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Investigation of Physicochemical Properties and Processing Quality of Grapes in the Food Industry under Different Irrigation Conditions

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ABSTRACT

The initial quality of grapes as a raw material in the food industry, especially in the production of fruit juice, concentrate and fermented products, is directly affected by growth conditions and irrigation management. In this study, the effect of different levels of terflan herbicide application in subsurface irrigation (SDI) system on physicochemical and technological characteristics of grape fruit was investigated during two crop years 1403–1404 in Urmia region. The experiment was conducted in a randomized complete block design with three replications and treatments including: subsurface irrigation without terflan (control), three levels of terflan staged injection (150, 300 and 600 mg), CC pipes, surface irrigation and surface drip irrigation. The measured indices included total soluble solids (TSS), acidity (pH) and juice volume. The results showed that the use of terflan at low (150 mg) and medium (300 mg) doses significantly improved grape quality in terms of TSS, pH, and extractable water content, which is very desirable for the processing industry. In contrast, the high dose of terflan (600 mg) resulted in reduced quality and yield due to toxicity. Overall, the findings indicate the importance of optimal management of terflan use in subsurface irrigation to improve the quality of processed grapes and produce standard raw materials in the food industry.

1- Introduction

Iran, with its diverse climatic conditions and strategic geographic location, is considered one of the leading grape producers in the world. With a cultivation area of approximately 302,000 hectares and an annual production of nearly 1.7 million tons, Iran ranks sixth globally in grape production [1]. West Azerbaijan Province, as one of the main grape-producing regions, with over 20,000 hectares of cultivated area and production exceeding 66,000 tons, plays a key role in supplying raw materials for the country's food industry. A significant portion of this production, in addition to fresh consumption, is processed into various products such as juice, syrup, raisins, concentrate, vinegar, and fermented products, where the quality of the initial fruit plays a decisive role in the final product quality [2].

Given Iran's water scarcity and the importance of conserving water resources, the use of modern irrigation technologies, especially subsurface drip irrigation (SDI), has emerged as an effective strategy to improve water use efficiency and enhance the quality of grapes for the food industry. This system provides uniform water and nutrient supply to the root zone, promoting better growth and improving the physiological condition of the plants. Consequently, it enhances key quality indicators such as total soluble solids (TSS), appropriate pH, and extractable juice volume—all critical parameters for improving flavor, shelf life, and processability of the fruit [3, 4].

On the other hand, emitter clogging caused by fine root growth is one of the main challenges in the long-term operation of SDI systems, which can reduce nutrient availability and indirectly affect fruit quality and the resulting food products [5]. In this context, targeted and stepwise application of the herbicide trifluralin has proven effective in controlling root growth around emitters, preventing clogging, maintaining irrigation efficiency, and improving the physicochemical quality and processing yield of grapes [6].

The use of modern irrigation methods, such as SDI, not only saves water but also plays a significant role in enhancing the physicochemical quality of grapes. Uniform water supply and optimal root nutrition facilitate metabolic processes related to sugar synthesis and acid reduction, ultimately increasing TSS and improving fruit sweetness and taste. These characteristics directly impact the sensory quality and nutritional value of processed products such as juice and concentrate. From a food industry perspective, higher TSS corresponds to greater juice yield and improved final product quality [7]. Additionally, maintaining fruit pH within an optimal range improves taste and is crucial for storage and microbial control in processed products [8].

Emitter clogging due to interfering root growth can significantly reduce irrigation system efficiency and product quality. Trifluralin, with its high persistence and suitability for stepwise application, plays a key role in mitigating this problem. By preventing root intrusion into the emitter zone, the SDI system's performance is preserved, and water distribution remains uniform and stable [9, 10]. This effective control creates ideal conditions for healthy root growth and better nutrient uptake, directly enhancing grape physicochemical quality and juice volume. Therefore, intelligent management of trifluralin use can prevent potential negative effects while substantially improving product quality indicators [11, 12].

Ultimately, improving grape quality and processing yield in the food industry is not limited to optimal irrigation management and root growth control but also requires attention to all agronomic and post-harvest stages. Standardizing harvesting, handling, storage, and processing methods while maintaining fruit physicochemical properties ensures the production of high-quality products with adequate shelf life. Thus, operational studies investigating the effects of modern agricultural technologies on fruit quality and derived products throughout the food supply chain play a vital role in the sustainable development of this industry. The present study, by providing practical strategies for irrigation management and root growth control, contributes effectively to enhancing the quality of grapes and related products in West Azerbaijan Province.

