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Effect of Foliar Application of Castor Oil and NAA on Physicochemical Properties of Apple (*Malus pumila Mill.)* Fruits

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ABSTRACT

This study aimed to evaluate the effects of foliar application of castor oil and naphthalene acetic acid (NAA; commercially known as Stavals) on the physicochemical characteristics of apple (Malus pumila Mill.) fruits under Iraqi environmental conditions. The experiment was conducted during the 2024 growing season using a randomized complete block design (RCBD) with three replicates. Twenty-seven uniform trees were subjected to nine treatments, including individual and combined applications of castor oil (3% and 5%) and NAA (30 and 60 mg L^{-1}). The results demonstrated that foliar treatments significantly ($P \leq 0.05$) improved key physical attributes of the fruits. In particular, the combined application of 5% castor oil and 60 mg L^{-1} NAA resulted in the highest fruit moisture content and juice percentage, along with a substantial reduction in fruit cracking compared to the control. Conversely, chemical characteristics such as total soluble solids (TSS), anthocyanin content, and vitamin C showed a decreasing trend under most treatments, although the differences were not consistently significant across all treatment combinations. In conclusion, the combined foliar application of castor oil and NAA represents a promising strategy for improving the physical quality and reducing physiological disorders of apple fruits. However, further optimization is required to achieve a balance between enhancing physical traits and maintaining chemical and nutritional quality.

***Keywords*:** Foliar Application, Castor Oil, Malus pumila, Mill, NAA, Fruit Quality.

INTRODUCTION

Apple (Malus pumila Mill.) belongs to the family Rosaceae, which includes many economically important fruit species. Apple is considered one of the most widely cultivated fruit crops worldwide due to its high nutritional value, desirable taste, and wide consumer acceptance. Apple fruits are rich in sugars, organic acids, vitamins, antioxidants, and dietary fiber, making them valuable for both fresh consumption and industrial processing [1,2].

Despite its economic importance, apple fruits are frequently exposed to several physiological disorders during the ripening stage, including fruit cracking, excessive moisture loss, softening, and undesirable changes in sugar-acid balance. These disorders reduce marketability, storage potential, and overall fruit quality [3]. Therefore, improving fruit quality and reducing pre-harvest disorders are major objectives in apple production systems.

Several approaches have been investigated to alleviate such problems, including the use of plant growth regulators, natural oils, and antitranspirant compounds. Among these substances, stavals is a commercial product containing naphthalene acetic acid (NAA), a synthetic auxin known to regulate cell expansion, improve tissue elasticity, and enhance fruit development. Auxins may also reduce cracking by increasing the extensibility of epidermal tissues and improving fruit water relations.

Castor oil is a vegetable oil obtained from the seeds of Ricinus communis L. and is characterized by a high proportion of ricinoleic acid. Its film-forming and hydrophobic properties make plant-derived oils potential candidates for reducing surface water loss and modifying fruit surface conditions. [2, 4].

Previous studies also indicated that NAA applications may improve moisture retention, reduce cracking percentage, and influence chemical constituents of fruits such as acidity and vitamin C content [5, 1, 6]. Likewise, antitranspirant

such as Vapor-Gard have shown positive effects on reducing cracking and preserving fruit quality in apples [7]. However, limited studies have investigated the combined effect of castor oil and NAA on apple fruit quality under Iraqi conditions.

Therefore, the objective of the present study was to evaluate the effect of foliar application of castor oil and NAA, individually or in combination, on the physicochemical properties of local apple fruits, and to determine the most effective treatment for improving fruit quality at maturity.

Materials and Method

Experimental Site and Plant Material

The experiment was conducted during the 2024 from April to August, in a private orchard located in Kirkuk, Iraq. 27 healthy and uniform trees of local summer apple (Malus pumila Mill.), aged eight years, were selected for the study. Trees were similar in vigor, canopy size, and general management conditions, and were planted at a spacing of 7 × 7 m.

Treatments and Foliar Application

The experiment included two main factors:

NAA: it was applied at concentrations of 30 and 60 mg L^{-1}, while castor oil was applied at concentrations of 3% and 5%. The treatments were applied individually and in combination, in addition to an untreated control. Foliar applications were performed twice during the 2024 growing season, on 5 and 15 April 2024. The spray solutions were applied using a hand-operated sprayer until runoff, ensuring uniform and complete coverage of the tree canopy, including leaves and developing fruits. A wetting agent was added to all spray solutions at a concentration of 1 g L^{-1} to improve spreading and adhesion on plant surfaces [8]. The applications were carried out during the early fruit-development stage. The same application procedure and timing were used for all treatments to ensure uniformity among experimental units.

