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Large-scale study on the influence of thinning practices on yield and fruit quality attributes in 'Mejhoul' dates

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ABSTRACT

Fruitlet thinning is an important task for date palm growers, particularly for producing high-quality fruit in the 'Mejhoul' cultivar. The present study aimed to explore whether a causal relationship exists between active thinning strategies and passive fruit abscission to trees' performance in terms of tree yield as well as fruit weight and quality. The thinning practices of six experienced growers in the Southern Arava region were characterized over three consecutive seasons, in four adjacent trees per plot. Five growers tested alternative thinning protocols with varying fruit loads. Fruitlets were counted immediately after thinning (April–May) and before bunch coverage (July). Tree yield, fruit weight and quality were assessed after the harvest both in the orchard and in the packinghouse. The study reveals that fruit abscission was very high at the beginning of the thinning season, where growers left more fruit per bunch, and was lower as the thinning season progressed. Although heavier fruit loads increased the final yield, it also increased fruit abscission, and generally reduced fruit weight. While seasonal variations are the main factors affecting fruit quality parameters, such as skin separation and dry rings, our results suggest a secondary effect of fruit load. The comparable thinning experiments suggest that higher fruit loads increased the incidence of dry rings but reduced the proportion of fruits with low skin separation. These findings can help optimize thinning protocols and improve harvest outcomes.

1. Introduction

1.1. 'Mejhoul' dates

Dates are an important tree crop cultivated in arid regions of the world. They have been traditionally cultivated in desert oases in the Middle East and North Africa. During the 19th and 20th centuries cultivation was expanded to most arid regions in other continents of the world. 'Mejhoul' (also called 'Medjool' or 'Medjoul') is an elite cultivar originating from Morocco [1]. Following its introduction to the USA [2], and further expansion to Israel [3], 'Mejhoul' has become an elite date product praised for its large size, semi-dry and soft texture and perfect appearance in contrast to other dried dates. Approximately 100,000 tons of 'Mejhoul' were produced globally during 2020 and quantities continue to rise [1]. Israel has become the world leader in 'Mejhoul' cultivation (with approximately 6600 Ha, 45,000 tones) and marketing. To achieve its excellent qualities specific growing protocols and marketing strategies have been developed [2–4].

1.2. Date palm inflorescences and fruit bunches

Dates are a dioecious monocot fruit crop with male and female flowers developing on separate date palm trees. The female flowers develop in large inflorescences, each at the base of a leaf at the palm's crown. Twenty to thirty inflorescences develop on each mature tree, depending on environmental conditions, the age of the tree and horticultural practices. These inflorescences grow in three typical whorls—upper, center and lower—according to their location in the crown. The upper whorls are usually larger and develop earlier than the lower ones. Each inflorescence is covered by a spathe, a hard and fibrous

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leaf like structure that encircles the inflorescence and protects it. The inflorescence is composed of a peduncle (fruit stalk), several dozen unbranched rachillea (spikelets, strands), with 50–100 flowers developing on each spikelet. The inner spikelets are shorter with fewer flowers. Following artificial pollination by a mixture of pollen collected from numerous male trees, the flowers develop into fruitlets. The structure of 'Mejhoul' inflorescences and fruit bunches has been detailed in earlier studies [4–6].

1.3. 'Mejhoul' date thinning: importance and methods practiced in Israel

Growers' revenues are determined by the total yield per tree and by the specific unit price. As an elite product, 'Mejhoul' cultivation revenue is directly impacted by both the fruit weight and internal and external quality. The growers aim to achieve both a high yield per tree and a high price per kilogram. Large fruits with perfect appearance gain high prices in the markets (Fig. 1A). After harvesting, the dates undergo processing and are sorted into various predetermined categories defined by a combination of fruit weight and quality. The two major quality parameters are the presence of dry rings (Fig. 1B), which are very dry fruit with light colored rings on the fruit shoulders, that are thought to be caused by extreme hot and dry weather conditions during late fruit ripening and the level of skin separation (Fig. 1C), where the fruit skin separates from the flesh [7–9]. Another quality parameter is Rutab fruit, which is a very wet fruit not fully ripened. Dry rings and Rutab can be partially cured post-harvest, in the packinghouse.

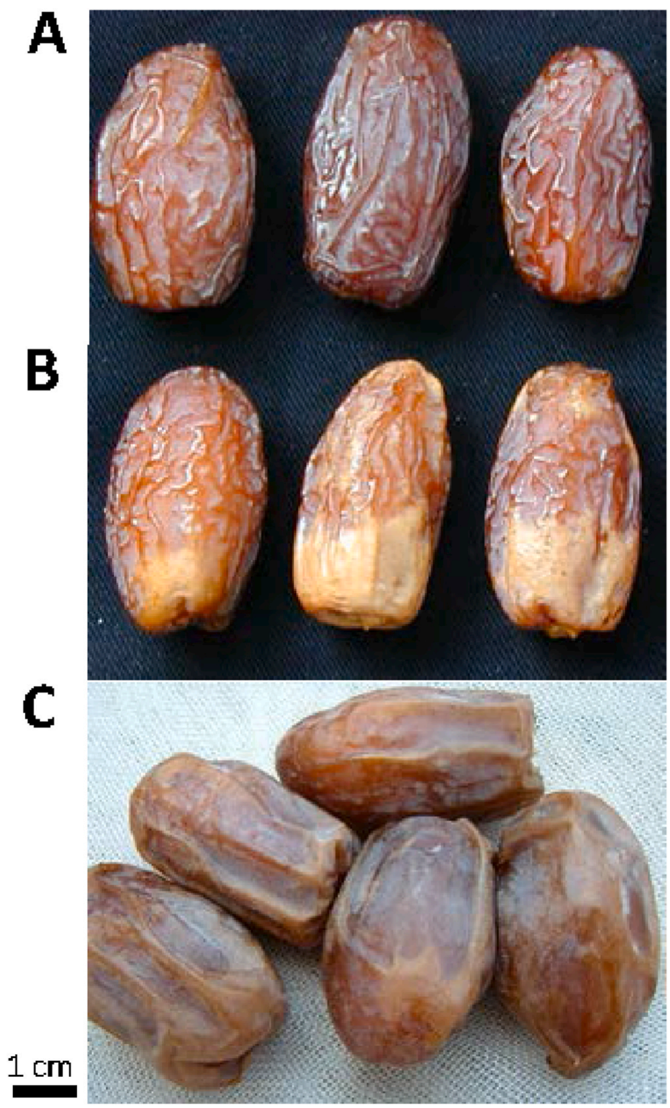

Fig. 1. 'Mejhoul' date fruits of different qualities. A. High quality fruits; B. Dry rings on the shoulders of extra dry fruit; C. Skin separated fruits (photo by Baruch (Buki) Glasner, adpted with permission).

