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RESEARCH ARTICLE

The Effect of High-Fructose Corn Syrup on the Physico-chemical and Sensory Properties of Frozen Ripe and Half-Ripe Bananas: An Experimental Industrial Scale Study

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Abstract

Edible coatings have been investigated recently as an effective and eco-friendly alternative to protect and preserve foods (e.g., from oxygen exchange and water transfer) and for shelf-life extension. Nowadays, advanced freezing methods, such as individual quick freezing (IQF), have various benefits which have enabled new applications of the technology in food products and in the food industry. Insofar, research has not been conducted to assess the use and effects of high-fructose corn syrup (HFCS) as an edible coating on the shelf-life extension of ripe and half-ripe frozen bananas (i.e., via IQF). In this research, the novel combined method of using a HFCS as edible coating and IQF were applied to avoid the enzymatic browning of banana slices during freezing.

In this experimental study, the effects of 55% HFCS, as an edible coating, on firmness, colour intensity, total phenolic content (TPC), and sensory properties (colour, aroma, taste, and overall acceptance) of ripe and half-ripe bananas were examined after IQF. The highest overall acceptance was observed for coated half-ripe bananas followed by coated ripe bananas. The use of 55% HFCS for coating IQF bananas can improve the quality and delay enzymatic browning, especially in half-ripe bananas.

KEYWORDS
high-fructose corn syrup, individual quick freezing, coating, total phenolic content, banana

Introduction

Bananas are grown in tropical and subtropical areas such as Africa, Indonesia and Malaysia and are one of the most widely consumed fruits worldwide (Maseko, Regnier, Meiring, Wokadala, & Anyasi, 2024; Phillips et al., 2021). The fruit is a dietary staple for hundreds of millions of people and contains vitamin B6, vitamin C, manganese and dietary fibre which can contribute to a healthy balanced diet (Kumari, Gaur, & Tiwari, 2023; Phillips et al., 2021). The most common commercial variety of the fruit is the Cavendish banana which is generally starchy and may be eaten ripe or half-ripe. However, like other fruits, bananas are susceptible to enzymatic reactions and a variety of chemical, physical and microbial spoilage. At the beginning of the ripening process bananas tend to become sweeter and more yellow. As ripening continues bananas will eventually start to overripen by producing ethylene gas which leads to its enzymatic browning [Cho et al. 2016].

Freezing is often used for the long-term preservation of many foods, especially perishable foods, including fruits and vegetables (Rahman & Velez-Ruiz, 2020). The discussed process can provide a significant extension (e.g., weeks, even months) to an otherwise very short shelf life. During freezing, the extreme cold temperature (~-18°C) retards the growth of microorganisms and slows down the chemical changes that can affect food quality and impact food spoilage. Further, freezing is one of the most widely used methods of banana preservation, which allows the fruit's taste, texture, and nutritional value to be retained better than several other preservation methods [Pruthi 1999].

Fluidization, also known as individually quick freezing (IQF), is a modified technique of air-blast freezing wherein foods, especially those with the potential for clustering, are individually quick frozen. IQF is achieved by blasting cold air from beneath a conveyor belt, as food travels through a tunnel and is frozen as individual and separate food pieces. The technique can freeze foods within less than ten minutes and is an effective means of freezing small pieces of raw material to prevent the formation of large clusters. The latter is beneficial as cluster formation can introduce difficulties in handling and in further food processing. Given that bananas spoil easily, conventional methods of refrigeration cannot adequately preserve the fruit's original organoleptic qualities (e.g., freshness and texture). Bananas, especially when sliced, are prone to clumping together. During conventional freezing these clumps can become frozen solid leading to less manageable clusters. To address these quality issues, IQF has been suggested as the optimum preservation method for frozen bananas. Using the fluidization technique, banana slices can be frozen individually and kept separate, thus preventing them from adhering to each other and forming semi-permanent, frozen clusters [Kocira et al. 2021].