Experimental Design

The experiment was arranged according to a Randomized Complete Block Design (RCBD) with three replications. Each treatment replicate consisted of one tree, and each tree represented an experimental unit. The experiment consisted of the following nine treatments:

Control (water spray), Castor oil 3%, Castor oil 5%, NAA 30 mg L^{-1}, NAA 60 mg L^{-1}, Castor oil 3% + NAA 30 mg L^{-1}, Castor oil 3% + NAA 60 mg L^{-1}, Castor oil 5% + NAA 30 mg L^{-1} and Castor oil 5% + NAA 60 mg L^{-1}

Fruit Sampling

At commercial maturity, 10 fruits were randomly harvested from each experimental tree and transported immediately to the laboratory for physical and chemical analyses.

Physical Characteristics

•Peel moisture content (%), Pulp moisture content (%), Juice percentage (%) andFruit cracking percentage (%)

Chemical Characteristics

•Total soluble solids (TSS, %) using a hand refractometer, Total titratable acidity (%) expressed as citric acid equivalent, Anthocyanin content in fruit peel (mg 100 g^{-1} fresh weight) and Vitamin C content in juice (mg 100 mL^{-1} juice)

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) according to the Randomized Complete Block Design (RCBD), with three replications and one tree as the experimental unit. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. Means followed by the same letter within each column are not significantly different according to DMRT at the 5% probability level. [4].

Results and Discussion

Physical Characteristics

Peel and Pulp Moisture Content

The results presented in Table 1 clearly show that foliar application of castor oil and NAA significantly improved the moisture content of both peel and pulp compared with the control treatment.

The lowest values were recorded in untreated fruits (51.56% for peel and 58.81% for pulp), whereas all treated plants showed a gradual increase in moisture content. The highest values were observed under the combined treatment of 5% castor oil + 60 mg L^{-1} NAA, reaching 60.12% and 64.67% for peel and pulp, respectively. The increase in moisture content can be attributed to the physiological role of naphthalene acetic acid (NAA), which enhances cell wall extensibility and facilitates water uptake into plant tissues through increased cell wall plasticity and proton-mediated loosening [5].

In addition, castor oil likely reduced transpiration losses by forming a thin protective layer on the fruit surface, which

limits water evaporation and improves internal water balance [3]. These results are in agreement with findings reported by [7], who observed that the application of antitranspirant improved moisture retention and fruit quality in apple.

Juice Percentage

A similar trend was observed for juice percentage, where all treatments increased juice content compared to the control (45.41%). The increase was more pronounced under combined applications, with the maximum value (48.81%) obtained from the treatment of 5% castor oil + 60 mg L^{-1} NAA. The increase in juice percentage is likely associated with enhanced hydration of fruit tissues, resulting from reduced transpiration and improved water uptake. Auxins such as NAA promote cell expansion and increase cell volume, which contributes to greater accumulation of juice within fruit tissues [9]. Furthermore, the effect of castor oil in reducing water loss may have contributed to maintaining higher internal moisture, thereby enhancing juice yield.

Fruit Cracking Percentage

Fruit cracking percentage was significantly reduced by all treatments compared to the control. The highest cracking rate (25.94%) was recorded in untreated fruits, while the lowest value (7.89%) was obtained under the combined treatment of 5% castor oil + 60 mg L^{-1} NAA. This reduction can be explained by the role of auxins in enhancing peel elasticity and improving the extensibility of epidermal cells, allowing the fruit skin to withstand internal pressure during growth [7]. Additionally, the application of castor oil may reduce rapid fluctuations in fruit water status by limiting transpiration, thereby minimizing stress on the fruit surface and reducing cracking incidence [1].

These findings are consistent with previous studies that reported the effectiveness of plant growth regulators and antitranspirant in reducing fruit cracking in apple and other fruit crops [6]. These results are also partially consistent with previous findings on pomegranate and other fruit crops, where NAA and antitranspirant improved fruit resistance to cracking and enhanced water relations [10].

