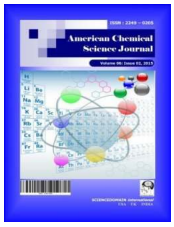

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Effect of Infra-red Drying on the Stability of Physicochemical Properties, Phenolics, Flavonoids and on Antioxidant Activity of *Allium sativum*

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Authors' contributions

This work was carried out in collaboration between all authors. Author LJ design the study, analyzed the spectral data, performed the statistical analysis and wrote the first draft of the manuscript. Author TA performed the in vitro antioxidant assays. Author ZF managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In this work, the effect of infrared drying temperatures on the physicochemical properties and antioxidant capacity of *Allium sativum* was investigated. The following parameters were analyzed: proximal composition, mineral content, total phenolics content, and total flavonoids content. The antioxidant activity was evaluated by means of DPPH, ABTS and and β-carotene assays. Results have shown that a significant alteration in the physicochemical properties was produced at high drying temperatures. However, both total phenolic content and flavonoid content decreased as drying temperature decrease. Thermal processing seems to preserve antioxidant activity at higher temperature.

Keywords: Antioxidant activity; garlic; infrared drying; physicochemical properties.

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1. INTRODUCTION

For many centuries various species of genus Allium have been used as vegetables and spices, and as folk medicines for the curing of various diseases [1]. Garlic (*Allium sativum L*.), belongs to the Liliaceae family. It's a common food spice used widely in many parts of the world. It has been cultivated for centuries all over the world on account of its culinary and medicinal properties [2,3]. According to [4], the garlic cultivation area, yield and production in Tunisia are reported as 3000 ha, 25,000 tons, respectively.

Even today, the medical use of garlic is widespread and growing. Epidemiological, clinical, and preclinical studies have shown close relation between dietary habits, including garlic intake, and the occurrence of disease. Furthermore, garlic was investigated extensively for health benefits, which has resulted in more than 1000 publications over the past decade [5]. It is considered to be one of the best disease-preventive foods, based on its potential and varied effects [6]. A wide array of therapeutic effects, such as hypolipidaemic, antiatherosclerotic, hypoglycaemic, anticoagulant, antihypertensive, antimicrobial, antidote and hepatoprotective, has been reported [7,1]. Most of its prophylactic and therapeutic effects are mostly attributed to the fresh garlic content, rich in γ-glutamylcysteine and many other sulfur-containing compounds in it, which are responsible of the typical odor of garlic [8,9] and giving it a characteristic flavour formed during storage and processing [10-13].

Studies were carried out on the antioxidant properties of garlic and its derivates [14-16]. The antioxidant activity of Allium plants has mainly been attributed to a variety of sulphur-containing compounds and their precursors [17]. According to [18], allicin, diallyl disulphide and diallyl trisulphide appeared to be the main antioxidative compounds in the garlic volatiles. However, [19] demonstrated that alliin [(+)-S-allyl-lcysteine sulphoxide], a precursor of allicin, does not have antioxidative activity in a linoleic acid oxidation system.

Dehydration is one of the most widely used methods for fruits and vegetables preservation. Its main objective is the removal of water to the level at which microbial spoilage and deterioration reactions are minimized. However, it is well known that during hot-air drying, vegetables undergo physical, structural, chemical and nutritional changes that can affect quality attributes like texture, color, flavor, and nutritional value [20]; in addition, the removal of water from the agricultural or food materials is very energy consumption process. The efficiency of the drying of waste materials is an important economic consideration with respect to both energy and time. Therefore, in this study, infrared (IR) drying technique was used to achieve an increase of the effective thermal processing.

IR drying is based on the action of infrared wavelength radiation from a source, which interacts with the internal structure of the sample and thus increases its temperature and favors the evaporation of its moisture content. Moreover, IR energy is transferred from heating element to the sample product without heating surrounding air. Thus, in this radiating process the temperature of the inner layers of the sample is higher than that of the surrounding air. As a result, the drying of the sample takes place from inner to outer layers via both radiation and convection thermal phenomena. This leads to a high rate of heat transfer with respect to conventional drying.

The basic requirements for a vegetable dryer are that it must achieve the required amount of drying in a reasonable time, obtain a product of acceptable quality, and minimize operative costs [21]. Besides, the increasing demand for high-quality shelf-stable dried products requires the optimization of the drying process conditions, especially temperature, with the purpose of accomplishing not only the efficiency of the process but also the final quality of the dried product [22].

