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Investigating the effects of ethephon (2-chloroethylphosphonic acid) on Persian walnut fruit quality

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Abstract: The darkness of the kernel and the lack of simultaneous ripening of the mesocarp and endocarp are among the most significant challenges in Iranian walnut orchards. The mentioned problems appear more in areas with hot and humid summers. The research focused on the quality of the kernel in terms of colour and marketability, as well as the dry matter of the kernels. Additionally, the ease of mesocarp separation from endocarp was examined. Experimental trials were designed with 27 treatment combinations to address the mentioned issues using varying concentrations of 2-chloroethylphosphonic acid (ethephon) at different harvest dates. In this study, using 1 920 ppm of ethephon on August 22nd resulted in the best quality walnut kernels and mesocarp. Researchers in this project successfully achieved the highest quality of walnut kernels and nuts in a region where over 90% of the harvest consisted of dark-kernel walnuts.

Keywords: ethephon; kernel darkness; ripening; walnut

Walnuts, scientifically known as *Juglans regia*, belong to the Juglandaceae family, which encompasses 20 different species. Walnuts are a great source of phospholipids, proteins, vitamin E, and unsaturated fatty acids, which provide numerous nutritional benefits (Geng et al. 2021). Furthermore, they are known for their high levels of arginine/lysine, antioxidants, phytosterols, and polyesters (Melkamu et al. 2008). Studies have demonstrated the potential of walnuts in preventing cardiovascular issues, highlighting their positive impact on health (Ni et al. 2022). Compared to dried ones, fresh walnut kernels have higher moisture content and are richer in phenolic acids and antioxidants (Chatrabnous et al. 2018). The distinct flavour of fresh walnuts makes them more appealing to consumers than completely dried kernels (Grosso et al. 2020). The Iranian walnut variety is particularly susceptible to various factors that can impact its quality (Akin, Erdem 2018; Askary et al. 2014). However, peeled or unpeeled fresh walnuts are more susceptible to microbial contamination and pathogen infestation during the post-harvest period (Shirani et al. 2020). The quality of walnuts significantly relies on pre-harvest processing practices (Aini et al. 2019; Jha et al. 2012). Delaying the harvest negatively affects fruit quality, while endogenous ethylene has been found to affect crop protection positively (Aini et al. 2019). Typically, there is a 2–3 week gap between kernel ripening and the regular harvest of walnuts. During this period, the walnut kernels tend to darken in colour (Ortiz et al. 2019). As the fruit ripens, the quality of the kernel gradually declines until the nut is completely dried. Previous research has indicated that delaying the harvest due to prolonged

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fruit mesocarp ripening can adversely impact kernel quality, including factors such as kernel transparency and susceptibility to insect infestation (Ortiz et al., 2019). Therefore, exploring methods and substances that can facilitate ripening acceleration without causing any detrimental effects is crucial.

Ethephon is a synthetic compound that serves as an exogenous source of ethylene in horticulture (Keshavarzi et al. 2021).

Given these findings, the present study was conducted to examine the impact of ethephon on walnut ripening. The evaluation focused on factors such as kernel colour, the ripening of the fruit mesocarp at the appropriate time, and the harvesting process.

As indicated in the literature review, the stages of endocarp and mesocarp development in walnuts differ. The endocarp, containing the walnut kernel, matures 2 to 3 weeks earlier than the mesocarp. During this period, the walnut kernel is exposed to various physiological challenges and disease-causing factors. In regions with warm and humid summers, these challenges become more pronounced. Kernel darkening, lack of uniformity, and mesocarp residues on the endocarp are among the most significant problems in walnut cultivation in these areas. The present experiment takes a step towards addressing these issues through the use of 2-chloroethylphosphonic acid. By employing different concentrations of this substance in various harvests and conducting mathematical calculations in a split-plot design, the optimal concentration of ethephon at the appropriate time is selected. Ultimately, this contributes to achieving the highest quality walnut harvest.

MATERIAL AND METHODS

For the investigation of the effect of ethephon and harvest time on walnut kernel quality, walnut trees in the Mazandaran province were selected. The choice of this region was deliberate, as it exhibits a warmer climate and higher relative humidity compared to other walnut-growing regions, including cold regions. This specific climate in the selected region allows for the study of harvest time and fruit quality due to a significant time gap between kernel maturation and mesocarp maturation, which negatively impacts kernel quality. Approximately 60–85% of the harvested walnut kernels in this region tend to exhibit black or brown colouration. Therefore, it was feasible to examine the impact of harvest dates and ethephon application on the quality of the kernel (reducing the darkness of the walnut kernel and increasing the dry matter of the kernel), it was possible to facilitate the separation of the mesocarp from the endocarp in this region more than any other region.

