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Advances in the quality characteristics of fried potato products with air frying technology: a mini review

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Hot air frying is a relatively new technology for producing fried foods, therefore, the objective of this review is to know the impact of this frying technology on the quality properties of fried potato products, addressing its effect and recommendations with the series of scientific studies in the literature. According to research available, the moisture content decreases with frying, but the final moisture contents are higher by about 35% compared to traditional frying. In the texture analysis, acceptable characteristics are obtained, and the lightness decreases with frying, attributing the desirable color characteristics of fried foods, in addition, in sensory attributes, no differences were found in flavor and crispiness between hot air frying and traditional frying, but in appearance, color and overall acceptability were higher in conventionally fried potatoes. In conclusion, future work should focus on assessing the impact on health and biofunctional properties (*e.g.* resistant starch, antioxidant properties) by the consumption of fried potato products, due to the scarce information available and the importance that this represents, since the literature has focused on quality parameters.

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Sustainability spotlight

This review article, titled "Advances in the quality characteristics of fried potato products with air frying technology: a mini review", delves into the impact of air frying technology on fried potato products. The focus is on the innovative use of this technology in some quality properties and the growing demand for potatoes. By exploring the latest developments and applications, this article highlights the potential and challenges of hot air frying. The article contributes to the current discourse on promoting responsible practices in the food sector, we hope to inspire further research and innovation and steer the food industry towards a more sustainable and responsible future.

Introduction

Palm oil is one of the most used in frying because of its cheapness, but its impact is very expensive, since it requires large planting areas causing deforestation and therefore the displacement and/or death of the animals that lived there, however, fried foods are popular worldwide.[1] These types of foods are known for the crispy and tasty characteristic, but unfortunately, fried foods have a high fat content and reach in some cases 1/3 of the food by weight.[2] Each gram of lipids generates 9 kcal (38.2 kJ) being higher caloric intake than in proteins and carbohydrates of 4 kcal,[3] therefore, the consumption of foods rich in lipids such as those obtained by traditional frying are an important factor in the increase of overweight or obesity which increases the risk of other diseases such as diabetes, cardiovascular diseases, high blood pressure, strokes and at least 13 types of cancer according to the National Cancer Institute,[4] of the United States Government. Fried potatoes usually have a higher oil content (~40%), which is considered unhealthy due to the excess of fats, and in turn produce a diversity of biochemical reactions (Maillard), such as acrylamide.[5] Because of this, research and development work is conducted to provide healthier options in potato frying, such as the innovation of the frying process to introduce foods with less oil to the market, but maintaining the desirable sensory attributes of the fried potato that consumers require.[6,7] As an alternative, a healthier approach to frying food is hot air frying technology, where no oil or fat is required for frying.[8–10] Air fryers are currently available in the market in addition to being economically accessible to most of the population, on the other hand, potato is one of the most consumed foods internationally, and deep frying is the most used process of frying potatoes.[11] Therefore, the objective of this work was to know the impact of hot air frying technology on the quality properties of fried potato products, since they are the most consumed fried foods worldwide. Likewise, to produce a source of information for future research on the effect of this process, with the

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compilation of data available in the literature. And thus, to provide a source of information for researchers and the general population on the effect of this frying process.

Potato production and general information

Currently, the chemical composition of potato is widely studied by various authors,[12–16] so in this review a table was not added in this regard nor discussed. On the other hand, potato production data from the Food and Agriculture Organization[17] are shown in Fig. 1a. At the international level, there is a decrease in potato production, according to the observed trend, but the tons produced each year are still important, so it is necessary to look for alternatives for its use. At the national level (Mexico), according to the trend in Fig. 1b, production and its participation at the international level.[18] The importance of this section was to highlight that there is an important potato production, so making the most of this tuber is necessary, being an alternative to use hot air frying technology in the production of fried potato products, resulting in a relevant option. It is necessary to mention that in hot air frying different geometries of potato products could be obtained, obviously the design would depend on the type of cut previously made to the potato, as shown in Fig. 2.

