Comparative study on the volatile compounds and sensory characteristics of some locally produced potato chips

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ABSTRACT

This study was carried out to evaluate the volatile compounds in the headspace of two types of fried potato chips (A and B), flavoured with salt only. The impact of seasoning addition (tomato, onion and cheese) that are highly preferred by consumers on the flavour quality of these two potato snacks was investigated. A comparative study concerning fat contents, headspace volatiles and sensory characteristics was carried out between the two brand types of tested potato chips. The results indicated that the lipid content of the two brand types of potato chips ranged from 28.65 to 33.41% in all tested traditional potato chips. The gas chromatography-mass spectrometric (GC-MS) analysis of the headspace volatiles of all samples revealed the presence of 86 volatile compounds with total higher content in all brand B varieties than brand A. The identified compounds included different chemical groups such as; sugar and Maillard degradation products, lipid degradation products, sulfur containing compounds, terpenes and miscellanies compounds. The total amount of lipid degradation products in samples A and B was lower than that of Maillard reaction, sugar degradation, or both products. The results revealed that sample A_s showed higher scores for all investigated attributes compared to sample B_s. The odour intensity and onion flavour scored higher values in sample A_{co} than sample B_{co}. Whereas, the taste attribute and cheese flavour showed the opposite trend. Concerning the tomato seasoned potato chips, sample B_t showed higher scores for all investigated sensory attributes compared to sample A_t.

Keywords: potato chips, potato chips with salt, cheese and onion, tomato flavour, odour intensity.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important vegetable crops grown in Egypt. It is the fourth most important world crop after rice, wheat and maize. It is a major source of inexpensive energy. Moreover, potato is used in many industries, such as French fries, chips, starch and alcohol production (Elhakim *et al.*, 2016).

In Egypt, potato chips are considered one of the most important products of food industry and they are the top choice for between-meal munching for adults and children (Allshouse *et al.*, 2002). Potato crisp is a fragile but firm slice of potato that has been cooked by deep-frying in vegetable oil and to which edible salt (powder or brine) or permitted food grade spices, colour and flavour may have been added (Surkan *et al.*, 2009; Godswill *et al.*, 2018).

The potato chip or crisp is considered one of the most popular snacks globally (Dhital *et al.*, 2018). Some authors define a snack as a portion of food, smaller than a regular meal, generally eaten between meals**.** Snack food manufacturers produce mainly two kinds of potato crisps: the traditional crisps from fresh potatoes, which are produced from thinly slicing and deep frying of them, and the typical restructured potato crisps from potato dough, which are molded into desired shapes by extruding or pressing before frying, such as Pringles (Pedreschi *et al.*, 2018).

Traditionally, potato crisps are produced by oil frying to a temperature well above the boiling point of water (180°C), causing evaporation of water inside the product, and the formation of a crust. Besides cooking foods very quickly, this unit operation also provides unique sensorial attributes attractive to the consumer, such as colours, aromas, flavours and textures that improve the overall palatability (Pedreschi *et al.*, 2018).

Consumer's acceptance of food stuffs is closely related to their flavours. Volatiles from potato snacks are usually classified based on the mechanism of formation (Whitfield and Last, 1991; Comandini *et al.*, 2011; Raigond *et al.*, 2015). These volatiles are lipid oxidation products, Maillard, sugar degradation or all such products and small amounts of endogenous flavour compounds (Loon *et al.*, 2005)

Chips flavour is affected by many factors including potato tuber composition, frying oil composition and temperature and the time of frying (Martin and Ames 2001). Studies on the volatile compounds of potato chips have been reviewed by Jansky (2010). More than 500 volatile compounds were identified in the volatiles of French fries and potato chips showing a similar aroma (Comandini *et al*, 2011). Among the 150 volatile compounds identified in the volatiles of potato chips, 60 compounds are lipid degradation products, with the polyunsaturated fatty acids of the frying oil likely to be their main precursors (Warner *et al.,* 1997).

Flavour stability in seasoned snack food, such as potato chips, is of great importance because of its relationship with the quality and acceptability of foods over the shelf life but is often difficult to control. Cheese and onion seasoning helps in slowing the lipid oxidation in deep-fried potato crisps and consequently controls both the shelf-life stability of seasoning and seasoned products (Agarwal *et al.,* 2018). Cheese flavour is one of the most important criteria determining consumer choice and acceptance (Avsar *et al.,* 2004). Cheese flavouring agent, because of its rich flavours, convenient application, lower cost and long shelf life, is used in a variety of products including, by way of example only, breads, salad dressings, cheese spreads, pizza toppings, sauces and snack foods (El-Shayeb *et al.,* 2017).

Tomato seasoned potato chips are very popular among consumers, however, no studies could be found regarding the impact of tomato flavour on the odour profile of potato chips. Flavour and aroma are essential parameters of quality in tomatoes. Characteristic tomato flavour results from taste components, aromatic volatiles and a complex interaction between them (Yilmaz 2001). Among over 400 volatile compounds determined in tomatoes, only a limited number is considered essential to the aromatic component of tomato flavour. Volatiles in fresh tomatoes and leaves are formed from lipids, carotenoids, amino acids, terpenoids (C10 and C15), lignin and other sources. The pleasant sweet-sour taste of tomatoes is mainly due to their sugars (primarily the reducing sugars, glucose and fructose) and organic acids (citric and malic acids) are the major organic acids content (Tandon *et al.,* 2000).

Flavour analysis using a variety of methods has been conducted for many years to help the development of new products, to understand the nature of existing products, to study shelf-life, and to maintain quality of foods, beverages, products for oral care, and other products such as oral pharmaceuticals and tobacco (Meilgaard *et al.,* 2006; Lawless and Heymann, 2010).

Flavour evaluation is usually carried out by sensory and/or instrumental analysis. Sensory descriptive tests involve the detection and description of both qualitative and quantitative sensory components of a product by trained panels. Descriptive tests can establish a relationship between sensory and instrumental results (Comandini *et al*., 2011). An important factor affecting consumer preferences of a fried food is its flavour which is defined as the combined perception of aroma, taste and mouthfeel sensation (Montaser *et al.,* 2017). However, sensory methods are sometimes expensive to implement, may be time-consuming when used properly, and sometimes cannot be implemented "on-line" for immediate feedback.

