

# Skin pitting of kiwifruit: Case-study of sustainable post-harvest management in northern Italy through the application of oregano essential oil

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**Abstract:** Skin pitting in kiwifruit (*Actinidia* spp.) is an increasing phytopathological concern primarily due to fungal infections caused by the biotic agent *Cadophora luteo-olivacea*. This disorder significantly impacts the commercial quality of fruits, reducing their post-harvest shelf life, marketability, and profitability for growers. This case study explores a novel natural post-harvest treatment using oregano essential oil (*Origanum vulgare*) as a potential solution to mitigate the disorder. Results indicated a symptoms reduction of about 37% with respect to the control, yet these fruit had a higher firmness.

**Keywords:** *Actinidia*; oregano; essential oil; *Cadophora luteo-olivacea*.

## 1. Introduction

Kiwifruit (*Actinidia* spp.) is an economically important fruit crop, cultivated widely for its high nutritional value and consumer demand (Mian, Iseppi, et al., 2022; Bassi et al., 2023). Despite its popularity, the crop is vulnerable to several diseases (Mian et al., 2023), with post-harvest skin pitting recently becoming a major concern (Di Francesco et al., 2021). Skin pitting appears as shallow depressions on the surface of kiwifruit, negatively affecting its appeal and market value (Davide Spadaro et al., 2010). The main pathogen responsible for skin pitting in kiwifruit is *Cadophora luteo-olivacea*. This fungal species has been isolated from kiwifruit with symptoms of skin pitting in several production regions (Di Francesco, Di Foggia, et al., 2022). *C. luteo-olivacea* enters through natural openings or small injuries in the fruit skin, leading to localized necrosis and pitting (Tomada et al., 2024). Once the pathogen infiltrates the fruit, it can trigger tissue degradation, although the exact mechanism remains poorly understood (Di Francesco et al., 2024). At any rate, post-harvest conditions worsen skin pitting, being recognized and charged as the most important factors (Di Francesco, Neri, et al., 2022). Handling fruit roughly during harvest, packing, or transportation can cause micro-injuries to the skin, which become entry points for fungal pathogens (Xia et al., 2024). Furthermore, improper storage conditions, such as elevated humidity and poor ventilation, further encourage fungal activity, leading to the development of visible symptoms during storage or distribution (Jurick II and Adaskaveg, 2024). Long storage periods, particularly under suboptimal conditions, can lead to increased susceptibility to skin pitting (D. Spadaro et al., 2010). Thus, the disease results in significant economic losses for kiwifruit producers (Jabeen et al., 2022). Fruits affected by the disorder are often downgraded in quality, leading to reduced prices and marketability.

The cost of implementing fungicide management strategies for post-harvest treatments, add to the financial burden on growers. Furthermore, the application of fungicides in post-harvest raises concerns among costumers due to their potential risk for human health and the negative impact on the environ-

ment (Palou et al., 2016; Pimentão et al., 2024). Post-harvest fungicide dips or treatments with natural compounds like essential oils or fungal bio controlling strains can reduce fungal activity on the fruit surface (Di Francesco et al., 2021, 2024; Jabeen et al., 2022; Tomada et al., 2024). The Oregano essential oils are promising antimicrobial agents (Rodriguez-Garcia et al., 2016; Ai et al., 2022) due to the presence of phenolic compounds (Avila-Sosa et al., 2010; Castilho et al., 2012). In this context, this case study started from a kiwifruit orchard located in Northern Italy, where a sudden outbreak of skin pitting was observed on fruits just after 25 days of post-harvest storage. Based on this, the study aimed to evaluate the effectiveness of oregano (*Origanum vulgare*) essential oil (OEO) as a natural post-harvest treatment to stop/mitigate skin pitting.