Weight and quality of 'Mejhoul' fruits at harvest are dependent on fruit load, which is in turn dependent on the level of fruit set following pollination, the number of fruitlets left on the bunches following thinning and the level of fruitlet natural drop (abscission) during development [10]. Fruit thinning protocols regulate the yield of the tree. By reducing the number of developing fruits more resources can be allocated to the remaining fruits, increasing the fruit weight and improving its quality. While each fruit bunch contains several thousand fruitlets, only a few hundred (usually between 300 and 500 per fruit bunch) are left on the bunch to allow their maximal growth. Typically, this allows a yield of 90–170 kg for a mature tree, depending on the tree's age, the number of fruit bunches thinned and left on the tree, the geographic and climatic conditions of the orchard, and the grower's limitations and preferences [3,5]. Thinning can be practiced at three scales – controlling the number of bunches, controlling the number of remaining spikelets in each fruit bunch, and controlling the number of fruitlets per spikelet [4]. Ideal thinning should leave a defined number of bunches, spikelets on each bunch, and a specific number of fruitlets per spikelet by manually removing individual fruitlets at intervals along the spikelets. Although this approach is occasionally still practiced for 'Mejhoul' thinning in the USA [2] and in other countries, it is impractical in large plantations in Israel due to high labor cost and time constraints. In practice, manual thinning in Israel is performed by removing the inner (higher) spikelets from the bunch and shortening the remaining spikelets with secateurs [3].

Since the majority of the fruitlets are thinned considerably reducing fruit load, timely and accurate thinning is very important in order to have an effect on fruit weight and the yield at harvest. Ideally, thinning should be done during a 4-5-week period that starts immediately following fruit set (about 5 weeks after pollination), and finishes before reaching the rapid growth stage of the fruitlets. The number of spikelets remaining on the bunch and the number of fruitlets on each bunch are part of the thinning strategy of each grower. The growers' decisions are based on multiple factors like the specific bunch whorl, the specific timing of thinning in the season, the expected natural shedding, the circumference of the bunch rachis, historical data of thinning and on long-term historical production results of the growers (Saraf et al., under review).

Fruit thinning is one of the most labor consuming tasks in the orchard. Limitations like the orchard size, the available labor and machinery, i.e., high platforms required to access the trees' crowns, constrain the time of thinning execution. Sometimes the growers have to start thinning early, before they know the level of fruit setting and other times. Doing so, they may be late in finalizing the process in parts of the orchard. Some growers thin the entire tree in one step, while others prefer to begin early—starting with the upper bunches that emerge first and return to the trees multiple times for more precise thinning. This strategy removes a lot of the load earlier and optimizes the final load by correction of thinning after fruit setting and early fruitlet abscission. The present study aimed to explore whether a causal relationship exists between active thinning strategies and passive fruit abscission, and how these relate to trees performance in terms of yield, fruit weight and quality.

2. Materials and methods

2.1. Experimental sites

The present research took place in the Southern Arava region of Israel, home to twelve large date-growing establishments owned by local cooperative communities (Kibbutz). Most growers receive cold storage and packing services from Ardom Cooperative, a modern, local packinghouse. Most growers use an orchard management system database service to manage their date orchards (Tamarika©, Ardom Communications, Israel). As leaders in date cultivation actively seeking innovations to enhance their orchard management practices, six growers participated in this research program (Fig. 2). All participants are active date growers with at least fifteen years of experience in date cultivation management. Participants manage orchards of varying sizes from 73 to 122 ha. On three consecutive years (2021–2023), each of the six growers made four adjacent trees available for fruitlet counting, harvest yield logging and fruit sampling.

To investigate the effects of different fruit loads in comparable thinning treatments on yield, fruit weight and quality, in the years 2022 and 2023, the growers were encouraged to implement, in addition to their planned commercial thinning protocol, an alternative experimental protocol with a higher or lower fruit load, according to their wish. One grower in the year 2022 and four in the year 2023 applied the additional experimental protocols. The alternative experimental thinning was performed on four additional trees adjacent to the commercially thinned trees. Aside from the differences in thinning protocols, all trees within each plot received identical treatment, including year around optimal irrigation and fertilization. Table 1 provides details on the plots participating in the study.

2.2. *In-field fruitlet counting*

Four adjacent trees per grower, initially left unmarked to prevent worker bias, were selected each year for evaluation. Visits were coordinated with growers. Survey fruit counts were performed immediately after the first round of thinning (from the end of March to the beginning of April), post-completion of thinning in cases where thinning was performed in two rounds (from the end of April to mid-May), and approximately two months later, around mid-July, just before the fruit bunches were covered with net bags in preparation for the harvesting period. On each visit, the research team followed the thinning process by randomly selecting two bunches from each whorl, six bunches in total per tree. If, on the first visit, the center or lower whorl bunches had yet to develop and open up, the team revisited the trees on a later date, immediately following the completion of the thinning execution by the growers, to select the bunches missing and complete the count of six bunches. The team counted and recorded the number of spikelets in each of the selected bunches and the number of fruits in five presentative spikelets per bunch. The research team marked the bunches for future reference on each visit. Field counting generated a dataset in which each data point included the trees and plots, the date of counting, the number of bunches on a tree, and for two bunches of each whorl, the number of spikelets left in a bunch and the number of fruitlets on a spikelet (Suppl. Table 1).

Table 1
Participating Plots. Details on the number of trees and their planting year for each of the plots participating in the study. In all plots, trees were spaced 8 × 10 m apart, equating to 125 trees per hectare.

Grower	Trees per plot	Planting Year	Study Participation Years
Grower-1	463	2010	2021–2023
Grower-2	525	2005	2021–2023
Grower-3	992	2002	2021–2023
Grower-4	422	1996	2021–2023
Grower-5	979	2002	2021
	917	1995	2022,2023
Grower-6	952	2008	2021
	625	2008	2022,2023

The number of fruits·spikelet^{-1} $\left(f_{s,w}\right)$ were averaged across all spikelets sampled from bunches of a certain whorl (w)—upper, center, or lower—across four trees. The number of spikelets·bunch^{-1} (s_w) were averaged across all bunches of a certain whorl, across four trees. The average fruitlets·bunch^{-1} (f_w) was calculated as the multiplication of the average spikelets (s_w) and the averaged fruit·spiklet^{-1} $\left(f_{s,w}\right)$, for each whorl, as in Equation 1.