Experimental design. The test was conducted using a split-plot design with a randomised complete block design comprising three replicates. The study focused on harvest date (factor A) and ethephon application (factor B). Harvest date was explored at three different levels, while ethephon treatment was examined across nine levels after dilution (Table 1).

Accordingly, a total of 27 treatment combinations were allocated within each block. Eight levels with different concentrations of ethephon were defined in the experimental design, along with a control level. The ethephon levels were defined so that the effects of various concentrations on the sample could be observed. Level 9 was defined with a very high concentration to assess the possible harmful effects of ethephon on mesocarp and endocarp tissues.

Conducting the experiment. Each group of three trees was treated as a separate block to conduct the test. The fruits from each tree were harvested on one of the three specified dates and subsequently immersed in a solution containing ethephon. It is important to note that ethylene production can be induced by various forms of injury, such as mechanical damage, high winds, birds pecking, pests, and pathogens. In the case of fruit being damaged during harvest or transportation, autocatalytic ethylene production is triggered, which can overlap with the ethylene produced by the ethephon. Therefore, conventional harvesting methods could not be employed as they may damage the mesocarp, leading to inconsistent experimental units. To ensure the integrity of the experiment, the fruits were carefully collected at different times from each tree, taking precautions to prevent any damage. Following the harvest, the fruits from each individual tree were carefully placed

Table 1. Investigated the main and minor factors, along with the levels of the factors

Factor A – harvest date		
A1 = Aug 22nd	A2 = Aug 31st	A3 = Sept 9th
Factor B – ethephon* concentration (ppm)		
B1 = 0 (control)	B2 = 120	B3 = 240
B4 = 480	B5 = 720	B6 = 960
B7 = 1 200	B8 = 1 920	B9 = 4 800

*purchased from the market; 48% pure

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into separate bags to ensure their protection during transportation. These bags were then consolidated into a larger sack. The fruits underwent a thorough washing process to eliminate any dust or debris. Subsequently, the fruit tails were trimmed to the level of the green rind, ensuring that no damage caused by the tails of other fruits remained. From each tree, only healthy fruits were selected, and they were then divided into nine equal-sized lots for further analysis and evaluation (5 fruits per bag).

The fruits from each batch were immersed in the ethephon solution, corresponding to one of the specific concentration levels, for 20 seconds. After immersing, the treated fruits were carefully placed inside pre-prepared cloth bags made of cotton, measuring 22 × 19 cm. After carefully placing the fruits inside bags, the bags were sewn shut and subjected to a controlled environment with a relative humidity ranging between 80% and 85% and a constant temperature of 18 °C. This specific combination of temperature and humidity has been proven to promote the maximum production of ethylene by the ethephon. It is worth noting that the optimal temperature range for ethylene synthesis through the action of ethephon falls within the interval of 16 °C to 29 °C. Moreover, maintaining a humidity level of 80–85% helps prevent significant moisture loss in the fruits, which could lead to adverse effects on the mesocarp when exposed to ethephon, thereby accelerating the ripening process. After 8 days, the bags were opened, and the effectiveness of ethephon in mesocarp separation facilitation from endocarp was assessed and ranked on a scale from 0 to 25. A score of 0 indicated complete attachment of the mesocarp to the endocarp, while a score of 25 indicated complete cracking and detachment of the mesocarp from the endocarp without the need for a knife. The qualitative attribute of mesocarp separation facilitation from endocarp needs to be quantified to obtain the necessary values for completing the variance analysis table. To achieve this, an evaluator separated the mesocarp from the endocarp using a knife. The degree of ease in mesocarp separation was then assigned a numerical value ranging from 0 to 25 for each fruit.

After separating the mesocarp from the endocarp, the nuts were exposed to sunlight for three days until completely dried. Subsequently, the nuts were shelled to evaluate the walnut kernels in terms of quality (kernel colour) and quantity (amount of dry matter). The walnut kernels were scored on a scale of 0 to 20 for transparency and darkness, where a light cream colour received a score of 20, light brown scored between 2 and 4, and a completely dark colour received a score of 0. For scoring each walnut kernel, it was divided into four parts, and each section was individually scored. Then, the kernels of the walnuts of levels 1 and 3 of the main levels were considered to measure dry matter (quantitative quality).

For the calculation of the dry matter of walnut kernels in each experimental unit, the kernels were initially crushed and weighed individually. The empty containers and the containers with the crushed kernels were subsequently subjected to autoclaving at a temperature range of 110–100 °C. Following autoclaving, the moisture (M) percentage was obtained using equation (1):

$$M\ (\%) = (W_0 - W_1)/(W_0 - W_p) \times 100 \qquad (1)$$

where: W_0 – weight of the plate and samples before drying; W_1 – weight of the plate and samples after drying; W_p – empty plate weight.

