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# Effect of co-extraction of pomegranate seed oil with green tea leaves on the extraction yield and quality of extracted oil

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**Abstract –** Co-extraction of pomegranate seed oil (PSO) with green tea leaves (GTL) (0 [control sample], 2.5, 5, 7.5, and 10% w/w) was conducted by cold-press to evaluate the extracted oil quality during storage. The extraction yield was similar to the control sample up to 5% w/w of GTL. Total phenol and chlorophyll content were increased in the extracted oils with increasing the level of GTL. The acid and peroxide values were increased during the storage and the lowest values were achieved for PSO with 5% GTL. Rancimat analysis also confirmed the PV results, therefore using 5% GTL led to providing the highest induction period (11.5 h). Consequently, using 5% of GTL during the extraction of PSO by cold-press could result in an appropriate extraction yield and also present higher oxidation stability. This method does not need any antioxidant extraction from herbs and is very cost-effective, time-efficient, and uses no chemicals.

**Keywords:** oil extraction / oxidative stability / quality / cold-press

**Résumé – Effet de la co-extraction de l'huile de pépins de grenade avec des feuilles de thé vert sur le rendement d'extraction et la qualité de l'huile extraite.** La co-extraction de l'huile de pépins de grenade (PSO) avec des feuilles de thé vert (GTL) (0 – échantillon témoin –, 2,5, 5, 7,5, et 10 % p/p) a été réalisée par pression à froid pour évaluer la qualité de l'huile extraite durant son stockage. Le rendement d'extraction était similaire à celui de l'échantillon témoin jusqu'à 5 % p/p de GTL. La teneur en polyphénols totaux et en chlorophylle a augmenté dans les huiles extraites avec l'augmentation du taux de GTL. Les indices d'acide et de peroxyde (PV) ont augmenté pendant le stockage et les valeurs les plus basses ont été obtenues pour la PSO avec 5 % de GTL. L'analyse Rancimat a également confirmé les résultats du PV. Ainsi, l'utilisation de 5 % de GTL a conduit à fournir la période d'induction la plus longue (11,5 h). Par conséquent, l'utilisation de 5 % de GTL pendant l'extraction de PSO par pression à froid pourrait offrir un rendement d'extraction optimal et présenter également une plus grande stabilité à l'oxydation. Cette méthode ne nécessite pas d'extraction d'antioxydants à partir de plantes et est très rentable, efficace en termes de temps et n'utilise aucun produit chimique.

**Mots clés :** extraction d'huile / stabilité à l'oxydation / qualité / pression à froid

## Highlights

– Pomegranate seed oil has many applications in the pharmaceutical, cosmetic and food industries.
– Co-extraction of pomegranate seed oil with green tea leaves was conducted by cold-press.
– The oil extraction yield was not affected up to 5% w/w of green tea leaves incorporation.
– Incorporating green tea leaves during pomegranate seed oil extraction could produce high-quality oil.
– This method is very cost-effective, time-efficient and uses no chemicals.

## 1 Introduction

Pomegranate (*Punica granatum* L.) has been consumed since ancient times due to its nutritional value (Khoddami *et al.*, 2014). It has been originated in the Himalayas and Mediterranean region and has mostly grown in tropical and

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subtropical countries such as India, Iran, China, and the USA (Khoddami *et al.*, 2014; Paul and Radhakrishnan, 2020).

Pomegranate seed is accounted as a by-product of the pomegranate juice industry. Pomegranate seeds are a rich source of oil corresponding to 12–20% of total seed weight (Costa *et al.*, 2019; Drinić *et al.*, 2020). Pomegranate seed oil (PSO) contains many valuable components including vitamin E, sterols, and more important the "punicic acid". PSO has a remarkable effect on health due to its high content punicic acid (18:3, 9-*cis*, 11-*trans*, 13-*cis*) varies from 32–87%. Other main fatty acid of PSO are C18:2 (up to 24%) followed by C18:1 (up to 17%), 18:0 (up to 2.6%) and 16:0 (up to 4.6%) (Khoddami *et al.*, 2014). Beneficial properties of PSO have changed the pomegranate juice residues from low-value by-products (mainly as waste) to high valuable biomaterial (Khoddami *et al.*, 2014; Tian *et al.*, 2013). Today, PSO has medicinal, health, and food uses especially for its punicic acid, which has pharmaceutical effects (de Melo *et al.*, 2016). However, PSO, due to its high content of unsaturated fatty acid profiles, is sensitive to oxidation (Costa *et al.*, 2019; Drinić *et al.*, 2020; Rezvankhah *et al.*, 2022).