In the modern food system, food may have to travel thousands of miles to arrive at its destination. However, throughout its journey it may undergo changes in ripeness and quality that impact its final organoleptic properties and acceptability, especially for perishable items, like fruit. Innovations in packaging and the development of food additives are often used for food preservation. However, consumers are increasingly looking for cleaner, and environmentally conscious products with recognizable ingredients free from chemical additives and preservatives. Coatings on foods can be applied to limit the contact of the food product with the environment contributing to the preservation and quality of the food (e.g., control of the surface moisture preventing the agglomeration, adhesion, or disintegration of food) or to modify the food's functional properties [Zambrano-Zaragoza and Quintanar-Guerrero 2019]. Coatings must ensure that the product is stable throughout its shelf life, therefore, coating processes are often completed by a stabilizing process, e.g. such as freezing.

Edible coatings have seen a significant recent increase in development and application for the preservation of foods, particularly perishable products such as fruits. These edible coatings can serve as an environmentally friendly technology which can be applied on many products to control moisture transfer, gas exchange, volatiles, or oxidation processes [Dhall 2013]. Edible coatings include polysaccharides (e.g., starch, cellulose, pectin, alginates, chitosan), proteins, lipids, and composite polymers to form coating films. Due to their relative abundance in nature and low cost, polysaccharides, such as starch, are widely used as edible coatings for foods.

Several studies have been conducted on the use of edible coatings to increase the shelf life of bananas. Findings showed that the polysaccharide-based coatings resulted in retarded colour development, lower acidity, greater firmness of the bananas, delay banana ripening, prolongation of the commercial shelf-life of bananas but also coated bananas demonstrated reduced weight loss and vitamin C loss or post-harvest quality maintenance for over 30 days, depending on the solution applied [Kittur et al. 2001, Baez–Sañudo et al. 2009, Suseno et al. 2014, Soradech et al. 2017, Ziedan et al. 2018, Thakur et al. 2019, Li et al. 2019, Dwivany et al. 2020].

Sugar syrups with a sugar content of 30-60% are typically used to fully cover fruit, serving as a barrier against oxygen transmission and browning. Packing fruit with sugar or syrup generally enhances its colour, flavour, and texture [Kendall 2008]. Covering peach slices with a sugar syrup containing 50-55% sugar limited the migration of oxygen into the fruit tissue. The browning rate of red sour cherries decreased when they were immersed in a 60% sucrose syrup and stored in hermetically sealed containers at -6.7°C [Chaves et al 2018].

High-fructose corn syrup (HFCS) is a sweetener made from processed corn-starch. The fructose in the syrup is obtained by the enzymatic conversion of the corn-starch to glucose then to fructose. Fructose is the sugar found in fruits and as HFCS is less expensive and has a wide range of purported benefits, HFCS has replaced sucrose in a wide range of applications in the food industry (Hosseini, Azarikia, Borhani, & Gholami, 2021; Khorshidian et al., 2021; Kognou et al., 2022). Corn is a highly versatile crop known for its high yields and its use in producing a wide variety of food products and ingredients, such as cereals, flours, oils, starch, and sugars for fermentation processes. HFCS is made through wet milling, wherein the starch is separated from the other parts of the corn and used to make a syrup, which is mainly composed of glucose. This syrup is then converted, refined, and filtered into liquid mixtures of either 42% or 55% fructose (Jiao, Chen, Han, & Chang, 2022; Khorshidian et al., 2021). HFCS 42% is mainly used in processed foods, cereals, baked goods, and some beverages, whereas HFCS 55% is used primarily in soft drinks (Khorshidian et al., 2021). Research has been conducted into the use of HFCS as a type of edible starch-based coating for food products. However, so far there have been no studies to show the use of HFCS as an edible coating for extending the shelf life of bananas.

Innovative preservation techniques and the use of IQF are crucial for preventing enzymatic browning, thereby ensuring the preservation and optimal taste and texture of bananas. Therefore, the combined application of edible coatings and IQF is investigated as a novel preservation technique to maximize the retention of the quality and sensory properties of bananas. This study aims to assess the effect of HFCS 55% as an edible coating on selected characteristics of IQF bananas. It was hypothesized that HFCS 55% could delay enzymatic browning, increase firmness, and improve colour, aroma, taste, and overall acceptance of IQF bananas.