Table 1. Effect of foliar application of castor oil and NAA and their combinations on selected physical characteristics of apple fruits at maturity

Treatments	Peel moisture (%)	Pulp moisture (%)	Juice (%)	Cracking (%)
Control	51.56 e	58.81 d	45.41 d	25.94 a
Castor oil 3%	54.92 cd	61.86 bc	45.96 cd	12.46 cd
Castor oil 5%	55.87 c	62.13 bc	47.12 bc	11.84 cd
NAA 30 mg L^{-1}	52.70 de	60.96 c	45.86 cd	17.01 b
NAA 60 mg L^{-1}	56.76 bc	61.01 c	46.01 cd	13.70 bc
Castor oil 3% + NAA 30 mg L^{-1}	58.44 ab	62.31 bc	47.53 abc	11.40 cd
Castor oil 3% + NAA 60 mg L^{-1}	58.61 ab	63.74 ab	47.94 ab	9.33 cd
Castor oil 5% + NAA 30 mg L^{-1}	59.03 ab	63.08 abc	48.10 ab	8.45 d
Castor oil 5% + NAA 60 mg L^{-1}	60.12 a	64.67 a	48.81 a	7.89 e

Means within the same column followed by the same letter(s) are not significantly different at $p \leq 0.05$ according to Duncan's Multiple Range Test (DMRT).

Chemical Characteristics

Total Soluble Solids (TSS)

The results in Table 2 indicate that total soluble solids (TSS) were slightly reduced by most treatments compared with the control. The highest TSS value (16.61%) was recorded in untreated fruits, while the lowest value (15.65%) was observed under the combined treatment of 5% castor oil + 60 mg L^{-1} NAA. The reduction in TSS may be attributed to the dilution effect caused by increased water content in fruit tissues, as previously observed in Table 1. Enhanced water retention leads to a decrease in the concentration of soluble sugars and other dissolved solids.

Total Acidity

The results in Table 2 showed that total acidity was significantly affected by the applied treatments, showing a decreasing trend compared with the control (3.01%). The lowest acidity values were recorded under combined treatments, particularly 5% castor oil + 30 mg L^{-1} NAA (2.70%). The results are in agreement with [5], who reported a reduction in fruit acidity following NAA application.

Anthocyanin Content

The results in Table 2 indicate that anthocyanin content in the fruit peel showed a gradual decrease under all treatments

compared with the control (134.34 mg 100 g^{-1} FW). The lowest value (129.80 mg 100 g^{-1} FW) was recorded in fruits treated with 5% castor oil + 60 mg L^{-1} NAA.

This reduction may be attributed to dilution effects resulting from increased fruit moisture content, as well as possible alterations in pigment biosynthesis due to changes in fruit physiology under the influence of growth regulators. However, it is important to note that anthocyanin content is a critical quality attribute related to fruit coloration. Therefore, a decrease in this parameter may negatively affect the visual quality and market preference of apple fruits.

Vitamin C Content

Vitamin C content was also influenced by the treatments, with the highest value recorded in the control (15.09 mg 100 mL^{-1}) and the lowest value (13.83 mg 100 mL^{-1}) observed under the combined treatment of 5% castor oil + 60 mg L^{-1} NAA. The reduction in vitamin C content may be explained by the dilution effect associated with increased water content, as well as enhanced oxidative metabolism during fruit maturation.

The results of the present study demonstrate that while foliar application of castor oil and NAA effectively improved physical characteristics such as moisture content and reduced fruit cracking, it also resulted in moderate reductions in certain chemical quality attributes, including TSS, anthocyanin, and vitamin C.

This trade-off suggests that the treatments primarily enhance water relations and physical integrity of the fruit, rather than biochemical accumulation of metabolites. Therefore, the practical application of these treatments should aim to balance improvements in physical quality with the maintenance of nutritional and sensory attributes. The observed inverse relationship between moisture content and TSS or vitamin C supports the hypothesis that dilution effects play a key role in determining fruit chemical composition under antitranspirant treatments.

Table 2. Effect of foliar application of castor oil and NAA and their combinations on selected chemical characteristics of apple fruits at maturity

Treatments	TSS (%)	Total acidity (%)	Anthocyanin (mg 100 g^{-1} FW)	Vitamin C (mg 100 mL^{-1} juice)
Control	16.61 a	3.01 a	134.34 a	15.09 a
Castor oil 3%	16.01 a	2.86 a	132.00 abc	14.41 a
Castor oil 5%	16.13 a	2.81 a	131.00 bc	14.37 a
NAA 30 mg L^{-1}	16.47 a	2.95 a	133.00 ab	14.28 a
NAA 60 mg L^{-1}	16.38 a	2.92 a	132.50 abc	14.60 a
Castor oil 3% + NAA 30 mg L^{-1}	15.91 a	2.79 a	130.00 c	14.29 a
Castor oil 3% + NAA 60 mg L^{-1}	16.06 a	2.71 a	130.00 c	14.22 a
Castor oil 5% + NAA 30 mg L^{-1}	15.89 a	2.70 a	129.80 c	13.96 a
Castor oil 5% + NAA 60 mg L^{-1}	15.65 a	2.72 a	129.80 c	13.83 a

Means within the same column followed by the same letter(s) are not significantly different at $p \leq 0.05$ according to Duncan's Multiple Range Test (DMRT).