Instrumental methods for examining flavour have also been developed to provide feedback about the individual compounds associated with flavours. Those methods take many forms, but all are based on separation, identification, and quantification of compounds either in headspace or the actual product matrix (Maarse, 1991). The analysis of volatile compounds in food is commonly performed using gas chromatographic (GC) techniques, employing very sensitive technologies capable of detecting trace levels of volatile compounds. It is fundamental that GC detection has high efficiency, especially for volatile compounds, present at trace levels, can be easily perceived during sensory analysis (low perception threshold) and can contribute significantly to the flavour profile of cheese (Hummel *et al.,* 1997).

The aim of the present work is to compare the volatile profile of two potato chip brands that are highly popular locally among Egyptian consumers, especially for children. The study was extended to evaluate the impact of seasoning addition (tomato, onion and cheese) on the headspace volatiles and sensory qualities of these two potato snacks. The oil content of each sample was determined, due to its effect on the overall quality of potato chips flavour.

MATERIALS AND METHODS

Materials

Potato chips samples

The manufactured potato chips samples (which represent of the most common brands distributed in the Egyptian local markets) were collected from the most frequently consumed brands (different producers, A and B); for each brand, three varieties of potato chips were chosen (unseasoned, seasoned with cheese &

onion and tomato). These potato chips represent a major portion of the potato chip products processed in the Arab Republic of Egypt.

All potato chips samples (manufactured at same date) were purchased from local market. The samples, packed in plastic bags, were transported to the laboratory until analyses. The code number of each tested potato chips sample was shown in Table (1).

Ingredients of tested potato chips

The basic composition of the investigated samples is fresh potato, vegetable oil and food additive such as some flavouring agents.

Authentic compounds and standard n-paraffin (C8-C20) were purchased from Sigma-Aldrich CO. (St. Louis, MN, USA) and Merck (Darmstadt, Germany), respectively. All other chemicals were analytical grade.

Methods

Preparation of tested samples

The different potato chips samples were crushed in a mill cup blender and made homogeneous, then subjected to oil extraction, sensory analysis, isolation and identification of headspace volatiles.

Determination of lipid content (%)

Fat content was determined by extracting a weighed sample of 10g with petroleum ether (boiling point 60 - 80°C) in a Soxhlet apparatus for 16 h. The extract containing lipid and petroleum ether was evaporated over steam bath and dried in an oven at low temperature (50 °C), weighed and lipid percent was calculated according to the method described by AOAC (2011).

Analysis of volatile compounds by Gas chromatography / mass spectrometry

Extraction of volatile compounds

About 100g of tested potato chips samples were placed in a conical flask containing 500 ml distilled water. The mixture solution was stirred using teflon-coated magnetic bar at 60 ºC. The volatiles were purged with purified nitrogen (grade of N_2 > 99.99%), at flow rate 100ml/min for 5h to three cooling traps at low temperature (ice – water/ice – acetone/dry ice – acetone). Volatile chemicals collected in each trap were recovered with diethyl ether – pentane (1:1, v/v). The solvents containing volatiles were dried over anhydrous sodium sulphate for 12 h and concentrated with a Vigreux column (25 cm) to final volume of 100 µl. (Fadel *et al.*, 2006).

Characterization of volatile compounds by GC/ MS analysis

The analysis was carried out by using a coupled gas chromatography Hewllet-Packard (5890)/ mass spectrometry Hewllet-Packard (5890), (Bremen, Germany). A fused silica capillary column DB5 (60 m × 0.32 mm i.d.) was used. The oven temperature was maintained initially at 50 ºC for 5 min, then programmed from 50 to 250 ºC at a rate of 4 ºC/min. Helium was used as the carrier gas at a flow rate of 1.1 ml/min. The injector and detector temperatures were 220 and 250 ºC, respectively. The mass spectrometry was operated in electron impact mode (EI) 70.ev, mass range *m/z* 39-400 amu. The retention indices (Kovats index) of the separated volatile components were calculated with hydrocarbon (C8-C20, Aldrich Chemical CO.) as references. The isolated peaks were identified by matching with data from the library of mass spectra (NIST) (version 2.0) and comparison with those of authentic compounds and published data (Adams, 1995). The amount of each individual compound was expressed as total ion chromatogram (TIC).

Sensory analysis of tested potato chips

Sensory analysis was aimed to monitor the differences in sensory attributes between the investigated potato chips A and B regarding each type (Table 1). Sensory evaluation was carried out according to Majcher and Jeleń (2005) with some modifications. In the present study, each type of potato chips brand A was compared to the same type of brand B, such as: A_s compared with B_s, A_{co} compared with B_{co} and A_t compared with B_t. Ten panelists were drawn from the Chemistry of Flavour and Aroma Department, National Research Center and Food Science and Technology Department, Faculty of Agriculture, Al-Azhar University. All were requested to evaluate the sensory attributes to determine the acceptability of the samples regarding odour, taste, seasoning perception such as salt, cheese & onion, tomato and overall acceptability. The individual panelists separately scored each attribute on a category scale 0.0 (not perceptible) to 10.0 (strongly perceptible). The analysis was carried out in triplicate.

Statistical analysis

The data were statistically analyzed by using the Statistical Package for Social Science (SPSS) computer program software; (version 20.0 produced by IBM Software, Inc., Chicago, USA) of a completely randomized design as described by Gomez and Gomez (1984). All obtained results are expressed as mean ± standard error (SE). The statistical analysis was performed using a one-way analysis of variance (ANOVA) followed by Duncan's multiple range tests according to the procedure of Armitage (1971).

RESULTS AND DISCUSSION

Fat content is one of the most important parameters checked during the quality control processes. It affects the product's texture. The factors that influence fat uptake include: the quality of the raw material, the type of oil fraction and the technological process, with temperature and frying time being the two main parameters (Mazurek *et al.*, 2016).

The lipid content of the two brand types of tested potato chips is listed in Table (2). The lipid content ranged from 28.65 to 33.41% in all tested potato chips with and without different flavouring agents. However, in the two brands, the seasoned samples showed higher oil content compared with the unseasoned samples.