The dry matter percentage of the kernel was determined through the application of equation 2, which is as follows:

$$\text{Kernel's dry matter } (\%) = 100 - M\ (\%) \qquad (2)$$

Data analysis. The average scores of the samples obtained (mesocarp separation scores from endocarp, walnut kernel quality scores, and percentage of walnut kernel dry matter) from each experimental unit were computed. It is important to mention that Duncan's test was employed to evaluate the statistical significance of mean comparisons in this experiment.

RESULTS AND DISCUSSION

Investigating the effect of ethephon on fruit ripening. The simultaneous ripening of the mesocarp and endocarp, as titled in the Introduction section, does not occur. The indication of mesocarp ripening is the separation of the mesocarp from the endocarp, and a decrease in this adhesion suggests that mesocarp ripening is underway, completing the final stages of ripening. Based on this, scoring the ease of separating mesocarp from endocarp due to ethephon is proposed as a characteristic of walnut fruit ripening (Table 2).

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Table 2. Average evaluation scores for facilitating mesocarp separation from endocarp on three harvest dates with different ethephon concentrations

Harvest date	Ethephon concentration (ppm)								
	B1 = 0	B2 = 120	B3 = 240	B4 = 480	B5 = 720	B6 = 960	B7 = 1 200	B8 = 1 920	B9 = 4 800
A1 = Aug 22nd	12.000	11.973	12.127	13.500	14.627	15.710	17.043	17.293	16.917
A2 = Aug 31st	13.167	13.167	16.500	16.400	17.167	18.467	19.540	19.777	19.233
A3 = Sept 9th	17.567	18.767	19.833	20.100	20.233	21.333	21.267	21.667	22.100

Ease of separating the mesocarp from the endocarp is considered one of the indicators of walnut fruit ripeness. Accordingly, this indicator was achieved by scoring from 0 to 25 by the experimenter

Furthermore, a positive correlation is observed between higher concentrations of ethephon and increased fruit ripening, leading to the separation of the mesocarp. Furthermore, the highest values across the various ethephon levels are consistently associated with the harvest date of Sept 9th.

The data obtained from this experiment were initially analysed using a split-plot design. Subsequently, *Ea* (trial error associated with the main factor) was assessed in conjunction with *Eb* (experimental error associated with the secondary factor). The required calculations were executed to finalise the other parameters of the variance analysis table and the polarisation operation (Table 3).

The results indicate statistically significant variations in fruit maturation levels among the experimental blocks, as well as among the different harvest dates and concentrations of ethephon. Moreover, there is no observed correlation between factor A (harvest date) and factor B (ethephon concentration), suggesting that these factors independently influence fruit ripening.

The effects of treatments. To interpret the variance analysis table more effectively and provide a clearer explanation of the achieved success, it is imperative to present a table of fruit ripening averages on three harvest dates and the corresponding averages at the nine levels of ethephon treatment. Additionally, the classification of each level using the Duncan test is necessary. The comparison of average fruit ripeness among different harvest dates was performed using Duncan's test at a significance level of 0.01 (Table 4).

The highest average maturity is observed on Sept 9th, while the lowest average is recorded on Aug 22nd. Consequently, mesocarp separation becomes easier during the normal harvest period (Figure 1). The "class A" concentration is identified as the most effec-

Table 3. Analysis of data variance in terms of fruit ripening of walnuts

Source of change	Degree of freedom	Sum of squares
Block	2	510.041**
Factor A (harvest date)	2	223.418**
Factor B (ethephon concentration)	8	35.822**
A × B	16	1.526ns
Error	52	4.341
Total	80	–

**significance at 0.01 level; ns – non-significant

Table 4. Comparison of average ripeness across different harvest dates (classifications)

Harvest date	Average ripeness (score)	Class
A1 = Aug 22nd	14.577	C
A2 = Aug 31st	17.135	B
A3 = Sept 9th	20.319	A

The three main levels of factor A (harvest date) were compared with each other (Duncan's test). Accordingly, in the classification, the highest score belongs to class A