Equation 1. Average number of fruits per bunch (fruits·bunch^{-1}) for each whorl (w)

$$f_w = f_{s,w} \cdot s_w$$

where:

s_w = mean number of spikelets (s) on a bunch, i.e., spikelets·bunch^{-1}

$f_{s,w}$ = mean number of fruits (f) on a spikelet, i.e., fruits·spikelet^{-1}

f_w = mean number of fruits (f) on a bunch, i.e., fruits·bunch^{-1}, for whorl (w)

$w = whorl \in \{upper, center, lower\}$

Number of bunches·tree^{-1} (b) was averaged across the four trees

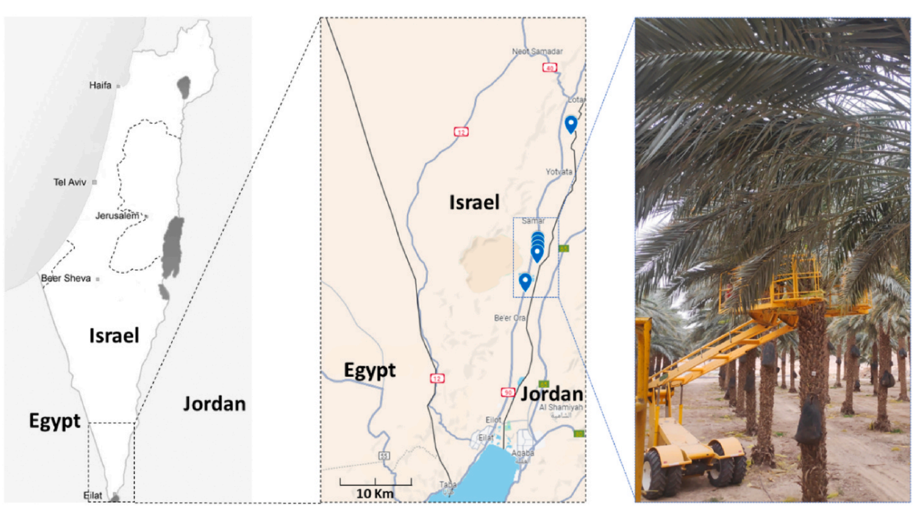

Fig. 2. Geographical Overview and Experimental Site Location. **Left**: A Schematic map of Israel. Map lines delineate study areas and do not necessarily depict accepted national boundaries. The dashed inserted box represents the Southern Arava region. **Center**: Enlarged Southern Arava region, with accompanying regions of Egypt and Jordan. Locations of participating farms are marked with blue pins. **Right**: Medjool date palm orchard, Southern Arava. Most horticultural tasks, including thinning, are performed on the crowns of tall trees, requiring high platforms for access (photo by Yael Salzer).

sharing the same thinning protocol (higher load or lower load) on each year (2021, 2022, 2023). As most of the bunches are in the central whorl, the number of bunches per upper, central, and lower whorls according to the common practice are typically estimated as 1/4:1/2:1/4, respectively. The estimated averaged fruits·tree^{-1} is the sum of the weighted number of bunches multiplied by the averaged fruits·bunch^{-1} across the three whorls, as in Equation 2.

Equation 2. Average number of fruits per tree (fruits·tree^{-1})

$$f_{tree} = b \cdot \left[\frac{1}{4}\cdot f_{w=\text{upper}} + \frac{1}{2}\cdot f_{w=\text{center}} + \frac{1}{4}\cdot f_{w=\text{lower}}\right]$$

where:

$b = \textit{mean number of bunches on tree}$

Each year the dates of bunch pollination (conducted in multiple rounds per plot) and thinning were logged. Each year (2021, 2022, 2023), fruits per bunch and fruits per tree were calculated across four trees per thinning protocol (commercial load and in five cases, higher load or lower load) after thinning was completed (*post-thinning*) and before the fruit bunches were covered with nets in preparation for harvest (*before-coverage*). The abscission ratio, representing the spontaneous reduction of fruit from the thinning date to the bunch coverage stage, was calculated for each whorl, thinning protocol (higher fruit load, lower fruit load), and year (2021, 2022, 2023), as shown in Equation 3.

Equation 3. Abscission ratiop

$$abscission = \frac{f_{w,post-thinning} - f_{w,\text{before}-coverage}}{f_{w,post-thinning}}$$

where:

$f_w = \textit{mean number of fruits } (f) \textit{ on a bunch}$

$w = whorl \in \{upper, center, lower\}$

2.3. Fruit harvest

Date fruits were harvested selectively in multiple rounds from August to October each year. The growers harvested the fruits into special harvesting trays and left them below each tree. On each harvest round, the research team weighed each tree yield (kg·tree^{-1}). During each harvest round, the research team randomly sampled approximately 100 fruits from each tree; a total of four to eight hundred fruits each year for each thinning protocol. Each fruit was weighed individually (g). The individual fruits were categorized into four individual fruit weight categories, following the industry's standards: less than 15 g, 15 g–18 g, 18 g–23 g, and 23 g or more. The percentage of each fruit weight category was calculated for each thinning protocol (higher fruit load, lower fruit load) and year. The estimated yield (kg) of each weight category was determined by multiplying the percentage of the category by the average tree yield for the corresponding protocol and year.

Following the harvest, fruit pallets were transferred to the packinghouse and stored at −18 °C until sorting. Fruit harvested from the same four trees across all rounds was consolidated into a single batch, yielding approximately 400–600 kg. Upon completion of all harvest rounds, each batch—identified by grower and thinning protocol—was sorted at the packinghouse, by the automatic sorting machine, into 23 predefined commercial categories. The categories were based on individual fruit weight and quality criteria according to the standards of the marketing cooperative—level of skin separation, the presence of dry rings or Rutab fruit. For instance, a category might be linked to fruit weight of 18 g–23 g with no skin separation, while another category with the same fruit weight of 18 g–23 g includes up to 15 % skin separation. The packinghouse raw data was consolidated and processed into three quality parameters of skin separation categories—0-5 %, 5–25 %, 25–40 %, two ripening stage categories—Rutab and dry rings, and two additional general categories—damaged (rotten, eaten by birds, etc.) and other. For each batch of fruit harvested from the same four trees, grouped by thinning protocol, grower, and year, the relative proportion of each quality parameter was calculated based on its weight as a fraction of the total batch weight.

2.4. Analyses

2.4.1. The effect of thinning fruit load and date on abscission

To assess how the timing of thinning completion and the remaining fruit load influence abscission, polynomial models were fitted to the data, with thinning completion date expressed as days of the year, starting at January 1st (d). To address non-normality, given that abscission is constrained between 0 % and 100 %, abscission values were transformed as shown in Equation 4. Models of degree one through five, incorporating fruits·bunch^{-1} ($f_{w,\text{ post-thinning}}$) and days since January 1st (d), were evaluated based on root mean squared error (RMSE), adjusted R^2, and Bayesian information criterion (BIC) to balance model fit with complexity, identifying the model with the optimal predictive accuracy and minimized overfitting risk.

Equation 4. Log transformation of abscission level (a, log-odds of abscission) and inverse transformation to recover the abscission level from a

$$a = \log\left(\frac{abscission}{100 - abscission}\right)$$

$$abscission = \frac{e^a}{(1 + e^a)}$$

2.4.2. Effect of fruit load on yield and fruit weight

To investigate the accumulated influence of fruit load—an outcome derived from both the thinning protocol and natural abscission—on tree performance in terms of yield and fruit weight, the number of fruitlets per tree (fruits·tree^{-1}) counted before fruit bunch coverage (mid-July) were correlated with the total harvested yield (kg·tree^{-1}) and the partial yield (kg·tree^{-1}) of four fruit weight categories at harvest (less than 15 g, 15 g–18 g, 18 g–23 g, and 23 g or more).

2.4.3. Seasonal effect on fruit quality parameters

To investigate the impact of season on fruit quality, a Kruskal-Wallis one-way ANOVA [11] was conducted to assess differences in the relative proportions of three skin separation categories (0–5 %, 5–25 %, 25–40 %) and two ripening stages (Rutab and dry rings) across different harvest years.