## 2. Materials and Methods

### 2.1. Oregano oil

The resulting formulation is currently undergoing patenting due to its potential applications in plant health management and sustainable agriculture. Briefly, the oregano essential oil was obtained through steam distillation, a widely employed method for extracting volatile compounds from aromatic plant tissues. Fresh aerial parts of oregano were finely chopped and loaded into a 2.5 L stainless-steel steam distillation system (Sigma-Aldrich, Germany, Aldrich® Kugelrohr™). The plant material was placed in the distillation chamber above a boiling flask containing distilled water. Steam was generated by heating the system to 98–100 °C, allowing it to permeate the plant matrix and facilitate the release of essential oil components. The distillation was carried out for 2-3 hours, ensuring complete volatilization of aromatic compounds. The vapor-phase mixture of water and volatiles was then passed through a condenser (Sigma-Aldrich, Germany, Synthware™) maintained at 10-15 °C using a recirculating chiller. The condensate was collected in a graduated separation vessel, where the oil spontaneously separated from the aqueous phase. The essential oil layer was recovered using a glass pipette, and traces of moisture were removed by drying over anhydrous sodium sulphate for 12-24 h. The oil was subsequently filtered through 0.45 µm PTFE filters (Millipore, Italy, Milan), then transferred into amber glass vials (Avantor Sciences, Italy), and stored at 4 °C until use. From an industrial perspective, this method ensures reproducibility, scalability, and preservation of key bioactive molecules.

### 2.2. Experimental Design

The experiment was conducted on fruits of the cv. ‘Hayward’ using a completely randomized design with two treatments: Control: Fruits untreated after harvest, OEO Treatment (OEO Treatment): Fruits treated with a 0.75% (v/v) oregano essential oil solution. Each treatment included four biological replicates, with 30 fruits per replicate (total n = 240 fruits). Fruits were submerged in the respective treatments for two minutes, air-dried, and then stored at 0.8 - 1.5 °C with 90% relative humidity until the evaluation.

### 2.3. Pathogen Identification and Assessment of Skin Pitting

To determine the presence of fungal pathogens, symptomatic fruit samples (n = 30) were collected from affected storage batches. Fungal isolation was performed on potato dextrose agar (PDA) (CPC Biotech srl, Monza Brianza, MI, Italy), followed by DNA extraction using the InstaGene™ Matrix kit (Bio-Rad, USA). The fungal strains were molecularly identified using the specific primers Cad (KSDA)-f2 (5'-GTG GCG GGG CTA CCC TAC-3') and Cad (KSDA)-r1 (5'-GCT GGC AAG TAG ACC TAC CG-3') (Di Francesco et al., 2023).

PCR reactions contained 200 µM of each of the four dNTPs, 0.4 µM of each primer, 1.5 mM MgCl<sub>2</sub>, 0.625 U of GoTaq Flexi DNA Polymerase (Promega, WI, USA), and 1 µL of diluted DNA template. The amplification was performed in a MiniAmp Plus cycler (Thermo Fisher Scientific) under the following conditions: initial denaturation at 94 °C for 2 min; 35 cycles of denaturation at 94 °C for 40 s, annealing at 58 °C for 30 s, and extension at 72 °C for 40 s; followed by final extension at 72 °C for 7 min.

PCR products were electrophoresed on 1.5% agarose gels, stained with GelRed (Biofab, Roma) and visualized under UV light. The amplified DNA was purified with a Nucleospin Extracts II Kit (Macherey–Nagel, Germany) and Sanger sequenced by an external company. The resulting sequences were compared to those of the GenBank database (<https://www.ncbi.nlm.nih.gov/BLAST/>) using the BLASTN search tool.

Skin pitting incidence was evaluated at the end of the storage period. The number of affected fruits showing symptoms was recorded for each replicate. Results are reported in the text as percentages.

