
 444 apparent increase in measured firmness. In contrast, in fruits such as fresh jujube, vacuum  
 445 packaging primarily contributes to maintaining firmness by slowing moisture loss and  
 446 physiological softening, rather than inducing mechanical compression. Additionally, in  
 447 conventional storage conditions, moisture loss due to package permeability and ambient  
 448 environment can further contribute to increased firmness of oleaster during prolonged storage  
 449 (Moradinezhad and Dorostkar, 2021). Song et al. (1998) also showed that the firmness of  
 450 jujubes stored in controlled atmosphere conditions was lower.

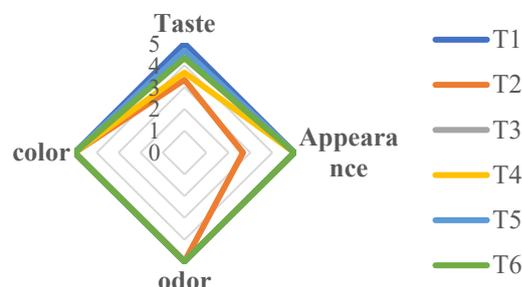
451 **Table 3.** Comparison of the oleasters packaged under different treatments.

Treatments	Weight loss	Firmness	b*	$\Delta E$
T1	1.12 <b>b</b>	1.01 <b>bc</b>	29.04 <b>abc</b>	15.54 <b>a</b>
T2	0.90 <b>b</b>	1.20 <b>a</b>	28.59 <b>bc</b>	12.59 <b>ab</b>
T3	0.92 <b>b</b>	0.87 <b>c</b>	28.11 <b>c</b>	14.53 <b>ab</b>
T4	1.09 <b>b</b>	1.04 <b>b</b>	30.47 <b>ab</b>	14.94 <b>ab</b>
T5	0.98 <b>b</b>	1.12 <b>ab</b>	27.72 <b>c</b>	12.23 <b>b</b>
T6	3.24 <b>a</b>	1.22 <b>a</b>	30.99 <b>a</b>	13.75 <b>ab</b>

452 (T1: 45°C for 15 minutes and packaging under normal conditions; T2: 45°C for 25 minutes. and  
 453 packaging under vacuum conditions; T3: 45°C for 29 min. and packaging under nitrogen conditions; T4: -  
 454 18 °C for 90 min. and packaging under nitrogen conditions; T5: without pretreatment and packaging under  
 455 nitrogen conditions; T6: without pretreatment and packaging under warehouse conditions).

456  
 457 Sensory evaluation revealed that the applied treatments had a significant impact on the taste  
 458 and appearance of the oleaster samples, as confirmed by analysis of variance. **Although Fig. 6**  
 459 **illustrates descriptive sensory trends, statistical comparisons were performed using ANOVA.** The  
 460 lowest taste score was observed in samples packaged under vacuum conditions (T2). This  
 461 response may be attributed to the compression of the porous oleaster tissue under vacuum, which  
 462 resulted in increased firmness and reduced oral acceptability. Other treatments did not show  
 463 statistically significant differences in taste. Regarding appearance, vacuum packaging caused  
 464 noticeable deformation and surface wrinkling of the oleaster fruits, which negatively influenced  
 465 panelist scores. **Moradnejad and Dorostgar (2021) demonstrated that sensory attributes such as**  
 466 **texture, juiciness, sweetness, and appearance in fresh jujube were closely associated with**  
 467 **physicochemical parameters, including weight loss, firmness, browning index, and color**

468 characteristics under different packaging atmospheres. These findings support the present results,  
 469 indicating that changes in physical properties induced by packaging conditions can directly  
 470 influence sensory acceptance in fleshy fruits such as oleaster.



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472 **Fig. 6.** Radar plots illustrating sensory attribute trends among treatments. Statistical  
 473 significance was determined by ANOVA (data not shown). (T1: 45°C for 15 minutes and  
 474 packaging under normal air; T2: 45°C for 25 minutes and packaging under vacuum; T3:  
 475 45°C for 29 minutes and packaging under nitrogen; T4: -18 °C for 90 minutes and  
 476 packaging under nitrogen; T5: without pretreatment and packaging under nitrogen; T6:  
 477 without pretreatment and packaging under traditional warehouse conditions).

478

479 Analysis with a Completely Randomized Design showed no significant difference in  $a^*$  and  
 480  $L^*$  values between stored samples ( $p < 0.01$ ). As shown in Table 3, treatments T1, T4, and T6  
 481 belonged to the same statistical group and exhibited comparatively higher  $b^*$  values. Treatment  
 482 T1 exhibited a relatively high  $\Delta E$  value; however, it did not differ significantly from most other  
 483 treatments, except for T5, which showed the lowest color change. The increase in the amount of  
 484  $\Delta E$  is due to the development of non-enzymatic browning reactions (Chung *et al.*, 2014). The  
 485 start of non-enzymatic browning reactions is from the reaction between the free amine groups of  
 486 the protein and the glycoside hydroxyl group of reducing sugars or carbonyl compounds such as  
 487 aldehydes and ketones. During heating, the amine and hydroxyl compounds increase, so the rate  
 488 of non-enzymatic browning reactions increases (Ozdemir and Devres, 2000) Heat has caused  
 489 the color change of the samples after the storage time to increase compared to the initial samples  
 490 before the treatments were applied. Khayyat *et al.* (2018) also showed that the oleasters dried at  
 491 45°C had lower  $a^*$ ,  $b^*$ , and  $L^*$ , compared to those heated at higher temperatures. They related  
 492 this color change to the browning reactions, such as the Maillard reaction and the oxidation of  
 493 ascorbic acid. Bagheri *et al.* (2016) showed that the  $b^*$  parameter decreases significantly with  
 494 increasing temperature and time of roasting peanuts. Song *et al.* (1998) demonstrated that storing  
 495 jujubes increases  $a^*$  but decreases  $b^*$  and  $L^*$ .