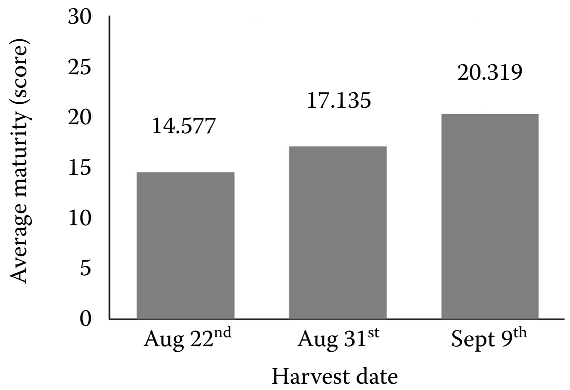

Figure 1. Comparison of maturity levels across different harvest dates

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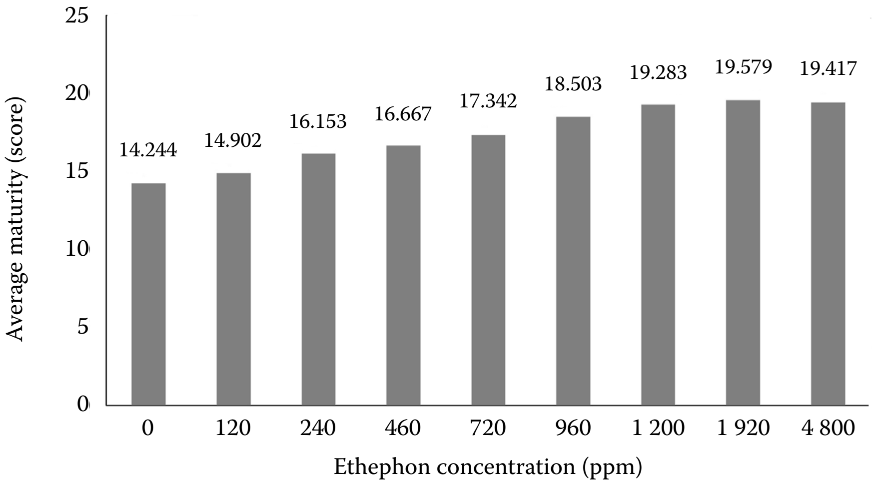

Figure 2. Average fruit maturity in different ethephon concentrations

tive for promoting walnut ripening. The findings indicate that as the ethephon concentration increases, fruit ripening improves. This trend continues until the eighth level of factor B (1 920 ppm ethephon). Notably, there is a significant difference between the eighth and control levels at the 5% level. However, fruit ripening is reduced at the ninth level of factor B (4 800 ppm) compared to the eighth level (Figure 2).

Table 5. Comparing the average fruit maturity in different levels of ethephon concentration (classifications)

Ethephon concentration (ppm)	Average ripeness (score)	Class
B1 = 0 (control batch)	14.244	F
B2 = 120	14.902	EF
B3 = 240	16.153	DEF
B4 = 480	16.667	CDF
B5 = 720	17.342	BCD
B6 = 960	18.503	ABC
B7 = 1 200	19.283	AB
B8 = 1 920	19.579	A
B9 = 4 800	19.417	AB

All levels of factor B (ethephon concentration) were compared with each other (Duncan's test). Accordingly, in the classification, the highest score belongs to class A. The presence of similar letters indicates that the groups are in the same stratified class

The influence of ethephon on walnut kernel quality. Following the separation of the mesocarp from the endocarp and sun drying, the nuts were shelled and evaluated for kernel quality (Table 5). Additionally, the results of comparing the average fruit maturity at various ethephon concentration levels using Duncan's test at a significance level of 5% are shown in the mentioned table.

The highest quality within each level B corresponds to the harvest on Aug 22nd, whereas the lowest quality is observed on Sept 9th (Table 6). Notably, there is a significant decline in average fruit maturity in the A1 and A2 levels as the ethephon concentration reaches level B9 (4 800 ppm). The excessive ethylene present in this concentration of ethephon is likely to react with the biochemical compounds in the kernel, consequently diminishing its quality (Table 7). To form a variance analysis table, we require the data pertaining to the evaluation of kernel quality. The data should include the average kernel quality scores for nine ethephon treatments across three harvest dates.

The results reveal statistically significant differences in the effects of the test blocks, as well as a notable distinction in kernel maturity among different harvest dates ($P < 0.05$). However, there is no significant

Table 6. The mean of kernel quality data (average evaluation scores)

Harvest date	Ethephon concentration (ppm)								
	B1 = 0	B2 = 120	B3 = 240	B4 = 480	B5 = 720	B6 = 960	B7 = 1 200	B8 = 1 920	B9 = 4 800
A1 = Aug 22nd	12.720	12.92	14.238	14.334	14.250	14.380	14.960	15.020	9.860
A2 = Aug 31st	10.070	10.783	10.61	10.813	10.960	11.800	11.600	12.557	9.570
A3 = Sept 9th	9.820	8.793	7.850	6.710	5.917	7.613	6.693	6.557	7.775

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Table 7. Walnut kernel quality (kernel colour) variance analysis

Source of change	Degree of freedom	Sum of squares
Block	2	317.636**
Factor A (harvest date)	2	236.583**
A error	4	18.855
Factor B (ethephon concentration)	8	4.411[ns]
A × B	16	5.362[ns]
B error	41*	703.4
Total	75	–

*due to the loss of 5 units, the error rate of the test error was reduced by five digits
**significance at 0.05 level; ns – non-significant

difference in fruit maturity across various ethephon concentrations. Additionally, the correlation analysis indicates that factor A (harvest date) and factor B (ethephon concentration) influence fruit ripening independently.

The average comparison. Table 8 presents a comparative analysis of walnut kernel quality among various harvest dates.