#### 2.4. Firmness and soluble solids content

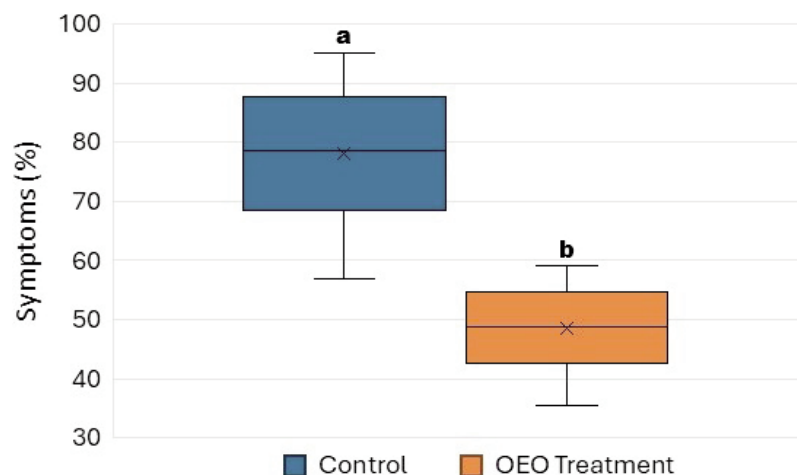
Soluble solids content (°Brix) was measured by equatorially cutting the fruit, and 1-3 juice drops were squeezed on the prism surface of a digital refractometer (Atago PR32, Fischer Scientific, Milan, Italy) (Mian, Cipriani, et al., 2022). Fruit firmness was measured using a Fruit Texture Analyser (FR-5120, Guss supplies, Norfolk, VA, USA) fitted with a 7.9 mm penetrometer probe after removal of skin and flesh to a depth of approximately 1 mm. The probe was driven into the flesh at 5 mm/s to a depth of 7.9 mm, and the maximum force was recorded as the firmness value. Firmness was measured twice at the equator of each fruit, with the two measurements taken at 90° to each other and averaged. Firmness was measured as N (Mian et al., 2025).

#### 2.5. Statistical Analysis

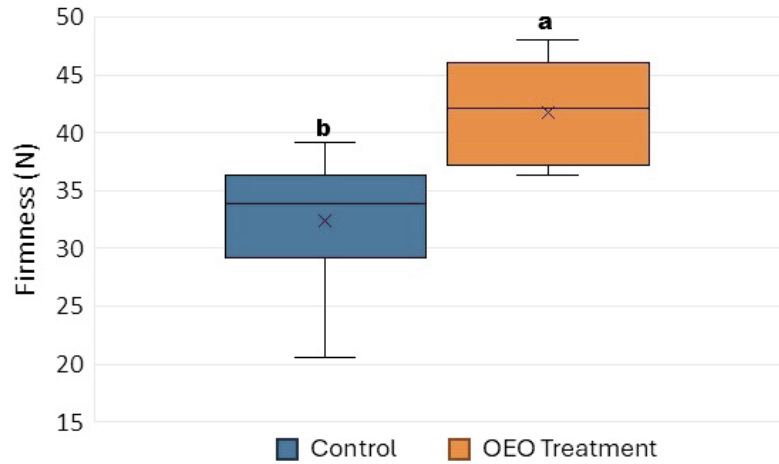
Data were analysed using one-way analysis of variance (ANOVA), followed by Tukey’s HSD test for post-hoc comparisons ( $\alpha = 0.05$ ). Before running the ANOVAs, normality and homoscedasticity were checked using Shapiro-Wilk. All statistical analyses were conducted using R software v. 4.2.1 (R Core Team, 2021).

### 3. Results

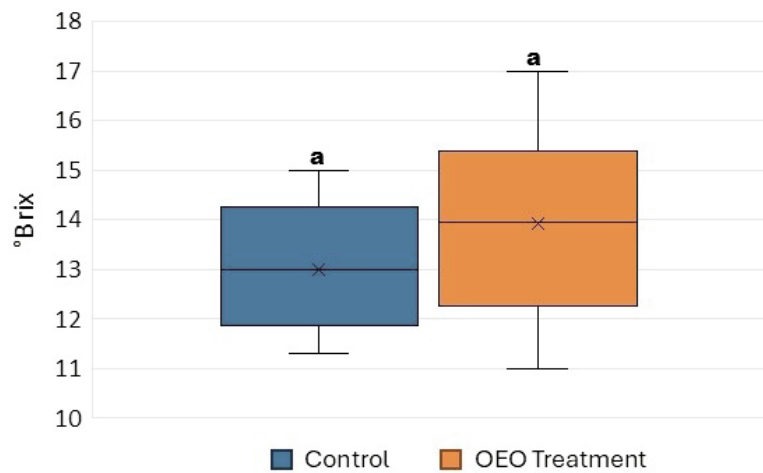
OEO treatment significantly reduced the incidence of skin pitting compared to the untreated Control ( $p < 0.05$ ) (Fig. 1). The mean incidence in the control group was 78.2%, whereas in the OEO-treated fruits, skin pitting was reduced by 37.8% (Value = 48.64%,  $p < 0.05$ ). Furthermore, fruits treated with OEO exhibited significantly higher firmness values compared to the control ( $p = 0.0021$ ) (Fig. 2). The mean firmness of treated fruits was 42.1 N, whereas control fruits had a mean firmness of 32.4 N. Soluble solids content (°Brix) did not differ significantly between treatments ( $p = 0.21$ ), with both treated and untreated fruits showing comparable sugar accumulation levels (12.98 and 13.92 °Brix, in the Control and OEO Treatment, respectively) (Fig. 3).



