

## Assessment of Quality Loss Due to Hail Impact in Citrus Plants

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**Abstract.** *In recent years, the frequency and intensity of natural disasters affecting the agricultural sector have increased considerably as a consequence of climate change. Citrus orchards located in the southern regions of Azerbaijan are particularly vulnerable to these changes. Hail events cause substantial damage to both the productivity and quality parameters of citrus fruits. This article examines the quality losses occurring in citrus fruits during hailstorms and evaluates the socio-economic implications of these losses for local farming households. Natural phenomena such as hailstorms negatively influence agriculture by reducing both product quantity and quality. Mechanical injuries inflicted on fruits diminish their marketability, shorten shelf life and result in lower sales prices. Consequently, the accurate estimation of quality loss is a prerequisite for the correct monetary valuation of damage. Based on field observations and farm level from the Lankaran and Astara regions, the proportions of hail damage, crop loss, and market price changes were analyzed. Furthermore, the effectiveness of existing insurance mechanisms and the extent of implementation of technical anti-hail protection measures were assessed, and the principal challenges faced by farmers were identified.*

**Keywords:** *citrus orchards, hail damage, quality loss, socio-economic impact, agriculture, climate risk*

### Introduction

Citrus cultivation is one of the promising branches of agriculture in the subtropical zones of Azerbaijan. The “State Program for the Development of Citrus Fruit Growing in the Republic of Azerbaijan for 2018–2025”, prepared in accordance with Presidential Decree No. 3227 dated September 12, 2017 “On additional measures for the development of citrus fruit, tea and rice production in the Republic of Azerbaijan”, aims to strengthen state support for citrus production, ensure the effective utilization of sectoral potential and stimulate citrus fruit output (President of the Republic of Azerbaijan, n.d.).

Citrus (Latin: *Citrus*) is a genus belonging to the family Rutaceae within the order Sapindales. The internationally recognized scientific name of the genus is *Citrus* L., 1753 (Linnaeus, 1754). Citrus fruits (lemon, orange, tangerine, grapefruit, etc.) are widely cultivated in the subtropical zones of Azerbaijan and possess considerable economic significance.

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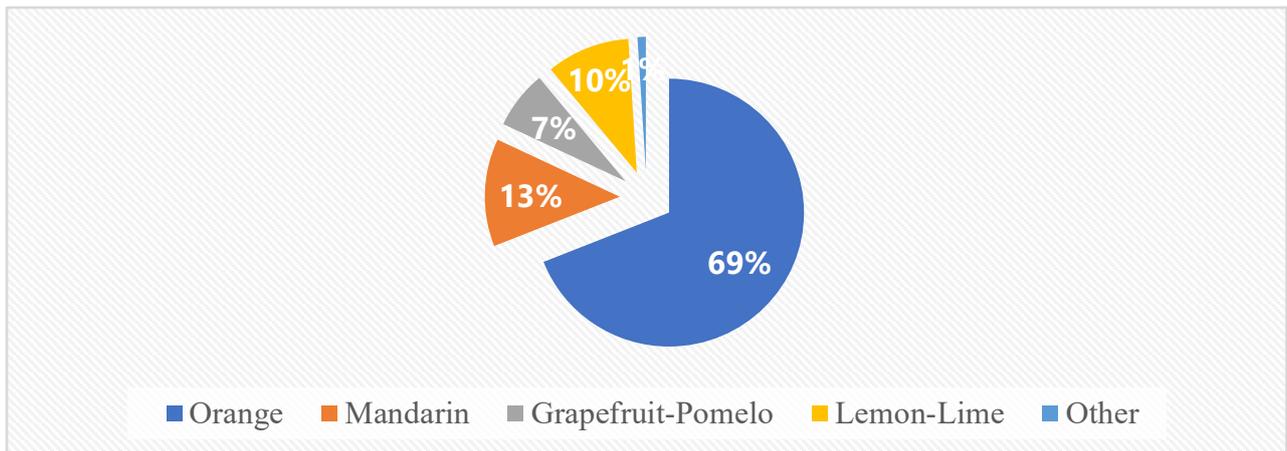
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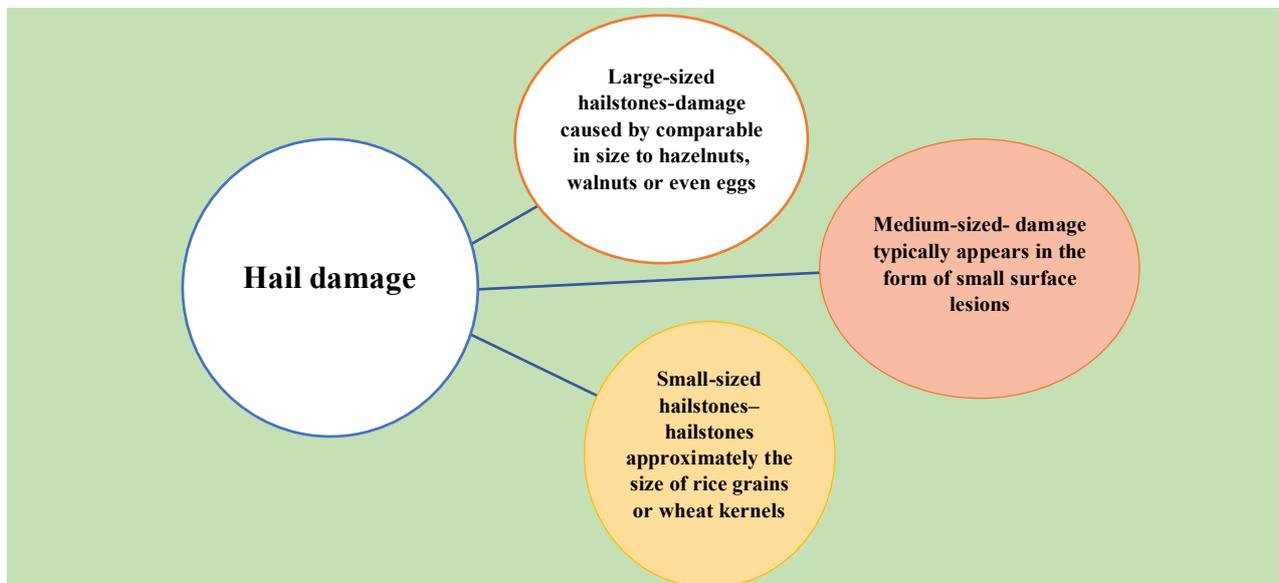
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**Figure 1.** Distribution of global citrus fruit production by species