The present results revealed that for all tested samples the oil content was lower than the recommended value (within the permissible values ≥ 42%), reported by the Egyptian Standard Specifications (2005**),** of potato chips. On the other side, the lipid content in tested potato chips brand B with salt only and also with cheese and tomato flavours was more than that found in tested potato chips brand A. Furthermore, the lipid content in both tested samples brands A (28.65%) and B (31.70%) with salt was lower than those obtained in flavoured tested samples, which recorded 30.45 and 31.92 % of tested samples of brand A, 33.28 and 33.41% of tested samples brand of B with cheese and tomato flavours; respectively. These results are consistent with the findings of Minihane and Harland (2007), Pedreschi *et al.* (2012), Mazurek *et al.* (2016), kalnina *et al.* (2017) and Caetano *et al.* (2018) who reported that the fried potato chips contain rather high amounts of fat (35-40%). These results may be due to the moisture loss during deep-fat frying that results in oil uptake, which may amount to as much as 40% of total product weight (Pedreschi *et al.*, 2012).

Volatile compounds identified in fried potato chips seasoned with salt only

As shown in Table (3), the total amount of volatile compounds in sample B were 2.72 folds higher than in sample A. The increase in the total amount of the volatile compounds in sample B compared with sample A may be due to several factors; (i) the higher oil content in B than A (Table 2); (ii) the sinuous surface of sample B may increase the amount of loaded volatile compounds; (iii) different frying condition and different potato varieties.

A total of 57 volatile compounds were identified in the two samples (A_s and B_s) (Table 3). These compounds were classified into five main chemical groups; lipid degradation products, sugar degradation and/or Maillard reaction products (not involving sulfur-containing amino acids), sulfur-containing compounds, terpenes and miscellanies flavour compounds. Most of the identified compounds have been reported previously as volatiles from fried potato chips (Loon *et al.*, 2005; Comandini *et al.*, 2011).

Sugar degradation and Maillard reaction products

The aroma compounds produced by Maillard reaction and/or sugar degradation products included: Strecker aldehydes (4), diketones (2), pyrazines (6), furans (4), acetic acid and ethyl pyrrole (Table 3).

The total ion chromatograms (TIC) of these chemical classes were 26.57×10^6 and 69.36×10^6 in the two samples A_s and B_s, respectively. Approximately 85.6 % of the aroma compounds identified in head space volatiles of French-fried potato chips were generated from sugar degradation and/or Maillard reaction, not involving sulfur-containing compounds (Loon *et al.*, 2005; Cha *et al.*, 2019).

The di ketones 2,3- butandione (1) and 2,3-pentandione (10) are sugar degradation products and contribute to caramel and buttery note. They were identified among the active compounds from French fries (Loon *et al.*, 2005).

2-Methyl butanal (6), 3-methyl butanal (7), phenylacetaldehyde (46) and benzaldehyde (33) are strecker aldehydes of the amino acids; isoleucine, leucine and phenylalanine, respectively (Martin and Ames, 2001a). Their major formation pathway seems to be oxidative deamination-decarboxylation of the corresponding amino acids via strecker degradation (Sanches-Silva *et al.*, 2005). Whereas, benzaldehyde (33) is produced by interaction of sugar with phenylalanine (Fong and Yaylayan 2008).

Compared to the previous studies, the total yield of 2- methyl butanal and 3-methyl butanal showed a relatively lower level (3.13×10^6 and 16.44×10^6) in sample A and B; respectively.

These two compounds were the predominant compounds in the volatiles of fried potatoes (Loon *et al.*, 2005) and accounted for 81% of the total volatiles. Their low presentation in this study may be attributed to their oxidation to 2-methyl butanoic acid (25) and 3- methyl butanoic acid (26), respectively (Loon *et al.*, 2005), which were represented at high content (7.92×10^6 and 15.56×10^6) in the volatile of sample A and B, respectively. Compounds (25 and 26) do not seem to give a distinct note but may influence the perceived aroma as a whole.

The seven identified pyrazines were: 2-methyl pyrazine (20), 2,5- dimethyl pyrazine (29), 2,3- dimethyl pyrazine (30), vinyl pyrazine (31), 2- ethyl-3-methyl pyrazine (40), 2- vinyl -6-pyrazine methyl (41) and 3-ethyl -2,5 –dimethyl pyrazine (47) (Table 3). Pyrazines are typical products of Maillard reaction (Corrales *et al.*, 2017; Yu *et al.*, 2019). Generally, they are associated with positive sensory perception in deep-fried potato crisps such as nutty, brown, roasted and baked, but also associated with a negative sensory perception such as raw and musty (Agarwal *et al.*, 2018). Pyrazines are mainly formed from glutamine and asparagine, the most abundant amino acids in potatoes (Dresow and Böhm, 2009; Krishnakumar and Visvanathan, 2014).

2- Methyl pyrazine (20) was the major identified compound in sample A_s (6.94×10^6) and it showed approximately similar amount (6.88×10^6) in sample B_s. 2,5-dimethyl pyrazine (29) and 2- ethyl-3-methyl pyrazine (40) comprised 5.77×10^6 and 5.42×10^6 in sample B_s, respectively whereas, they showed less amounts (1.87×10^6 and 1.60×10^6) in samples A_s. These compounds were the predominant pyrazines identified in the volatiles of potato chips fried in palmolein (Martin and Ames, 2001).

The five furans identified in the present study were vinyl furan (11), dihydro-2-methyl (2H)-furanone (18), 2-furfural (21) 5- methyl -2-furfural (35) and 4- hydro -3,5-dimethyl -3(2H)-furanone (48), with total amounts of 1.98×10^6 and 6.64×10^6 in sample A and B, respectively (Table 3). 2-Furfural (21) is a typical sugar degradation product, and it possesses a pungent sweet note. 4-Hydro-3-5-dimethyl -3 (2H)- furanone (furaneol) (48) is formed via Maillard reaction from 2- hydroxyl propanal, and its oxidation product is 2- oxopropanal (Belitz *et al.*, 2004).

Lipid degradation products

During frying, the hydroperoxides are formed as primary products of lipid oxidation. These products are unstable and decompose to secondary oxidation products. Deep fat frying causes evaporation of water, which moves away from food into the surrounding oil that replaces some of the lost water. This process leads to a product with extremely high-fat content (Moreira *et al.*, 1995; Nayak *et al.*, 2016).