Therefore, the aim of this work is to study the effect of IR drying temperature on physicochemical properties, mineral content, total phenolic and flavonoid content, and antioxidant activity that occurred during the drying process of *Allium sativum* cultivated in Tunisia.

2. MATERIALS AND METHODS

2.1 Plant Material

Raw garlic (*Allium sativum L*.) was purchased from local market at the peak of its maturity. The garlic samples were prepared manually. The edible parts were divided into five parts: One of them was used as fresh (raw) garlic (FG), and four others (G-40; G-50; G-60; and G-70) were dried at 40℃, 50℃, 60℃, and 70℃, respectively. After drying, samples were

pulverized into fine powder using a grinder (MF 10 basic mill, GMBH & Co., Staufen, Germany).

2.2 Chemical Properties

Moisture and Ash of garlic samples were determined according to [23]. Nitrogen concentration was obtained by applying the Kjeldahl method, and the protein concentration was estimated using a nitrogen factor of 6.25. The lipid content was analyzed gravimetrically following Soxhlet extraction. The crude fibre was estimated by acid/alkaline hydrolysis of insoluble residues. The pH was determined by potentiometric measurement at 20℃ with pH meter. The acidity was determined by titration with NaOH to pH 8.1, expressing the results in grams (g) of anhydrous citric acid/100 g. All measurements were done in triplicate.

2.3 Mineral Contents

Minerals Potassium, Phosphor, Sulfur, Calcium, Sodium and Magnesium were determined by flame photometry and atomic absorption spectrometry after the digestion of an H_2SO_4, HNO_3 and $HClO_4$ mixture as described by [24]. All determinations were done in triplicate.

2.4 Drying Process

Infrared drying is manifested by an electromagnetic field conveyed by frequencies which excites the water's molecules. The molecular agitation which results from it causes intermolecular shocks that involve a heating of the product and thus the vaporization of the water's molecules. The procedure consists in placing a sample of 40±0,1 g of the product, cut in thin layer (thickness of 3 to 5 mm) inside the device and on an aluminum support placed on the top of the balance. A schematic diagram of the experimental apparatus is shown in Fig. 1.

The technical data of the above infrared dryer and moisture analyzer equipment is as following:

Frequency: 50-60 Hz
Power consumption (max): 660 VA
Temperature range: 40-160℃
Reproducibility of the temperature: 1%
Graduation: 1℃
Time switch (range): 0-300 min
Reproducibility (sample=1g): 0.2%
Resolution of balance: 1 mg

The amount of evaporated water during drying was determined at about 2 min interval in each drying temperature. The samples were dried until they reached a constant weight. Drying tests were replicated three times at each temperature and averages weight loss are reported. Moisture content (g water/g dry matter) was determined using the following equation:

$$M = \frac{(W_0 - W) - W_1}{W_1} \quad (1)$$

Where M is moisture content (g water/g dry matter), W_0 is initial weight of sample, W is the amount of evaporated water, W_1 is the sample dry matter mass.

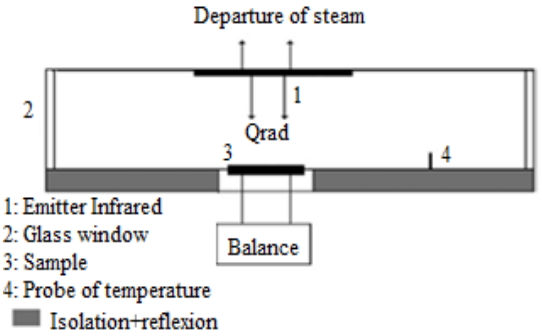

Fig. 1. Experimental apparatus: IR moisture analyzer

2.5 Rehydration Process

Rehydration of the dehydrated samples (40, 50, 60, and 70℃) was done in triplicate using approximately 5.00±0.05 g of dried sample. Each sample was placed in a glass beaker filled with 200mL of distilled water at 20℃ for 10h. The excess water was then allowed to drain for several minutes. Finally, the sample were weighed, packed, and stored at 4℃.

2.6 Extracts Preparation

After IR drying, 5 g of dried samples (G-40, G-50, G-60, and G-70) were extracted in magnetic stirring with 50 mL of methanol (100%) for 30 min. Extracts were kept for 24 h at 4℃, filtered through a Whatman filter paper, and evaporated to dryness under vacuum. Then, the extract was tested for total polyphenolic content, total flavonoid content, and antioxidant activity. In each assay, the activities of the extracts dried by infrared were compared with the value of the extract from raw garlic (FG).