As illustrated in Figure 1, oranges rank first in global production volume. Mandarins occupy second place with approximately 13%, while lemons and limes collectively account for about 10% (Hasanov & Aliyev 2011; FAO, 2021). According to data from the State Statistical Committee of the Republic of Azerbaijan, in 2024, mandarin orchards constituted 71.8% (3278.5 ha) of the total cultivation area (4564.1 ha). Lemons (15.4%) and oranges (12.8%) follow, respectively (State Statistical Committee of the Republic of Azerbaijan).

The productivity and quality of citrus crops are strongly influenced by agro-climatic factors (frost, hail, snow, wind, storms, floods, excessive rainfall etc.). Among this hazards, hailstorms are particularly destructive, causing severe losses in both yield and quality. Mechanical impacts, surface deformation and spotting of fruits during hail events significantly increase the proportion of non-marketable produce.



**Figure 2.** Categories of damage based on hailstone size

## Methods

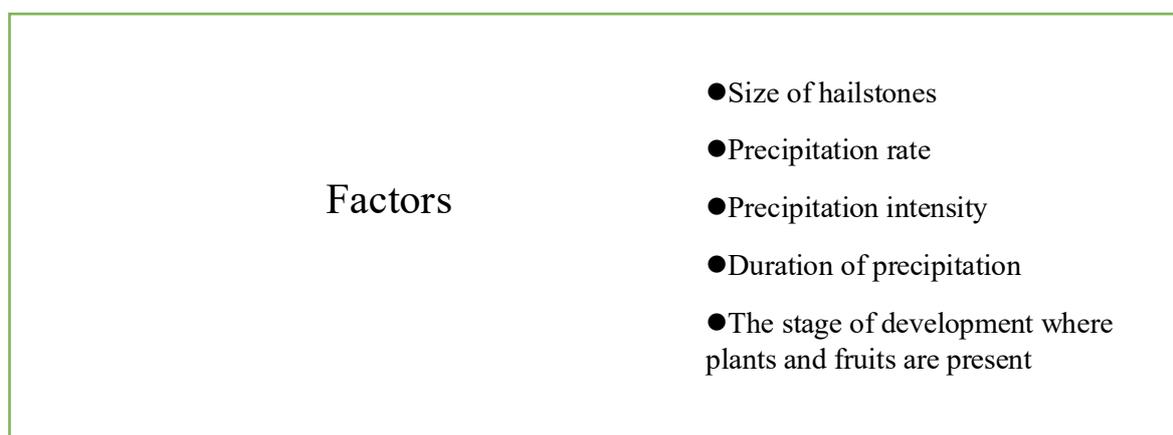
Sampling and registration procedure:

*Exclusion of fallen fruits:* Fruits that fall to the ground as a result of hail are recorded as a quantitative loss but are excluded from quality loss calculations. Quality loss is determined solely for fruits remaining on the tree canopy.