However, as shown in Table (3), the total amounts of lipid degradation products in samples A and B (15.70×10^6 and 47.48×10^6 respectively) were lower than that of Maillard reaction and/or sugar degradation products (26.57×10^6 and 69. 36×10^6). This finding may be attributed to that the heat transfer from oil to the products is more favorable for sugar degradation and/or Maillard reaction than for lipid oxidation (Loon *et al.*, 2005). At the same time, the melanodines formed from Maillard reactions are known to have an anti-oxidative effect (Morales and Jiménez-Pérez, 2001) and subsequently affect lipid oxidation.

The lipid-derived volatile compounds are corresponding to different chemical classes, aldehydes (9), ketone (2), alcohols (3), carboxylic acid (3), esters (3), furans (3) and hydrocarbons (2) (Table 3). These compounds are considered as secondary oxidation markers for lipid oxidation.

Among the nine aldehydes, hexanal (15) was the abundant compound in sample B (15.76×10^6) whereas; it showed much less amount (2.00×10^6) in sample A. It is a typical oxidation product of lineoleic acid and used as a marker of lipid oxidation (Sanches- Silva *et al.*, 2005 and Comandini *et al.*, 2011).

The amount of nonanal (52) in sample B (1.12×10^6) was three and half fold higher than its amount in sample A (0.31×10^6). Hexanal and nonanal were detected at high concentrations in the volatiles of French fried potatoes (Loon *et al.*, 2005). The first compound is the predominant degradation product of 2,4-decadienal (E, Z) (62) which is formed from linoleic acid (Hammond, 1993 and Diaz *et al.*, 2015).

Loon *et al.* (2005) confirmed the fact that 2,4-decadienal (E,Z) (62), 2,4- decadienal (E,E) (63) and 2,4 (E,E) nonadienal (57) contribute to the deep–fried note. These compounds were identified as the main volatile compounds in palmolein fried potato chips (Comandini *et al.*, 2011).

The two identified ketones, 3-heptanone (24) and octenal (39) are oxidative degradation products of unsaturated fatty acids (Careri *et al.*, 1994). They were identified among the volatiles of potato crisps (Sanches-silva *et al*., 2005).

Three alcohols, 1-octen -3-ol (36), dodecanol (76) and tetradecanol (84) are shown in Table (3), with total amount 2.30 × 10^6 and 1.94 x 10^6 in samples A and B, respectively. They have a minor significant role in flavour of fried potatoes. The three identified carboxylic acids are hexanoic acid (37), decanoic acid (68) and dodecanoic acid (81). They are formed by lipid oxidation or by deamination of amino acids during the frying process. Therefore, their high presentation indicates the advanced lipid oxidation state (Sanches- Silva *et al.,* 2005).

The three identified esters, ethyl decanoate (69), methyl dodecanoate (78) and ethyl dodecanoate (82), accounted for 0.82 × 10^6 and 0.52 × 10^6 in sample A and B, respectively. These compounds are esterification products of carboxylic acid and alcohols (Guillén *et al.,* 2004).

The lipid degradation furans reported in Table (3) are methyl furan (2), tetrahydrofuran (3), 2- ethyl furan (9) and pentyl furan (38). 1-octen- 3-ol and 2-pentyl furan are degradation products of linoleic acid and are responsible for fatty and fruity notes (Neff *et al*., 2000).

Sulfur-containing compounds

The total yield of the three identified sulfur compounds, 1,2 dimethyl disulfide (12), methional (28) and dimethyltrisulfide (34), showed low representation in both samples A and B (0.97×10^6 and 2.95×10^6, respectively). These compounds are Maillard reaction products and characterized as sulfuryl and onion flavour (Loon *et al.,* 2005). These compounds comprised low amount of the total volatiles of French fries (Loon *et al.,* 2005). Methional, a strecker aldehyde of methionine, is a potent odorant of French fries flavour (Wagner and Grosch, 1997; Majcher and Jeleń, 2005). The low amount of methional might be due to its masking by 2,5 - di methyl pyrazine (Oruna-Concha *et al.,* 2001).

Miscellanies compounds

Styrene (27) is a benzene derivative that contributes to the sweet and balsamic aroma note (Zhang *et al.,* 2020 *and* Corrales *et al.,* 2017). It is naturally synthesized by several plant species (Fernandez *et al*., 2005) and significantly increased at high temperatures. It was found in the headspace volatiles of fried potatoes (Loon *et al.,* 2005). Limonene (42) was detected in the volatiles of French fries (Loon *et al.,* 2005). 2-Isobutyl-2-methoxy pyrazine (54) was detected in the volatiles of raw and boiled potato. β-damascenone (E) (70) was reported as a degradation product of carotenoids (Majcher and Jeleń, 2005). It is present in raw foods, and its amount increases during different heat processing.

Volatile compounds identified in headspace of fried potato chips seasoned with cheese and onion

A total of 55 volatile compounds were classified into five main chemical groups; Maillard reaction and sugar degradation products, lipid degradation products, sulfur-containing compounds, terpenes and miscellanies compounds.

As shown for potato chips seasoned with salt only (Table 3), the total volatiles in sample B_s (124.48×10^6) were higher than in sample A_s (47.74×10^6). Most of the identified compounds were previously identified in headspace of potato chips seasoned with salt only (Table 3). Some of the volatile compounds reported in Table (3) are specific aroma compounds of onion and cheese. Butandione (1) was represented by 1.16 × 10^6 and 1.20 × 10^6 TIC in sample A_{co} and B_{co}, respectively. This compound possesses buttery note (Avsar *et al.,* 2004) and reported as an active aroma compound in cheddar and Swiss cheeses (Castada *et al.,* 2019).

The identified acids; acetic acid (5), butanoic acid (16), 3- methyl butanoic acid (26), haxanoic acid (37), dedcanoic acid (68) and dodecanoic acid (81) were found in the volatiles of different cheese types (Avsar *et al.,* 2004 and Hayaloglu and Karabulut, 2013). Acetic acid and butanoic acid are produced by lipolysis or by fermentation of lactose or lactic acids whereas, 3- methyl butanoic acid is produced by metabolism of leucien (Curioni *et al.,* 2002). Compounds 16 and 37 are the principal acids in Turkish cheese (Hayaloglu and Karabulut, 2013). Their importance is due to their low perception thresholds as well as the fact that they are precursors for the formation of methyl ketones, alcohols, lactones and esters (Pinho *et al.,* 2004).