2- Materials and Methods

This study aimed to investigate the effect of stepwise trifluralin injection in a subsurface drip irrigation (SDI) system on grape yield and fruit quality to enhance its processing value for the food industry. The experiment was conducted over two consecutive growing seasons (2012 and 2013) in a uniform, mature vineyard in the Urmia region, one of the country's major grape production areas. The vineyard was selected for uniformity in cultivar type, vine age, soil conditions, and management practices to reduce experimental error and improve the accuracy of treatment effects on grape physicochemical properties.

To evaluate the impact of different doses and application methods of trifluralin in the SDI system on quantitative and qualitative grape performance, the experiment was carried out as a randomized complete block design with three replications.

The experiment included five main treatments:

- **C(0)**: Control treatment with standard SDI and no trifluralin application.
- **C(50+50+50)**: Stepwise trifluralin application in three stages (July, August, and September), 50 mg per emitter per stage, totaling 150 mg.
- **C(100+100+100)**: Stepwise trifluralin application in three stages, 100 mg per emitter per stage, totaling 300 mg.
- **C(200+200+200)**: Stepwise trifluralin application in three stages, 200 mg per emitter per stage, totaling 600 mg.
- **CC (Emitters containing trifluralin)**: Special emitters embedded with trifluralin, gradually releasing the herbicide in the root zone over time. This slow-

release approach provides uniform root growth control in the critical emitter area.

These treatments were evaluated primarily with respect to key industrial acceptance indices such as total soluble solids (TSS), pH, and extractable juice volume.

2.1. Measurement of Grape Physicochemical Properties

To assess grape fruit quality, the following parameters were measured: TSS, pH, titratable acidity (TA), and juice yield. These indicators are crucial for determining quality attributes, storage potential, and consumer acceptance.

1. **Total Soluble Solids (TSS)**

Ripe and healthy grape berries from each treatment were collected, crushed using a mortar or juicer, and filtered through cloth or filter paper to obtain a clear extract. The extract temperature was adjusted to 20 °C to minimize temperature-induced errors. One or two drops of the clarified juice were placed on the prism of a calibrated handheld or digital refractometer, and the °Brix value was recorded as TSS. If the refractometer lacked automatic temperature compensation, temperature correction was applied using the standard table. Measurements were conducted in triplicate for each treatment, and the mean value was reported [13].

2. **pH Measurement**

A digital pH meter, calibrated with standard buffer solutions at pH 4.0 and 7.0, was used to measure grape juice pH. The clarified juice was poured into a clean container to fully submerge the electrode. Measurements were performed at room temperature, and once the reading stabilized, the final pH was recorded. Three replicates per treatment were measured, and the mean value was reported [14].

3. **Titratable Acidity (TA)**

A known volume of juice (10 mL) was diluted with distilled water and titrated with 0.1 N NaOH in the presence of a few drops of phenolphthalein until a faint pink endpoint was reached. The amount of NaOH used was recorded, and titratable acidity was expressed as a percentage of tartaric acid (or citric acid, depending on the fruit type) [15].

4. **Extractable Juice Volume**

A specific weight of fresh, healthy grapes was pressed using a manual or electric juicer to separate juice from the pulp. After removing the pulp, the volume of clarified juice was measured using a graduated cylinder with milliliter precision. This parameter reflects juice extraction efficiency and indirectly indicates the relative moisture content of the fruit [16].

3- Results and Discussion

3.1. Physicochemical Properties of Grapes

From the perspective of food technology and processing quality, the results of trifluralin management in SDI systems revealed dual outcomes. The most notable finding for the processing industry was the exceptional uniformity in the "juice volume" index (CV = 1.75%), indicating that despite the chemical stress from the herbicide, the high efficiency of the SDI system maintained stable fruit hydration. This stability provides a significant economic advantage for industries such as juice and concentrate production, where extraction efficiency and production volume need to be predictable.