*Sampling:* A defined number of fruits (e.g. 50) are collected from the damaged area using a random sampling approach to represent the overall damage level.

*Classification:* Sampled fruits are categorized according to established regulatory tables.

Large hailstones striking fruits or peduncles cause fruitdrop, cracking of the peel, perforation and abscission of leaves, and cracking of bark on branches and shoots. Additionally, such injuries create favorable conditions for bacterial and fungal infections, which may result in dieback of branches and shoots (Adigozelova & Huseynov, 2025; Babayeva & Mammadov, 2025), Medium-sized hailstones generally do not cause fruit abscission; however, they produce superficial wounds on fruits, leaves, and branches leading to tissue darkening. These wounds often enlarge as fruit development continues (Ozdemir & Aksoy, 2018). Small-sized hailstones rupture oil glands in the fruit peel, primarily affecting fruits and leaves (Training material, 2021) (Agrarian Insurance Fund, 2021; TARSIM, 2019).



**Figure 3.** Factors affecting hail damage severity

Although hailstone size, velocity, intensity and duration are critical determinants of damage, the phenological stage of plants is equally important. In other words, hail events occurring outside sensitive developmental stages may not result in yield losses (Aliyev, 2020).

## Results and Discussion

Hail, like other plants, affects citrus crops in two ways, causing quality and quantity losses. The first is the loss of commercial value of the product, which manifests itself in the change in appearance as a result of damage to the fruit peel. The second is the loss of yield due to the fall of flowers and fruits to the ground due to the effects of hail. Depending on the size and depth of the wounds on the fruit, the market value is classified as harmless, slight, moderate, severe, and very severe damage, as shown in Table 1 below (Agrarian Insurance Fund, 2021).

**Table 1.**  
Variation in quality loss in citrus crops during hail events

Quality loss (in points)	Damage level	Total area of injury (cm <sup>2</sup> )	Depth of damage (mm)	Quality loss (%)
1	Harmless	0	0	0
2	Slight	2	2	25
3	Moderate	3	3	50
4	Severe	5	5	75
5	Very severe	Fragmented	Fragmented	100

When calculating quality loss, fruits that fall to the ground as a result of hail are not taken into account. The fruits remaining on the plant's canopy (50 pieces) are collected without selection and classified in the above order. As can be seen from the table, the area of damaged peel on the fruit is 2 cm<sup>2</sup> and a depth of 2 mm, this causes a 25% loss in quality. When the area and depth of hailstones increase to 3 cm<sup>2</sup> and 3 mm, the damage loss increases to 50%, respectively (Figure 3).



**Figure 4.** Visual classification of hail damage on mandarin fruits

As can be seen from the picture, the first fruit from the left is completely healthy since it was not hit by hailstones. Damages of minor diameter and depth are observed on the second fruit. In the third fruit, the damage caused by hailstones has increased in both volume and depth, which has caused a loss of quality that reduces its appearance and commercial value. The fruits shown in the fourth and fifth pictures will certainly have no commercial value since they have been severely damaged by hailstones. In such cases, it is advisable to collect the damaged product and deliver it to juicing plants for the purpose of extracting fruit juice. Of course, in the above cases, the remaining damage is paid to the insured by the Agricultural Insurance Fund. The calculation of quality loss in citrus plants is given in Table 2.