As shown in Table (3), 3-methyl butanoic acid (26) was the major compound identified in headspace of the two samples A and B (10.86×10^6 and 20.82×10^6, respectively). This compound is produced from the oxidation of 3-methyl butanal (McSweeney and Sousa 2000; Castada *et al.,* 2015). The aldehydes reported in Table (3) are produced by catabolism of fatty acids or amino acids via decarboxylation or deamination (McSweeney and Sousa 2000).

Hexanal (15), a lipid degradation product, was the predominant aldehyde in sample A_{co} and B_{co} (5.36 and 8.22 × 10^6, respectively). 2-Methylbutanal (6) and 3-methylbutanal (7), strecker aldehydes of isoleucine and leucine, accounted for 0.0 and 2.80 × 10^6 in sample A_{co} and 0.80 and 2.28 × 10^6, respectively in sample B_{co}. These compounds contribute to nutty flavour in aged cheddar cheese (Avsar *et al.,* 2004; Whetstine *et al.,* 2006). 3-Methylbutanal (6), hexanal (15) and pentanal (14) were the predominant aldehydes identified in Turkish cheese (Hayaloglu and Karabulut, 2013). Aldehydes are transitory compounds and do not accumulate significantly in cheese as they rapidly transform into alcohols and corresponding acids (Bovolenta *et al.,* 2014). A strong negative correlation was found between 3- methyl butanoic acid and 3- methyl butanal (McSweeney and Sousa 2000; Castada *et al.,* 2015).

Six sulphides were identified and reported in Table (3) such as methional (28), methyl-1-propenyl disulfide (32), dimethyl trisulfide (34), iso propely propyl disulfide (44), dipropyl disulfide (51) and dipropyl trisulfide (76), with total amount of 7.45× 10^6 and 15.80 × 10^6 in sample A_{co} and B_{co}, respectively. Among these compounds, 32, 44, 51 and 67 are generally associated with onion sensory perception (Villière *et al*., 2015).

Limonene (42), the only terpene identified in the present study, comprised 0.40 and 1.79 × 10^6 in sample A_{co} and B_{co}, respectively (Table 3). This compound was the most abundant terpene identified in Turkish cheese and it is associated with citrus like note (Nogueira *et al.,* 2005). Limonene, dipropyl disulfide, dimethyl trisulfide, methyl-1-propenyl disulfide, isopropyl propyl disulfide and 3-methylbutanal were identified with cheese and onion seasoned potato crisps as specific compounds (Agarwal *et al.,* 2018).

Volatile compounds identified in headspace of tomato seasoned potato chips

A total of 41 volatile compounds were identified in headspace of the two potato chips samples (A_t and B_t) seasoned with tomato flavour. The identified compounds were classified into five main chemical classes; sugar degradation and Maillard reaction products, lipid degradation products, sulfur containing compounds, terpenes and miscellanies compounds.

Among the identified compounds, several compounds are considered as key odorants of tomato aroma. As previously mentioned, the total volatiles of sample B were higher than that in sample A (Table 3). 3-Methyl butanal (7), hexanal (15), hexanol (23), hexanoic acid (37), nonanoic acid (58), 2-decanal (59), (E,Z) 2,4 decadienal (62), (E, E)-2,4-decadienal (63), dedcanoic acid (68), dodecanoic acid (81), methional (28), limonene (42), isobutyl thiazole (45), guaiacol (49), 2- phenyl alcohol (50), methyl salicylate (55) α-terpineol (56), geranial (60), geraneol (61), eugenol (64), geranyl acetone (73) and β-Ionone (77) were reported as important tomato aroma compounds (Alonso *et al.,* 2009; Güler and Şekerli, 2013; Selli *et al.,* 2014). Isobutyl thiazole accounted for 3.86×10^6 and 4.85×10^6 in samples A and B, respectively and it was described as tomato leaves-like aroma (Alonso *et al.,* 2009).

Cis-3- Hexanal (tomato leaf-like fresh, cut grass) is considered one of the most contributors to tomato aromas (Selli *et al.,* 2014). The absence of this compound in the present study may be correlated to the extraction technique of volatile compounds. In a previous study (Alonso *et al.,* 2009), cis-3- hexanal was found in simultaneous steam distillation extraction (SDE) and hydrodistillation (HD) of tomato flavour, but wasn't in solid phase micro-extraction (SPME). Hexanal accounted on 2.53× 10^6 and 10.46×10^6 of the total volatiles of samples A and B, respectively (Table 3). It was the main compound in traditional tomatoes with abundance percentage in head space of around 40% of total volatiles (Alonso *et al.,* 2009).

The peak area of 2. phenyl ethanol (floral) was found in quantities of 0.23 and 1.27×10^6 in the volatiles of samples A and B, respectively. It was previously detected by Tandon *et al.* (2001) as potent odorants in red-ripe stage tomatoes. Geranyl acetone (Lavender, fruity, and rose sweet aroma) (Alonso *et al.,* 2009) is the main volatile compound from lycopene degradation in tomatoes (Krumbein *et al.,* 2004).

β-Ionone is consistently present in tomato at all stages of ripening. It is oxidative breakdown product of β-carotene. Methyl salicylate was predominant volatile compound in green tomato (Güler and Sekerli, 2013).

Sensory analysis of tested potato chips samples

The Fig. (1 a, b and c) shows the results of sensory analysis of the potato chips samples A and B seasoned with salt only, cheese and onion and tomato flavour. As illustrated in the obtained results in Fig. (1 a), it is obvious that the salt seasoned potato chips brand A showed higher scores for all investigated sensory attributes compared to brand B.

Regarding cheese and onion seasoned potato chips (Fig. b), the low score of the overall acceptability of sample B_{co} compared with sample A_{co}, may be correlated to the unacceptable oily flavour detected by the panelists. The odour intensity and onion flavour scored higher in sample A_{co} than sample B_{co}. Whereas, the taste attribute and cheese flavour showed the opposite trend. Concerning the tomato seasoned potato chips, sample B_t showed higher scores for all of the investigated attributes compared to sample A_t (Fig. c).