2.4.4. Exploration of comparable thinning protocols

To examine the effects of varying fruit loads on yield, fruit weight, and quality under comparable thinning protocols, growers were invited to implement an additional experimental thinning approach. This approach involved modifying fruit loads—either higher or lower than their standard commercial thinning—on four adjacent trees, according to each grower's discretion. T-tests were performed to compare the yield of trees (kg·tree^{-1}) and the distribution of individual fruit weights between each pair of comparable thinning protocols. To investigate the impact of fruit load on fruit quality, the difference in relative proportions between higher and lower load protocols was calculated for three skin separation categories (0–5 %, 5–25 %, 25–40 %) and two ripening stages (Rutab and dry rings) for each comparable thinning protocol. A t-test was conducted to assess whether the calculated difference significantly deviated from 0 for each skin separation category and ripening stage.

3. Results

In total, twenty-three sets representing different thinning protocols (6 for 2021, 7 for 2022, and 10 on 2023) were included. Each thinning protocol was monitored on four adjacent trees. The four trees were visited at least twice for fruitlets counting, and once or twice at harvest. The after thinning and before coverage averaged fruit·bunch^{-1} of whorl and fruit·tree^{-1} are provided in Suppl. Table 1. Four growers performed thinning in two stages—reducing the load on the upper bunches in mid-March to early April and thinning the lower whorl bunches at mid-April to early May. At the early stage, growers tended to leave a higher load on the trees, with an average of 6600 fruitlets per tree, with considerable variation ranging from 3400 to 13,000 across different growers and seasons. Bunches thinned later in the season had fewer fruits remaining than those thinned earlier. The calculated abscission levels for each thinning event, i.e., average abscission of a bunch in a whorl, by a specific protocol for a specific grower in a year, is presented in Suppl. Table 2.

3.1. The effect of thinning date and fruit load on abscission

We examined the impact fruit load and date of end of thinning on abscission level at bunch coverage. Fig. 3 plots the abscission ratio associated with each averaged number of fruitlets left per bunch (fruits·bunch^{-1}) for a specific whorl (lower, center, upper) in a given farm and year (2021, 2022, 2023). Five polynomial linear models of degrees one through five were developed, with their respective RMSE, adjusted R^2, and BIC (Bayesian information criterion) values displayed in Suppl. Fig. 1. After considering the trade-off between model fit and complexity, the second-degree model, with adjusted $R^2 = 0.72$, RMSE = 10.2, and BIC = −79.71, was selected as the most balanced and interpretable providing reliable predictive accuracies. The selected model is detailed in Equation 5 and visualized as a surface plot in Fig. 3. Abscission was significantly higher at the beginning of the season. Indeed, growers thinning early in the season left more fruit per bunch. Abscission decreased as the season progressed, particularly during the later thinning stages.

Equation 5. Log transformed abscission (a) as a function of thinning date (d, days since January 1st) and fruits left on bunch after thinning ($f_{w,thinning}$).

$$a = -0.09{*}d + 0.006{*}f_{w,thinning} + 0.0002{*}d^2 - 0.00002{*}d{*}f_{w,thinning} - 0.000001{*}f_{w,thinning}{}^2$$

3.2. Effect of fruit load on yield and fruit weight

The correlation between the number of fruitlets per tree (fruits·tree^{-1}), counted at fruit bunches coverage (mid-July) in preparation for the harvesting period, tree yield (kg·tree^{-1}), and the partial weight (kg·tree^{-1}) of each of the four fruit categories at harvest (less

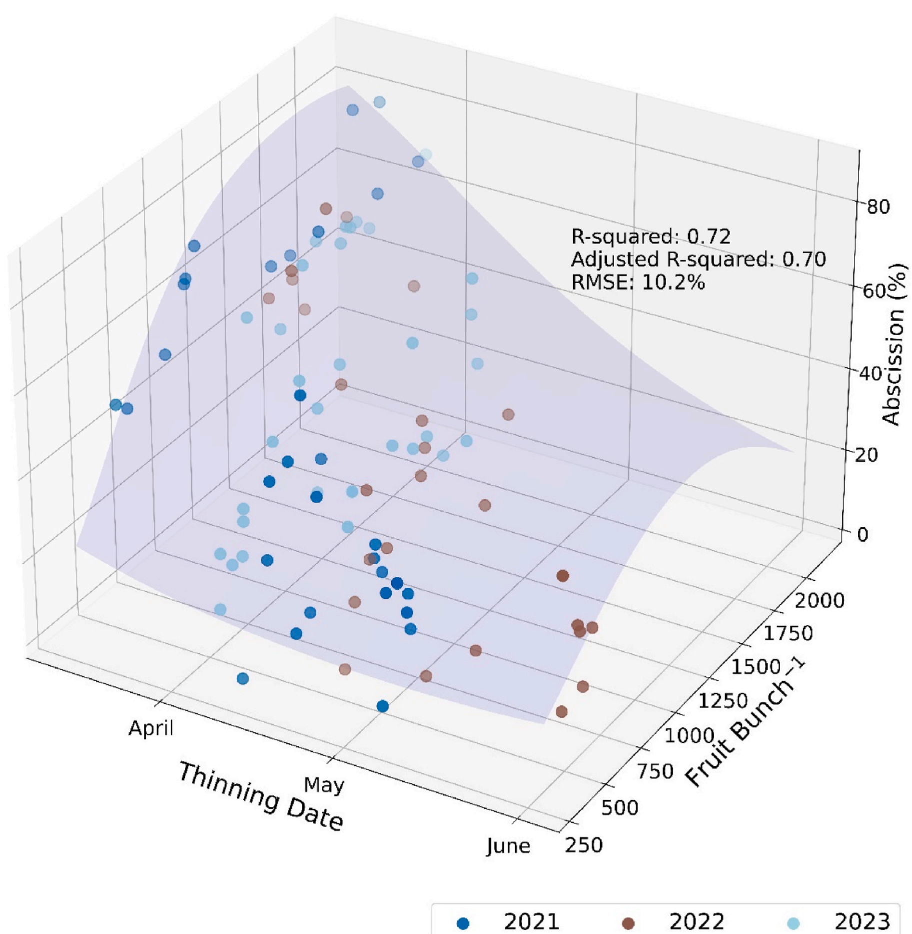

Fig. 3. Abscission ratio by thinning date and post-thinning fruits on bunch. Each dot represents the average number of fruitlets left per bunch (fruits·bunch^{-1}) for a specific whorl (lower, center, upper) in a given farm and year (2021–2023), with colors denoting different years. The abscission ratio (%)—calculated as the difference between fruit counts at the end of thinning and before bunch coverage, divided by the end-of-thinning counts (Equation 3)—was averaged across all bunches within each whorl, thinning protocol, and year. Thinning dates are shown as month and day to reflect days since January 1st of the corresponding year. Surface plots depict the back-transformed (Equation 4) abscission values calculated in Equation 5.

than 15 g, 15 g–18 g, 18 g–23 g, and 23 g or more) is presented in Fig. 4. A significant positive correlation was found between the number of fruits counted before bunch coverage and the total average yield per tree ($R^2 = 0.48$, $p = 0.0002$). Significant correlations were found between fruits counted before bunch coverage and the yield of three fruit weight categories (kg·tree^{-1}): below 15 g ($R^2 = 0.24$, $p = 0.0137$), 15 g–18 g ($R^2 = 0.37$, $p = 0.005$), and 18 g–23 g ($R^2 = 0.47$, $p < 0.001$). However, no significant correlation was observed for the largest fruit weight category, 23 g or more ($p = ns$).