**Table 2.**  
Calculation of quality loss during hail risk event

Trees examined N	Tree yield before damage (kg)	Fruits falling to the ground due to risk		Classification of damage in fruits (%)					Quality loss (%)	Quality loss damage ratio (%)	Total loss ratio (%)
		kg	%	0	25	50	75	100			
A	B	C	D	0	25	50	75	100	E	F	D+F
1	20	3	15,00	13	10	14	7	6	33,5	28,5	43,5
2	30	8	26,7	15	8	12	10	5	34,4	25,3	52,0
3	39	13	33,3	7	15	10	11	7	31,4	20,9	54,2
Avg.	29,7		25,0							24,9	49,9

It should be noted that fruits that fell to the ground or remained on the tree but experienced a 100% quality loss due to hail impact were considered as fallen fruits. As shown in the table, in this case the loss amounted to 25.0%. The damage resulting from loss was 24.9%. Thus, it was determined that the total damage to a citrus orchard caused by hail accounted for 49.9% of the total. It is important to note that the yield of fruit trees can usually be determined using two methods:

1. By calculating: Number of main branches per tree × number of lateral branches per main branch × number of twigs per lateral branch × average number of fruits per twig × average weight of a fruit ÷ 1000.
2. By canopy assesment: All fruits in ¼ of the tree canopy are examined and counted. The resulting number is multiplied by four to estimate the average number of fruits per tree, which is then multiplied by the average fruit weight to determine the tree's average yield.

For a citrus orchard, planted with a spacing of 5x3 meters, there are on average 666 trees per hectare. During the calculation, the average yield per tree was 29.7 kg, which is equivalent to 197.8 centners per hectare. Therefore, the loss of yield due to both quantitative and qualitative factors in the citrus orchard amounted to be 98.0 centners per hectare (197.8 x 49.9%). Naturally, in the such cases, the remaining loss is compensated to the insured by the Agrarian Insurance Fund. Both the insurance sum, the insurance premium and insurance payout are calculated as follows:

- The insurance amount is calculated using the following formula: Insurance sum= Area x expected yield per hectare x market price per center. In our example, for a 5 hectare orange orchard in Lankaran, with an expected yield of 197.8 centners per hectare and a market price of 150 AZN per center, the insurance sum amounts to 148,500 AZN (5×197,8×150).

- Insurance premium = insurance sum x insurance rate/100 According to the decision of the Board of the Agrarian Insurance Fund dated December 30, 2021, No. 26/21 (Ministry of Justice of the Republic of Azerbaijan, n.d.), the “Conditions for Agrarian Insurance of Orange Plants” provide coverage for damage to the fruit part of orange plants caused by the following risks: hail, fire, earthquake, landslide, hurricane, storm, flood, frost, excessive snowfall, wild animal attacks, plant diseases and pests. In this case, the insurance rate for the Lankaran-Astara region was accepted as 2.56%. The insurance rate for the coverage of quality loss due to hail is 1.05%. If the farmer wishes to insure the crop against quality loss as well, then the total insurance rate is 3.61% and the calculated as follows: Insurance premium = 148500 x 3.61%/100 = 5360.86 AZN. The insured pays 50% of the premium, which in our example is 2680.43 AZN.

- Insurance payout = 148500 x 49.9% – 148500 x 10% = 59251.5 AZN.

Here, 49.9% represents the damage caused by hail in terms of both quantity and quality loss. The 10% is the unconditional deductible (the portion of the loss not covered by insurance and borne by insured).

*Management strategy for damaged crops* – The most appropriate strategy for crops with minimal or no commercial value is industrial processing.

*Delivery to juice factories* Delivery: It is advisable to collect damaged produce (not indiscriminately, i.e. regardless of the degree of damage) and deliver it to juicing plants for juice extraction. This prevents total loss and provides the farmer with an additional, albeit minimal, source of income.

*Cost Considerations*: This process involves taking into account collection costs, transportation costs, and the price offered by the plant. Sometimes, handing over for processing can be more cost-effective than leaving the product in the field.

*The Role of the Agrarian Insurance Fund* – The Agrarian Insurance Fund (AIF) plays a decisive role in reducing the financial risks of agricultural producers.

*Compensation for loss*: In the above cases (i.e., when an insured event occurs), the cost of the remaining damage, including loss of quality, is paid to the insured by the Agrarian Insurance Fund.

*Calculation basis*: The amount to be paid by the AIF is calculated based on the percentage of quality loss determined by assessing the fruits remaining the tree canopy. The financial equivalent of these loss percentages is precisely defined in the Fund's regulations.

*Objective*: This mechanism protects farmers from significant economic losses caused by natural disasters, enabling them to continue production activities and restore investments.

## Conclusion

Accurate assessment of quality loss in fruits due to hail damage is fundamental for agricultural management and insurance mechanisms. Targeted evaluation of crop damage (area and severity) allows farmers to make informed decisions regarding the timing of market sale or industrial processing. Together with the Agrarian Insurance Fund, this process ensures the resilience and financial security of the agricultural sector.

## 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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