2.7 Total Polyphenol Content (TPC)

Total phenolic content of the (methanol) extracts was determined using Folin-Ciocalteu method [25] slightly modified by [26]. An aliquot of diluted sample extract was added to 0.5 mL of distilled water and 0.125 mL of the Folin-Ciocalteu reagent. The mixture was shaken and allowed to stand for 10 min, before addition of 1.25 mL of 7% w/v sodium carbonate. The solution was then adjusted with distilled water to a final volume of 3 mL and mixed thoroughly, and held for 90min at room temperature. After incubation in dark, the absorbance of the resulting blue color was measured at 760 nm. Gallic acid was used as a standard, and total phenolic content of plant extracts was expressed as milligrams of gallic acid equivalents per gram of dry weight (mg GAE/g DW) through the calibration curve with gallic acid. Data reported of three replications.

2.8 Total Flavonoid Contents (TFC)

Total flavonoid content was measured using a colorimetric method developed by [27]. A 500 µL aliquot of diluted sample or standard solution of (+)-quercetin were mixed with 1.5 mL methanol, 0.1 mL of $AlCl_3$ solution (10%), 0.1 mL of potassium acetate (1M), and 2.8 mL of distilled water. After 30 min incubation at room temperature, the absorbance of the mixture was determined at 415 nm. Total flavonoid content was expressed as µg of quercetin equivalents per gram of dry weight (µg QE equivalent/g DW). All samples were analyzed in triplicates.

2.9 Determination of Antioxidant Assays

2.9.1 Scavenging ability on DPPH radical

The radical scavenging activity of the extracts against DPPH (2, 2'-diphenylpicrylhydrazyl) radical was measured according to [28], slightly modified as follow: One milliliter of different dilutions of extracts were added to 0.25 mL of daily prepared methanol DPPH solution (0,1 mM). The mixture was shaken vigorously and left standing at room temperature for 30 min in the dark. The absorbance of the resulting solution was then measured at 517 nm and corresponded to the ability of extracts to reduce the stable radical DPPH to the yellow-colored diphenylpicrylhydrazine. Control sample was prepared without adding extract. The antiradical activity was expressed as IC_{50} (mg/mL), the extract dose required to cause a 50% inhibition. A lower IC_{50} value corresponds to a higher antioxidant activity of plant extract. The ability to scavenge the DPPH radical was calculated using the following equation:

$$\mathrm{DPPH}_{\text{scavenging effect}}\ (\%) = \left[\frac{A_0 - A_1}{A_0} * 100\right] \qquad (2)$$

Where A_0 is the absorbance of the control, and A_1 is the absorbance of the sample. All samples were analyzed in triplicate.

2.9.2 ABTS assay

ABTS (2,2'-azinobis-3-ethylbenzothiazoline-6-sulphonate) radical-scavenging activity of extracts was determined according to [29]. The ABTS·+ cation radical was produced by the reaction between 5 mL of 14 mM ABTS solution and 5 mL of 4.9 mM potassium persulfate ($K_2S_2O_8$) solution, stored in the dark at room temperature for 16 h. In a final volume of 1 mL, the reaction mixture comprised 950 µL of fresh ABTS solution and 50 µL of the garlic extract at various concentrations. The reaction mixture was homogenized and its absorbance was recorded at 734 nm. All measurements were done after at least 6 min and were recorded as A_{sample}. The absorbance of the blank (with same chemicals, except sample) was recorded as $A_{(blank)}$. The inhibition percentage of ABTS radical was calculated using the following formula:

$$ABTS\ (\%)_{scavenging\ effect} = \left[\frac{(A_{blank} - ABTS_{sample})}{A_{blank}}\right] * 100 \qquad (3)$$

ABTS scavenging ability was expressed as IC_{50} (mg/mL). All samples were analyzed in triplicate.

2.9.3 β-carotene bleaching test

The method described by [30] was used with a slight modification. A β -carotene and linoleic acid solution was prepared by dissolving 0.5 mg of β-carotene in 1 mL of chloroform then adding 25 µL of linoleic acid and 200 mg Tween 40. Chloroform was evaporated under vacuum and 100 mL of aerated distilled water were added.

