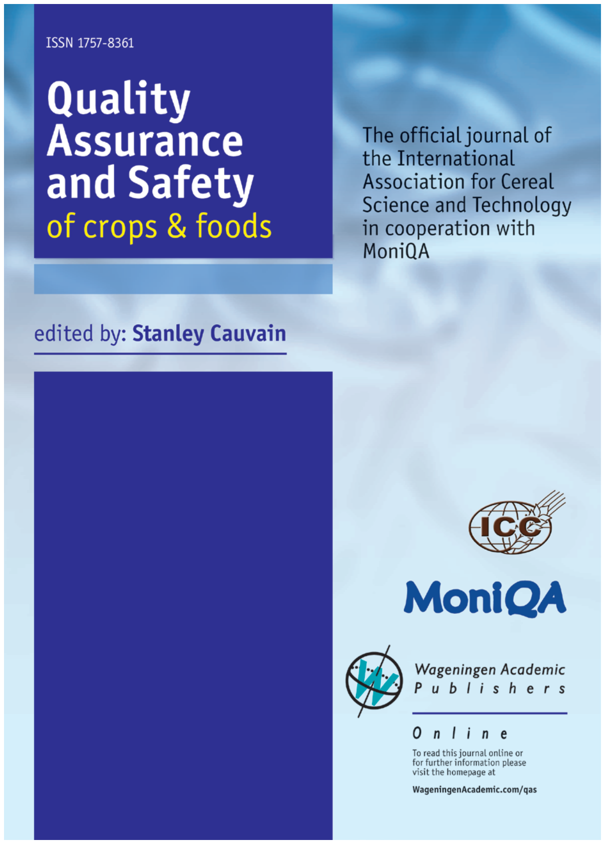

ISSN 1757-8361
Quality Assurance and Safety of crops & foods
The official journal of the International Association for Cereal Science and Technology in cooperation with MoniQA
edited by: Stanley Cauvain
ICC
MoniQA
Wageningen Academic Publishers
Online
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## Publication information

Quality Assurance and Safety of Crops & Foods:
ISSN 1757-837X (online edition)

Subscription to 'Quality Assurance and Safety of Crops & Foods' (4 issues, calendar year) is either on an institutional (campus) basis or a personal basis. Subscriptions can be online only. Prices are available upon request from the publisher or from the journal's website (www.WageningenAcademic.com/qas). Subscriptions are accepted on a prepaid basis only and are entered on a calendar year basis. Subscriptions will be renewed automatically unless a notification of cancelation has been received before the 1st of December.

Further information about the journal is available through the website www.WageningenAcademic.com/qas.

## Paper submission

http://mc.manuscriptcentral.com/qas

## ICC and MoniQA

'Quality Assurance and Safety of Crops & Foods' is the official journal of the International Association for Cereal Science and Technology in cooperation with MoniQA

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# Effects of oven and microwave drying on phenolic contents and antioxidant activities in four apple cultivars

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Received: 8 June 2014 / Accepted: 3 February 2015


**RESEARCH ARTICLE**

## Abstract

Fresh fruits can be preserved for later consumption using methods such as drying. However, fruit quality can significantly decline during processing. This study investigates the effects of microwave and oven processing on the preserved quality of dried apple. Heating experiments were performed at two different microwave output powers of 180 and 540 W. Moisture contents of 'Starking' and 'Pink Lady' apple samples dried in a microwave at 180 W were substantially lower than those of other apple cultivars and control groups. Total phenolic contents, 325.94 mg/100 g (Pink Lady) to 475.63 mg/100 g (Starking), and antioxidant activity levels, 325.94 mg/100 g (Pink Lady) to 475.63 mg/100 g (Starking), of apples subjected to microwave heating at 540 W were higher than those in apples subjected to 180 W microwave heating and oven drying at 50 and 70 °C. The total phenolic contents of control apple cultivars ranged from 87.81 mg/100 g (Golden) to 136.25 mg/100 g (Pink Lady), whilst the total phenolic contents of apple cultivars dried in an oven at 70 °C ranged from 299.06 mg/100 g (Pink Lady) to 395.31 mg/100 g (Starking). The antioxidant activity values of control apple cultivars ranged from 11.55 (Pink Lady) to 21.78% (Starking), whilst the antioxidant activity values of apple cultivars dried in a 70 °C oven ranged from 38.87 (Pink Lady) to 52.49% (Granny Smith).

