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Original article

New Emerging Technique to Intensify Convective Air Drying Process: Impact of Interval Starting Accessibility Drying (ISAD) on Quality Attributes of Strawberries Fruits

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Abstract

Due to their high moisture content, strawberry fruits are very perishable. Fruits drying has been of rising interest during the last decades. Nevertheless, for heat-sensitive products such as strawberries, during drying, there is a difference between moisture located at the surface and inside the product. As a consequence, fruits suffer cracks or even more cells rupture. To address these issues, ISAD process was proposed in this study. The obtained results are very promoting and present ISAD as a relevant solution to problems caused by the conventional drying method. Indeed, the physicochemical parameters characterization demonstrated that ISAD technology improves certain quality parameters, in term of total color difference, total polyphenol content retention and textural quality of strawberry fruits. It is noteworthy that color change for ISAD-treated samples decreased significantly ($p<0.05$) as compared to that of continuous drying. Moreover, it was found that increasing the tempering time periods gradually enhanced this positive impact. Texture property of ISAD treated fruits was measured. ISAD treated slices were less firm (softest) compared to conventionally treated ones. Finally, minimum loss of polyphenol compound occurred in ISAD dried samples. The quality attributes were well maintained while dried with ISAD regime. This can be attributed to the redistribution of moisture during tempering period, since it helps reducing temperature and moisture gradients and therefore the internal stresses within the product and thus final product quality.

Keywords: Strawberries, Convective drying, ISAD, Color, Texture, Polyphenols.

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INTRODUCTION

Convective air-drying process is one of the most known preservation methods which extensively reduces the weight and volume of vegetables and brings benefits, such as minimizing packing, storage, and transportation costs. Nevertheless, for heat-sensitive products such as strawberries, Partial air-flow drying undergoes fundamental problems such as low operation performance and short reliability of the equipment. Moreover, drying time is an important factor, which could reflect the operation cost, the energy consumption and the quality attributes of the end product as well. In addition, during drying step, there is a difference between moisture located at the surface and inside the product. The surface that is in direct contact with the air tends to dry more than the central part. Regrettably, fruit surface has no elastic plasticity and does not withstand very strong hygro-thermo-mechanical constraints. As a consequence, with drying intensity, fruits suffer cracks or even more cells rupture. Indeed, during the drying process, external transfers are not considered as limiting phenomena for drying kinetics, it is only the internal transfers considered as the driving force controlling and limiting the whole operation of hot air drying. Indeed, overheating during convective drying induced texture compactness as a result of shrinkage phenomena and case hardening (Hajji et al., 2022). Thus, the water is entrapped in the dense solid matrix and its movement toward the external surface and its removal become more difficult (Mounir et al., 2012).

Consequently, this study was carried out to propose and develop for the first time, as part of this thesis research, a new emerging technique to solve the main part of these problems: Intevral Starting Accessibility Drying (ISAD) is based on subjecting, strawberries samples to an instantaneous action of hot air during drying, close to the starting accessibility time, at 40°C and air flow velocities of 3.5m/s, where the heat is supplied discontinuously, at short regular time intervals (15s). During short rest or tempering periods (between 1 and 5 min), fruit sample does not receive hot air. This research is dedicated to the study of ISAD operating conditions effects on strawberries quality, in terms of: color properties, polyphenols content and textural property (firmness index). Strawberries fruits were subjected to both continuous and ISAD regimes under different tempering times or periods (from 1 to 5min). Experimental results demonstrate the positive effects of ISAD procedure on color preservation and polyphenols retention. Moreover, it was found that increasing the tempering time periods gradually enhanced this positive impact. Unlike fruits obtained from continuous drying, ISAD treated slices were less firm (softest) compared to conventionally treated ones. ISAD technique could be regarded as an excellent intensified alternative to be tested for other food products.

MATERIALS and METHODS

Sample preparation

Fresh strawberries fruits were purchased from a local supplier in Tunis (Tunisia) and stored in a refrigerator at 4°C for 24h until use. Fruits were removed from refrigeration and left for equilibrium at room temperature before experimentations. They were washed and dried with absorbent tissue paper. Following this step, strawberries fruits were manually cut into discs with 0.5± 0.12cm, using a stainless-steel knife perpendicularly to the main axis.