300 µL of each extract were added to 2.5 mL of this mixture and incubated in a 50℃ water bath for 2 h. Reading of all samples were performed immediately (t=0) and after 2 h of incubation. Distilled water was used as a control, instead of the sample extract, and prepared in the same

manner as the samples with antioxidants from garlic. The absorbance was measured at 470 nm

$$AA\% = \frac{\beta-\text{carotene content after 2h assay}}{\beta-\text{carotene content}} \times 100 \quad (4)$$

Tests were carried out in triplicate. Extract concentration providing 50% inhibition (IC_{50}) was obtained by plotting inhibition percentage versus extract concentrations.

2.10 Statistical Analysis

All quantitative analyses were expressed as mean value ± SD for three replicates. Differences among treatments for each parameter studied in garlic were determined by using the one-way ANOVA test at 95% confidence interval. The statistical differences between the treatment groups were estimated using the Tukey test for multiple comparisons. Statistical analysis were conducted using SPSS, version 14.0.

3. RESULTS AND DISCUSSION

3.1 Moisture Content of Garlic Slices during Drying

Initial moisture content of (FG) was 1,96±0,11g water/g dry matter and final moisture content of four drying samples was as follows 1.39, 1.27, 1.14, and 1.05 (g water/g dry matter), for G-40, G-50, G-60 and G-70, respectively. The drying time for reaching the equilibrium moisture contents at different drying temperatures is shown in Table 1.

The moisture content values obtained for the drying temperatures 40-50-60-70℃ were converted into the moisture ratio (MR). The dimensionless moisture ratio might be obtained using the following equation [31]:

$$MR = \frac{(M_t - M_e}{(M_0 - M_e)} \quad (5)$$

Nevertheless, the moisture ratio was simplified to $M_t/M_{0,}$ where M_t and M_0 are the moisture content at any given time and the initial moisture content, respectively.

Dehydration curves of garlic at 40, 50, 60 and 70℃ are presented in Fig. 2. Drying time decreased considerably when temperature was increased from 40 to 70℃. At higher temperature the rate of water evaporation from the food increases thus causing a reduction in drying time. The decrease in the drying time with an increase in drying temperature for garlic slices have been observed by [32-34] with different methods of drying.

The effect of temperature on the dehydration rate of garlic at 40, 50, 60 and 70℃ temperatures is indicated in Fig. 3. It can be seen that higher drying rates were obtained at higher drying temperatures. The moisture decreased faster at higher drying temperatures in all cases, as expected. Therefore, a higher drying temperature produced a higher dehydration rate and consequently the drying time decreased due to the increase of heat transfer inside the garlic slices, and the acceleration of water migration inside them.

A constant drying rate period was not observed in all cases. The same results have been found for other vegetables in previous reports, in which only the falling drying rate period has been observed [35-39].

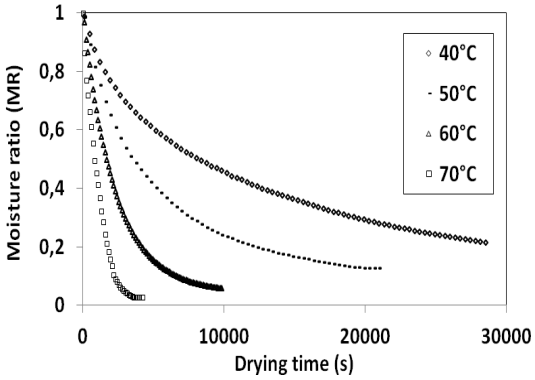

Fig. 2. Drying curves of garlic at different temperatures

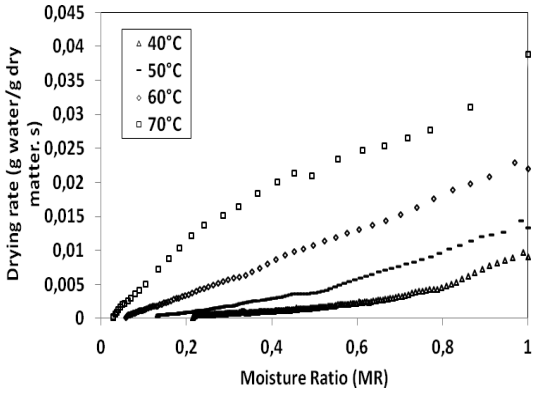

Fig. 3. Drying rates versus moisture content of garlic at different temperatures

3.2 Variation of Chemical Properties during Drying

Analysis of fresh garlic (on 100 g of fresh weight) presented an initial moisture content of 64.88±1.20 g; crude protein (nitrogen×6.25) of 7.69±0.24 g; total lipids of 1.78±0.03 g; crude fibre of 2.84±0.18 g; crude ash of 2.30±0.19 g. Similar results were found by [40].