**Keywords:** antioxidant, apple, drying, microwave, oven, total phenolic content

## 1. Introduction

Fruits have high nutritional value and are excellent sources of sugar, proteins, ascorbic acid, and minerals. Apples also are used therapeutically for different illnesses because they promote gastric secretion absorption, toxin elimination, and diuretic effects (Campeanu *et al.*, 2009; Harsan *et al.*, 2006). Apples are considered a good source of dietary minerals (Nour *et al.*, 2010). Global trends show that marked increases in the consumption of refined foods, which are deficient in vitamins and minerals, can cause health problems (Ivey and Elmen, 1986). Polyphenols are phytochemicals with health-protective properties such as antioxidant, antimicrobial, and anticancer activities, and they have been shown to promote cardiovascular health (Bendini *et al.*, 2006; Cetkoviv *et al.*, 2008; Chu *et al.*, 2000).

Dried fruits provide greater nutrition than many other processed foods, but different drying methods have different effects on fruit nutritional qualities. Microwave drying has several distinct advantages compared with conventional heat drying (Megahed, 2001; Rosenberg and Bogl, 1987), including speed of operation, energy savings, precise process control, and faster start-up and shut-down times (Decareau, 1992). The microwave heating effect on fruit nutrients depends on fruit tissue thickness and quality (Giese, 1992). The heating period during microwave drying is relatively short compared with oven drying, and moisture loss is greater during oven drying than during microwave drying (Bouraoui *et al.*, 1994). Much of the moisture loss during microwave drying occurs during the second drying period. The moisture distribution in spherical fruits is determined during this second period

by experimental measurements of moisture profiles and computer simulations.

Dielectric heating with microwave energy has been used in commercial food product applications for drying fruits and vegetables. There is a renewed interest in exploring the unique characteristics of microwave heating for drying heat-sensitive materials (Funebo and Ohlsson, 1998). In general, microwave drying meets the four major requirements for food drying: speed of operation, energy efficiency, cost savings, and quality of dried products (Gunasekaran, 1999). Several excellent reviews describe new drying technologies such as hybrid drying (Cohen and Yang, 1995; Nijhuis *et al.*, 1998; Vega-Mercado *et al.*, 2001; Zhang *et al.*, 2003). Andrés *et al.* (2004) studied the drying kinetics of apple cylinders under combined hot-air microwave dehydration. They reported that higher microwave power reduces drying time more efficiently than higher air temperature. They developed an empirical model for fresh and impregnated apples to estimate the drying kinetic constants as a function of air temperature and microwave power. Microscopic examination of tissue characteristics indicate that process variables affect the drying kinetics and result in different macro- and microstructures of the final product. Therefore, the aim of the current study is to determine the effects of oven and microwave drying on total phenolic contents and antioxidant activity values in dried apple.

## 2. Materials and methods

### Materials

Fresh apples (*Malus* spp.) were purchased from a shopping centre in Konya, Turkey, in October 2013. The following four cultivars were used for this study: Golden, Granny Smith, Pink Lady, and Starking. Fruits were transferred to the laboratory in cool bags and washed with clear distilled water (without peeling the skin). Apples were kept in a refrigerator (4 °C) until use.

### Drying process

Apples were removed from the refrigerator, washed, peeled, sliced into 3-4 mm slices using a grater, and dried in an oven at 50 or 70 °C or in a microwave at 180 or 540 W. Approximately 50-60 g were sliced for each apple cultivar, and were immediately spread on stainless steel trays and transferred to the hot-air ovens, or were placed on the turntable in a microwave oven. Apple slices were dried for 4 days at 50 °C, for 12 hours at 70 °C, for 1 hour at 180 W, or for 20 minutes at 540 W.

### Extraction process

Dried samples were ground into powder with a grinder (Grinder KG49; Delonghi Appliances, Treviso, Italy). Methanol (15 ml) was added to 0.5 g of ground sample (Joshi *et al.*, 2011). The resulting slurry was stirred for 16 hours and centrifuged for 15 minutes at 4,000 rpm. The supernatant was removed from each sample and used for analyses of total phenolic content and antioxidant activity.

### Determination of total phenolic content and antioxidant activity

Total phenolic content was determined using the Folin-Ciocalteu reagent (Yoo *et al.*, 2004). The free radical scavenging activity of the extract was determined using 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Lee *et al.*, 1998). Total phenolic contents were calculated using a standard calibration curve prepared from gallic acid. Total phenolic content results are reported as gallic acid equivalents in mg per 100 g fruit. Antioxidant activity results are expressed as percentages.