Partial air drying

Partial air drying experiments were run in a laboratory-scale convective air dryer, developed in National Institute of Agronomy, Tunisia (INAT) at air temperature of 40°C and air velocity of 3.5 m s^{-1} . In order to succinctly describe ISAD process, the concept of active time and tempering periods were applied in this study. Moreover, selection of the alternative active and tempering time for all experiments used in this research work is based on preliminary essays performed within the research unit (PATIO) and La Rochelle, with the same equipment applied for continuous drying(Gliguem et al., 2021).

Quality evaluation

Moisture content determination

Moisture content of fresh and treated strawberries were measured using hot airoven (WT-Binder, E53, Germany) according to the standard method at 105 ˚C during 24 h(Hajji et al., 2019). The results were presented as an average of three measurements. Fresh strawberries fruits (RM) used had an initial moisture content of 90.25g/100g wb.

Color evaluation

The color of treated samples dried under continuous and ISAD techniques were measured directly on the product surface using a handheld tristimulus colorimeter ((Konica Minolta CR-410, Tokyo, Japan) and color was recorded using CIE L; a; and b color spaces where L indicates lightness, and its value ranges from 0 (black) to 100 (white), a is a measure of greenness (-a)/redness (+a) and b is the grade of blueness (- b)/yellowness (+b).

The colorimeter was calibrated against a Minolta standard-white reflector plate before each color measurement. The color parameters were averaged over 9 measurements. Derived color parameter total color difference (ΔE) was calculated using the following equation1(Hajji et al., 2020):

$$\mathbf{TCD} = \sqrt{((\mathbf{L}_0 - \mathbf{L})^2 + (\mathbf{a}_0 - \mathbf{a})^2 + (\mathbf{b}_0 - \mathbf{b}))^2} \quad \text{Equation 1}$$

Where L_0, a_0, and b_0 are (fresh strawberry sample color parameters) and L, a, and b are dried fruits samples color parameters.

Phytochemical Analysis

Sample extracts Preparation. For strawberry samples extraction, 0.5 g of each sample were weighted in a 30 ml centrifuge tube, and 10 ml of acidified methanol (1.0 % HCl in methanol, v/v) were added and agitated for 2 h at room temperature in darkness. The sample suspensions were centrifuged at 6000 rpm for 10 min at 4°C and the supernatants were stored at -20°C until analysis (Alonzo-Macías 2013).

Total phenolic content TPC. The phenolic content in strawberries extracts was determined by the Folin-Ciocalteu reagent using Gallic acid as the reference compound: in the case of quince fruit, 125 µl of the prepared extract was mixed with 500 µl of distilled water in a test tube followed by the addition of 125 µl of Folin-Ciocalteu reagent. The samples were well mixed and then allowed to stand for 6 min before adding 125 µl of a 7% aqueous sodium carbonate solution.

Water was added to adjust the final volume to 3000 µl. The resulting mixtures were vortexed and allowed to stand for 90 min in the dark at room temperature (Ben Haj Said et al. 2013). For strawberries fruits, 0.02 ml of the extracts was oxidized with 0.1 ml of 0.5 N Folin-Ciocalteu reagent, and then the reaction was neutralized with 0.3 ml sodium carbonate solution (20%). After incubation for 2 h at 25 °C, quantification was achieved (Singleton et al. 1999; Alonzo-Macías 2013).

The absorbance was measured for both extracts types at 760 nm with a JENWAY 6715UV/V spectrophotometer. Finally, absorbance values were compared with those of standards prepared similarly with known Gallic acid concentrations. Total polyphenols content of treated dehydrofrozen strawberries samples were expressed as grams of Gallic acid equivalents per 100 gram dry basis (g GAE/100 g db) for three replications, through the calibration curve with Gallic acid in the range of 0–500 µg/ml(Roy et al. 2007).

Texture measurement

The texture of treated strawberries was evaluated using a texture analyzer measured through a puncture test. Fruit firmness measurement was conducted by a PertenTVT 6700 universal texture analyzer with a 2mm diameter cylindrical stainless probe, at a constant speed of 1 mm/s. The maximum force peak was expressed as a firmness value in Newton(Hajji et al., 2019). The results were averaged over fifteen measurements.

Statistical Analysis

All statistical analyses were performed using the analysis design procedure of Statgraphics Plus software for Windows (1994, version 4.1, Levallois-Perret, France), with source of variance being the tempering time (min). In order to determine the differences in among the media of the total color difference, and maximum force rupture between samples, one-way ANOVA tests were performed, followed by post-hoc test (multiple range test: least significant differences LSD) to compare means. A P value < 0.05 was considered significant. Data are presented as mean ± standard deviation (±SD).