Table 2 shows the mean values and standard deviations of the composition (moisture, ash, protein, fat, fiber, pH and acidity) results obtained for fresh and dry-rehydrated samples on (g/100 g d.m). Significant differences were found between temperature and the properties mentioned ($p < 0.05$). The moisture content of fresh garlic was higher than rehydrated samples due to cell wall damage caused by the temperature; products with lower final moisture contents were obtained at 60 and 70℃.

Similar results were obtained for the other parameters, the rehydrated samples showed decreased levels of protein, fat, and ash compared to fresh garlic. The loss of protein could be due to denaturation or changes in solubility during drying, which may have caused the proteins to leach out into the rehydration water. The decrease in ash content from 6.55 (fresh garlic) to 4.13 g (sample dried at 70℃) may have occurred as a result of the leaching of soluble inorganic compounds into the rehydration water. The decreased lipid content from 5.07 to 0.91 g in the fresh garlic and at 70℃ respectively, may be due to enzymatic hydrolysis during the first drying period [41]. Crude fibre, the second most plentiful component in garlic samples, was relatively constant in all samples.

In the same table, there was no major variation in pH with values ranging from 6.15 to 6.21, showing the same tendency of acidity. Similar results were found by [42], working on dehydrated red pepper.

3.3 Variation of Mineral Contents during Drying

Table 3 shows the mineral content of fresh and rehydrated garlic at different drying temperatures. K, P and Mg were the predominant mineral in the fresh and rehydrated samples; the peak values in the fresh garlic were: 4364; 1729 and 341,03 (mg/100 g d.m), respectively. The K content in the fresh garlic was three times higher than those in the rehydrated samples. Whereas, Mg in FG was approximately twice the content in the sample dried at 70℃.

However, all rehydrated samples showed a considerable decrease in mineral content with respect to the fresh samples, due mainly to differences in solubility and the leaching of inorganic compounds into the rehydration water. In fact, according to [24], the mineral content may vary widely among vegetables, depending on several factors such as temperature.

Table 1. Drying time and equilibrium moisture content of samples at different drying temperatures

Drying temperature (℃)	Drying time (min)	Equilibri um moisture content (g water/g dry matter)
40	482	1.39±0.172
50	314	1.27±0.095
60	164	1.14±0.066
70	74	1.05±0.043

Values are means ± standard deviation

Table 2. Mean values of chemical properties of garlic dried at different temperature (g/100g d.m)

Analysis	Samples				
	FG	G-40	G-50	G-60	G-70
Moisture (g water/g dry matter)	1,84±0,04^{a}	1.31±0.07^{a}	1.26±0.006^{b}	1.13 ±0.066^{c}	1.04±0.003^{c}
Ash (%)	6.55±0.210^{a}	3.52±0.095^{c}	3.94±0.064^{b}	4.09±0.048^{b}	4.13±0.145^{b}
Protein (N×6.25)	21.60±0.985^{a}	15.88±0.109^{b,c}	15.23±0.143^{c}	16.59±0.461^{b}	16.10±0.127^{b,c}
Fat	5.07±0.16^{a}	2.27±0.02^{b}	2.09±0.04^{b}	1.63±0.08^{c}	0.91±0.02^{d}
Crude fibre	8.08±0.018^{c}	8.84±0.12^{a}	8.72±0.03^{a}	8.34±0.10^{b}	7.86±0.06^{d}
Energy (Kcal/100g)	1181.3±14.8	4022.4±23.4	3605.7±38.7	3512.0±9.4	3377.7±21.2
pH	6.15±0.05^{a}	6.15±0.064^{a}	6.17±0.04^{a}	6.20±0.02^{a}	6.21±0.03^{a}
Acidity (% citric acid)	0.108±0.005^{a}	0.105±0.003^{a,b}	0.098±0.003^{a,b}	0.091±0.003^{a,b}	0.098±0.009^{b}

Chemical components as per weight of dry matter (DM). Values are expressed as means ± standard deviation (n = 3). Means with different letters in the same row were significantly different at the level P < 0.05

Table 3. Mean values of various mineral contents in garlic (mg/100 d. m)