Materials and Methods

In this study 60 kg of Cavendish bananas were purchased from a market, 30 kg of which were ripe whilst the other 30 kg were half-ripe bananas (Chiquita brand). The bananas were inspected for damage and any damaged bananas were excluded from the study. The remaining bananas were then sorted by ripeness (i.e., half-ripe and ripe, Figure 1). For the purposes of this research bananas at stage 3 would be classified as half-ripe whereas

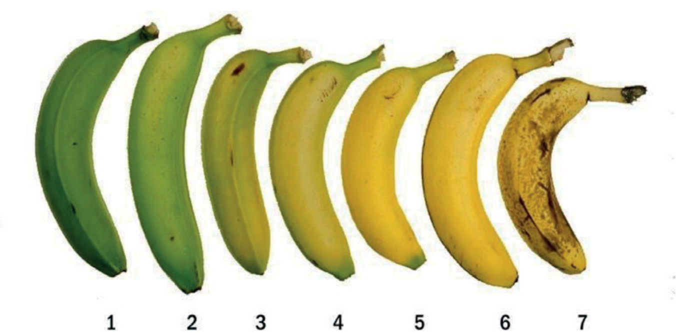

Figure 1. Bananas at varying stages of ripeness. For the purposes of this research the banana at stage 3 would be classified as half-ripe whereas the banana at stage 5 would be classified as ripe.

Figure 2. IQF tunnel freezer (left) and the frozen banana slices (right)

bananas at stage 5 would be classified as ripe. Then, the bananas were peeled by hand followed by automated slicing to a thickness of 2 cm using a slicing machine (Sormac, Netherlands) at a frequency of 1-5 Hz. Four samples of sliced frozen bananas were prepared: 1) ripe bananas coated with HFCS, 2) ripe bananas without HFCS and 3) half-ripe bananas coated with HFCS and 4) half-ripe bananas without HFCS. After slicing, half of the banana samples were dipped in a tasteless and odourless solution of 55% HFCS (Glucosan Co., Iran) for two minutes and then drained of excess syrup in steel drainers. This helped to ensure a more even coating of HFCS, the slices were then placed in the IQF tunnel (Advanced Equipment Inc., Figure 2) at a temperature of -40°C for seven minutes. The core temperature of the banana samples was then measured to ensure it was -18°C by plunging the sensor probe of the thermometer into the fruit. To limit impact oxidation and browning. The banana samples were subsequently packed in polyethylene zip-lock bags to ensure minimal air permeability. The uncoated sliced banana samples were placed immediately in the IQF tunnel belt freezer and were then stored for over one month at a sub-zero temperature, between -18 to -20°C. Firmness and colour intensity of the banana samples were evaluated immediately. Sensory properties of colour, aroma, taste, and overall acceptance of the banana slices were evaluated one month after IQF. Samples were prepared and frozen at Nobar Sabz Agro Industrial Complex (Tehran, Iran), and assessments were conducted in the Zakariya Razi Laboratory Complex at the Islamic Azad University of Tehran and College of Agriculture and Natural Resources at the University of Tehran, Iran.

Texture assessment

A texture analyser device (Brookfield CT3, USA) with a 4500 g load cell and a speed of 2 mm/s as well as a diameter cylinder probe (TA25/1000) was used to assess the firmness (N) of the samples. The test was conducted with three replicates.

Colorimetry test

The colour of the samples was determined using a precision colourimeter (NR145, China) which was calibrated prior to testing. The precision colorimeter device offers objective measurements of colour lightness, red/green, and yellow/blue. Lightness (L*) ranges from 0 (black) to 100 (white), red/green (a*) ranges from positive values indicating red to negative values indicating green, and yellow/blue (b*) ranges from positive values indicating yellow to negative values indicating blue. The test was conducted with three replicates.

