# A Review on Explosion Puffing Technology for Fruits andVegetables

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***Abstract*—Explosion puffing is a new technology used for controlling the texture of fruits and vegetables, which has attracted attention from academia and industry in recent years. It has broad prospects, and the explosion-puffed products are natural, of the best quality, nutritious, crispy and easy to store. In this paper, the characteristics of explosion puffing and its products were introduced. The process, product quality and mechanisms of the technology were reviewed. Finally, the research direction and development trends of this technology were discussed.**

***Index Terms*—Fruits and vegetables; explosion puffing; texture; processing**

## I. Introduction

Vegetables and fruits are important sources of vitamins, dietary fiber, minerals, etc. Because of high moisture content, vegetables and fruits are perishable and usually need to be further processed. Meanwhile, with the changes of life style, convenient foods or snacks with excellent texture and flavor have become a trend of processed fruits and vegetables. Fruit and vegetable chips which have porous and loose structure are quite appealing to the consumers because of their crispy texture and attractive flavor. Porous and loose structure can be achieved by hot air drying, freeze drying or puffing. Hot air drying technology has developed rapidly in recent years, but there are still issues unresolved satisfactorily, for example, the speed of dehydration is low, the product quality is poor [1], [2]. Vacuum freeze-dried fruits and vegetables are with good quality, but the long drying time, large energy consumption and expensive equipment has limited the promotion of the technology in the fruit and vegetable drying [3]-[6].

Explosion puffing is a new texture regulatory approach of fruits and vegetables, which combines the advantages of hot air drying and vacuum freeze-drying, and overcomes the shortcomings of low-temperature vacuum frying, so it is particularly suitable for deep processing of fruits and vegetables. Explosion puffing whose products are called "21st Century" food can be used to produce new natural fruit and vegetable chips, fruit and vegetable nutrition powder, spices used in snack foods or materials used to produce new health food [7]. Explosion puffed products are in large demand around the world which means a great market prospect, so it has been the subject of extensive studiesIn this paper, characteristics of explosion puffing and its products were introduced. The research status of the technology was reviewed. Finally, the research direction and development trends of this technology were discussed and it is hoped that this review would lay a scientific basis for the development of explosion puffing.

## II. Overview of Explosion Puffing

The puffing experiments were conducted using the experimental explosion puffing drying equipment system (Fig. 1), which consists of a puffing chamber, vacuum chamber, vacuum pump, decompression valve, air compressor and steam generator. The puffing processes were as follows. First, in the puffing chamber, the samples were placed on a stainless steel grid and the decompression valve was closed. The samples were heated to 95℃ by the steam generator and maintained at this temperature for 5 min. During sample heating, the puffing chamber was inflated to an absolute pressure of 0.2 MPa by the air compressor, and the vacuum chamber was evacuated to approximately 100 Pa (absolute pressure) by the vacuum pump. In the depressurizing treatments, the absolute pressure was decreased from 0.2 MPa to 100 Pa in the puffing chamber by opening the decompression valve. The temperature of the puffing chamber decreased from 95 to 75℃. The puffed samples were vacuum-dried for 180 min under these conditions, yielded puffed fruit chips. All the parameters were determined by preliminary studies [2], [8]-[11].

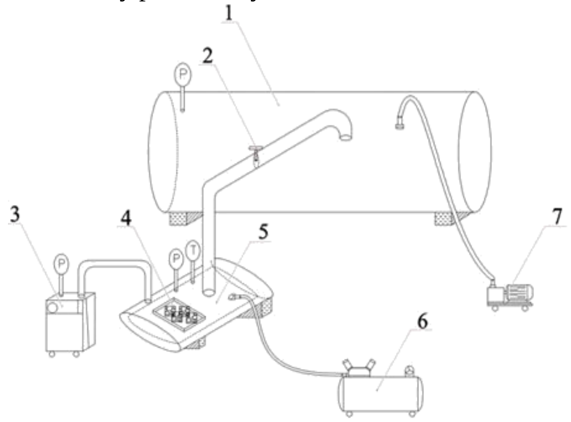


Figure 1. Schematic diagram of explosion puffing drying device and accessories: 1, vacuum chamber; 2, decompression valve; 3, steam generator; 4, samples; 5, puffing chamber; 6, air compressor; 7, vacuum pump.

Manuscript received May 1, 2018; revised August 1, 2018.


doi: 10.18178/ijfe.4.4.332-336

So far, explosion puffed fruit and vegetable chips are “the third generation” of new product following the deep fat fried chips and the low-temperature vacuum fried chips. Explosion puffing is characterized by wide raw material sources such as apple, banana, peach, jujube, wolfberry, pineapple, kiwi fruit, carrot, potato, sweet potato, etc. First, no additives are introduced into the fruit and vegetable chips during processing, so the product is natural and with crispy texture. Second, because of the relatively low temperature, heat-sensitive vitamins and other nutrients are concentrated and reserved. Third, the dried product can be stored for long time so that the corruption and biological deterioration is greatly reduced during storage and transportation, leading to lower costs [12], [13].