Minerals	FG	G-40	G-50	G-60	G-70
Fe	11.71±0.190^{a}	10.42±0.075^{c}	10.54±0.131^{c}	10.92±0.075^{b}	10.38±0.046^{c}
K	4364.0±34.4^{a}	1247.3±18.6^{b}	1158.0±15.5^{c}	1428.0±15.5^{d}	1333.3±11.1^{e}
P	1729.7±40.2^{a}	1547.6±48.0^{b,c}	1569.7±32.1^{b}	1446.6±22.2^{c}	1490.3±54.0^{b,c}
Mg	341.03±17.49^{a}	279.50±11.07^{b}	250.88±15.25^{b}	248.17±10.01^{b}	206.02±11.22^{c}
Na	150.58±3.06^{a}	148.64±1.24^{a}	145.46±3.09^{a}	143.60±1.83^{a}	147.13±5.34^{a}
Ca	104.45±6.10^{a}	58.27±4.69^{b}	59.47±5.01^{b}	64.57±6.11^{b}	63.85±4.64^{b}

Mineral content as per weight of dry matter (DM).Values are expressed as means±standard deviation (n = 3). Means with different letters in the same row were significantly different at the level P < 0.05.

3.4 Total Phenolic and Flavonoid Contents

Table 4 shows total phenolic content (TPC) (mg GAE/g Dry weight) and total flavonoid content (TFC) (µg CE/g dry weight) for FG and dried samples respectively. TPC in all infrared drying samples were slightly higher than that of FG, it ranged from 0.60 to 0.98 (mg GAE/g DW). Our values were lower than those reported by [43], who compared TPC of raw garlic, bleached garlic for 90" and boiled garlic for 10' and found that the TPC ranging from (6.23-9 mg GAE/g DW), but higher than those reported by [43], who compared the TPC of 3 garlic cultivars and found that the content ranged from 0.075 to 0.115 mg GAE/g DW. Further, all samples from garlic dried by infrared or FG showed almost same total flavonoid content (5.2 to 5.6 µg QE/g DW) (Table 4), our values were higher than those reported by [5] who obtained 4.16 µg QE/g but lower than those of [44] who obtained 0.32-0.56 mg CE/g DW. However, the results of [5] and [44] were found using other extraction solvent and conditions, as well as different total phenolic content assays and total flavonoid content assays. The meteorological conditions, season and post-harvest conditions have been lately reported as additional source of variance in the TFC [45].

Processing methods are known to have variable effects on TPC of plant samples. Results of this study showed that IR drying methods preserves the TPC and TFC. TPC of all IR-dried samples were slightly higher than that of FG (Table 4). Furthermore, all the extracts from garlic dried by infrared showed similar TFC than that of FG. It can be observed that an increase in drying temperature induces a raise on the total phenolic content. The formation of phenolic compounds at high temperature might be because of the availability of precursors of phenolic molecules by non-enzymatic interconversion between phenolic molecules [46].

Table 4. Total phenol and flavonoid contents for the studied extracts of garlic

Garlic extract	Total phenolics (mg GAE/g DW)	Total flavonoids (µg QE/g DW)
FG	0.60±0.006	5.5±0.09
G-40	0.66±0.004	5.4±0.03
G-50	0.72±0.005	5.2±0.04
G-60	0.87±0.007	5.5±0.01
G-70	0.98±0.006	5.6±0.04

Values are means ± standard deviation

Many studies have reported increase in TPC of plant samples following thermal treatments [26], [47-49]. Increase in TPC following thermal treatment has been attributed to the release of bound phenolic compounds brought about by the breakdown of cellular constituents, and the formation of new compounds with enhanced antioxidant properties. In this context, [50] reported that various compounds of garlic prepared at high temperature and pressure might be changed to polyphenol compounds.

Therefore appropriate food processing can improve the properties of naturally occurring antioxidants and induce the formation of new compounds with antioxidant properties. The antioxidant potential of phenolic compounds is dependent on the number and arrangement of the hydroxyl groups as well as the presence of the electrondonating substituent in the ring structure [51].

3.5 Antioxidant Activity

The total antioxidant activities of vegetables cannot be evaluated by any single method, due to the complex nature of phytochemicals [52]. Two or more methods should always be used in order to evaluate the total antioxidative effects of vegetables. Accordingly, the antioxidant activities of the methanol extracts of garlic was determined by three different methods: DPPH (1,1-diphenyl-2-picrylhydrazyl) assay, ABTS assay and β-carotene bleaching test.