Oil oxidative stability can be improved using antioxidants being added after extraction (Drinić *et al.*, 2020). Antioxidants have several types and mainly they are divided into two synthetic and natural ones. There are concerns about the consumption of synthetic antioxidants due to their potential adverse health effects (Drinić *et al.*, 2020).

Recently, attention to the use of natural antioxidants has increased, and especially consumers prefer to use natural antioxidants instead of synthetic ones (Drinić *et al.*, 2020). The oils can be enriched with natural antioxidants and, thus, the oxidation and rancidity are retarded and oil quality is improved during storage (Osanloo *et al.*, 2021).

Plants are rich in polyphenolic compounds, which potentially indicate antioxidant activity and radical scavenging activity. Green tea leaves (GTL) are one of the richest sources of polyphenolic compounds (Li and Jiang, 2010; Musial *et al.*, 2020).

There are many options, such as using antioxidants, extraction of oils from mixed seedoils, and pretreatments of seedoils before oil extraction, to enhance oxidative stability of oils. Dehghan-Manshadi *et al.* (2020) applied infrared (IR)-assisted spouted bed drying (SBD) as a potential alternative to the traditional hot air drying for heat-sensitive components of flaxseeds. Mazaheri *et al.* (2019a) reported that microwave treatment of black seed before the oil extraction reduced lipase activity more effectively. They reported that the treatment of black seeds with microwaves and soaking them before extracting oil in a cold-press raised the oil oxidative stability. Nain *et al.* (2021) reported that using green tea enhanced the oxidative stability of DHA-rich oil by reducing the formation of peroxides and secondary oxidation products. Drinić *et al.* (2020) used pomegranate peel extract in PSO individually or with a combination with BHT to enhance the oxidative stability of the oil. Mazaheri *et al.* (2019b) investigated the cold-press extraction of sunflower and black cumin seeds and reported that seeds mixing caused an increase in oxidative stability, which increased from 6.78 to 9.69 h.

All of the above-mentioned ways to enhance extracted oils' oxidative stability have advantages and disadvantages. One new way can be blending seedoils with plant materials high in bioactive compounds such as GTL and their coextraction by the press. Therefore, the aim of this work is the enhancement of PSO oxidative stability using GTL as a natural antioxidant. Co-extraction of antioxidant compounds of GTL with PSO as a new method of extraction can be highlighted in industrial applications concerning the production of oil with improved oxidative stability and high content of bioactive components.

## 2 Materials and method

### 2.1 Materials

Pomegranates seeds, which were separated from the Iranian pomegranate cultivar (Saveh Sweet White Peel) after juice extraction, were purchased from local market (Tabriz, Iran). Green tea leaves (*Camellia sinensis* L.) were obtained from local tea market (Tabriz, Iran). All chemical materials were provided from Sigma-Aldrich Co. (St. Louis, Missouri, United States).

### 2.2 Extraction process

PSO was coextracted with green tea leaves using a mechanical screw press apparatus (model P500R, Anton Fries, Germany) (Piravi-Vanak *et al.*, 2022; Rostami *et al.*, 2014). First, pomegranate seeds and green tea leaves were conditioned to moisture contents of 6.4% and 3.7% based on the preliminary oil extraction yield. Then, the mixture of PSO and GTL at a level of 0 (control sample), 2.5, 5, 7.5, and 10% (w/w) simultaneously undergone the extraction process by screw press apparatus. The temperature of extracted oil was not raised over 40 °C during the oil extraction by cold-press. Extracted oil samples were kept for 90 days at room condition in a dark place and their quality was analyzed on the extraction day and every 30 days of storage.