The results demonstrate significant variations in the average quality of walnuts harvested on Sept 9th compared to those harvested on the other two dates ($P < 0.05$). There is no significant difference in kernel quality between walnuts harvested on Aug 22nd and Aug 31st, with both exhibiting relatively favourable levels of quality. However, the lowest kernel quality is observed in walnuts harvested on Sept 9th. This suggests that as the typical harvest date approaches, there is a decline in kernel quality (Figure 3).

Ethephon concentration effects. According to the variance table, the different concentration levels of ethephon (factor B) did not yield significant changes. The discrepancy may be attributed to a significant decline in quality observed with an increase in the ethephon level in factor A3 (harvest date: Sept 9th), as well as data overlap between this subfactor and others. The third level of factor A (harvest date: Sept 9th) should be excluded to address this issue. In other words, the two-level data, as classified in Table 8 within a classification, are utilised to form the analysis of the variance table (Table 9). Table 9 presents the revised analysis after removing sub-factor A3 and its associated data, considering only subfactors A1 and A2.

Table 8. Comparison of walnut kernel quality across different harvest dates (classifications)

Harvest date	Average quality (score)	Class
A1 = Aug 22nd	13.425	A
A2 = Aug 31st	10.981	A
A3 = Sept 9th	7.533	B

The three main levels of factor A (harvest date) were compared with each other (Duncan's test). Accordingly, in the classification, the highest score belongs to class A

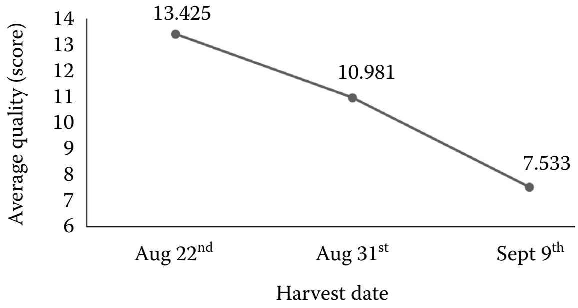

Figure 3. The comparison of average walnut kernel quality across different harvest dates

The results of comparing kernel qualities, excluding sub-factor A3 from the calculations, are presented in Table 10.

Table 10 illustrates that an increased concentration of ethephon corresponds to improved nut quality. However, when the fruit is treated with a concentration of 4800 ppm, the kernel quality is significantly reduced, resulting in the lowest average quality ob-

Table 9. Variance analysis of walnut kernel quality without the A3 sub-factor

Sources of change	Degree of freedom	Sum of squares
Block	2	227.523[ns]
Factor A (harvest date)	1	80.596[ns]
A error	2	29.747
Factor B (ethephon concentration)	8	9.190**
A × B	8	1.465[ns]
B error	29	606.2
Total	50	–

**significance at 0.01 level; ns – non-significant

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Table 10. The average kernel quality comparison across the two harvest dates (classifications)

Ethephon concentration (ppm)	Average quality (score)	Class
B1 = 0 (control batch)	11.395	BC
B2 = 120	11.852	AB
B3 = 240	11.495	BC
B4 = 480	12.608	AB
B5 = 720	12.605	AB
B6 = 960	13.09	AB
B7 = 1 200	13.28	AB
B8 = 1 920	13.788	A
B9 = 4 800	9.715	C

All levels of factor B (ethephon concentration) were compared with each other (Duncan's test). Accordingly, in the classification, the highest score belongs to class A. The presence of similar letters indicates that the groups are in the same stratified class

served at this level. The toxic effect of high concentrations of ethephon at 4 800 ppm is evident (Figure 4).

The effects of ethephon on walnut kernels' dry matter (density). As observed in Figure 3, the highest kernel quality is associated with the A1 level, while the lowest quality corresponds to the A3 level. Accordingly, the analysis of dry matter was conducted for these two levels. The comparison is made between the dry matter of the first level of factor A (representing the initial harvest time associated with the highest quality) and the third level of factor A (representing the final harvest time where mesocarp separation occurs easily, even without the use of ethephon) (Table 11). These levels are compared by examining the average values of the levels, as mentioned earlier.

The outcomes of the kernel density analysis of variance are outlined in Table 12 (data were first analysed as splits and then polarised because *Ea* or *Eb* was not significant).

The findings displayed in Table 12 reveal a significant difference in kernel density ($P < 0.01$) and a consistent impact on kernel density across various harvest dates ($P < 0.01$). Additionally, a statistically significant difference was observed in ethephon concentration concerning kernel density ($P < 0.05$). No significant correlation was detected between factor A (harvest date) and factor B (ethephon concentration).

Table 13 presents the mean kernel density values for the experimental groups subjected to varying levels of ethephon treatment.