Hot air frying technology

Foods traditionally are cooked by dipping them in fats or oils and this technique is called deep frying.[2] But consumers have begun opting for an alternative frying method, hot air frying, because it uses less oil during the process compared to traditional frying while maintaining similar taste and appearance.[20,21] Hot air frying is a technology to obtain fried food by means of an emulsion containing oil droplets in a stream of hot air, where this process occurs in a chamber in which the food is in continuous motion to promote homogeneous interaction between the food and the external way of emulsion. Also, the food is gradually dehydrated while the typical crust of fried food is generated and under these processing conditions, the final food has an oil content 80% less than with conventional frying,[1,9,22,23] and with a low-calorie content.[24] Therefore, reducing oil consumption can contribute not only to economic savings, but also to a lower intake of unhealthy fats (saturated, trans fats) and fewer calories, which can help control weight, control the level of LDL (bad) cholesterol, hence, decreasing the risk of heart attack, stroke or other major health problem.[25] The hot air fryer (Fig. 3) is designed to circulate considerably hot air at high speed in a manner that mimics the movement and flow of heat currents in a pot of boiling oil, to brown the outside of the food while cooking inside. In addition, the airflow inside the equipment is forced over the food in a way much like a convection oven.[9,26] The heat and mass transport phenomena involved in frying processes are faster for traditional frying than for hot air frying. Also, although the frying temperature is the same in both cases, heat transfer is faster when the fluid passes is oil than when it is air, so the result is at longer frying times for air frying.[27] It is currently possible to buy fryers designed on this principle to produce low-fat French fries. This technology not only exerts better health benefits, is also has environmental advantages, such as decreasing oil consumption and achieving zero effluent discharge.[28] On the other hand, Table 1 shows a compilation of the operating conditions for potato frying, showing that the average temperature used is 180 °C at different frying times. The table can be useful for both food scientists and the public because it gives a broad overview of frying conditions.

Quality characteristics of hot air fried potato products

Acrylamide content (AC)

Acrylamide is generated in food, and is formed from acrolein, which originates from the degradation of lipids (oxidized fatty acids or glycerol), and acrolein is generated when lipids are heated at high temperatures,[39] and acrylamide at high

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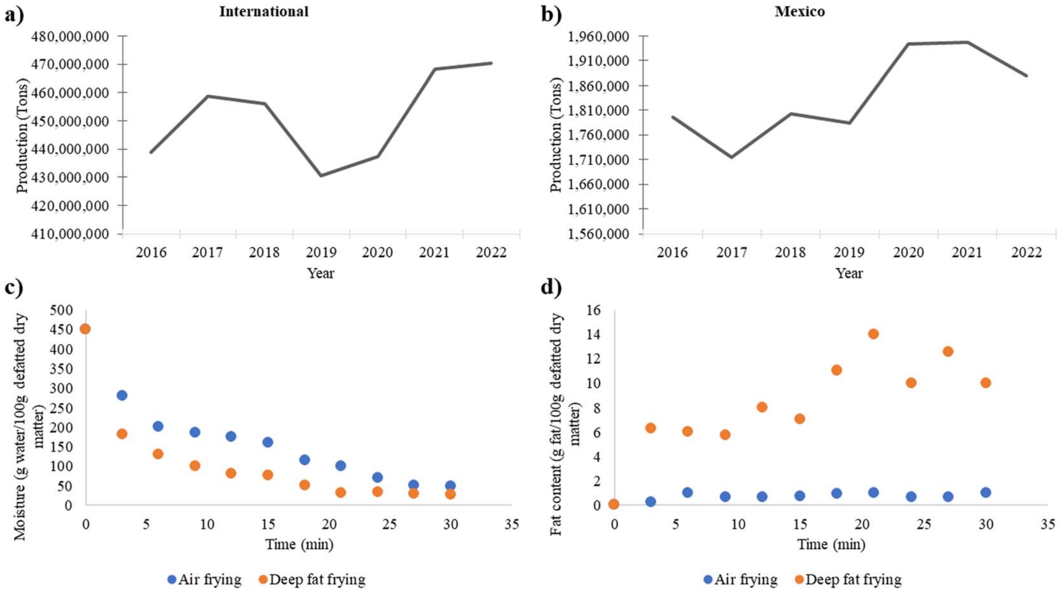

Fig. 1 Seven-year trend in potato production at (a) international and (b) National (Mexico) levels. Prepared by the author with data obtained from the Food and Agriculture Organization[17] and Servicio de Información Agroalimentaria y Pesquera.[18] (c) Moisture content trend at different times and (d) fat content trend at different times (adapted from Dong *et al.*[5] and Teruel *et al.*[19]).

Fig. 2 Geometry of fried potato products that could be obtained with hot air frying technology.