#### Extraction yield

The extraction yield (EY) was calculated based on the weight of obtained oil after extraction and the weight of pomegranate seed powder as the following equation (Rezvankhah *et al.*, 2018):

$$Extraction\ yield\ (\%) = \frac{Extracted\ oil\ amount\ (g)}{initial\ seed\ powder\ (g)} \times 100 \quad (1)$$

### 2.3 Determination of total phenolic content

The total phenolic content of PSO enriched with GTL was determined using the Folin-Ciocalteu method according to the method of Womeni *et al.* (2016) with brief modification. Firstly, 1 mL of oil samples (1 mg/mL) that dissolved in ethanol was mixed with 1 mL of diluted Ciocalteu reagent (1:10, v/v) and 3 mL of sodium carbonate 7%. The prepared mixtures were kept in a dark place at an ambient temperature for 30 min. The absorbance of oil mixtures was determined at 760 nm using a UV-Vis spectrophotometer. Also, pure ethanol was used as the control, and gallic acid at the concentration of 0–0.06 mg/mL was used as a standard. Eventually, the TPC of oil mixtures was expressed as milligram gallic acid equivalents (GAE)/gram samples.

### 2.4 Determination of chlorophyll

Chlorophyll content of PSO enriched with GTL was determined at 670 nm in cyclohexane using the method of Sahin *et al.* (2017). The chlorophyll concentration was expressed as mg of pheophytin per kg of oil.

### 2.5 Determination of acid value (AV)

AV was determined by potentiometric titration in an automatic titrator model G20 (Mettler Toledo, Urdrof, Switzerland) according to Costa *et al.* (2019). Briefly, oil acidity was analyzed by titrating PSO enriched with GTL dissolved in 45 mL acetone: ethanol (1:1, v/v) with 0.4 M NaOH until pH 11. AV was expressed as % punicic acid.

### 2.6 Determination of peroxide value (PV)

The PV was measured according to the method described by Rezvankhah *et al.* (2019). Determination was conducted by titration of 0.1 N KI saturated solutions of the oil with 0.1 N $Na_2S_2O_3$ and starch as an indicator. PV was expressed in mg oxygen equivalent per kg of oil ($meqO_2$/kg-oil).

### 2.7 Rancimat analysis

The oxidative stability of PSO before and after enrichment was evaluated by the Rancimat method at 110 °C in a Rancimat apparatus (Metrohm 743; Metrohm Co., Herisau, Switzerland) according to Costa *et al.* (2019). The oxidation process was conducted upon 2.5 g oil samples at the mentioned temperature at an air velocity of 20 L/h while monitoring mixtures until a sharp increase in the water conductivity corresponded to the oil stability index. The stability of oil mixtures was expressed as the induction period (IP).

### 2.8 Statistical analysis

All data were conducted in three replications and provided in mean and standard deviation. The statistical analysis was conducted by one-way ANOVA and the mean difference between the data was implemented by the Duncan test at the probable level of 5% ($P < 0.05$) using SPSS software (IBM SPSS Statistics 23).

## 3 Results and discussion

### 3.1 Extraction yield

The extraction yield in the cold-press extraction method is affected mainly by the temperature and also moisture content of the seed (Naebi *et al.*, 2022). The effects of the incorporation of green tea leaves on the extraction yield of PSO were evaluated during the mechanical press. Incorporation of GTL at a concentration ranging between 2.5 to 5% did not have a significant effect ($P < 0.05$) on the extraction yield (6.3 to 6.1%) (Fig. 1). However, incorporation of higher than 7.5% significantly reduced the extraction yield. It was thought that GTL at higher concentrations made a mechanical obstacle against the elicitation of oil from the ground seed texture. Eikani *et al.* (2012) reported that the cold-pressing method indicated 4.29% extraction efficiency. Our extraction yield values were higher which can be attributed to the variety and also process condition.