Table 13 reveals that the highest mean values are associated with the fourth treatment, while the lowest average percentage of dry matter in the kernel is observed in the sixth and seventh treatments. As a result, the fourth treatment exhibits a significant differ-

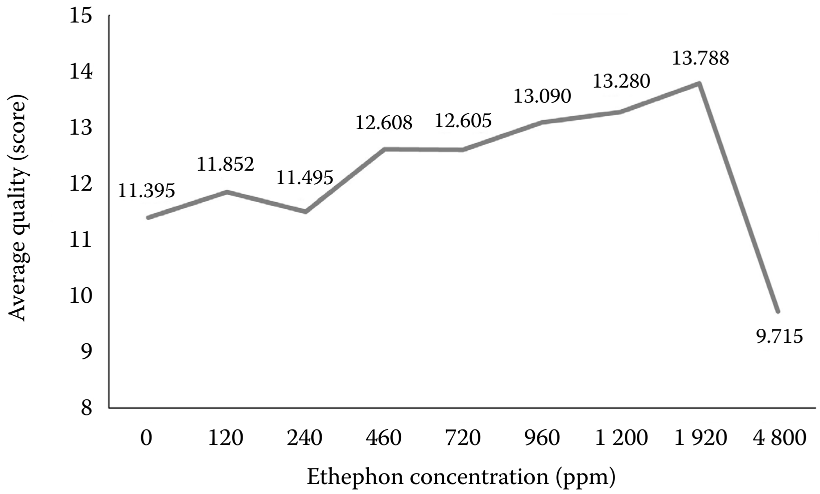

Figure 4. Comparison of mean walnut kernel quality across different ethephon levels in two harvest dates

Table 11. Walnut kernel average dry matter data (%)

Harvest date	Ethephon concentration (ppm)								
	B1 = 0	B2 = 120	B3 = 240	B4 = 480	B5 = 720	B6 = 960	B7 = 1 200	B8 = 1 920	B9 = 4 800
A1 = Aug 22nd	95.412	95.412	95.215	95.289	95.245	95.565	94.785	94.778	94.479
A3 = Sept 9th	94.833	94.782	93.993	96.187	95.591	94.230	93.841	94.434	94.657

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Table 12. Variance analysis of walnut kernels' dry matter

Sources of change	Degree of freedom	Sum of squares
Block	2	52.541**
Factor A (harvest date)	1	1.326^{ns}
Factor B (ethephon concentration)	8	1.547*
A × B	8	0.608^{ns}
Error	30	0.620
Total	49	–

*,**significance at 0.05, 0.01 level, respectively; ns – non-significant

Table 13. The mean of kernel density across different ethephon concentrations (classifications)

Ethephon concentration (ppm)	Average kernel density (%)	Class
B1 = 0 (control batch)	95.123	ABC
B2 = 120	94.999	ABC
B3 = 240	94.641	BC
B4 = 480	95.716	A
B5 = 720	95.578	AB
B6 = 960	94.507	C
B7 = 1 200	94.220	C
B8 = 1 920	94.606	BC
B9 = 4 800	94.568	BC

All levels of factor B (ethephon concentration) were compared with each other (Duncan's test). Accordingly, in the classification, the highest score belongs to class A. The presence of similar letters indicates that the groups are in the same stratified class

ence from the sixth and seventh treatments, while the remaining treatments do not differ significantly from each other. Comparing Figure 2 with Figures 4 and 5, it becomes evident that there is no conclusive relationship between ethephon concentration and the percentage of dry matter in the kernel, contrary to what was observed for fruit quality and maturation traits.

The findings of this study emphasise the significance of employing ethephon for the efficient removal of mesocarp residues and the attainment of uniform nuts. Here, a few very important points must be mentioned. A higher ethephon concentration facilitated the easier separation of the mesocarp (Figure 6). In certain experimental instances, the green mesocarp also exhibited darkening when subjected to a high ethephon concentration. At such concentrations, small and shallow cracks were observed in the mesocarp. Notably, the impact of ethephon on green mesocarp separation was more pronounced in trees with late-maturing fruits.

Figure 7 displays two nut samples in which the mesocarp is detached from the endocarp. The first sample (Figure 7A) was treated without the use of ethephon, while the second sample (Figure 7B) was treated with 960 ppm of ethephon.

It is evident that in the control sample, the mesocarp remains firmly attached to the endocarp, necessitating the manual removal of the mesocarp using a knife. Previous investigations have revealed that the closer the harvest date, the easier it becomes to separate the mesocarp and obtain clean nuts devoid of any mesocarp remnants.