DPPH is a free radical and accepts an electron or hydrogen radical to become a stable diamagnetic molecule [53]. The reduction capability of DPPH radical was determined by the decrease in absorbance induced by plant antioxidants.

Results in Fig. 4 demonstrated that all samples exhibited dose-dependent DPPH radical scavenging activities expressed as IC_{50} values. The free radical-scavenging capacity was different between the fresh garlic and the dried garlic extracts. Most of the extracts from garlic dried by infrared showed slightly higher activities than that of FG. The methanolic extract dried by infrared at 70℃ (G-70) showed higher activity (IC_{50}= 2.87 mg/mL) than those of other extracts followed by G-60 (IC_{50}= 3.02 mg/mL), G-50 (IC_{50}= 3.29 mg/mL), G-40 (IC_{50}= 4.17 mg/mL) and FG (IC_{50}= 4.25 mg/mL). Drying temperature increased the free radical-scavenging activity, what might be due to the highest total phenol content amongst all the analyzed samples, indicating a positive correlation between the total phenol content and the DPPH assay (R^2=0.705). These results are in a good agreement with those of [54,55]. In contrast, [43] reported lower correlation between the antioxidant activity and the TPC of different garlic species. At this point, it seems that the contradictory results are most probably due to the differences in the methodology and the experimental conditions used, as well as by the use of vegetables from different geographical regions, grown in different climatic and different storing conditions. This can be an explanation of different results shown by many researchers.

The potential of garlic extracts to scavenge free radicals was also assessed by their ability to quench $ABTS^{\cdot+}$. Fig. 4 depicts the concentration-dependent decolourization of $ABTS^{\cdot+}$, expressed as IC_{50} values, by IR dried methanolic extracts in comparison with FG. As evidences by this figure, FG extract showed the lowest activity with IC_{50}= 6.12 mg/mL value, while, the most powerful extracts was obtained from G-70 extract with IC_{50}= 4.84mg/mL. Statistical analysis revealed good association between TPC and the ABTS assay results (R^2=0.634), such trend supports our previous conclusion about the implication of phenols in the observed antioxidant activity.

The two methods (DPPH and ABTS) gave similar antioxidant activity trends for FG and for IR dried garlic extracts. According to [56], the antioxidant activities against ABTS or DPPH were correlated with the concentration, chemical structures, and polymerization degrees of organ antioxidants. The earlier published data [43] also indicated great differences in results of scavenging activities of garlic bulb extracts, relating them partially to the polarity of extraction medium and consequently to the content of different phenolic compounds.

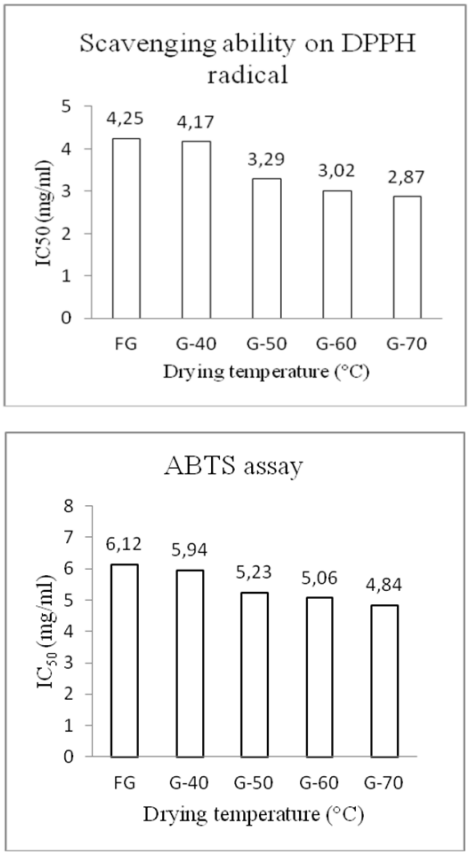

Fig. 4. Scavenging activity, expressed as IC_{50} values (mg/mL), on DPPH and ABTS radicals of fresh and dried extracts of garlic.