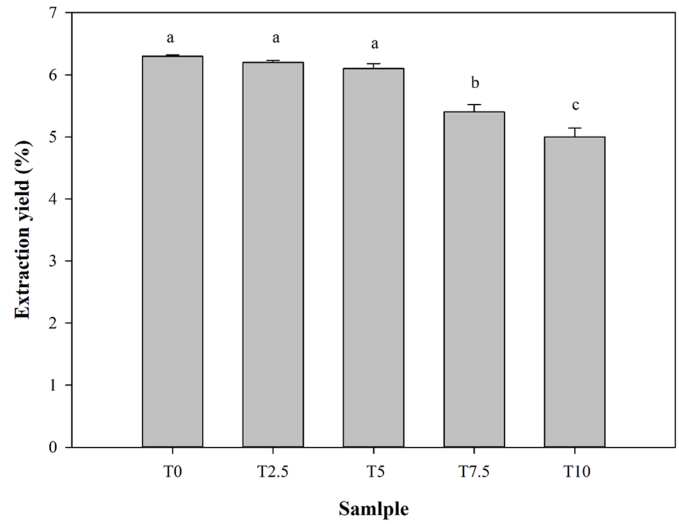


**Fig. 1..** Extraction yield of pomegranate seed oil mixed with green tea leaves at the conditioned moisture content of 6.4% and 3.75%. T0, T2.5, T5, T7.5, and T10 indicate pomegranate seed (control sample), pomegranate seed with 2.5% green tea leaves, pomegranate seed with 5% green tea leaves, pomegranate seed with 7.5% green tea leaves, pomegranate seed with 10% green tea leaves, respectively.

It has been reported that a heating process by temperature 75 °C and moisture content of output seeds in the confine of 6.3–6.5% have yielded the highest extraction efficiency that resulted in high-quality oil production and by-products with the minimum remaining oil content according to the previous studies (Rostami *et al.*, 2014). Also, Naebi *et al.* (2022) declared that the optimum moisture content which gave the highest oil yield (33.5%) was 7.5%. The extracted PSO main fatty acids were punicic acid (C18:3) up to 76% as the main fatty acid followed by linoleic acid (C18:2) about 8.2%, oleic acid (C18:1) about 7.6%, palmitic acid (C16:0) about 4.6% and stearic acid (C18:0) about 2.6% (Khoddami *et al.*, 2014).

### 3.2 Total phenolic content

GTL is rich in antioxidants mainly catechins include epicatechin, epigallocatechin, epicatechin gallate, epigallocatechin gallate, and flavonoid compounds including caffeic acid, quercetin, hesperidin, and hesperetin that inherently increase the TPC (Ebrahimi Monfared *et al.*, 2022; Musial *et al.*, 2020; Palit *et al.*, 2008; Samadi and Raouf Fard, 2020; Yeasmen and Orsat, 2021). Although it has been reported that PSO has a high content of phenolic compounds (Costa *et al.*, 2019; de O Silva *et al.*, 2019), the incorporation of GTL significantly enhanced the TPC of extracted PSO (Tab. 1). Phenolic acids, quercetin and naringenin have also been found in PSO (Costa *et al.*, 2019).

TPC ranged between 2.7 to 12.1 mg GAE/g for control and PSO with 10% incorporated GTL, respectively, which shows

**Table 1.** Total phenol content of extracted pomegranate seed oil incorporated with green tea leaves during the storage.

| Sample | Storage time (day) | | | |
|---|---|---|---|---|
| | 1 | 30 | 60 | 90 |
| T0* | 2.7Be** | $2.3^{Ce}$ | $3.4^{Ad}$ | $3.7^{Ad}$ |
| T2.5 | $3.4^{Bd}$ | $2.8^{Cd}$ | $5.9^{Ac}$ | $6.1^{Ac}$ |
| T5 | $5.6^{Cc}$ | $4.4^{Dc}$ | $6^{Bc}$ | $7.8^{Ab}$ |
| T7.5 | $8.2^{Ab}$ | $4.7^{Cb}$ | $5.3^{Bb}$ | $8^{Ab}$ |
| T10 | $12.1^{Aa}$ | $10^{Ba}$ | $12.2^{Aa}$ | $11.9^{Aa}$ |

* For samples see Figure 1.
** Different small superscripts indicate the significant difference between the samples while the different capital superscripts indicate the significant difference between the days ($P < 0.05$).