**Figure 1.** Skin pitting symptoms incidence (%) of Control group fruits, and OEO Treatment fruits. Values assigned by different letters are statistically different at  $p < 0.05$  applying the Tukey HSD test.



**Figure 2.** Flesh firmness of Control group fruits, and OEO Treatment fruits. Values assigned by different letters are statistically different at  $p < 0.05$  applying the Tukey HSD test.



**Figure 3.** Soluble solids content of Control group fruits, and OEO Treatment fruits. Values assigned by different letters are statistically different at  $p < 0.05$  applying the Tukey HSD test.

#### 4. Discussion

The results of this study highlight the effectiveness of oregano essential oil as alternative to fungicides for post-harvest application to mitigate skin pitting in kiwifruit, as it was already ascertained in other context (Plotto, Roberts and Roberts, 2002). The reduction in disease incidence observed in treated fruits suggests that OEO has strong potential as an alternative to conventional fungicides (Almasaudi et al., 2022), which are often associated with concerns regarding residue accumulation, pathogen resistance, and environmental impact (McLaughlin et al., 2023). The ability of OEO to limit fungal proliferation and oxidative stress could offer a sustainable strategy for maintaining fruit quality during storage (Lopez-Reyes et al., 2010).

The reduction in skin pitting incidence by 37.8% in OEO-treated fruits demonstrates its antimicrobial activity, likely due to the presence of bioactive compounds such as carvacrol and thymol (Zamuner et al., 2023). These phenolic components have been well-documented for their antifungal properties, which may have contributed to restricting the growth of *Cadophora luteo-olivacea* in our study. Additionally, the observed increase in fruit firmness in OEO-treated samples suggests that the treatment may have reinforced tissue integrity, potentially through mechanisms involving reduced enzymatic degradation and oxidative damage (Hodges et al., 2004).

Importantly, the study confirmed that OEO treatment did not significantly affect soluble solids con-

tent, indicating that the natural ripening process remained unaffected. This is a crucial consideration for post-harvest treatments, as excessive alterations to ripening physiology could impact market acceptance and consumer satisfaction (Hayat et al., 2023). The maintenance of sugar accumulation in treated fruits further supports the practical application of OEO without compromising organoleptic quality.

Despite these promising findings, further studies are needed to optimize OEO application methods, concentrations, and possible synergies with other post-harvest treatments. While the study employed a specific solution, 0.75% (v/v) OEO, higher or lower concentrations could yield different efficacy levels, thus deserving additional investigation. Moreover, potential effects on fruit sensory attributes, including aroma and flavour, should be evaluated to ensure consumer acceptability. Another key aspect requiring further exploration is the mode of action of OEO in mitigating skin pitting. While its antimicrobial and antioxidant properties have been proposed as contributing factors (Jaradat et al., 2016; Ben Mirri, 2025; Mutlu-Ingok et al., 2020; Salvi et al., 2022), deeper biochemical and physiological analyses are necessary to elucidate its precise role in maintaining fruit integrity. Additionally, the economic feasibility of large-scale implementation in commercial kiwifruit production must be assessed, particularly in comparison with existing post-harvest management strategies (e.g., 1-MCP, Sadeghian et al., 2025). In conclusion, this study provides preliminary evidence that oregano essential oil can serve as an effective, natural, and sustainable intervention for controlling post-harvest skin pitting in kiwifruit.

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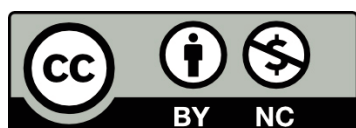
**Conflicts of Interest:** The authors declare no conflict of interest.

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