RESULTS and DISCUSSION

Effect of ISAD treatment on color proprieties

Color is one of the most important quality attributes of foods as it is critical in the acceptance of food products by consumers. In order to study the impact of ISAD operating parameter (Tempering time (min)), on the drying stage, color experiments were carried out on strawberries samples before and after drying procedure (Fig 1 (a).).

As it is depicted in figure 1(a), compared to continuous convective dried products (tempering time =0min), ISAD treatment decreased the overall color change. Indeed, it is reduced to 24.77 % for only 1 min of tempering time of strawberries. In addition, this reduction of total color change is more prominent ($p < 0.05$) with increase of tempering time. Actually, total difference color reaches a reduction of 62% for ISAD treatment with 5 min of tempering period. This is due to the decrease of both enzymatic and non-enzymatic browning reaction. In fact, an instantaneous effective drying time (15s) associated to short tempering time reduce the total sensible heat transferred from the drying air to the product. Several research works stated that heat sensible food products, especially with high polyphenols content, underwent a serious deterioration during conventional drying, mostly caused by enzymatic and non-enzymatic browning. The polyphenol oxidase (PPO) and peroxidase (POD) are prone to enzymatic browning. Nonenzymatic browning includes a wide number of reactions such as Maillard reaction, caramelisation, and chemical oxidation of phenols(Snoussi et al., 2021). During tempering period, due to moisture gradient established inside the product during drying, there is moisture migration from the interior to the surface, until the moisture in the entire product is almost uniform. This moisture redistribution, beyond of reducing product temperature, had a significant effect in reducing thermal damage and, thus color change. Moreover, it is noteworthy that during conventional drying compared to ISAD technique, convective air circulation contains a high level of oxygen which in turn stimulated the enzymatic browning reaction between the oxygen and total phenol content with the presence of polyphenol oxidase (PPO) and induced higher total color difference value.

Effect of ISAD treatment on TPC

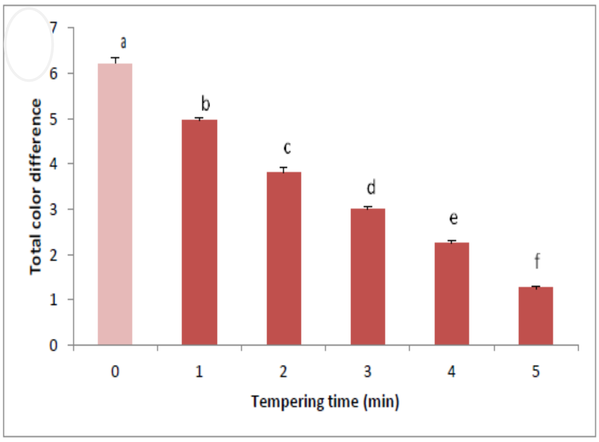
Interest in phenols has greatly increased in recent years because of their antioxidant ability, which is intimately associated with potential benefits for human health. The initial phenolic content was 3.4g AGE/100g db for strawberry sample. Levels of phenols for unprocessed fruits were in the range of those reported by other authors(Amami et al., 2016). Differences connected with fruits total polyphenols content were closely related to the cultivation techniques and cultivar(Núñez-Mancilla et al., 2014).

As summarized in Fig 1(b), the total phenolics yields of quince and strawberries fruits decrease significantly (p). Indeed, once these healthpromoting compounds are exposed to continuous drying conditions, TPC, which are usually stable within the original fruit matrix, are highly vulnerable to deterioration, due to their thermolabile characteristic(U.H.Joardder et al., 2015). Interestingly, the application of the ISAD technique on strawberry fruit provides higher retention of polyphenolic component compared to conventional drying method. Indeed, all ISAD treated samples at different tempering periods (from 1 to 5 min) showed an increasing trend in TPC retention. As it follows from Fig 1 (b), thanks to tempering periods, periodical cooling cycles prevent overheating, and thereby decomposition of polyphenol compounds of strawberries. Furthermore, ISAD technique with 5 min tempering time resulted in better TPC retention. Indeed, the water that migrated to the surface during tempering allows surface temperature to stay close to the wet bulb temperature: At the same time, water content equilibrium through the fruit sample leads to a more uniform temperature over the slab making core fruit temperatures lower and closer to wet bulb value. Thus, fruit sample is more protected against overheating. During tempering periods, the additional moisture will also limit the risk of over drying at the surface, which can lead to excessive dehydration stresses. In addition, the reduced exposure to elevated temperatures also induces better product quality, as active compounds are better retained(Defraeye, 2016).