**Table 2.** Chlorophyll content of extracted pomegranate seed oil incorporated with green tea leaves during the storage.

| Sample | Storage time (day) | | | |
|---|---|---|---|---|
| | 1 | 30 | 60 | 90 |
| T0* | 0.18Ae** | $0.18^{Ad}$ | $0.15^{ABe}$ | $0.12^{Be}$ |
| T2.5 | $2.1^{Ad}$ | $2^{Ac}$ | $1.7^{Bd}$ | $1^{Cd}$ |
| T5 | $4.3^{Ac}$ | $3.9^{Bb}$ | $2.8^{Cc}$ | $2.8^{Cc}$ |
| T7.5 | $5^{Ab}$ | $4^{Bb}$ | $3.3^{Cb}$ | $3.5^{Cb}$ |
| T10 | $8.6^{Aa}$ | $6.5^{Ba}$ | $6^{Ca}$ | $6^{Ca}$ |

* For samples see Fig. 1.
** Different small superscripts indicate the significant difference between the samples while the different capital superscripts indicate the significant difference between the days ($P < 0.05$).

the positive effect of GTL incorporation on the TPC on PSO. High TPC (10.44 mg GAE/g sample) content was reported for the PSO extracted by cold-pressing from the variety Torshe Malas Iran (Khoddami *et al.*, 2014).

It has been reported that GTL has a high content of polyphenolic compounds, which can donate antioxidant activity (Hu *et al.*, 2021; Musial *et al.*, 2020; Palit *et al.*, 2008). Catechins are the prominent polyphenols of GTL that can render antioxidant and preservation effects (Palit *et al.*, 2008; Unno *et al.*, 2018). The addition of tea polyphenols to oil has shown other beneficial impacts (Palit *et al.*, 2008; Samadi and Raouf Fard, 2020). For instance, it has been reported that rice bran oil cold performance quality was improved after the addition of tea polyphenols. Indeed, rice bran oil retained clear at 0 °C for 5.5 h when tea polyphenols concentration was 0.08% w/w, which could recrystallize in rice bran oil before rice bran crystallization and further promote the nucleation of rice bran oil (Wang *et al.*, 2021).

### 3.3 Chlorophyll content

The plants are rich in natural pigments such as carotenoids and chlorophylls. GTL is also rich in chlorophylls and incorporation of them enhances the chlorophyll content. The addition of GTL significantly ($P < 0.05$) increased the chlorophyll content of PSO on all days of storage (Tab. 2). It has been reported that extracted PSO by the supercritical $CO_2$ method did not have detectable chlorophyll (de O Silva *et al.*, 2019). Storing had also a significant effect and chlorophyll content was decreased during 90 days of storage. This reduction was associated with chlorophyll degradation (Li *et al.*, 2019; Sahin *et al.*, 2017). It should be also pointed out that the addition of a high amount of chlorophyll to the oils with higher PUFAa has sensitizing effects and can increase oxidation (Machado *et al.*, 2022; Rezvankhah *et al.*, 2018, 2019; Roshanak *et al.*, 2016). Chlorophylls can promote the initial autooxidation by their ability to generate alkyl hydroperoxides (Machado *et al.*, 2022;. Rezvankhah *et al.*, 2018). Based on current reports, the presence of high content of chlorophylls in the extracted oil can reduce the oil oxidative stability (Rezvankhah *et al.*, 2018, 2019). So, the incorporation of a high amount of GTL into PSO can have adverse effects on oxidative stability.

### 3.4 Acid value

AV is associated with the free fatty acids and for PSO, punicic acid is principal (Goula and Adamopoulos, 2012; Keskin Çavdar *et al.*, 2017; Tian *et al.*, 2013). The higher the AV determination, the lower the quality of the obtained oil (Drinić *et al.*, 2020). Degradation of triacylglycerol molecules especially occurs during storage due to the presence of oxidation parameters such as inducing moisture, metals, oxygen, etc. (Rezvankhah *et al.*, 2018, 2019, 2020).