3.3. Seasonal effect on fruit quality parameters

Fig. 5 presents the relative proportion of the quality parameter of fruit from the combined harvest of the four trees treated with the commercial protocol, grouped by grower and year. A one-way ANOVA indicated statistically significant differences between years for the 5 %–25 % skin separation ($H = 6.44$, $p = 0.03$) dry-rings ($H = 10.52$, $p = 0.005$) and damage ($H = 6.17$, $p = 0.045$) categories. Large variation was detected between different growers and different years. In 2021 and in 2023 relatively low levels of skin separation were detected and higher levels of fruits with dry rings were observed. On the other hand, in 2022 almost no dry fruit with rings were observed and the level and severity of skin separation was generally higher. Over the three consecutive years, we could not single out any grower who consistently demonstrated superior fruit quality performance.

3.4. Exploration of comparable thinning protocols

In total, four growers (one of them over two years) provided pairs of comparable protocols—the commercial protocols applied in their plots and an experimental one with different, higher or lower, fruit loads. Each grower applied each of the protocols to four adjacent trees grown in the same plots. Three growers experimented with a higher load protocol, which involved leaving more fruit on the tree, while two experimented with a lower load protocol, leaving less fruit on the tree, relative to their commercial protocol. This allowed us to explore the effect of the thinning protocol on natural abscission and the trees' overall performance on the same plots. The commercial and experimental thinning protocols and the corresponding abscission levels are presented in Suppl. Tables 1 and 2, respectively. Fig. 6 displays a timeline illustrating key stages: the dates of pollination, completion of thinning, and bunch coverage. It also shows the fruit load values derived from the higher and

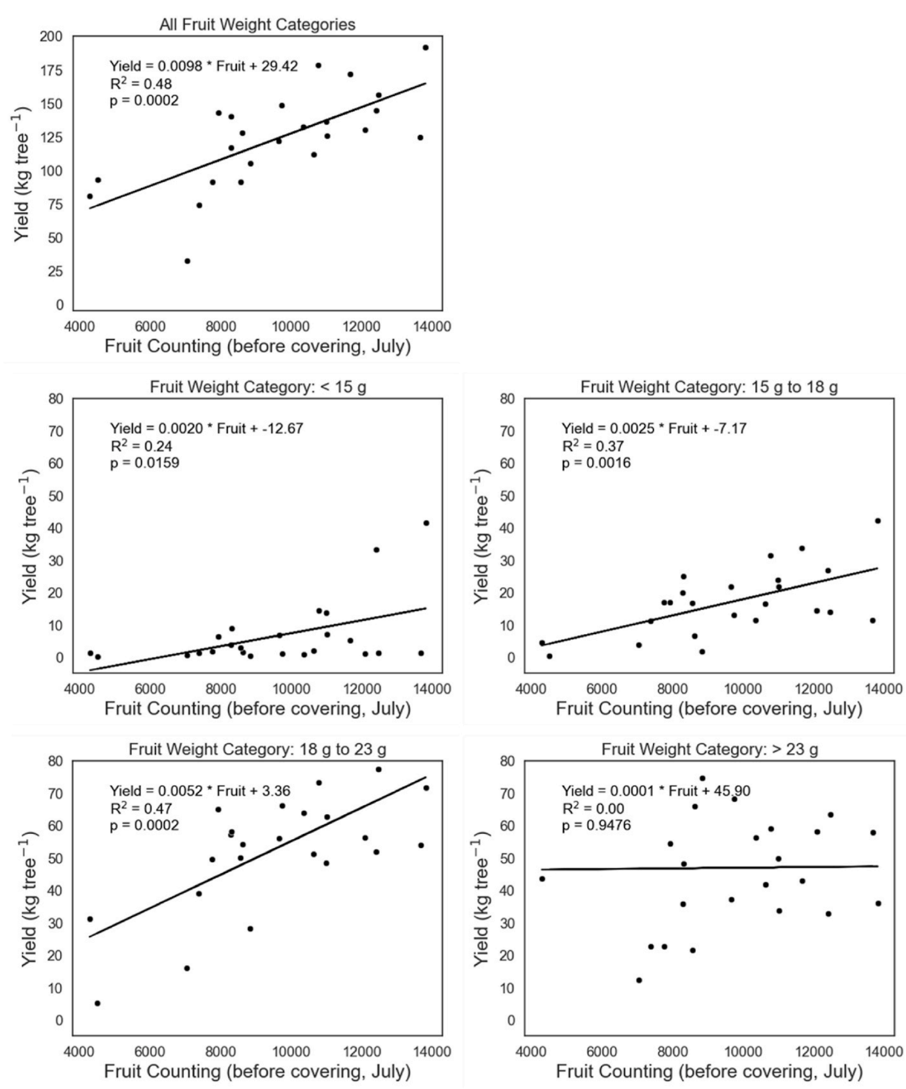

Fig. 4. Effect of fruit load on total harvested yield and partial yield (kg·tree^{-1}) across four fruit weight categories. Tree fruit load (fruit·tree^{-1}) was calculated from fruit counts recorded just before bunch coverage in mid-July, while total and partial yields in four weight categories (<15 g, 15–18 g, 18–23 g, and >23 g) were sampled in-field during harvest. Each dot represents the average yield from four trees under the same thinning protocol, in the same plot, and year. Linear equations illustrate the correlation between fruit load and yield, along with statistical significance.