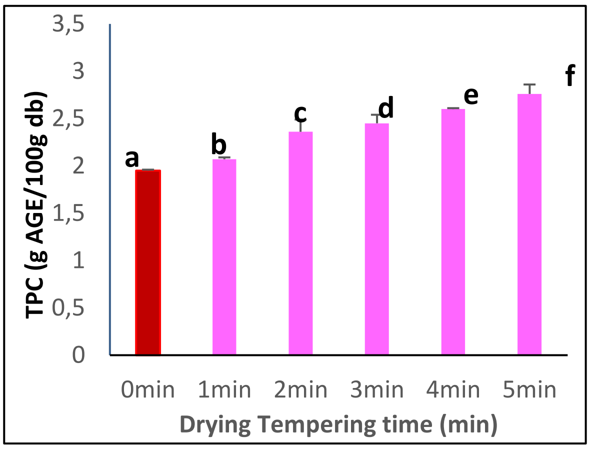
Effect of ISAD treatment on strawberries firmness

Textural changes, that may occur in Strawberry fruits during ISAD- assisted dehydrofreezing process at 40°C and 3.5 m/s, using the maximum forcé puncture (MFP: firmness index) are shown in Fig 1 ©. The MFP reflects the breaking of the outer layer of the fruit slices when penetrated by the puncture element.

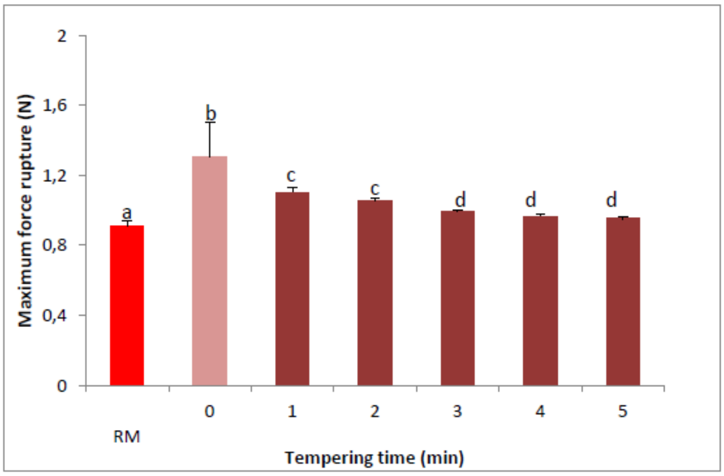
Figure showed, a decrease of fruit firmness under ISAD conditions, due to the softening of fruit tissue. The overall texture of strawberries at any tempering time is characterized by a lower maximum force puncture value compared to the conventional convective drying (tempering time =0 min). This allowed the study of not only the softening of fruit tissues during ISAD regime but also of the crust formation and its development. Indeed, it was observed that strawberries samples, dried at ISAD regime at different tempering times, required minimum force puncture to break the outer layer as compared to continuous drying ones, and this is due to a better uniform water redistribution in samples layer. Soysal et al. (2009) stated that product temperature during drying process is an important key to achieve a good quality dried products. This contributes to minimizing the quality degradation and thermal damage, thus leads to an improvement of fruit texture during drying process.



(a)



(b)



(c)

Figure 1. Effect of tempering time on (a) Total color difference; (b) polyphenols content and (c) firmness index of strawberry fruit

Conclusions

The obtained results are very promoting and present ISAD technology as a relevant solution to problems caused by the conventional drying method. In fact, with ISAD treatment the final quality degradation of the product can be minimized without compromising the drying performance to reach the desired final moisture content. Indeed, the physicochemical parameters characterization demonstrated that ISAD technology improves certain quality parameters, in term of total color difference, total polyphenol content retention and textural quality of strawberry fruits. It is noteworthy that color change for ISAD-treated strawberries samples decreased significantly as compared to that of continuous drying. Moreover, it was found that increasing the tempering time periods gradually enhanced this positive impact. Texture property of ISAD-treated fruits was measured. The slices were less firm (softest) compared to conventionally treated ones. Finally, minimum loss of polyphenol compound occurred in ISAD dried samples. Unlike products obtained from continuous drying, the quality attributes of strawberries fruits were well maintained while dried with ISAD regime. This can be attributed to the instantaneous drying action (15s) and the redistribution of moisture and temperature during tempering period, since the tempering helps reducing temperature and moisture gradients and therefore the internal stresses within the product and thus final product quality.

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