It was observed that incorporation of GTL especially at higher concentrations increased the AV (Tab. 3). Also, the incorporation of the GTL enhanced the AV during the storage time. The lowest amount of AV (0.1%) was obtained for the

**Table 3.** The acid value of extracted pomegranate seed oil incorporated with green tea leaves during the storage.

| Sample | Storage time (day) | | | |
|---|---|---|---|---|
| | 1 | 30 | 60 | 90 |
| T0* | 0.9Dc** | $1.1^{Cd}$ | $1.8^{Bc}$ | $2.1^{Ab}$ |
| T2.5 | $0.9^{Dc}$ | $1.2^{Cc}$ | $1.5^{Bd}$ | $1.8^{Ac}$ |
| T5 | $0.1^{Dc}$ | $1.2^{Cc}$ | $1.7^{Bc}$ | $1.9^{Ac}$ |
| T7.5 | $1.3^{Db}$ | $1.8^{Cb}$ | $2.01^{Bb}$ | $2.2^{Ab}$ |
| T10 | $1.5^{Ca}$ | $2.1^{Ba}$ | $2.3^{Aa}$ | $2.4^{Aa}$ |

* For samples see Figure 1.
** Different small superscripts indicate the significant difference between the samples while the different capital superscripts indicate the significant difference between the days ($P < 0.05$).

**Table 4.** Peroxide value of extracted pomegranate seed oil incorporated with green tea leaves during the storage.

| Sample | Storage time (day) | | | |
|---|---|---|---|---|
| | 1 | 30 | 60 | 90 |
| T0* | 2.2Da** | $3.7^{Ca}$ | $4.9^{Ba}$ | $5.2^{Aa}$ |
| T2.5 | $2.1^{Da}$ | $2.3^{Cc}$ | $2.7^{Bd}$ | $2.9^{Ad}$ |
| T5 | $2.2^{Ba}$ | $2.3^{Bc}$ | $2.9^{Ac}$ | $3^{Ad}$ |
| T7.5 | $2.3^{Ca}$ | $2.4^{Cc}$ | $3^{Bc}$ | $3.4^{Ac}$ |
| T10 | $2.3^{Da}$ | $2.8^{Cb}$ | $3.5^{Bb}$ | $4.7^{Ab}$ |

* For samples see Figure 1.

sample with 5% GTL on day 1 and the highest amount (2.4%) was obtained for PSO with 10% GTL on day 90. Drinić *et al.* (2020) reported that the AV was 0.84 mL/g, Dadashi *et al.* (2013) reported 3.78 and 8.36 mL/g for n-*hexane* extraction while 0.63 mL/g for cold-press technology (de Melo *et al.*, 2016).

### 3.5 Peroxide value

Although the incorporation of GTL increased the oil AV, the presence of phenolic compounds can reduce the oxidation rate associated with their antioxidant activity (Maqsood *et al.*, 2014). Also, PSO inherently has antioxidant activity mainly due to the presence of tocopherols and phytosterols (Costa *et al.*, 2019; de Melo *et al.*, 2016). According to Table 4, PV was determined after the incorporation of various concentrations of GTL and during storage. PV was decreased after the addition of 2.5% to PSO while higher concentration had even inducing effects on the oxidation of PUFAs (Bahmaei *et al.*, 2005; Palit *et al.*, 2008). The highest PV (4.7 meq-$O_2$/kg-oil) was obtained for PSO enriched with 10% GTL and the lowest amount (2.1 meq-$O_2$/kg-oil) was obtained for PSO with 2.5% GTL. The addition of a sufficient not excessive amount of polyphenol-rich source to the oils with high susceptibility to oxidation can retard the oxidation and inhibit the propagation (Mazaheri *et al.*, 2019a, 2019b; Palit *et al.*, 2008). However, the higher the polyphenol content, and also the higher the chlorophyll content the higher peroxyl radical production, and thus, oxidation was increased (Li *et al.*, 2019; Rezvankhah *et al.*, 2019). Li *et al.* (2019) declared that residues of chlorophyll induced oxidative rancidity and deterioration through photooxidation in rapeseed oil. They reported that PV of rapeseed oil exposed to light increased significantly, especially for the oil with a high content of chlorophyll. It was also consistent with reports by Bahmaei *et al.* (2005) that pigments present in oil impart an undesirable color and also promote oxidation in the presence of light. Regarding the storage, it was observed that PV was increased in all samples. However, the sample with 2.5% GTL indicated lower PV than control and other samples with higher GTL concentrations (Maqsood *et al.*, 2014). Incorporation of the high amount of GTL into the PSO-rich PUFAs leads to an increase in sensitivity of oil to oxidation since chlorophylls act as light adsorbents and, therefore, oil oxidation be propagated (Rezvankhah *et al.*, 2018, 2019). In addition, based on the current studies, the addition of herbs event without extraction can raise the oil oxidative stability (Ebrahimi Monfared *et al.*, 2022; Nain *et al.*, 2021). As reported by Ebrahimi Monfared *et al.* (2022), the addition of matcha GTL increased the oil oxidative stability led to a higher shelf-life of muesli. Also, Kırmızıkaya *et al.* (2021) reported that black, green, and white tea infusions and powder improved the oxidative stability of minced beef throughout refrigerated storage.