CONCLUSION

In the present study two potato chips brands A and B which are the most acceptable to the Egyptian consumers were chosen and subjected to a comparative study concerning their flavour qualities. Three similar varieties of each brand were selected in this study such as unseasoned potato chips (salt only), cheese and onion seasoned potato chips and tomato seasoned potato chips. In general, the total content of the headspace volatiles of all sample varieties of potato chips B was higher than their similar varieties of potato chips A. A total of 86 volatile compounds were identified in the present study with higher concentration in B than A, especially for the most contributors to the characteristic aroma of each variety. The sensory evaluation revealed that the overall acceptability of potato chips A flavoured with salt A_s and cheese and onion A_{co} scored higher values than potato chips B_s and B_{co}. While tomato seasoned potato chips scored higher for all investigated sensory attributes. These differences between the two potato chips brands may be correlated to the different oil content, potato tubers, and time and temperature of frying.

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Table 1. The code numbers of tested potato chips samples.

Brand code	Cod. No.	Sample collected with different flavour (Cod. Name)
A	A_s	Salt
	A_{co}	Seasoned cheese &onion flavour
	A_t	Tomato flavour
B	B_s	Salt
	B_{co}	Seasoned cheese &onion flavour
	B_t	Tomato flavour

Brand A and B: fried potato chips locally produced by two companies. A_s: Potato chips flavoured with salt (brand A); B_s: Potato chips flavoured with salt (brand B); A_{co}: Potato chips flavoured with cheese and onion (brand A) B_{co}: Potato chips flavoured with cheese and onion (brand B); A_t: Potato chips flavoured with tomato (brand A); B_t: Potato chips flavoured with tomato (brand B).

Table 2. lipid content (%) of tested potato chips (Means ± SE).

Potato chips samples		Lipid content (%)
brand A	Salt	$28.65{\pm}0.07^{c}$
	Seasoned cheese	$30.45{\pm}0.11^{b}$
	Tomato	$31.92{\pm}0.15^{ab}$
brand B	Salt	$31.70{\pm}0.04^{ab}$
	Seasoned cheese	$33.28{\pm}0.08^{a}$
	Tomato	$33.41{\pm}0.11^{a}$

a,b,c Means in the same column with different superscripts are different significantly ($p < 0.05$)

Table 3. Volatile compounds identified in headspace of different types of flavoured potato chips.

Peak No.	(K.I.)	Compounds	TIC (values ×10^6)					
			A_s	B_s	A_{co}	B_{co}	A_t	B_t
Sugar degradation and Maillard reaction products (not involving sulfur containing amino acids)								
1	**610**	2,3- Butandione	0.46	4.84	1.16	1.20	0.27	1.09
5	**650**	Acetic acid	0.15	1.73	0.28	0.80	0.26	1.07
6	**654**	2-Methylbutanal	1.52	3.68	—	0.80	—	—
7	**664**	3-Methylbutanal	1.61	12.76	2.80	2.28	1.66	5.39
10	**697**	2,3Pentandione	0.51	1.54	—	—	—	—
11	**713**	Vinyl furan	—	0.40	—	—	—	—
17	**820**	1- Ethyl pyrrole	0.40	2.11	0.93	3.74	—	—
18	**822**	Dihydro-2-methyl(2H)-furanone	1.06	1.26	—	2.31	—	—
20	**831**	2-Methylpyrazine	6.94	6.88	1.02	1.63	0.42	1.44
21	**834**	2-Furfural	0. 39	3.90	—	0.11	—	—
25	**884**	2-Methyl butanioc acid	2.99	—	4.27	4.44	—	—
26	**888**	3-Methyl butanioc acid	4.93	15..56	10.86	20.82	5.45	27.24
29	**911**	2,5- Dimethyl-pyrazine	1.87	5.77	4.06	8.09	2.25	9.94
30	**923**	2,3- Dimethyl-pyrazine	—	0.31	—	0.36	—	—
31	**943**	Vinyl pyrazine	0.36	1.26	0.74	1.30	0.37	1.39
33	**969**	Benzaldehyde	0.21	0.88	0.54	1.00	0.29	0.83
35	**978**	5-Methyl-2- furfural	0.19	1.08	0.85	0.93	0.48	0.85
40	**1005**	2-Ethyl-3-methyl-pyrazine	1.60	5.42	4.34	7.66	2.70	10.06
41	**1027**	2-Vinyl-6-methyl-pyrazine	—	0.34	0.30	0.54	—	0.67
46	**1048**	Phenylacetaldehyde	0.81	—	1.25	1.68	0.72	—
47	**1073**	3-Ethyl-2,5- dimethyl-pyrazine	0.23	—	—	0.60	—	0.53
48	**1095**	4-Hydro-3,5-dimethyl-3-(2H)-furanone	0.34	—	0.42	—	—	—
Total			**26.57**	**69. 36**	**33.82**	**60.29**	**14.87**	**60.50**

Table 3. Continued…..

Peak No.	(K.I.)	Compounds	TIC (values ×10^6)					
			A_s	B_s	A_{co}	B_{co}	A_t	B_t
Lipid degradation products								
2	**621**	2-Methyl furan	0.18	3.28	—	—	—	0.77
3	**634**	Tetrahydrofuran	0.68	3.74	1.22	1.39	—	—
4	**635**	1-Butonol	—	—	0.48	1.40	—	—
8	**670**	Pentanal	0.18	0.92	—	—	—	—
9	**681**	2-Ethylfuran	3.81	11.27	—	8.29	—	—
13	**747**	2- Methyl-2-butanal	—	0.49	—	0.75	—	—
14	**767**	1-Pentanal	—	0.14	—	0.26	—	—
15	**799**	Hexanal	2.00	15.76	5.36	8.22	2.53	10.46
16	**809**	Butanoic acid	—	—	—	0.69	—	—
19	**826**	(E) 2- Ethyl-2-butanal	0.59	0.52	—	—	1.95	3.28
22	**851**	2-Hexanal (E)	—	—	—	0.63	—	—
23	**881**	Hexanol	—	—	—	—	2.83	5.83
24	**882**	3-Heptanone	—	0.32	—	—	—	—
36	**984**	1- Octen-3- ol	—	0.36	—	0.64	--------	11.17
37	**988**	Haxanoic acid	1.63	1.69	3.04	3.50	2.07	9.13
38	**993**	2- Pentyl furan	0.15	0.70	0.50	0.68	0.27	1.05
39	**999**	Octenal	—	—	—	0.26	—	—
43	**1038**	Benzyl alcohol	0.83	1.98	—	—	—	4.85
52	**1108**	Nonanal	0.31	1.12	0.32	0. 63	1.25	1.16
53	**1192**	Decanal	—	—	—	—	—	1.06
57	**1235**	2,4 (E,E)Nonadienal	0.26	—	—	0.61	—	—
58	**1259**	Nonanoic acid	—	—	—	—	—	0.54
59	**1263**	2-Decenal	—	—	0.21	—	—	—
62	**1299**	2,4 Decadienal (E,Z)	0.67	0.40	1.67	1.83	—	1.00
63	**1306**	2,4 Decadienal (E,E)	0.29	—	0.75	1.36	0.55	1.09
65	**1358**	Octadecanal	0.18	—	0.39	—	0.32	0.90
68	**1370**	Dedcanoic acid	0.20	—	0.41	0.41	0.53	1.48
69	**1385**	Ethyl decanoate	0.27	0.52	—	—	—	—
72	**1407**	Dodecanal	—	1.51	—	—	—	—
76	**1470**	Dodecanol	0.16	0.55	0.32	0.76	0.44	1.18
78	**1528**	Methyl decanoate	0.27	—	—	—	0.82	1.48
79	**1529**	α- Decalactone	—	—	1.25	0.88	—	—
80	**1547**	β- Decalactone	—	—	0.33	0.46	—	—