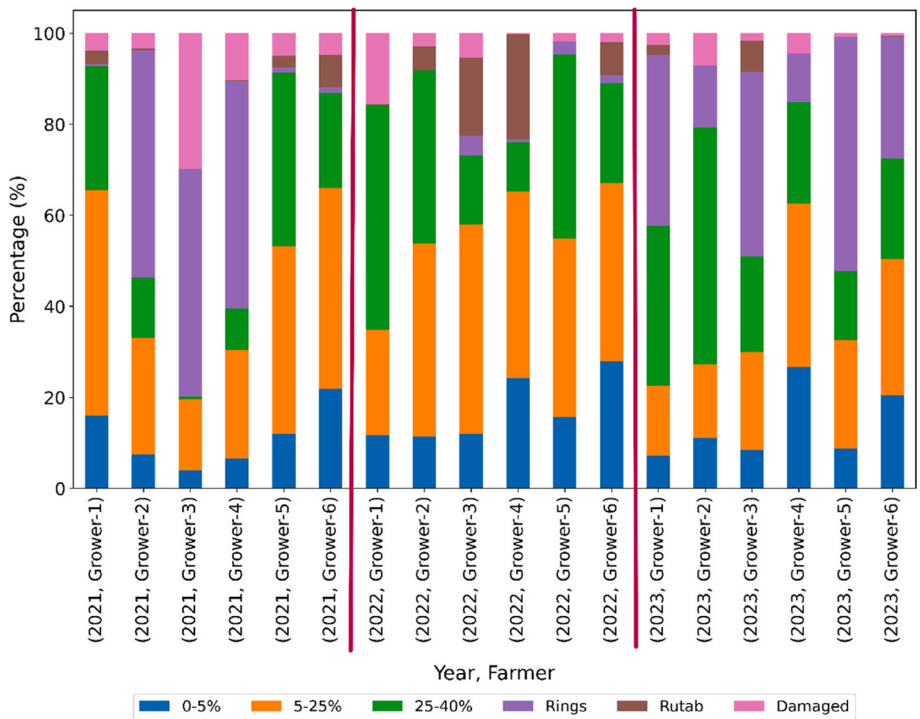

Fig. 5. Fruit quality distribution following commercial thinning protocols applied by six growers over three consecutive years. Fruits from four trees thinned by commercial protocols designed by each grower were sorted in the packinghouse for different quality criteria—level of skin separation, fruits with dry rings (and no skin separation) or Rutab (fruit harvested before completely drying, with a high percentage of water). Data is presented as percentage of each quality parameter from the total fruit yield.

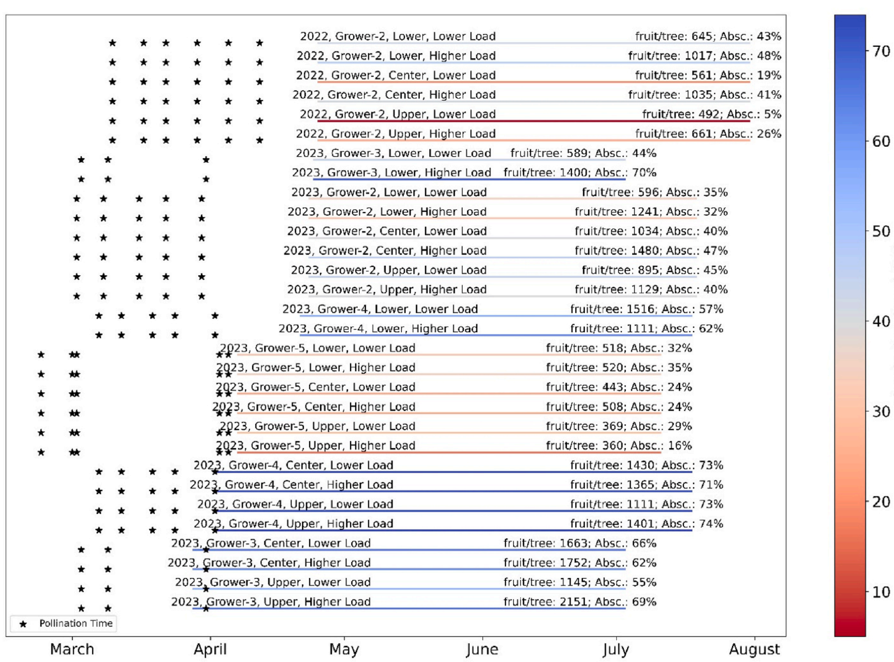

Fig. 6. Timeline of pollination, thinning completion, and bunch coverage for comparable thinning protocols, organized by whorl, grower, and year. Thinning completion, and bunch coverage are represented as the beginning and end of each hotizontal colored line, respectively. Text above each hotizontal line indicates fruit load levels upon thinning completion alongside corresponding level of abscission (Absc.). Fruit load levels at thinning completion represent fruit counts of two bunches per whorl on four trees per grower, per year, and per thinning protocol. The level of abscission is the ratio of the fruit left on each bunch between the two counts, immediately at the end of bunch thinning of each whorl and before bunch coverage (Equation 3). The level of abscission is also represented by color of the vertical line. Commercial pollination events applied to entire trees in the orchards are marked with an asterisk.

lower load protocols applied by each grower for a given year to each whorl, along with the corresponding abscission levels.

Very high abscission levels were observed mainly for the upper and central whorls during mid-April. Bunches of these whorls, or from the lower whorl thinned early in the season, exhibited higher abscission levels. In most cases, bunches thinned to higher loads showed increased abscission levels. This pattern was consistent both when comparing different protocols within each grower and when analyzing all protocols collectively.

The comparable thinning protocols resulted in different yields. The average tree yields (kg·tree^{-1}) for each protocol are summarized in Table 2. All comparable thinning protocols, the protocols with higher fruitlet load, have led to higher yield at harvest. This difference was statistically significant in two out of the five experiments. We compared the estimated yield (kg) of each fruit weight category and the fruit weight distribution across the five different plots and comparable protocols (Fig. 7). In all experiments, thinning protocol with higher fruit load has significantly shifted the fruit weight distribution toward smaller fruits (histogram panels, Fig. 7). Closer observation suggests that this shift is primarily due to a reduction in yield within the 23 g or more weight category, and an increase in the weight of the other three smaller weight categories. From a commercial perspective, this effect translates to only a slight decrease in the largest fruit category, 23 g or more, accompanied by a more pronounced increase in the other three fruit weight categories.

Fig. 8 presents the percentage of the quality parameter of fruit from the combined harvest of the four trees treated with the comparable higher or lower load protocol, grouped by protocol, grower and year. The proportion of dry rings and of fruits with low skin separation (5–25 %) differed significantly between the high-load and low-load thinning protocols ($t = 3.17$, $p = 0.0336$; $t = -3.40$, $p = 0.0274$, respectively). These results suggest that higher fruit loads may increase the incidence of dry rings while reducing the proportion of fruits with low skin separation (5–25 %). Differences in the relative proportions of fruits with no skin separation (0–5 %), high skin separation (25–40 %), and in the 'Rutab' fruit fraction between comparable protocols were not significant.

4. Discussion

Fruit thinning is an important horticultural task, essential to produce high-quality fruits and to fulfill market demands [12]. In 'Mejhoul' dates, thinning is specifically important to achieve the target fruit quality [3,4]. Thinning reduces the fruit load, and resulting yield, below the natural capacity, allowing for increased individual fruit weight and quality. However, the outcome of fruit thinning is often unpredictable, resulting in either over-thinning and lower yields or under-thinning, which leads to higher yields but smaller fruits. In the current project we characterized the effects of different thinning protocols used by 'Mejhoul' growers over three consecutive seasons on tree yield, fruit weight and quality. To remove other effects of post-thinning growing protocols, we also tested thinning to different fruit loads by the same growers within the same plots.