Based on the β-carotene bleaching test, undergoes rapid discoloration in the absence of an antioxidant. The presence of an antioxidant such as phenolics can hinder the extent of β-carotene destruction by ‘‘neutralizing” the linoleate free radical and any other free radicals formed within the system [57]. Fig. 5 depicts the inhibition of β-carotene bleaching by the fresh and dried extracts of garlic. All the extracts showed good scavenging activity for reduction of the radicals generated by the oxidation of linoleic acid and the activity was too close to each other with IC_{50} ranging from 3.42 to 3.89 mg/mL. G-70 extract showed the highest ability to prevent the bleaching of β–carotene. These results agreed

with data reported by [58], who found that fried garlic presented the highest antioxidant activity.

However, there was a weak correlation between total phenolic content and β-carotene bleaching test (R^2=0.376), suggesting that some compounds other than phenols, such as sulphur compounds or melanoidins might have been generated during drying.

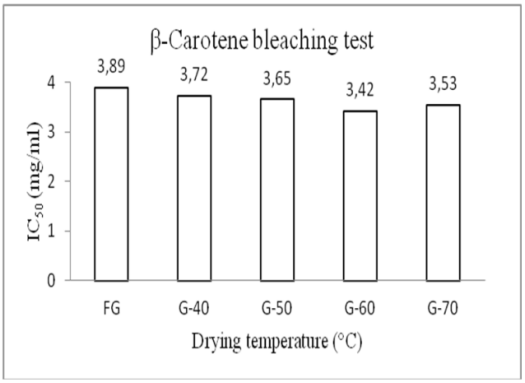

Fig. 5. Antioxidant activity expressed as IC_{50} (mg/mL) of fresh and dried extracts from garlic in β-carotene bleaching test

Garlic has been used as a medicinal agent for thousands of years; the protective effect of garlic is associated with its antioxidant properties [10]. In this context, several studies have been performed [14-16]. However, data on the effects of drying on antioxidant activity of vegetables are conflicting due to several factors, like drying method, type of extraction solvent, antioxidant assays used as well as interactions of several antioxidant reactions [59,46]. According to [60], the DPPH radical scavenging activity increased or remained unchanged depending on the type of vegetable and not on the type of thermal processing. [61] found that the aqueous extracts of boiled or raw garlic induced the same increase in plasma antioxidant activity in rats suggesting that the antioxidant properties of garlic were unaffected by boiling. [62] found that the capacity of garlic to inhibit lipid peroxidation was not affected by boiling (30 min at 100℃).

It was very interesting to identify the possible reasons and mechanisms behind the change of bioactive compounds and antioxidant activity after the different heat treatments. According to [44], the change can be explained by the physical properties (texture, color, matrix softening, increased extractability). Moreover, heat process, may increase or decrease garlic antioxidant activity, depending if polyphenolic antioxidant compounds are degraded or if Maillard reaction antioxidant products are generated during the thermal processing [63] given that accumulation of Maillard derived melanoidins have a varying degree of antioxidant activity. This could also enhance antioxidant properties at high temperatures [38,46].

In this study, the increase of antioxidant activities may be explained by the fact that since IR creates internal heating with molecular vibrations of materials, it may have the capability to break down the covalent complex molecular structures and release some antioxidant compound such as flavonoids, carotene, lycopene, tannin, ascorbate, flavoprotein or polyphenols from polymers [64]. Moreover, in IR drying, the electromagnetic wave energy is absorbed directly by the dried food with less energy loss. IR is thought to liberate and activate low-molecular-weight natural antioxidant compounds, because it heats materials without degrading the constitutive molecules of the surface and contributes to an even transfer of heat to the centre of the material. Many antioxidant phenolic compounds in plants are most frequently present in a covalently bound form with insoluble polymers [64]. If this bonding is not strong, IR treatment could liberate and activate low-molecular-weight natural antioxidants in plants [65]. This might explain the strong antioxidant activities of the extracts from garlic dried by IR.

4. CONCLUSION

The effect of Infrared drying temperature on physicochemical properties, mineral content, total phenolic content, total flavonoid content and antioxidant activity between 50 and 70℃ was investigated. Results have shown a minor alteration in the physicochemical properties of garlic at drying temperatures of 40, 50℃. However, the radical scavenging activity showed higher antioxidant activity at high temperatures (60–70℃) compared to low temperatures (40–50℃). In consequence, the infrared drying at different temperature was unable to eliminate the antioxidant activity of the extracts. These data suggest that the compound(s) involved in the scavenging capacity of garlic extracts are essentially heat stable. The results suggested that, IR drying is an effective and economical process and it may increase the bioactivity by liberating the covalently bound compounds. Therefore, the garlic dried by IR drying system could be used as a potential natural resource that has potent antioxidant activities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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