The experiment demonstrated that as the normal harvest date approaches, the required amount of ethephon for facilitating the separation of the mesocarp from the endocarp decreases. In fact, dur-

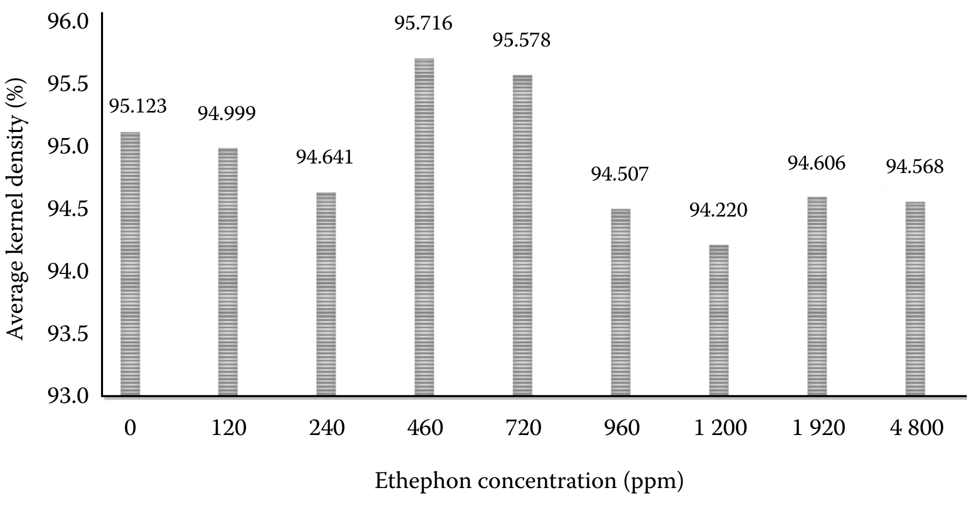

Figure 5. Comparison of average walnut kernels' dry matter (density) across different ethephon concentrations

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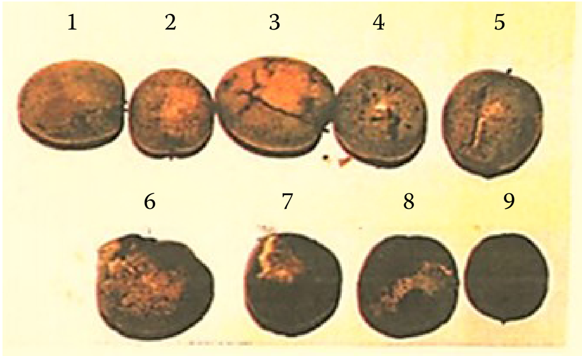

Figure 6. Comparison of fruits treated by different ethephon concentrations
1 – 0 ppm (cobtrol batch); 2 – 120 ppm; 3 – 240 ppm; 4 – 480 ppm; 5 – 720 ppm; 6 – 960 ppm; 7 – 1 200 ppm; 8 – 1 920 ppm; 9 – 4 800 ppm

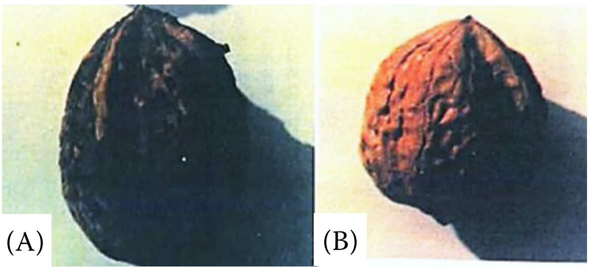

Figure 7. A nut harvested on Aug 22nd (A) not treated with ethephon and (B) treated with 960 ppm of ethephon

ing the normal harvest period, the ethylene naturally synthesised by the fruit acts synergistically with ethephon, enhancing its effectiveness.

As depicted in Figure 8, the control group and the treated fruit with the lowest concentration of ethephon exhibit the lowest scores. However, superior fruit quality in terms of mesocarp maturation is achieved by increasing the ethephon concentration and harvesting the fruits at the A3 factor level. It is worth noting that if the mesocarp separation score exceeds 15, farmers typically do not encounter any issues in this regard. However, for the purpose of highlighting yield differences in this experiment, we have set the scoring range to 25.

Therefore, employing ethephon for mesocarp peeling on Sept 9th appears unnecessary, which is close to the regular harvest time. During this period, the mesocarp can be easily separated from the endocarp without the use of ethephon. In other words, the fruits have undergone sufficient maturation stages, resulting in effortless separation of the mesocarp from the endocarp. Consequently, employing ethephon for this purpose, one week before the regular harvest time, lacks economic value. However, utilising ethephon 3–4 weeks prior to the regular harvest leads to the production of uniform nuts without any mesocarp residues compared to the control group.

The colour analysis of walnut kernels harvested on three different dates reveals distinct variations. Upon reviewing Figure 9, it is evident that the highest quality is associated with the samples collected on Aug 22nd, while the lowest quality is observed in the kernels harvested on Sept 9th.

The findings indicate that the application of ethephon at a dosage of 4 800 ppm has a detrimental impact on walnuts. At this dose, ethephon likely interacts with the phenolic compounds present in the walnut seeds, leading to a modification in kernel colour.