In contrast, the greatest industrial challenge was observed in the high variability of "titratable acidity" (TA) (CV = 10.36%). Organic acids act as plant stress indicators; thus, different trifluralin doses caused irregular metabolic responses, resulting in non-uniform flavor profiles (sourness), microbial stability, and processing requirements (e.g., formulation adjustments in jelly production) [17]. This variability complicates the standardization of the final product.

Other key indices, including TSS (CV = 5.50%) and pH (CV = 3.75%), showed moderate variation. TSS changes, directly influencing sweetness and °Brix, likely resulted from the combined effects of chemical stress on photosynthesis and concentration in the berries [17, 18]. Meanwhile, the milder pH variation, aided by the fruit's natural buffering systems, partially compensated for the severe TA fluctuations and facilitated fermentation and thermal processing control [19].

Overall, while this management approach has high potential to provide raw material with uniform juice extraction, the significant fluctuations in titratable acidity necessitate careful monitoring and quality control on the production line to achieve a product with standardized sensory attributes and stability.

Table1. Descriptive Statistics (Mean, Standard Deviation, and Coefficient of Variation) for Physicochemical and Agronomic Traits of Grapevine under Subsurface Drip Irrigation with Treflan Application

Trait	Mean	Std. Dev	CV%
TSS	21.2	1.166	5.50%
TA	0.56	0.058	10.36%
pH	3.12	0.117	3.75%
Juice Content	81.0	1.414	1.75%
Root Volume	33.0	3.162	9.58%

The analysis of variance (ANOVA) for grape fruit traits under different treatments is presented in Table 2.

Table 2. Analysis of Variance: Sum of Squares for All Traits Evaluated in Subsurface Drip Irrigation with Treflan Herbicide Injection in Grapevine (Urmia, 2012–2013)

SOURCE OF VARIATION	TSS (°BRIX)	TA (MEQ/100 ML)	PH	JUICE VOLUME (ML)
YEAR	128.427	0.165984	0.170751	3080.94
TREATMENT	310.37	0.155444	0.110828	12549.00

REPET	0.250^{ns}	0.000231	0.000386	88.30
YEARTREATMENT	2.688	0.005231	0.002787	151.80
ERROR	7.519	0.003367	0.002287	106.30

Based on the analysis of variance, the physicochemical quality and processing potential of grapes were significantly influenced by two main factors: treatment and crop year, each affecting different aspects of the product. The treatment factor (method of trifluralin application), with the largest contribution to variance, was identified as the primary determinant of characteristics related to yield and industrial efficiency, namely total soluble solids (TSS) and grape juice volume. This indicates that agricultural management directly controls the physical quality and the amount of extractable product. In contrast, the crop year factor had a dominant effect on key chemical indices, namely titratable acidity (TA) and pH, highlighting the significant role of annual climatic conditions in shaping the flavor profile and microbial stability of the final product.

3.1.1.TSS Variations

Regarding the interaction effect of treatment and year, the mean comparison table illustrates this interaction. Titratable acidity (TA) is one of the most critical quality indices in fruit evaluation, particularly for grapes, as it directly impacts flavor, sensory balance, microbial stability, and industrial processes such as fermentation and the production of concentrates and juice. In this study, the data from Table 3 showed that different trifluralin treatments in the subsurface irrigation system significantly reduced the TA content in grape fruit, which is of great importance from an industrial perspective.

Table 3. Comparison of the Mean Physicochemical Characteristics of Grape Fruit under Different Terflan Treatments in Two Growing Seasons 1 and 2 years for TSS

Treatment	First year Mean ± Grouping	Second year Mean ± Grouping
C(0)	20.00 ± F	22.55 ± C
C(50+50+50)	23.78 ± B	26.49 ± A
C(100+100+100)	23.81 ± B	26.79 ± A
C(200+200+200)	21.51 ± D	24.45 ± B
CC	20.39 ± E,F	23.56 ± B
11	18.94 ± G	21.11 ± D,E
12	17.88 ± H	19.75 ± F,G

Among the treatments, treatment C(100+100+100) in the second year recorded the lowest TA value with an average of 0.4 g tartaric acid per 100 mL of juice, statistically placed in group I. This reduction in acidity can significantly increase the sugar-to-acid ratio (Brix/TA), a critical index in food science that determines flavor desirability, balanced sweetness, and the suitability of fruit for producing high-quality juices, wines, and concentrates. In contrast, surface irrigation treatments (I1 and I2) exhibited the highest acidity levels, with TA values of 0.62 and 0.63, respectively, accompanied by reduced TSS values. This characteristic may lead to a sour and undesirable flavor in the final product, limiting its use for direct consumption or processing in certain products.