Total phenolic content (TPC) assessment

Total phenolic content in the samples was determined using the Folin-Ciocalteu (FC) assay with three replicates. For this purpose, the polyphenols in the samples were first extracted by pouring 100 g of each sample into the funnel fully covered by aluminium foil and then 300 ml of absolute ethanol (Bidestan Co., Iran) was added. Next, samples were placed in a shaker (Unimax 2010, Heidolph, Germany) for 24 hours (at 100 rpm and 40°C) to perform the extraction. The extracted samples were then filtered using a funnel through filter paper (Munktell) and concentrated by a rotary evaporator (Laborota 4003, Heidolph, Germany) with 337 mbar vacuum pressure, bath temperature of 60°C and speed of 100 rpm. Then, 40 μl of the diluted fruit extract was combined with 1.8 mL of FC reagent (Merck Co.) and diluted ten times with distilled water. After being kept for five minutes at room temperature in a dark room, 1.2 mL of sodium carbonate 7.5% w/v solution (Merck Co.) was added. The samples were then thoroughly mixed and kept at room temperature in a dark room for one hour. The absorbance of the samples was then measured using a UV-visible spectrophotometer (CARY 100 CONC, Varian Inc., Australia) at 765 nm. The standard calibration curve was plotted using gallic acid (Merck Co.) at 20-100 mg/L concentrations. The total phenolic content of the extracts was expressed as mg gallic acid equivalents (GAE) per gram of sample (GAE/g). The experiments were then repeated three times and the average values were reported [Hatami et al. 2014]. The obtained standard calibration curve of gallic acid for the determination of total phenolic content in the samples was $y=0.0177x-0.076$ ($R2=0.9959$).

Sensory assessment

The sensory properties of the samples (colour, aroma and taste, and overall acceptance) were evaluated by ten panellists using a 5-point hedonic scale where 1 indicated "dislike very much" and 5 indicated "like very much". Water was provided to rinse the mouth and coffee was provided for smelling each time a panellist carried out an evaluation.

Statistical analysis

Data were expressed as mean ± standard deviation (SD) and analysed in SPSS v.22 software using a one-way Analysis of Variance (ANOVA). Kolmogorov-Smirnov test results showed that the data had normal distribution ($p>0.05$). Following the ANOVA, a post-hoc analysis of Duncan's multiple range test (MRT) was applied to compare the sets of means.

Results

Comparison of firmness

The results of firmness comparison using Duncan's test are presented below in Table 1. All the banana samples demonstrated significantly different firmness values ($p<0.05$). Ripe banana samples without HFCS had the lowest firmness (5.90±0.00 N). After coating, banana sample firmness increased, this effect was greatest in the ripe samples which was an almost 5-fold increase from 5.9 without the HFCS coating to 25.81 N the HFCS coating. In addition, HFCS increased the banana sample shelf life for more than one month.

Table 1. Comparison of texture firmness between banana samples evaluated after IQF

Banana samples	L* (Lightness), Mean±SD	a* (Red/Green), Mean±SD	b* (Yellow/blue), Mean±SD
Ripe bananas without HFCS	59.1±0.02[a]	6.8±0.02[b]	21.7±0.3[c]
Ripe bananas with HFCS	59.9±0.03[b]	8.0±0.02[d]	22.0±0.02[d]
half-ripe bananas without HFCS	60.9±0.03[c]	7.0±0.03[c]	17.8±0.03[a]
half-ripe bananas with HFCS	61.6±0.05[d]	6.6±0.05[a]	19.2±0.04[b]

Note: Values with different letters are significantly different at $p<0.05$ according to Duncan's test

Comparison of the colorimetry test results

The results of the CIELAB values that were compared using Duncan's MRT are presented in Table 2. As shown the samples had significantly different colours ($p<0.05$) with ripe bananas without HFCS demonstrating the lowest lightness (L*: 59.1±0.02). After coating, both the ripe and half-ripe samples became lighter. Redness increased in the ripe bananas after being coated from 6.8±0.02 to 8.0±0.02, while it was reduced in the half-ripe bananas. This indicated that the HFCS had a significant effect in the half-ripe bananas on reducing redness. The half-ripe bananas without HFCS had the lowest yellow (b*: 17.8±0.03). After coating, the yellow intensity of both the ripe and half-ripe samples increased, mostly in the half-ripe samples. Further, the ripe banana samples with HFCS showed more enzymatic browning than the half-ripe samples with HFCS after six months.