## III. The Research Status

### A. Study on the Process of Explosion Puffing of Fruit and Vegetable and the Product Quality

As a new technology, researches on explosion puffing of fruit and vegetable are more concentrated in the process parameters and product quality. Major research institutions are USDA Eastern Regional Research Center, Institution of Agro-products Processing Science and Technology CAAS and Shandong Agricultural University.

Initially, optimal conditions for explosion puffing were determined by comparing drying curves and products between hot air drying and puffing. Currently, explosion puffing for different fruits and vegetables has been the subject of extensive study, and gained high quality products. At the same time the effect of process parameters of puffed products was determined [11], [14]-[19]. Puffing process parameters for banana were optimized by Saca *et al*. [20]. The results showed that the increase in porosity obtained by puffing clearly and reduced the total drying time compared with Conventional Air Dried (CAD) samples and had higher rehydration rate. During rehydration, solids loss was less, the product had better color, taste and texture. Nouviaire *et al.* [21] used “three-step method” to achieve explosion puffing for strawberry, and the effect of operating parameters, such as pressure and time, on water content of the puffed strawberry and drying process has been studied. Finally, puffing process was optimized according to the color of the product and puffing rate. Thuwapanichayanan *et al*. [22] demonstrated that the porous structure obtained by puffing could help to improve the drying speed and reduce volatilization of nutrients. Recently, Du L J *et al*. [23] investigated the effect of explosion puffing and sun-drying on phenolic acids, flavonoids, total phenolic content (TPC), and their antioxidant activity on jujube samples. The results revealed that explosion-puffed jujubes had a significantly higher TPC, which leads to a corresponding increase in antioxidant properties. Explosion puffing as an environmental-friendly and a commercially feasible technology could be developed to enhance the health functionality of jujubes.

Shandong Agricultural University has studied explosion puffing for apple, pear, sweet potato, carrot and pumpkin [24]-[30]. At present, a number of papers on explosion puffing of fruits and vegetables were published by Bi Jinfeng, Zhang Peizheng and He Xinyi et al, and the fruits and vegetables included apple, peach, jujube, pineapple, cantaloupe, kiwi, wolfberry, banana, pumpkin, potato, carrot, etc. Their researches have been focused on optimization of pretreatment process and puffing process of the technology. Most of these studies are experimental and lack of analysis of mechanisms.

### B. Study on the Mechanisms of Formation of Porous Structure in Puffed Food

During puffing, a series of quality changes may occur, including chemical changes such as browning, lipid oxidation and fading, physical changes such as rehydration, cracking, texture and flavor loss, nutritional changes such as vitamins loss, proteins loss and microbial growth, etc. The porous structure of the puffed food is formed during puffing process, therefore, the conditions and the formation mechanisms are the factors for the formation of porous structure of fruit and vegetable chips. Studies on mechanisms of the technology can help to better understand drying characteristics of fruit and vegetable so that it can help to determine process parameters and promote product quality.

### C. Studies on the Explosion Puffing Conditions for Fruits and Vegetables

Varnalis *et al*. [4] demonstrated that formation of a partially dried layer (PDL) on the surface of the potato cubes was necessary to achieve puffing and to maintain the shape of puffed product. The influence of blanching and drying conditions on the layer was investigated in the this study [4], and the results showed that blanching and drying reducedpermeability of the PDL limiting the escape of water vapor when puffing, so internal pressure of samples increased and resulted in an increase in volume of the puffed cubes. Puffing was achieved by creating a surface barrier to vapor by dipping the apple cubes in starch solution and manipulating the temperature and time of exposure [14]. Antonio *et al*. [31] used response surface methodology to study the high temperature short time processes of sweet potato slices. The results showed that the formation of surface sealing after osmotic treatment was of benefit to puff, shorten the processing time and reduced energy consumption. Later, Tabtiang *et al*. [32] studied how osmotic treatment affected the quality of a puffed fruit sample, viz. banana. It was found that osmotic dehydration could improve the color of puffed banana, but sucrose impregnation resulted in longer drying times and limited banana cell wall expansion due to the interaction between the hydroxyl group of sucrose and that of banana tissue. The morphology of osmotically treated banana was a hard and brittle texture. Liu Ziqiang [33] analyzed the specific process of puffing, the factors affecting puffing power and the mechanism of external energy conversion to puffing power. This research could provide a scientific basis for the development of explosion puffing of fruits and vegetables.

### D. The Growth and Deformation of Bubbles During Puffing

The structure, mechanical deformation, damage fracture resistance, heat and mass transfer, sound when chewing the puffed foods depend largely on the parameters such as pore size, structure and the thickness of solids between pores. These parameters depend on the characteristics of growth and deformation of pores, which has attracted more and more attention of researchers recently.