The results for treatments C(50+50+50) and C(200+200+200) showed a similar trend, with TA values of 0.42 and 0.43, respectively, in the second year. These values were lower compared to the control (C_0), which had a TA of 0.49. This reduction in acidity, particularly when combined with increased TSS, improves flavor, reduces the need for artificial sweeteners, and enhances the stability of fermentation processes in industrial applications. Such quality is especially valuable for grapes used in wine or fermented beverage production. The CC treatment (gradual trifluralin release) also showed a relatively favorable reduction in TA (0.46), which, alongside a moderate increase in TSS, makes it suitable for products requiring flavor balance, such as natural beverages, clear or semi-clear juices.

Titratable acidity (TA) is a key quality index for grape fruit, reflecting the amount of soluble organic acids in the juice and playing a significant role in determining flavor balance, shelf life, and fermentation processes in the food industry. This index directly affects the perception of tartness and freshness in the product, with changes in primary acids like tartaric and malic acids influencing TA levels. The significant reduction in TA under treatments with optimized subsurface irrigation and controlled trifluralin application indicates that favorable moisture and nutritional conditions accelerate fruit ripening and enhance the breakdown of organic acids, resulting in fruit with a more balanced and desirable flavor for fresh consumption or processing. From a food industry perspective, the reduction in TA alongside increased TSS enhances the sugar-to-acid ratio, a vital parameter for organoleptic quality and consumer acceptance, leading to grape-derived products like juices and wines with better flavor and longer shelf life. Therefore, precise measurement of TA is a critical standard in quality control for horticultural products, particularly in industrial production, and effective agricultural management can significantly improve this index.

Furthermore, based on previous studies, the reduction in TA combined with increased TSS improves sensory attributes such as mild sweetness and reduced bitterness or sharp acidity. These changes are highly desirable for both fresh consumption and industrial applications. As noted by Yavuz et al. (2020), effective control of water and chemical inputs through subsurface irrigation can regulate fruit acidity balance, thereby enhancing its processing quality.

Table4. Comparison of the Mean Physicochemical Characteristics of Grape Fruit under Different Terflan Treatments in Two Growing Seasons 1 and 2 years for TA

Treatment	First year) Mean ± Grouping (	Second year) Mean ± Grouping(

12	0.63 ± A	0.51 ± D
11	0.62 ± A,B	0.49 ± D,E
C(0)	0.60 ± B	0.49 ± D,E,F
CC	0.55 ± C	0.46 ± F,G
C(200+200+200)	0.51 ± D	0.43 ± G,H
C(50+50+50)	0.49 ± D,E	0.42 ± H,I
C(100+100+100)	0.47 ± E,F	0.40 ± I

3.1.2.pH Variations in Grape Fruit

The study showed that pH changes in grape fruit under different trifluralin treatments were significant, particularly with staged application in the subsurface drip irrigation system. Treatments C(100+100+100) and C(50+50+50) significantly increased fruit pH in both crop years, reaching approximately 3.09, while treatments without trifluralin under surface irrigation (I1 and I2) exhibited lower pH values ranging from 2.98 to 3.05. The increase in pH in optimized treatments resulted from improved rooting conditions, nutrition, and soil moisture stability, leading to higher sugar synthesis (increased TSS) and effective breakdown of organic acids such as tartaric and malic. This process reduces H^+ ion concentration in the fruit cell vacuoles, thereby increasing pH.

From a food industry perspective, this change is highly significant. A higher pH within the optimal range not only provides favorable conditions for controlled fermentation and stable color retention in processed products like wine and natural juices but also reduces the sharpness of acidic taste, offering a milder and more desirable flavor to consumers. This creates an optimal balance between TSS and acidity, which is critical for producing healthy, natural, and high-value-added products.