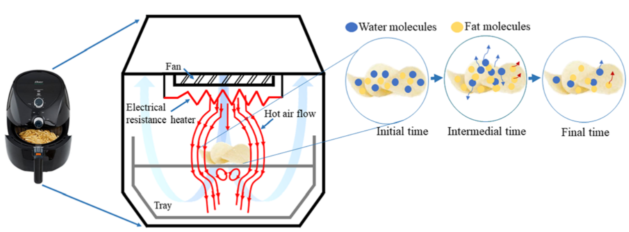

Fig. 3 Example of a general scheme from a hot air fryer (adapted from Teruel *et al.*[19]).

concentrations is considered toxic, causing mutations and DNA damage causing serious health problems.[1] In this sense, it is relevant the findings presented by Sansano *et al.*,[33] Basuny and Oatibi,[32] and Haddarah *et al.*[35] who reported a reduction of AC of more than half in a hot air frying compared to traditional frying potatoes. This lower AC between the two techniques could be associated with factors such as oil and oxygen content, in fact, oil absorption could be behind the AC, where a statical analysis ratified a significant correlation between oil content and acrylamide formation.[35] On the other hand, Giovanelli *et al.*,[34] and Santos *et al.*[38] reported no differences in AC in air and traditional frying potatoes, and no clear pattern was observed between processes or oils used. Dong *et al.*[5] found an increase in the acrylamide as process time and temperature increased. Thus, according to the reports presented in potatoes, hot air frying generates a lower concentration of acrylamide compared to traditional frying, thus having a positive impact on consumer health. This decrease in acrylamide could be explained due to glycerol produced from lipids (fat, oil), which forms acrolein through a dehydration reaction and this acrolein will oxidize to give acrylic acid, which reacts with ammonia from the amino acid asparagine in the proteins present, to produce acrylamide in lipid-rich foods after high temperatures, thus, low fat/oil fried potato products would produce low levels of acrylamide.[40] These results are favorable for international regulations, starting with the Food and Agriculture Organization of the United Nations (FAO), which conducted a consultation on the "Health implications of the presence of acrylamide in food", the World Health Organization (WHO) released a report warning that the unintentional presence of acrylamide in certain foods could be harmful to public health, the Food and Drug Administration (FDA) developed a "Guidance for Industry" that outlines strategies to help food producers, manufacturers and food service operators reduce acrylamide in the food supply, the CODEX Alimentarius published the Code of Practice for the Reduction of Acrylamide in Food (CAC/RCP 67-2009) which included recommended practices in the processing of potato products, finally, the European Union (EU) elaborated the "COMMISSION REGULATION (EU) 2017/2158" where mitigation measures and

Table 1 Operating conditions in the production of fried potato products using hot air technology

Food	Time (min)	Temperature (°C)	Model	Physicochemical and sensory characteristics	Reference
Potatoes	12, 15, 18, 21 and 24	180, 190 and 200	Toshiba ET-VD7250, Foshan, Guangdong, China	Higher moisture content, low acrylamide content, high levels of digestible starch. Regarding acceptability, the hardness and chewiness were similar to those fried with oils	5
	3, 6, 9, 12, 15, 18, 21, 24, 27 and 30	180	AH-9000 actifry (Tefal, Valencia, Spain) with a nominal power: 1400 W	Moisture content similar to fried potato products with oil (60–62%). Lower acrylamide content, greater luminosity and firmness in terms of consumer acceptability	1
	3, 6, 9, 12, 15, 18, 21, 24, 27 and 30	180	AH-9000 viva collection Airfryer HD9220/40, Philips	Ower fat content. Greater acceptability in terms of color, uniformity and texture, but with a dry mouthfeel	19
	—	140, 180 and 200	Airfryer Philips XL HD9240/90, Avance Collection, Amsterdam, The Netherlands with a power of 2100 W	Less crunchiness and greater hardness unlike fried potato products with oil	29
	25	185	Haier HAFJ2401A	Higher moisture content (53.6%), lower gelatinization (85.7%) and higher digestibility. Greater color and hardness compared to conventional frying	30
	—	180	SERIE 001 Actifry, Tefal, France, with a nominal power: 1400 W	Higher moisture content (35.25%). Decrease in the peroxide index. Flavor, color, texture, hardness and greasiness similar to fried potato products	31
	—	180	SERIE 001 Actifry, Tefal, France, with a nominal power: 1400 W	Lower moisture content, oil absorption, acrylamide and peroxide index. Flavor and texture similar to fried potato products with oil, however, acceptability was lower	32
	24 and 34	180	AH-9000 Actifry, Tefal, France, with a nominal power of 1400 W	Reduction in acrylamide content (90%)	33
	3, 6, 9, 12, 15, 18, 21, 24, 27 and 30	180	AH-9000 Actifry, Tefal, France, with a nominal power: 1400 W	Greater oil absorption and longer processing time	27
	12	200	Viva collection AirFryer HD 9220/20, Philips Italia, Milano, heated by a 1425 W resistance	Higher moisture and acrylamide content, lower acceptability in terms of flavor, aroma and creaminess	34
	15	175	—	Lower acrylamide content compared to conventional fried potato products	35
	—	180 and 200	Airfryer Philips XL HD9240/90, Avance Collection, Amsterdam, The Netherlands, with a power of 2100 W	Lower acrylamide content and oil absorption compared to conventional fried potato products	36
	—	218	—	Greater acceptability in terms of texture (toasted)	37
	20–25 (actifry) or 15–20 (airfryer)	—	Actifry (Tefal, SERIE001 model, France) with a nominal power of 1400 W, and Airfryer Philips, viva collection HD9220 model, The Netherlands, with a nominal power of 1425 W	Higher moisture and acrylamide content, as well as lower fat absorption (70%). Less acceptability in terms of color and aroma	38