Table .3 Continued…

Peak No.	(K.I.)	Compounds	TIC (values ×10⁶)					
			A_s	B_s	A_{co}	B_{co}	A_t	B_t
		Lipid degradation products						
81	1563	Dodecanoic acid	0.28	—	0.28	—	—	1.61
82	1592	Ethyl dodecanoate	0.28	—	0.51	0.93	0.33	1.62
83	1599	Hexadecane	0.10	0.64	—	—	1.52	4.85
84	1680	Tetradecanol	2.14	1.03	—	—	3.93	4.80
85	1685	α-Dodecalactone	—	—	1.83	7.29	—	—
86	1700	Heptadecane	0.24	0.54	—	—	0.55	2.43
		Total	15.70	47.48	18.87	41.87	19.89	71.74
		Sulfur compounds						
12	742	1,2-Dimethyl disulfide	0.32	0.41	—	—	—	—
28	896	Methional	0.31	0.23	0.51	1.29	—	1.03
34	971	Dimethyltrisulfide	0.34	2.31	1.98	2.67	1.44	4.59
32	951	Methyl-1- propenyl disulfide	—	—	0.26	0.31	—	—
44	1039	Iso propely propyl disulfide	—	—	3.32	8.86	—	—
45	1040	Isobutylthiazole	—	—	—	—	3.86	4.85
51	1106	Dipropyl disulfide	—	—	0.84	1.71	—	—
67	1363	Dipropyl trisulfide	—	—	0.54	0.96	—	—
		Total	0.97	2.95	7.45	15.80	5.30	10.47
		Trepenes						
42	1033	Limonene	0.27	0.73	0.40	1.79	—	0.46
50	1101	Phenyl alcohol	—	—	—	—	0.23	1.27
56	1200	α-Terpineol	—	—	—	—	0.55	1.78
60	1264	Geranial	—	—	—	—	0.20	0.74
61	1271	Geraneol	—	—	—	—	0.80	0.59
64	1351	Eugenol	—	—	—	—	0.42	1.26
71	1400	Methyl eugenol	—	—	—	—	2.68	5.63
73	1453	Geranylacetone	—	—	—	—	0.43	1.77
74	1459	β-(E)farnesene	—	—	—	—	0.43	1.04
75	1464	Ethyl cinnamate	—	—	—	—	0.56	1.43
77	1500	β-Ionone	—	—	—	—	1.63	4.15
		Total	0.27	0.73	0.40	1.79	7.93	20.12

Table 3. Continued….

Peak No.	(K.I.)	Compounds	TIC (values ×10^6)					
			A_s	B_s	A_{co}	B_{co}	A_t	B_t
Miscellanens compounds								
27	**893**	Styrene	0.41	0.72	0.41	0.72	—	—
49	**1096**	Guaiacol	—	—	—	—	0.53	2.35
54	**1193**	2-Isobutyl-3-methoxy pyrazine	2.68	2.95	0.77	0.43	—	—
55	**1194**	Methyl salicylate	—	—	—	—	0.32	1.01
66	**1359**	β-Damascenone (z)	—	—	—	—	0.49	1.25
70	**1399**	β-demascenone (E)	1.14	0.29	2.68	2.95	0.41	1.07
Total			**4.23**	**3.96**	**3.86**	**4.10**	**1.75**	**5.68**
Total of all volatiles:			**47.74**	**124.48**	**64.40**	**123.85**	**49.74**	**168.51**

TIC: Total ion chromatogram; **KI:** Kovats Index

A_s: Potato chips flavoured with salt (brand A); **B_s:** Potato chips flavoured with salt (brand B); **A_{co}:** Potato chips flavoured with cheese and onion (brand A)

B_{co}: Potato chips flavoured with cheese and onion (brand B); **A_t:** Potato chips flavoured with tomato (brand A); **B_t:** Potato chips flavoured with tomato (brand B).

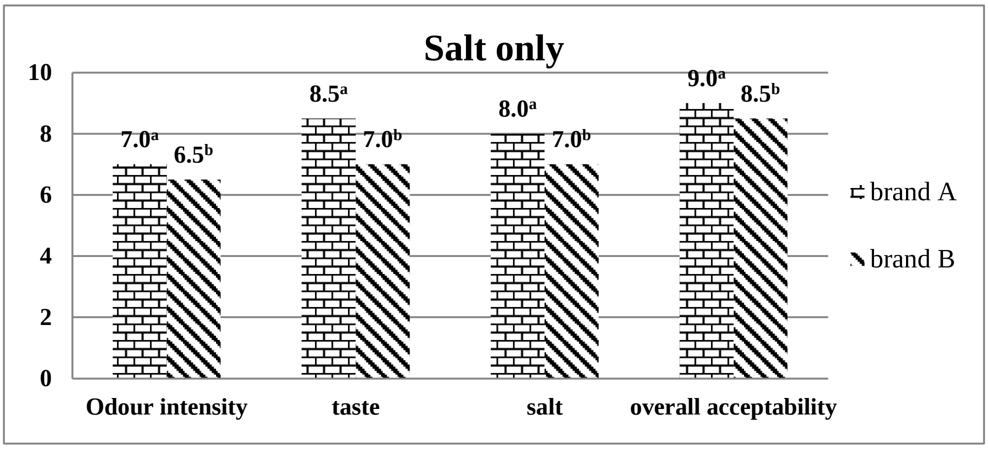

Figure1. Sensory characteristics of flavoured potato chips with salt. For each sensory attribute the values followed by different superscript low case letters are significantly different.