### Determination of fruit colour

Colour was measured in control and dried samples using a Konica Minolta colorimeter (Minolta CR-400 Chroma Meter; Konica Minolta, Inc., Osaka, Japan) and the three-dimensional $L^*a^*b^*$ colour system, in which $L^*$ represents lightness and $a^*$ and $b^*$ represent the opposing primary colours. $L^*$ is the vertical coordinate, with values ranging from 0 (black) to 100 (white); $a^*$ is the horizontal coordinate, with values ranging from -80 (green) to +80 (red); and $b^*$ is the horizontal transect coordinate, with values ranging from -80 (blue) to +80 (yellow).

### Statistical analyses

Average values were calculated by analysing the fruits in three independent experiments. Statistical significance of the results was determined by calculating analysis of variance (ANOVA) (Püskülcü and İkiz, 1989).

## 3. Results and discussion

The moisture content of dried apple cultivars differed among the cultivars and according to the drying method used. The lowest moisture content in dried fruit was 7.84% for 'Pink Lady' dried in a microwave at 540 W, whilst the highest moisture content was 9.89% for 'Golden' dried in an oven at 50 °C (Table 1). The moisture contents of 'Starking' and 'Pink Lady' dried in a microwave at 180 W were substantially lower than those of other apple cultivars and control groups. The total moisture contents, phenolic contents, and antioxidant activity values of four different apple cultivars (Granny Smith, Golden, Starking and Pink

Lady) subjected to different heating processes are presented in Table 1. Total phenolic contents and antioxidant activity values of apple samples dried in an oven or in a microwave were higher than those in control groups. Total phenolic contents and antioxidant activity values of apple samples dried in a microwave at 180 or 540 W were higher than those of samples dried in an oven at 50 °C or 70 °C (Table 1). Total phenolic contents and antioxidant activity values of samples dried in an oven were higher when the drying temperature increased from 50 to 70 °C (Table 1). A similar increase was observed for microwave drying when the power increased from 180 to 540 W (Table 1). The total phenolic contents varied among the samples as follows: for controls, 87.81 mg/100 g for 'Golden' to 136.25 mg/100 g for 'Pink Lady'; for samples dried in a 70 °C oven, 299.06 mg/100 g for 'Pink Lady' to 395.31 mg/100 g for 'Starking'; for samples dried in a microwave at 180 W, 230.94 mg/100 g for 'Pink Lady' to 396.25 mg/100 g for 'Starking'; for samples dried in a microwave at 540 W, 325.94 mg/100 g for 'Pink Lady' to 475.63 mg/100 g for 'Starking'. The antioxidant activity values varied among the samples as follows: for controls, 11.55% for 'Pink Lady' to 21.78% for 'Starking'; for samples dried in an oven at 70 °C, 38.87% for 'Pink Lady' to 52.49% for 'Granny Smith'; for samples dried in a microwave at 180 W, 38.45% for 'Pink Lady' to 61.88% for 'Granny Smith'; for samples dried in a microwave at 540 W, 49.61% for 'Pink Lady' to 78.81% for 'Granny Smith'.

We measured the colour of control and dried apples and determined the L*, a*, and b* colour values. The results are presented in Table 2. For control samples, L* ranged from 75.50 to 77.89, a* ranged from -0.60 to -3.90, and b* ranged from 16.93 to 23.44 (Table 2). The greatest change in L* with respect to the control value was observed in 'Starking' and 'Golden' after drying in an oven at 70 °C (Table 2). The least change in L* with respect to the control value was observed in 'Granny Smith', 'Golden', and 'Pink Lady' dried in a microwave at 180 W. The a* (redness) and b* (yellowness) values of all tested apple cultivars increased after drying by oven or microwave.

Table 1 shows that total phenolic content and antioxidant activity were relatively high in 'Granny Smith'. This is likely due to the reduction in moisture content and corresponding increase in concentrates. Fresh fruits and vegetables are dried after harvesting to reduce waste and spoilage and to extend their shelf life. Drying is a relatively simple process, in which the moisture content is removed from fruit by causing evaporation. There are many drying techniques, which depend on the product properties and the desired drying time (Abou ElHana, 2008). Dried fruits are widely used as ingredients for many processed foods such as baked goods, confectionery products, ice cream, frozen desserts, and yogurt. Dried apples are a significant raw material for many food products (Mandala and Anagnostaras, 2006).