reference levels are established to reduce the presence of acrylamide in food, as reviewed by Gonzalez *et al.*[41]

Moisture content (MC)

Moisture determination plays a fundamental role in the food industry, and in the case of the quality control standards of the frying industry say that the MC of the food should be in the range of 38–45% in wet weigh.[19] In the case of Andrés *et al.*,[27] Giovanelli *et al.*,[34] Shaker,[31] and Tian *et al.*[30] found a higher MC in hot air fried potatoes compared to traditional frying, because during traditional frying, the food is in full contact with the oil and dehydrated faster. Contrary case was reported by Basuny and Oatibi[32] who found the lowest MC in hot air fried potatoes compared to traditional frying. In other articles reported that MC decreases with frying time in the traditional method and in air frying of potatoes, explaining that the mechanism of water loss during frying has been elucidated as a dehydration process, there is a loss of MC, but according to scientific evidence in air frying the rate of moisture loss is lower than that obtained in traditional frying potatoes, this behavior can be observed in Fig. 1c.[5,19] In the case of the opposite results among the investigations, these could be due to the size of the sample together with the experimental conditions, since the different temperatures and times do make a significant difference (Table 1) and even if a small amount of oil is used when air frying, but in the case of the measurement methodology, some do not report the procedure but those that do use drying in the oven until reaching constant weight, so the measurement technique may not influence. Although these differences in MC could also be attributed to differences in planting and environmental factors during potato development and not only to processing conditions.[42] In addition, the frying process involves a series of mass transfer processes between the food and the liquid phase that result in a flow of water/steam from the food to the oil and an inflow of hot oil into the food.

Fat content (FC)

The role of fats and oils in human nutrition and quality control is one of the main areas of interest and research in food science. In this regard, Teruel *et al.*[19] reporting up to 15 times less oil content in hot air fried potatoes compared to traditional frying (Fig. 1d), attributing the differences in FC to the frying medium (oil or air) surrounding the potatoes. On the other hand, Andrés *et al.*,[27] Haddarah *et al.*,[35] Giovanelli *et al.*,[34] Shaker,[31] and Tian *et al.*,[30] found more than twice the FC in traditionally fried potatoes than in the hot air frying. For during frying, water vapors migrated from the food to the hot oil and the hot oil penetrated the food. Similarly, Basuny and Oatibi[32] found the highest oil absorption content was found in traditionally fried potatoes, while those made in a hot air frying had the lowest oil absorption. It can be concluded that frying evaporated the moisture and was replaced by oil in the traditional method, but not in hot air frying, it does not involve the addition of oil, so there was no change in the FC beyond that contained in the potatoes originally. In summary, hot air frying technology shows advantages in terms of reduced oil absorption in the potatoes, resulting in fewer calories in consumption and thus healthier fries.