### 3.6 Rancimat

Plants due to their phenolic compounds can enhance the oxidative stability of oils. In the present study, the incorporation of GTL increased the oxidative stability of PSO (Fig. 2). Concerning this, IP values were determined and the lowest

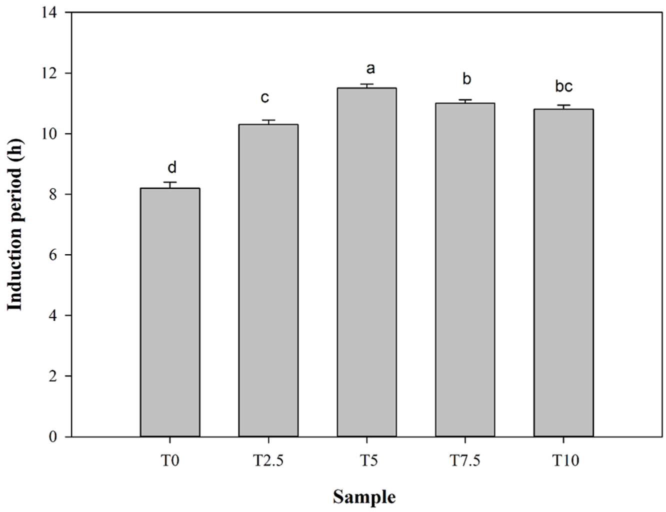


**Fig. 2.** The induction period of pomegranate seed oil with and without green tea leaves at various concentrations (2.5 to 10%). T0, T2.5, T5, T7.5, and T10 indicate pomegranate seed (control sample), pomegranate seed with 2.5% green tea leaves, pomegranate seed with 5% green tea leaves, pomegranate seed with 7.5% green tea leaves, pomegranate seed with 10% green tea leaves, respectively.

amount was obtained for control and the highest amount was obtained for PSO with 5% GTL. Based on the PV and AV results, a higher concentration of GTL induces oxidation due to the high content of chlorophyll and degradation of phenol functional hydroxyl groups, which propagate the oxidation (Li *et al.*, 2019; Womeni *et al.*, 2016; Ye *et al.*, 2020). Thus, a moderate amount of GTL can be more effective in retarding the oxidation. Womeni *et al.* (2016) used old Cameroonian GTL and BHT to evaluate the oxidative stability of RBD palm olein under forced storage conditions. Based on the Rancimat results, the oil with GTL had a higher induction time (24.8–28.9 h) compared with BHT (20.1–22.7 h). Due to the presence of gallic acid, epicatechin gallate, gallocatechin, and epigallocatechin gallate as the main phenolic antioxidants in GTL, the oils with these natural antioxidants would have higher oxidation stability (Womeni *et al.*, 2016). Mazaheri *et al.* (2019b) reported that co-extraction of sunflower oil with black seed oil increased the oxidative stability related to the presence of high phenolic compounds in black seed oil.

## 4 Conclusion

PSO lacking high oxidation stability was enriched with GTL at various concentrations (2.5 to 10%). Using up to 5% GTL did not affect the oil extraction yield. TPC as health-promoting components was increased in the PSO after the inclusion of GTL. In conclusion and general view and based on the factors related to the oxidative stability (AV, PV, and Rancimat analysis), it can be suggested that that PSO coextracted with 5% GTL has good quality and high oxidative stability. Therefore, the coextraction of oil from a mixture of plant materials and seed oils can be suggested as a safe, cost-effective, and time-efficient process for the industry.

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*Conflicts of interest*. The authors declare that they have no conflicts of interest in relation to this article.

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