Table 2. Comparison of the CIELAB values between the banana samples evaluated after IQF

Banana samples	Mean ± SD (mg GAE/100g dry sample)
Ripe bananas without HFCS	58.2±0.04[c]
Ripe bananas with HFCS	60.8±0.01[d]
half-ripe bananas without HFCS	38.4±0.03[a]
half-ripe bananas with HFCS	41.6±0.03[b]

Note: Values with different letters are significantly different at $p<0.05$ according to Duncan's test

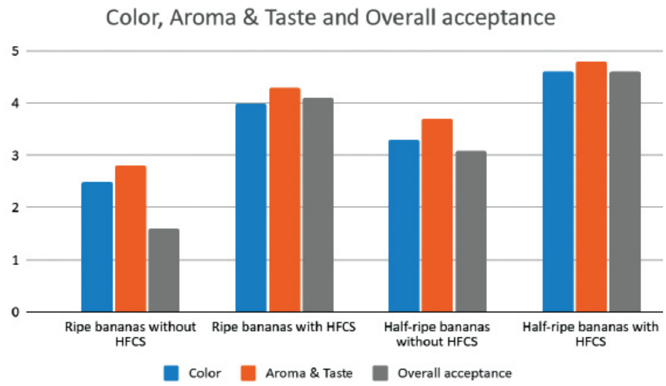

Figure 2. A comparison of the sensory properties between the banana samples

The comparison of sensory properties

Figure 2 illustrates the comparison of sensory properties (colour, aroma, taste, and overall acceptance) based on a 5-point hedonic scale. In terms of colour, 60% of the evaluators gave the highest score to the half-ripe bananas with HFCS ($\bar{x}$ =4.6) and regarding aroma and taste, 80% of evaluators gave the highest score to the half-ripe bananas with HFCS ($\bar{x}$ =4.8). The half-ripe bananas with HFCS also scored the highest overall acceptance ($\bar{x}$ =4.6).

Discussion

This is the first experimental study using high-fructose corn syrup (HFCS) as an edible coating to assess its application and effectiveness in extending the shelf life of ripe and half-ripe bananas frozen by IQF. Results of the texture analysis showed that the firmness of the banana samples increased significantly, mostly in the ripe samples, after coating by HFCS 55%. Results of the colorimetry test demonstrated that both the ripe and half-ripe samples became lighter significantly after using HFCS. The HFCS likely caused the bananas to have a more acceptable colour. The positive effect was more noticeable with the half-ripe bananas, as they maintained an acceptable yellow colour according to the panellists, whereas the ripe bananas turned more brownish. This highlights the effect of HFCS as an effective edible coating for preserving the aroma and taste of banana samples. Redness was reduced only in the half-ripe bananas, while the yellowness of both the ripe and half-ripe samples increased, mostly in the half-ripe samples.

Phenols or phenolic compounds are a class of chemical compounds which have at least one phenol group within their chemical structure. These compounds are a class of metabolites that result from the secondary metabolic pathways of plants, as such they are ubiquitously found in nature. Owing to the ability of phenolic hydroxyl groups to act as effective hydrogen donors, many phenolic compounds have been shown to demonstrate high levels of antioxidant activity [Stankovic et al. 2012]. However, foods containing phenolic compounds are also prone to enzymatic browning via the enzyme polyphenol oxidase (PPO). In the presence of oxygen PPO can convert phenolic compounds into melanin in a series of reactions that result in browning. Based on the results of total phenolic compound (TFC) the TFC concentrations were increased even after coating. Further, coating with HFCS delayed browning and increased banana shelf life up to one month. These results support the hypotheses of the present study and results are consistent with the findings of other studies that have reported the effectiveness of edible coatings in increasing the shelf life of bananas, although most of such studies were storage experiments involving whole bananas [Kittur et al. 2001, Baez-Sañudo et al. 2009, Suseno et al. 2014, Soradech et al. 2017, Ziedan et al. 2018, Thakur et al. 2019, Li et al. 2019, Dwivany et al. 2020]. For example, results from Baez-Sañudo et al. [2009] showed that a combination of 1-methylcyclopropene and a chitosan-based edible coating can be used to extend the commercial shelf-life of bananas by up to four days. They were postharvest studies in which the whole fruit was immersed in the coating matrix. Similarly, Suseno et al. [2014] examined the effectiveness of chitosan in improving the shelf-life and nutritional quality of the Cavendish banana. Their findings showed that chitosan coating was able to delay banana ripening and when compared to uncoated samples, the coated bananas demonstrated reduced weight loss and vitamin C loss. Soradech et al. [2017] used shellac and gelatine composite films to extend banana shelf-life. This resulted in slower decreases in weight loss, softening, and amounts of acid and sugar. Furthermore, when compared with uncoated bananas, the samples coated with the composite film showed better post-harvest quality maintenance for over 30 days. In a study, a rice starch-ι-carrageenan coating blended with sucrose ester was developed, resulting in a 40% extension in the postharvest life of bananas at room temperature (20°C). The coating effectively delayed ethylene production and slowed the starch degradation rate during storage. Additionally, this treatment reduced fruit weight loss, maintained firmness, and mitigated chlorophyll degradation in banana fruit. This resulted in a shelf life extension of 12 days, while untreated bananas ripened within just seven days. Another study demonstrated that an edible coating made from sago starch combined with cellulose nanofiber (CNF) effectively slowed the colour change in bananas and reduced their soluble solid content. In conclusion, sago starch coatings with 9% CNF proved to be effective in extending the shelf life of bananas at room temperature.