To fully realize the benefits of fruit thinning in increasing fruit weight, thinning in most fruit crops is typically practiced as early as possible on fruitlets or even flowers [12]. Similarly, 'Mejhoul' thinning is performed early in fruit development. However, the success of thinning is influenced by many factors. First, fertilization and level of fruit settings, which are influenced by various conditions, such as temperature, are difficult to estimate and remain largely unknown at the time thinning begins [13,14]. Second, the level of abscission may differ from season to season making its effect unpredictable. Also, temperatures during development may also affect fruit weight at harvest affecting the total yield. Therefore, the variability between years in terms of climate makes it difficult for the growers to predict in advance how these factors will interact with their thinning practice and affect fruit yield, weight and quality.

Large orchards, along with a shortage of workers or machinery, constrain the thinning protocols employed by the growers. We found that some growers begin thinning very early in the season, sometimes thinning the upper whorls while still pollinating the bunches in the lower whorl (Fig. 6). At this stage, the level of fruit set is not detectable. Fruitlet and fruit abscission occur throughout fruit development, with an early peak before and during early thinning practices [10]. This early peak in fruitlet drop leads to a high abscission rate for bunches thinned early in the season, as shown in Fig. 3. Our results support the knowledge of growers who recognize this phenomenon and, as a result, leave more fruitlets per bunch when thinning during the early stages, as shown in Figs. 3 and 6. Bunches thinned later in the season, however, are left with fewer fruitlets, resulting in lower abscission.

Another factor affecting abscission is fruit load. The greater the number of fruitlets left on a bunch, the higher the rate of abscission. This was observed in both the general thinning model (Fig. 3) and in comparisons of protocols with varying fruit loads within the same plots (Fig. 6). These finding reinforces our previous study that demonstrated that natural abscission, particularly during the late natural drop of large fruit occurring in June, has been shown to depend on the fruit load of both individual bunches and the entire tree [10].

The thinning process aims to find a compromise between the total yield and the weight of the individual fruit. As excepted, different thinning protocols applied in April and May, which increased fruit loads in June, resulted in higher yields at harvest. However, the effect was more pronounced in the lower weight fruit categories (less than 15 g, 15 g–18 g, 18 g–23 g, and 23 g or more) while the fraction of the highest fruit weight category (more than 23 g) was less dependent on tree's yield (Fig. 4). This pattern may result from thinning practices in 'Mejhoul' which, even under the higher loads protocols, remain significantly below the trees' natural production capacity. In the five sets of comparable thinning protocols in the same plots, higher fruit loads resulted in an increased yield with a significant shift toward smaller fruits. However, in these experiments, under similar environmental conditions, reduction in the quantities of the very large fruits was notable (Fig. 7). This suggests that factors other than fruit load, such as cultivation protocols or environmental conditions, may influence the largest fruit weight fraction.

While thinning is expected to affect yield and fruit weight, most Israeli growers regard fruit quality parameters—specifically skin separation and dry rings—to be dependent on environmental conditions. Skin separation is a fruit disorder characterized by detachment of the exocarp from the mesocarp tissue [7–9]. While there is a genetic component in skin separation, making some cultivars more susceptible [15], this disorder is mainly related to environmental conditions during development and ripening [8]. In Israel, a gradient in tendency of 'Mejhoul' orchards to exhibit skin separation across a climatic gradient suggests an association with increased humidity [3]. A recent study suggests that skin separation is induced by high diurnal, cyclic stressors of turgor pressure changes prior to the fruit's ripening stage [8] which leads to structural and cellular differences during development [16]. Dry rings are a quality syndrome characterized by the drying of the exocarp at the base of the fruit before ripening, resulting in the formation of a dry ring. Although

Table 2
Effect of comparable thinning protocols on tree yield (kg tree^{-1}).

Year	Grower	Thinning protocol		*t*-test	p-value
		higher load	lower load		
		tree yield (kg·tree^{-1})			
2022	Grower-2	148.365	104.772	10.055	8.73e-08
2023	Grower-2	144.568	135.825	0.93	3.68e-01
2023	Grower-3	191.428	178.145	0.911	3.73e-01
2023	Grower-4	125.27	111.355	1.28	2.48e-01
2023	Grower-5	91.03	74.098	3.012	9.33e-03