Conclusion

The present study demonstrates that foliar application of castor oil and Stavals (as a source of naphthalene acetic acid, NAA) significantly influenced the physicochemical characteristics of local apple fruits under the conditions of the 2024 growing season.

The combined treatments, particularly 5% castor oil + 60 mg L^{-1} NAA, were the most effective in improving physical fruit attributes, as evidenced by increased peel and pulp moisture content, enhanced juice percentage, and a marked reduction in fruit cracking. These improvements can be attributed to the synergistic interaction between enhanced tissue elasticity induced by NAA and reduced transpiration resulting from the film-forming properties of castor oil.

However, the treatments also resulted in moderate reductions in certain chemical quality parameters, including total soluble solids (TSS), anthocyanin content, and vitamin C. These changes are likely associated with dilution effects caused by increased water retention, as well as possible alterations in metabolic activity during fruit development.

Overall, the results indicate that foliar application of castor oil and NAA can be considered a promising approach for improving the physical quality and reducing physiological disorders in apple fruits.

Nevertheless, careful optimization of treatment concentrations and application timing is required to maintain a balance between physical enhancement and chemical composition, particularly for attributes related to nutritional value and fruit coloration.

Further studies are recommended to evaluate the long-term effects of these treatments under different environmental conditions, as well as their impact on postharvest performance and consumer acceptance.

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تأثير الرش الورقي بزيت الخروع وحمض النفثالين أسيتيك NAAعلى الخصائص الفيزيائية والكيميائية لثمار التفاح (*Malus pumila Mill.*)

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الخلاصة

هدفت هذه الدراسة إلى تقييم تأثير الرش الورقي بزيت الخروع وحمض النفثالين أسيتيك***(NAA*** ؛ المعروف تجاريًا باسم ***(Stavals*** في الخصائص الفيزيائية والكيميائية لثمار التفاح ***(Malus pumila Mill.)*** تحت الظروف البيئية العراقية. أُجريت التجربة خلال موسم النمو لعام 2024 باستخدام تصميم القطاعات العشوائية الكاملة ***(RCBD)***بثلاثة مكررات. شملت الدراسة 27 شجرة متجانسة خضعت لتسع معاملات، تضمنت الاستخدام المنفرد والمشترك لزيت الخروع بتركيزين (3% و5%) وحمض النفثالين أسيتيك بتركيزين (30 و60 ملغم لتر$^{-1}$).أظهرت النتائج أن معاملات الرش الورقي أدت إلى تحسين معنوي ***($P \leq 0.05$)*** في عدد من الصفات الفيزيائية المهمة للثمار. وقد حققت المعاملة المشتركة المكونة من زيت الخروع بتركيز 5% مع حمض النفثالين أسيتيك بتركيز 60 ملغم لتر$^{-1}$ أعلى محتوى رطوبي للثمار وأعلى نسبة للعصير، إلى جانب انخفاض ملحوظ في تشقق الثمار مقارنة بمعاملة المقارنة. وفي المقابل، أظهرت الصفات الكيميائية، بما في ذلك المواد الصلبة الذائبة الكلية ***(TSS)***، ومحتوى الأنثوسيانين، وفيتامين***C*** ، اتجاهًا نحو الانخفاض في معظم المعاملات، إلا أن هذه الفروق لم تكن معنوية بصورة منتظمة بين جميع المعاملات.
تُشير النتائج إلى أن الرش الورقي المشترك بزيت الخروع وحمض النفثالين أسيتيك يُعد استراتيجية واعدة لتحسين الصفات الفيزيائية وتقليل الاضطرابات الفسيولوجية في ثمار التفاح. ومع ذلك، فإن هناك حاجة إلى مزيد من الدراسات لتحديد التراكيز والبرامج التطبيقية المثلى بما يحقق التوازن بين تحسين الصفات الفيزيائية والحفاظ على الجودة الكيميائية والقيمة الغذائية للثمار.

الكلمات المفتاحية: الرش الورقي، زيت الخروع، التفاح ((Malus pumila Mill.، حمض النفثالين أسيتيك ((NAA، جودة الثمار.