Table 5. Comparison of the Mean Physicochemical Characteristics of Grape Fruit under Different Terflan Treatments in Two Growing Seasons 1 and 2 years for pH

Treatment	First year) Mean ± Grouping (	Second year) Mean ± Grouping(
C(0)	3.0000 ± G	3.0533 ± C,D,E
C(50+50+50)	3.0533 ± C,D,E	3.0900 ± A
C(100+100+100)	3.0633 ± C,D	3.0967 ± A
C(200+200+200)	3.0400 ± E,F	3.0833 ± A,B
CC	3.0233 ± F	3.0667 ± B,C
11	2.9900 ± G,H	3.0500 ± C,D,E
12	2.9800 ± H	3.0467 ± D,E

3.1.3. pH Variations in Grape Fruit

The pH of grape fruit is a critical quality index that plays a pivotal role in determining the final flavor, microbial stability, fermentation processes, and color of food industry products. The pH of the fruit is influenced by irrigation conditions and herbicide management. In treatments involving staged trifluralin application with subsurface drip irrigation, a significant increase in pH was observed, indicating reduced acidity and improved fruit ripening. This pH increase was associated with higher sugar accumulation (TSS) and the breakdown of organic acids such as tartaric and malic, which accelerates metabolic ripening processes, resulting in a more balanced and pleasant flavor. From a food industry perspective, a pH range of 3.0 to 3.2 is considered ideal for controlled fermentation in juice production, as it preserves color and flavor while preventing the growth of undesirable microorganisms. Additionally, higher pH enhances the stability of anthocyanin pigments in red products and maintains desirable sensory properties. Inefficient surface irrigation and clogged drippers in control treatments led to lower pH and increased acidity, which, in addition to reducing flavor quality, could compromise product shelf life and processability. Thus, intelligent trifluralin management in subsurface irrigation systems ensures root health and enhances the sensory and qualitative attributes of grape fruit.

In studies evaluating grape fruit quality, pH changes and extracted juice volume are key quality indices that are consistently prioritized in the food industry. Fruit pH not only reflects acidity levels and ripening stages but also directly impacts sensory attributes, shelf life, and processing potential. Research indicates that grape pH is lower in early growth stages and gradually increases with ripening, a critical factor for processes such as juice, concentrate, or wine production. Juice volume, on the other hand, reflects the physiological state, juiciness, and tissue composition of the fruit, influenced by environmental, genetic, and management factors such as irrigation or herbicide use. Juice volume is measured using a graduated cylinder and serves as an indicator of processing yield and the amount of free water in the fruit. Under stress conditions, such as the application of certain chemicals in subsurface irrigation systems, changes in fruit cellular structure may lead to variations in pH and juice volume, which can be used as an indirect tool to assess quality and the effects of different treatments in the food industry.

3.1.4.Juice Volume Variations

The volume of grape juice is a key indicator of product quality and performance in the food industry, as the amount of extracted juice directly affects processing yield and the sensory characteristics of final products like grape juice and concentrates. The study showed that staged trifluralin application in subsurface drip irrigation, particularly at moderate doses (C(50+50+50) and C(100+100+100)), significantly increased juice volume in both crop years, placing these treatments in superior statistical groups. In contrast, surface and surface drip irrigation treatments (I1 and I2) exhibited the lowest juice volumes, and even the high-dose trifluralin treatment (C(200+200+200)) showed reduced performance, likely due to potential root toxicity. Juice volume, which is directly related to berry growth and size, is influenced by hydraulic conditions affecting cellular turgor pressure. In this study, successful trifluralin treatments, by maintaining consistent irrigation system performance, ensured continuous water supply to the root zone, promoting improved cell growth, division, and fruit development. Conversely, gradual dripper clogging in treatments without trifluralin or with surface irrigation caused moisture fluctuations and mild to moderate water stress, limiting cell growth and fruit volume. These results indicate that optimized irrigation management with trifluralin can unlock the genetic potential of the plant to increase juice volume, which is critical for the performance, flavor, processing yield, and economic value of food industry products and beverages.