**Table 1. Total moisture content, phenolic content, and antioxidant activity in apple cultivars (mean ± standard deviation).**

| Process | Cultivar | Moisture (%) | Antioxidant activity (%) | Total phenolic content (mg/100 g) |
|---|---|---|---|---|
| Control samples | Granny Smith | 90.88±1.27 | 16.27±0.36 | 90.63±1.38 |
| | Golden | 90.52±0.98 | 17.19±0.97 | 87.81±1.69 |
| | Starking | 90.29±0.76 | 21.78±1.03 | 103.13±2.49 |
| | Pink Lady | 85.99±0.49 | 11.55±0.38 | 136.25±3.29 |
| Oven dried (50 °C) | Granny Smith | 8.55±1.72 | 34.45±0.56 | 260.31±3.78 |
| | Golden | 9.89±1.18 | 18.11±0.63 | 175.00±2.57 |
| | Starking | 8.29±1.21 | 35.30±1.47 | 277.50±2.89 |
| | Pink Lady | 8.56±0.79 | 19.75±0.87 | 166.88±2.59 |
| Oven dried (70 °C) | Granny Smith | 9.75±1.09 | 52.49±2.39 | 363.75±3.67 |
| | Golden | 9.88±1.36 | 35.04±1.29 | 306.25±3.49 |
| | Starking | 9.67±1.29 | 41.60±1.42 | 395.31±3.58 |
| | Pink Lady | 8.69±0.87 | 32.87±0.98 | 299.06±4.89 |
| Microwave dried (180 W) | Granny Smith | 8.04±1.28 | 61.88±2.48 | 352.19±4.57 |
| | Golden | 9.67±1.32 | 38.52±1.59 | 254.06±2.29 |
| | Starking | 8.58±1.43 | 57.09±2.78 | 396.25±3.95 |
| | Pink Lady | 8.73±1.38 | 38.45±1.54 | 230.94±3.67 |
| Microwave dried (540 W) | Granny Smith | 8.35±1.41 | 78.81±2.87 | 452.50±4.87 |
| | Golden | 8.99±1.47 | 55.12±2.39 | 367.81±3.39 |
| | Starking | 8.81±1.68 | 71.00±2.45 | 475.63±3.79 |
| | Pink Lady | 7.84±1.56 | 49.61±1.39 | 325.94±3.68 |

**Table 2. Colour values of apple cultivars.**

| Process | Cultivar | L* | a* | b* |
|---|---|---|---|---|
| Control samples | Granny Smith | 77.80 | -3.90 | 16.93 |
| | Golden | 77.89 | -3.26 | 23.44 |
| | Starking | 75.50 | -1.79 | 23.16 |
| | Pink Lady | 76.81 | -0.60 | 22.52 |
| Oven dried (50 °C) | Granny Smith | 70.72 | 8.48 | 29.66 |
| | Golden | 70.57 | 8.20 | 28.98 |
| | Starking | 60.85 | 12.53 | 32.56 |
| | Pink Lady | 64.38 | 10.43 | 26.37 |
| Oven dried (70 °C) | Granny Smith | 70.90 | 7.89 | 31.09 |
| | Golden | 58.21 | 10.44 | 32.59 |
| | Starking | 45.25 | 12.93 | 25.22 |
| | Pink Lady | 67.10 | 10.43 | 30.53 |
| Microwave dried (180 W) | Granny Smith | 73.18 | 4.90 | 35.54 |
| | Golden | 76.29 | 3.84 | 39.08 |
| | Starking | 64.44 | 12.07 | 39.18 |
| | Pink Lady | 76.07 | 5.42 | 30.44 |
| Microwave dried (540 W)z | Granny Smith | 66.37 | 7.21 | 29.24 |
| | Golden | 67.13 | 6.02 | 35.04 |
| | Starking | 63.84 | 7.62 | 33.22 |
| | Pink Lady | 66.63 | 8.71 | 34.04 |

Some drying processes can cause undesirable changes in the final product quality (Maskan, 2000).

Mandala and Anagnostaras (2006) investigated the effects of different osmotic pretreatments on air-drying kinetics and physical characteristics of the final product in dried apple. Funebo and Ohlsson (1998) proposed that trade-offs between drying time and fruit quality had to be evaluated when using microwave-based drying methods. Observed differences between oven- and microwave-dried apple samples may be due to differences in temperature, locality parameters, harvest period, cultivar type, nutritional status of the tree, and other factors that can influence the drying process. It is generally accepted that the phytochemical content and quality of dried products declines during processing.

## Acknowledgements

The authors extend their sincere appreciation to the Deanship of Scientific Research at King Saud University for funding our research group (No. RG-1435-049).

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