Our solution is a novel one and combines HFCS as an edible coating and IQF to avoid the enzymatic browning of banana slices during freezing. There is no literature data with which the obtained results could be compared directly. Some similarity can be found in the immersion pre-treatment of sliced banana using 0.25% quince seed mucilage and 0.05% ascorbic acid. This solution was recommended by Milani et al. [2020] to prevent enzymatic browning as well as maintain the quality of banana chips before the drying process.

The results of our study that was focused on sensory evaluation by ten sensory panellists showed higher liking scores for the colour, aroma, and taste of coated bananas, especially coated half-ripe bananas. The highest overall acceptance was reported for the coated half-ripe bananas followed by coated ripe bananas. The overall acceptance and preference for the half-ripe bananas with the HFCS coating could be due to the increased lightness of the bananas compared to other samples as a result of the HFCS. In the future, it will be worth determining the impact of HFCS on the activity of enzymes responsible for banana browning processes.

This study is not without its limitations. For example, bananas had to be distinguished and classified into two stages based on ripeness, half-ripe and ripe via ocular assessment (colorimetry). Peeling had to be done in aseptic conditions, however, the complete absence of bacteria is difficult to guarantee. The microbiologic parameters and weight differences after IQF were not measured which constitute the limitations of the study. In the future, it would be necessary to determine how the process of crushing bananas and the subsequent technological stages we use affect the microbiological quality of the final product. Moreover, it was difficult to find 55% HFCS in the market, therefore 55% HFCS had to be ordered for production. Further studies are recommended to assess the effect of coating by HFCS (42% and 55%) on quality, weight, and shelf life of other type of raw material prone to enzymatic browning (e.g., apple and mushroom) after IQF, and the effectiveness of IQF in the preservation of these fruits and vegetables.

Conclusions

In this research, an effort has been made to obtain high-quality sliced banana products without adding any preservatives or chemical additives. It was observed that the use of 55% HFCS for coating ripe and half-ripe banana slices frozen by the IQF method can improve banana quality (i.e., increased firmness, improved colour with increased yellowness and reduced redness, aroma, taste, overall acceptance) and delay the browning processes. These effects are greater in half-ripe bananas. Further, banana samples treated with the HFCS edible coating showed increased TPC which could have positive implications regarding human health and nutrition. Moreover, the application of the edible HFCS coating was also successful in delaying banana browning and resulted in an increased shelf life of up to one month. This is an important finding as bananas are highly susceptible to browning which can reduce consumer appeal and decrease overall acceptance. Furthermore, results from the sensory evaluation showed that the coated bananas were rated as the most acceptable in terms of colour, aroma, and taste, especially for the half-ripe samples.

HFCS as an edible food coating in tandem with IQF may serve as an effective means of preserving banana quality and extending shelf life thus helping to reduce food waste. This novel methodology can help produce a high quality, clean label frozen banana product which can appeal to modern consumers. HFCS as an edible coating and food preservation technique is also favoured as it can be created using readily available, natural, biodegradable materials, especially considering the climate crisis (e.g., reducing pollution and food waste). The application of this technology can jointly address concerns about the use of chemical preservatives and appeal to consumers in search of more natural and eco-friendly products. In conclusion, following more research and the exploration of new applications (e.g., mushroom, apple) the combined preservation method (i.e., IQF and HFCS edible coating) could greatly improve frozen produce quality, extend shelf life, and increase consumer acceptability.

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