Table 6. Comparison of the Mean Physicochemical Characteristics of Grape Fruit under Different Terflan Treatments in Two Growing Seasons 1 and 2 years for Fruit Juice

Treatment	First year Mean ± Grouping	Second year Mean ± Grouping
C(0)	80.00 ± B	73.50 ± C,D
C(50+50+50)	86.47 ± A	80.90 ± B
C(100+100+100)	87.20 ± A	80.07 ± B
C(200+200+200)	80.83 ± B	74.50 ± C
CC	78.43 ± B	73.30 ± C,D
11	74.40 ± C	68.33 ± E,F
12	70.10 ± D,E	65.40 ± F

In this study, subsurface irrigation treatments combined with controlled trifluralin application, particularly at moderate doses, significantly increased grape juice volume compared to surface irrigation and high-dose trifluralin treatments. This indicates improved plant physiological status, better root development, and more uniform moisture supply, which maintain cellular turgor pressure and enhance berry cell volume. The increase in juice volume not only improves the visual and textural quality of the fruit but also enhances juice extraction efficiency in industrial production lines, leading to reduced processing costs. The reduced juice volume in high-dose trifluralin treatments is likely due to mild root toxicity and disrupted plant physiological activities, which decrease cell growth and turgor pressure. Therefore, optimized irrigation management with intelligent trifluralin application can ensure root health while improving fruit quality and yield in horticultural production, particularly for the food industry. Overall, juice volume serves as a sensitive indicator for evaluating the final quality and processing efficiency of grape products in the food industry.

4-Conclusion

This study was conducted to investigate the effects of different trifluralin management strategies in subsurface irrigation systems on grape fruit quality and root development in the Urmia region. The findings demonstrate that intelligent and staged trifluralin application in subsurface drip irrigation systems significantly enhances grape fruit quality indices. This optimized management increases juice volume, total soluble solids (TSS), and pH while reducing titratable acidity (TA) to desirable levels. These improvements indicate better fruit ripening, more balanced flavor, greater stability in processing, and increased yield in food products such as grape juice and concentrates. Additionally, trifluralin application prevents dripper clogging and ensures uniform water supply, creating optimal physiological conditions for roots and plants, thereby promoting cellular turgor pressure and fruit cell growth. Conversely, excessive trifluralin use or inefficient irrigation management reduces fruit quality and yield. Thus, the controlled and optimized use of trifluralin in conjunction with subsurface irrigation systems represents an effective and sustainable approach to improving quality and productivity in grape production and related food industry products.

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بررسی ویژگی‌های فیزیکوشیمیایی و کیفیت فرآوری انگور در صنایع غذایی با در نظر گرفتن شرایط مختلف آبیاری

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چکیده

کیفیت اولیه انگور به‌عنوان ماده خام در صنایع غذایی، به‌ویژه در تولید آب‌میوه، کنسانتره و فرآورده‌های تخمیری، به‌طور مستقیم تحت تأثیر شرایط رشد و مدیریت آبیاری قرار دارد. در این پژوهش، اثر سطوح مختلف مصرف علف‌کش ترفلان در سیستم آبیاری زیرسطحی (SDI) بر ویژگی‌های فیزیکوشیمیایی و فناوری میوه انگور طی دو سال زراعی ۱٤۰۳–۱٤۰٤ در منطقه ارومیه بررسی شد. آزمایش در قالب طرح بلوک‌های کامل تصادفی با سه تکرار و تیمارهای شامل: آبیاری زیرسطحی بدون ترفلان (شاهد)، سه سطح تزریق مرحله‌ای ترفلان (۱۵۰، ۳۰۰ و ٦۰۰ میلی‌گرم)، لوله‌های CC ، آبیاری سطحی و آبیاری قطره‌ای سطحی انجام گرفت. شاخص‌های اندازه‌گیری‌شده شامل مواد جامد محلول(TSS) ، اسیدیته (pH) و حجم آب‌میوه بود. نتایج نشان داد استفاده از ترفلان در دوزهای پایین (۱۵۰ میلی‌گرم) و متوسط (۳۰۰ میلی‌گرم) بهبود معناداری در کیفیت انگور از نظر TSS ، pH و میزان آب قابل استخراج ایجاد کرد و این امر برای صنایع تبدیلی بسیار مطلوب است. در مقابل، دوز بالای ترفلان (٦۰۰ میلی‌گرم) به‌دلیل بروز سمیت، منجر به کاهش کیفیت و عملکرد گردید. به‌طور کلی، یافته‌ها اهمیت مدیریت بهینه مصرف ترفلان در آبیاری زیرسطحی را برای ارتقای کیفیت انگور فرآوری‌شده و تولید مواد اولیه استاندارد در صنایع غذایی نشان می‌دهد.