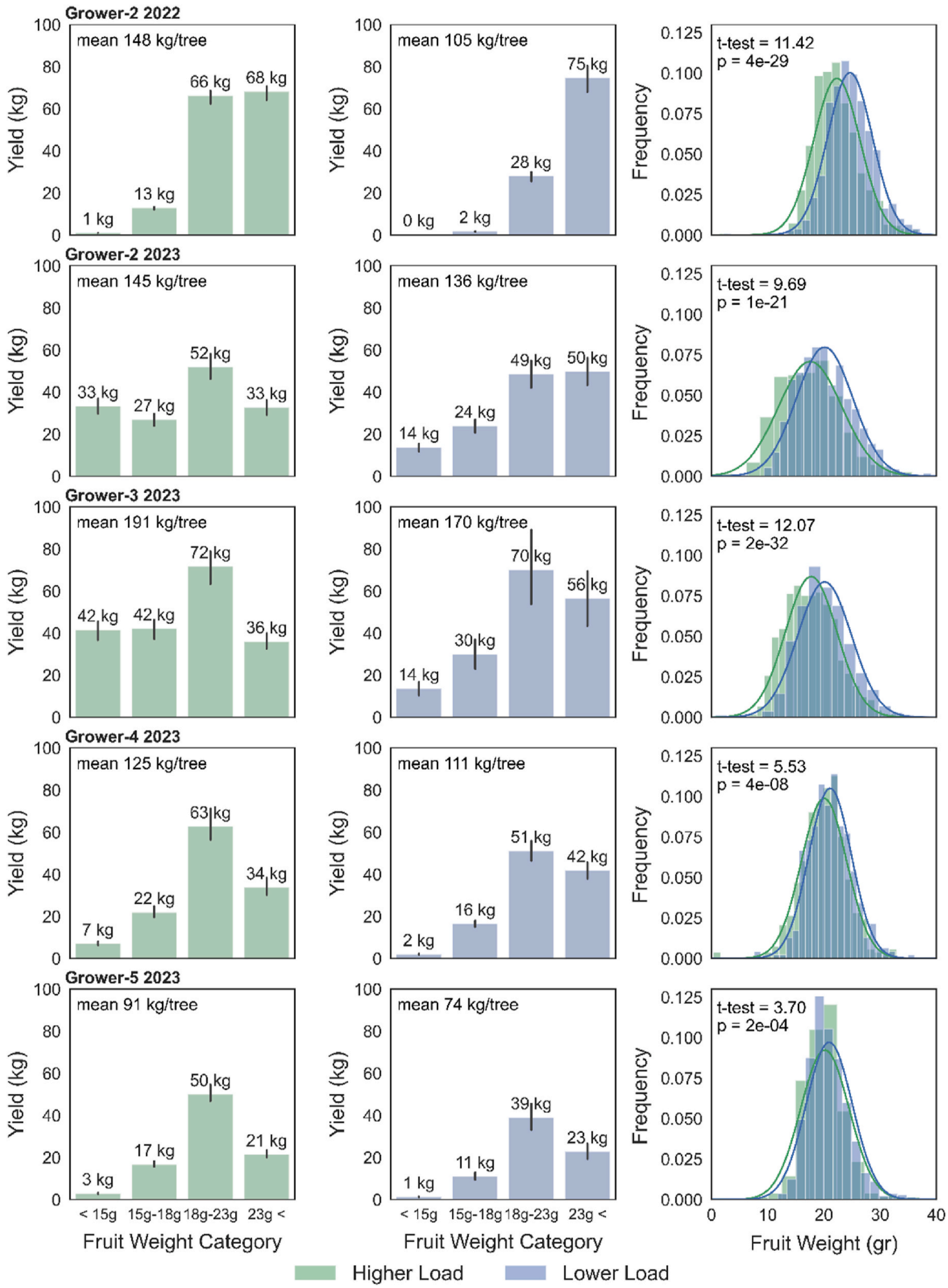

Fig. 7. Fruit weight category yield and fruit weight distribution of five comparable thinning protocols, higher and lower fruit loads, applied by grower in the same plot and year. Blue denotes lower fruit load protocol, Green denotes higher fruit load protocol. **Left and Middle:** Estimated yield (kg) for different fruit weight categories (less than 15 g, 15 g–18 g, 18 g–23 g, and 23 g or more) for each grower and year under both higher and lower thinning fruit load protocols. The mean total yield per tree is reported. **Right**: The distribution of individual fruit weights under the higher and lower thinning fruit load protocols, with a fitted curve for each.

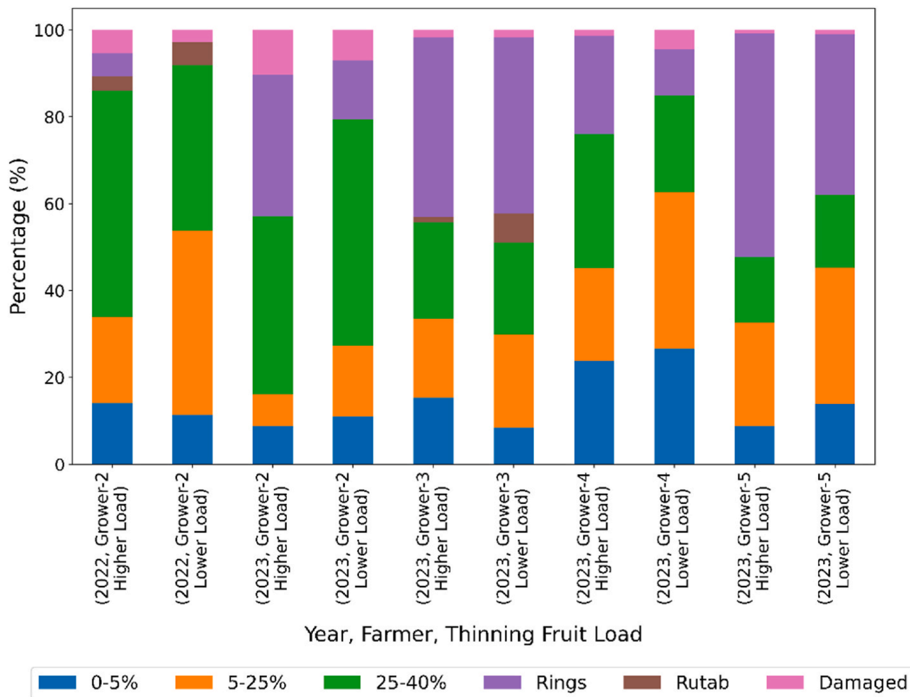

Fig. 8. Fruit quality distribution of five pairs of comparable thinning protocols, applied in the same plot and year. Percentage of quality parameter (skin separation categories—0-5 %, 5–25 %, 25 %–40 %, two ripening stage categories—Rutab and dry rings) represents relative weight from the total fruit yield. Data is presented as percentage of each quality parameter from the total fruit yield.

little is known about this phenomenon, it is suggested to be associated with very hot and dry weather conditions during fruit ripening (Tripler E., Borochov-Naori, H., unpublished results). Our results suggest that seasonal variations possibly due to environmental conditions are the main factors affecting these quality syndromes. In two seasons, 2021 and 2023, skin separation was common and in the third, 2022, dry rings were more abundant (Fig. 5). The findings of the current study suggest that climatic and seasonal differences play a role in fruit quality parameters. However, to address climate in terms of interannual and seasonal variation, further data needs to be collected over multiple seasons. The use of complex models would allow to explore and identify the main climate events that influence harvest outcomes. Recently, it was suggested that fruit thinning of 'Mejhoul' resulted in significantly higher percentage of first grade fruits with lower levels of skin separation than control non-thinned fruits [17]. As described above, the main factors affecting both skin separation and dry rings are environmental, climatic conditions during fruit development and ripening. However, comparing the pairwise experiments with different fruit load, suggest that there are secondary effects of the fruit load itself. In the majority of our pairwise fruit load comparisons, higher loads seemed to increase the incidence of dry rings while reducing the proportion of fruits with low skin separation (Fig. 8). Thinning to lower loads may increase the ventilation in the bunch, allowing faster drying, thus reducing high diurnal turgor stress, leading to reduced skin separation, while higher load may restrict water availability to each individual fruit during very hot days, causing drying of tissues and forming dry rings at the fruit bases. Additional experiments are required to better understand the processes of formation of both skin separation and dry rings, and the factors affecting them.

Date growers face complex decisions, navigating multiple constraints and unpredictable environmental conditions. In their thinning decisions, they may rely on both recorded data and information derived from their own experience, intuition, and acquired knowledge—much of which is often undocumented. Decision support systems (DSSs) can help growers manage their operations more effectively by collecting, maintaining, and analyzing data from various sources. A need for a DSS to support the thinning operation was also suggested for other fruit crops like apples or peaches [12,18]. However, a dedicated DSS for date thinning protocols has yet to be developed (Saraf et al., submitted). The results of the current study could serve as the foundation for developing a regional DSS for Medjool dates in the Southern Arava.

5. Conclusion

This study demonstrates that thinning practices in 'Mejhoul' date cultivation have a complex and multilayered impact on fruit yield, size distribution, and quality. Thinning early, with higher fruit retention, appeared to increase abscission and the proportion of smaller fruits. Importantly, fruit quality phenomena such as skin separation and dry rings appear to be primarily driven by climatic factors, moderated by seasonal variability, however, fruit load appeared to play a secondary role. These findings underscore the need for adaptive thinning strategies that integrate both agronomic knowledge and real-time environmental data. By capturing growers' experiential insights and combining them with empirical evidence, this research lays the groundwork for the development of a dedicated decision support system tailored to the unique challenges of 'Mejhoul' date production in arid regions.

CRediT authorship contribution statement

Yuval Cohen: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Avraham Sadowsky:** Writing – review & editing, Investigation. **Maia Nusinow:** Writing – review & editing, Investigation. **Noah Morris:** Writing – review & editing, Investigation, Data curation. **Tamir Tikochinsky:** Writing – review & editing, Investigation. **Yael Salzer:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Statement

During the preparation of this work, the authors used ChatGPT to correct grammar and improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2025.102346.

Data availability

No data was used for the research described in the article.

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