Analysing the dry matter content of the walnut kernels revealed that the timing of harvest minimally affects the dry matter composition. Consequently, it can be inferred that early fruit harvest not only yields white, high-quality kernels but also

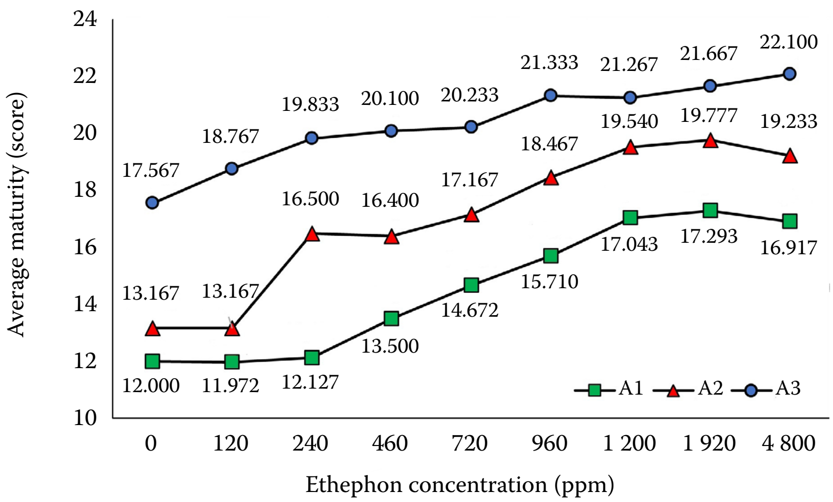

Figure 8. Average fruit ripening at different ethephon concentrations on three harvest dates (scoring based on the ease of separating the mesocarp from the endocarp)
A1 – Aug 22nd; A2 – Aug 31st; A3 – Sept 9th

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Figure 9. Comparison of kernels harvested on two different dates under the influence of the same ethephon concentration 1 920 ppm)

It is important to note that the quality of walnut kernels (kernel color) in the normal harvest (farmers' harvest) which is done in early October or late September is completely dark and similar to the image above (Sept 9th). Comparing the images of the two walnut kernels clearly proves the success of the project

has a small positive influence on the amounts of dry kernels obtained.

According to the study conducted by Martin (1971), the dry matter content of the kernel is influenced by the initial moisture level at harvest, while exposure to ethephon does not affect dry matter. However, in the case of treated trees, the green mesocarp of the fruit tends to crack, resulting in loss of nut moisture. Consequently, when measuring dry matter, these samples may exhibit higher values compared to the control group. Although the analysis of the variance table reveals a significant difference in dry matter and ethephon concentration, this distinction is attributed to the cracking of the green mesocarp and the subsequent reduction in the moisture content of nuts. In other words, ethephon does not enhance dry matter but diminishes the initial moisture content. This possibility is also given that ethephon accelerates the ripening process, it increases carbohydrate production, thereby having a slight impact on the increase in dry matter.

CONCLUSION

Although walnuts are classified as climacteric fruits, it is crucial for walnut fruits to reach their maximum maturity. In cases where the mesocarp is immature, ethephon can be applied to expedite fruit ripening. When temperatures exceed 30 °C, conditions conducive to walnut browning arise, resulting in a significant proportion of harvested walnuts displaying dark brown colouration and inadequate quality. In this experiment conducted under the specified conditions, the optimal harvest time for walnut trees is determined to be Aug 22nd. The walnut kernels achieve the highest quality by harvesting the crop at this specific time. This timing ensures that the mesocarp of the walnuts remains completely immature. Treatment with ethephon at a concentration of 1 920 ppm facilitates mesocarpv maturation, thereby facilitating the separation of the mesocarp from the endocarp in the most effective manner. The impact of various ethephon concentrations on walnut dry matter content revealed that ethephon augmented carbohydrate production, thereby expediting fruit ripening and consequently increasing the dry matter percentage of walnuts. As the harvest date approaches on Sept 9th, the percentage of dark-coloured kernels tends to rise. In summary, the general conclusion drawn from this experiment is as follows: In regions with warm and humid summers, where, naturally, the Persian walnut kernel is harvested in a dark brown or black colour, the product should be harvested three weeks before the harvest date under normal conditions. Subsequently, it should be treated with ethephon at a concentration of 1 920 ppm. In this way, the mesocarp easily separates from the endocarp, accelerating the ripening stages of the mesocarp and endocarp. This results in kernels that are completely light-coloured, white, or cream, obtaining not only marketability and high quality but also a slightly higher amount of dry matter. Of course, the desired colour of the walnut kernel (white or light cream) is so important that it puts other characteristics on the sidelines.

Also, increasing the concentration of ethephon to 4 800 ppm has caused a kind of toxicity for the walnut kernel.

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