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498 **CONCLUSIONS**

499 This study evaluated the combined effects of heating temperature, heating time, and  
500 packaging atmosphere on the quality attributes of oleaster fruit during long-term storage.  
501 The results demonstrate that these factors influence moisture content, weight loss, texture,  
502 and sensory properties, with observable differences among treatments under the  
503 investigated conditions. Response surface methodology was initially applied to model the  
504 effects of processing and packaging variables and to identify optimal conditions.  
505 Importantly, the predicted optimal treatments were subsequently validated  
506 experimentally. The validation experiments confirmed that the selected conditions  
507 resulted in improved moisture retention and textural stability compared with non-  
508 optimized treatments during storage. Under the validated optimal conditions, oleaster  
509 samples maintained acceptable quality attributes over the storage period, although some  
510 degree of variation among quality parameters was observed. These findings indicate that  
511 the combination of controlled heating pre-treatments (45°C for 29 minutes) and  
512 appropriate packaging atmosphere (laminated polyethylene-polyamide-polyethylene in a  
513 nitrogen atmosphere) can contribute to extending the storage potential of oleaster fruit  
514 (up to 10 months without significant quality loss). The findings contribute to the limited  
515 body of knowledge on postharvest physiology and packaging optimization of oleaster  
516 fruits. Further studies focusing on integrating active or intelligent packaging systems,  
517 broader statistical comparisons, pest dynamics, and large-scale validation are  
518 recommended to strengthen the applicability of these findings under commercial storage  
519 conditions. From a commercial perspective, the proposed pre-treatment and packaging  
520 strategy addresses key postharvest limitations of oleaster fruit, including moisture loss,  
521 excessive textural hardening, and sensory deterioration, thereby enhancing marketability  
522 and reducing postharvest losses during long-term storage under ambient conditions.

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626 بهینه‌سازی تیمارهای حرارتی و بسته‌بندی برای افزایش ماندگاری و کیفیت سنجد

627 سید حمیدرضا ضیاءالحق

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**چکیده**

630 این پژوهش با هدف افزایش ماندگاری میوه سنجد (*Elaeagnus angustifolia*) انجام شد؛ میوه‌ای که در مرحله  
 631 پس از برداشت با چالش‌هایی مانند کاهش وزن، تغییرات بافتی و افت کیفیت حسی مواجه است. اثر تیمارهای  
 632 حرارتی (۴۵، ۵۵ و ۶۵ درجه سانتی‌گراد به مدت ۱۵، ۳۰ و ۶۰ دقیقه) و برودتی (۱۸- درجه سانتی‌گراد به  
 633 مدت ۳۰، ۶۰ و ۹۰ دقیقه) در ترکیب با شرایط مختلف بسته‌بندی (هوای معمولی، خلا و ازت) از نظر ویژگی‌های  
 634 فیزیکی‌شیمیایی و حسی طی دوره نگهداری مورد ارزیابی قرار گرفت. نمونه‌ها به مدت ۱۰ ماه نگهداری شدند و  
 635 شاخص‌هایی شامل کاهش وزن، رطوبت، سفتی، شاخص‌های رنگی ( $L^*$ ،  $b^*$ ،  $a^*$ ) و ویژگی‌های حسی  
 636 اندازه‌گیری شد. با استفاده از روش سطح پاسخ، بهینه‌سازی عددی به‌منظور برآورد شرایط مؤثر بر حفظ کیفیت  
 637 در هر یک از شرایط بسته‌بندی انجام گرفت. نتایج بهینه‌سازی مبتنی بر مدل نشان داد که تیمار حرارتی در دمای  
 638 ۴۵ درجه سانتی‌گراد به مدت ۱۵ دقیقه در هوای معمولی، ۲۵ دقیقه در شرایط خلا و ۲۹ دقیقه در بسته‌بندی ازت،  
 639 و همچنین تیمار برودتی در دمای ۱۸- درجه سانتی‌گراد به مدت ۹۰ دقیقه همراه با بسته‌بندی ازت، از نظر  
 640 شاخص‌های منتخب کیفیت، شرایط مطلوب‌تری را فراهم می‌کنند. در مرحله دوم، نمونه‌های تهیه‌شده تحت شرایط  
 641 بهینه پیش‌بینی‌شده به مدت ۶ ماه در شرایط انباری نگهداری شدند. نتایج اعتبارسنجی نشان داد که نمونه‌های تیمار  
 642 حرارتی‌شده و بسته‌بندی‌شده در اتمسفر ازت، در مقایسه با نمونه‌های بدون تیمار، عموماً دارای سفتی کمتر و  
 643 پذیرش حسی بالاتری بودند، در حالی که نمونه‌های بسته‌بندی‌شده در شرایط خلا امتیاز ظاهری پایین‌تری نشان  
 644 دادند. به‌طور کلی، یافته‌ها بیانگر آن است که کاربرد توأم تیمار حرارتی ملایم (۴۵ درجه سانتی‌گراد به مدت ۲۹  
 645 دقیقه) و بسته‌بندی در اتمسفر اصلاح‌شده (۷۰ درصد ازت) می‌تواند پتانسیل بهبود قابلیت نگهداری سنجد را داشته  
 646 باشد. با این حال، انجام مطالعات بیشتر برای تأیید این نتایج در شرایط تجاری ضروری است.

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