Texture

The texture of the fried potato products is especially characterized by the development of a Surface crust, which is the parameter most appreciated by consumers, in addition to being an indicator of their quality. Heredia *et al.*[1] reported that in hot air frying the loss of firmness occurred more slowly, reaching a minimum value between 15 and 21 min depending on the penetrated applied to the potatoes and the crust formation started to appear after 18 min, due to the low evaporation rate. While Teruel *et al.*[19] did not observe differences between traditional and hot air frying methods for the crust at different times, but in the case of the central region of the potatoes, air fried potatoes showed higher hardness values than traditional fried potatoes, and the differences can be attributed to a lower degree of gelatinization occurring in hot air fried potatoes. On the other hand, Basuny and Oatibi,[32] Giovanelli *et al.*,[34] and Tian *et al.*[30] found that the hardness in hot air fried potatoes was notably higher than in traditionally fried potatoes, both in the crust and in the inner flesh and the differences could be attributed to the different processing conditions. In the case of Gouyo *et al.*[29] on hot air fried potatoes with the same 50% water loss revealed that an increase in temperature from 140 to 200 °C increased the values of crust crispiness and toughness. In general, in texture analysis studies have derived a wide variety of results, which could be attributed to the various operating conditions and even to the fryer model as shown in Table 1.

Color parameters

Color is considered one of the most important quality characteristics of fried potato products, where lightness (L^*) is an important parameter in the frying industry. It is known that consumers would note at potatoes that are too dark in color, so they should be properly fried under optimal conditions so that they do not burn.[2] Thus, Heredia *et al.*[1] did not detect variation in L^* during air frying non-penetrated and frozen potatoes, whereas, in blanched and fried potatoes, L^* increased until 9 min of frying and then was constant, and this could be explained considering that L^* depends on the amount of free water presented on the surface that benefits light reflection. Whereas Dong *et al.*[5] and Giovanelli *et al.*[34] showed a reduction in L^* compared to traditional frying, attributing the variation in color values to the difference in the frying process. Teruel *et al.*[19] found that L^* decreased with frying time in the traditional and hot air process, while a^* and b^* increased, and this is important with the potatoes becoming dark and yellowish red in color, thus, hot air frying can achieve the characteristic color of traditionally fried potatoes but requires a longer frying time. In contrast, Sansano *et al.*[33] in traditional frying L^* tended to decrease with processing time (∼75–40) resulting in a darkening of the potatoes, while it remained almost constant in hot air frying (∼75–55). In summary, according to the various works in air frying a color change is generated, decreasing the value of L^* with time and temperature of frying, and thus the potatoes obtain the characteristic color.

Sensory characteristics

The objective of this parameter is to measure sensory properties, in order to predict consumer acceptability, also one of the important concerns in the innovation of technologies focused on low-fat foods is the sensory aspect. Thus, Shaker,[31] and Tian *et al.*[30] compared traditionally fried potatoes with hot air fried potatoes, and these were not different in the sensory attributes of crispiness, odor, appearance, flavor, spreadability, and overall acceptability. But in color, hardness, and oilness, the quality of air fried potatoes outperformed traditionally fried potatoes. Basuny and Oatibi[32] found no differences in flavor and crispiness between hot air frying and traditional frying, but in appearance, color, and overall acceptability were higher in conventionally fried potatoes. Similarly, Giovanelli *et al.*[34] reported for potatoes obtained in traditional frying a better result in terms of oilness, odor and flavor than in the hot air frying. In summary, in hot air frying, according to research, sensory attributes similar in some parameters to traditional frying are obtained. Therefore, these are good results for a healthier diet, but with the characteristic flavor of conventional fried potato products.

Conclusions and suggestions for further research

In summary, research works using hot air frying potatoes are few, due to the novel technology it represents, so the impact of this work is relevant for food science and gastronomy. In addition, potato production at international levels is high, so using this frying method could help to provide a delicious and healthy alternative according to the results. The MC decreases with frying, but the final moisture is higher compared to traditional frying. The final FC is evidently lower compared to traditional frying, since no oil is required in the process, which leads to having a lower number of calories in the fried potato. In the texture analysis, acceptable characteristics are obtained. In color, L^* decreases with frying, attributing the desirable color characteristics of fried foods. The sensory characteristics are acceptable according to the results, so there is potential for processing the potatoes at the industrial level. Future research work should focus on evaluating the health impact of fried potato consumption by hot air frying, due to the limited information available in the literature and the importance this represents. We hope that in a few years this technology will be widely applied in industrial-scale production, although at present the design of equipment for this purpose is a challenge that food professionals will have to solve.

Conflicts of interest

The authors declare no conflict of interest.

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