Currently, researches on nucleation and growth of bubbles in the food material during puffing focused on vapor-induced extrusion and carbon dioxide-induced dough puffing. Physical model used to study bubble growth in food material is Cell Model which is accepted by most researchers. To study the mechanisms of water vapor bubble growth, based on Amon's [34] research, Kokini *et al*. [35] proposed a simplified mathematical model to predict bubble growth during corn starch extrusion. They believed that the water in the melt flash evaporated and entered into the pore, as a result the pore expanded due to rise of internal pressure. Meanwhile, the volume ratio of the extrudate was associated with Pvs/η (Pvs is vapor pressure, η is Melt viscosity). Kumagai et al. [36] used Young's modulus of the extrudate and differential pressure inside and outside a bubble to establish a model for prediction of the critical radius of puffed product. The predicted result was in good agreement with the experimental result, but shrinkage of the bubble was not considered in this model. Fan *et al*. [37] proposed dynamic model for bubble growth considering heat and mass transfer. They used the model which combined the power law model with Williams-Landel-Ferry (WLF) equation to describe rheological behavior, so the importance of the melt viscosity and the glass transition temperature was emphasized. Numerical results showed that the pore first experienced rapid growth and then shrank. The main determining factor for the deformation was viscosity of the melt, whereas the influence of surface tension could be almost ignored. However, bubble breakage and bubble coalescence were not considered in their study, thus there were some differences with the actual situation. Dynamics of microscopic bubble growth, relationship between the bubble growth and puffed product, and momentum, mass and heat transfer process during puffing for extruded starch-based material, was modeled by Wang *et al*. [38]. Then program was designed to solve differential equations numerically, and the result of numerical analysis was verified by experiments, but the constitutive equations of melt viscosity established were not well characterized by non-isothermal characteristics. Hailemariam *et al*. [39] took advantage of Cell Model to study isothermal growth of a $CO_2$ bubble in bread dough as the dough expanded, considering the viscoelasticity and surface tension. Pressure changes in the bubbles were described according to Henry's Law. Then the size of the extrudate was predicted. However, the research was carried out based on isothermal conditions, whether Henry's Law can be used to describe evaporation of liquid water needs to be further studied. Recently, Cheng et al. [40] used Buckingham's pi dimensional analysis method to model the extrudate expansion upon changing the extruder operation parameters. In Buckingham pi dimensional analysis method, the key process parameters were identified and dimensionless groups were formed. Then these dimensionless groups were related by a physical equation which could be rearranged to find the dependence of a specific property on other process parameters. They found a satisfactory correlation between the extrudate expansion values obtained from the model and the actual experiments. Fan *et al*. [41] developed a bubble growth model for expansion in cornstarch using computational fluid dynamics. They used William-Landel-Ferry equation (WLF formula) for capturing the impact of moisture as well as temperature (in the range where extrusion was carried out for expanded snacks) on starch viscosity.

The determining factors for formation of porous structure and characteristics of explosion puffed fruit and vegetable, are nucleation, growth and deformation of bubbles in samples, which is the same as extruded food. Nevertheless, explosion puffed foods and extruded foods are essentially different, but this aspect has not been reported.

## IV. Some Problems and Developing Trend

Researches on explosion puffing of fruit and vegetable are more concentrated in the processing parameters and product quality, while study on mechanisms is lacking. This technology has not been developed so well that there are still some problems existing:

Appropriate pretreatment and process

Pretreatment methods for explosion puffing affect drying time, product structure, and effectiveness of puffing. Puffing temperature, vacuum drying temperature and pressure difference have a great impact on the quality of explosion puffed products. Because studies on explosion puffing is still at an initial stage, in order to find appropriate pretreatment method and process for most of fruits and vegetables further study is needed.

### A. Retention of Nutrients

Although most of nutrients can be kept during explosion puffing, some nutriments have been damaged after pretreatment. Because of the high temperature during vacuum drying some of the nutrients are also damaged, such as vitamin C. How to reduce the loss of nutrients and how to better reserve nutrients are also need to be resolved.

### B. Judgment of the Drying Completion

At present, judgment of the drying completion mainly relies on experienced technical staff. Drying completion is determined through observation of the change of material, thus the result is affected by human factors. The result is not reliable. Therefore, physical models and the more accurate mathematical models are needed to be used to describe the explosion puffing process.

### *C. Storage Conditions*

Because of the improper storage, the product will become soft, the taste of the product worsen and the product polluted by the microorganism. Therefore, attention is required to understand the hygroscopic properties, determination factors for moisture changes, controlling mechanisms of product quality to improve the crisps quality, reduce production costs and extend shelf life.

## ACKNOWLEDGEMENT

This work was financially supported by the the Natural Science Foundation of Guangdong Province under grant No. 2014A030313452, and the Outstanding young teachers' fund in Guangdong under grant No. YQ2015025, and the National Natural Science Foundation of China (NSFC) under grant No. 31201401.

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