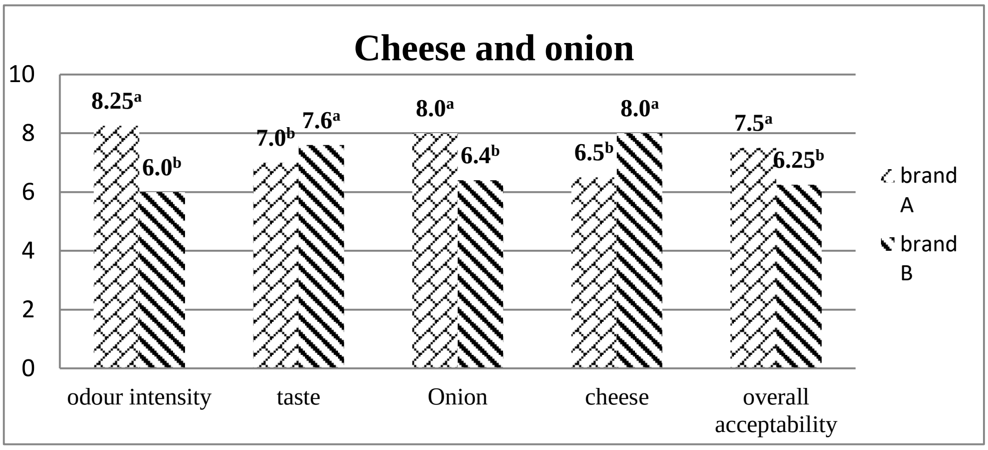

Figure2. Sensory characteristics of cheese and onion seasoned potato chips. For each sensory attribute, the values followed by different superscript low case letters are significantly different.

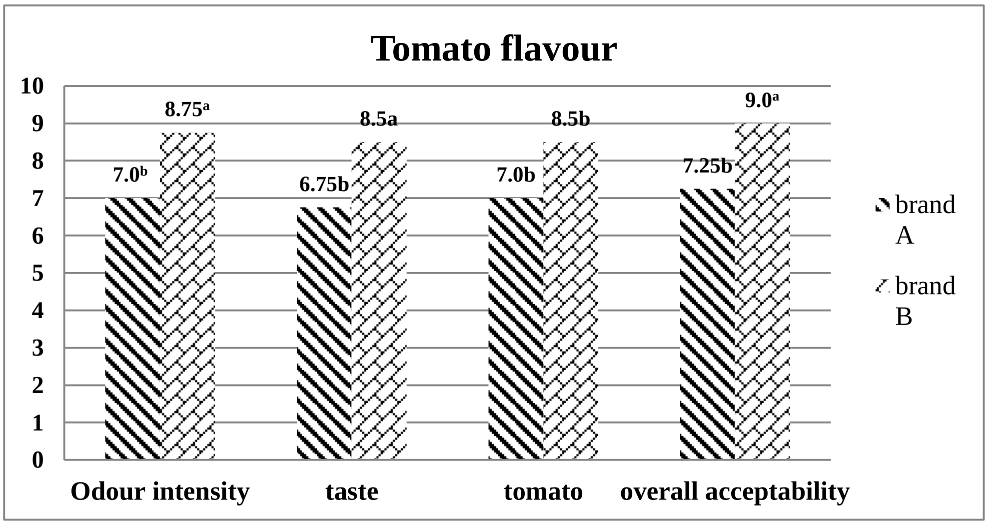

Figure3. Sensory characteristics of tomato seasoned potato chips. For each sensory attribute, the values followed by different superscript low case letters are significantly different.

دراسة مقارنة على المركبات الطيارة والخصائص الحسية لبعض رقائق البطاطس المنتجة محلياً

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الملخص العربي

تم إجراء هذه الدراسة لتقييم المركبات المتطايرة فى نوعين من البطاطس المقلية (أ ،ب) المنكهة بالملح فقط بالإضافة إلى دراسة تأثيرإضافة النكهات التي يفضلها المستهلكون بشدة (الطماطم والجبنة المتبلة) على جودة نكهة العينات محل الدراسة. كما شملت الدراسة أيضا مقارنة بين الخصائص الحسية والمركبات المتطايرة لنوعي رقائق البطاطس محل الدراسة. وقد أظهرت النتائج أن نسبة الدهون في العينات المختبرة تراوحت من 28.65 إلى 33.41٪ وأظهرت نتائج التحليل الكروماتوغرافي الغازي لجميع العينات وجود 86 مركبًا متطايرًا بمحتوى أعلى في جميع نكهات العينة (ب) مقارنة بالعينة (أ). وقد شملت المركبات المحددة مجموعات كيميائية مختلفة مثل نواتج تفاعل ميلارد، ونواتج تحلل الدهون، والمركبات المحتوية على الكبريت، والتربينات ومركبات أخرى. وقد كان المحتوى الكلي لنواتج تحلل الدهون في العينات أ و ب أقل من نواتج تفاعل ميلارد. كما أظهرت نتائج التقييم الحسي أن العينة (أ بنكهة الملح) أظهرت درجة أعلى لجميع الصفات التي تم تقييمها مقارنة بالعينة (ب) كما كانت كثافة الرائحة ونكهة البصل فى العينات المنكهة بالجبنة المتبلة أعلى في عينة (أ) عن العينة (ب) في حين أظهرت صفة الطعم ونكهة الجبن اتجاهًا معاكسًا. أما بالنسبة لرقائق البطاطس المنكهة بالطماطم أظهرت العينة (ب) درجة أعلى لجميع الصفات الحسية مقارنة بالعينة (أ).

الكلمات الاسترشادية: رقائق البطاطس، رقائق البطاطس بطعم الملح، الجبنة والبصل، نكهة الطماطم، كثافة الرائحة.