A review of drying technologies for the preservation of nutritional compounds in waxy skinned fruit

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Written for presentation at the
2004 North Central ASAE/CSAE Conference
Sponsored by the Manitoba Section of CSAE
Winnipeg, Manitoba, Canada
September 24-25, 2004

Abstract. There are various aspects that must be considered when drying small fruits, whether for the food or nutraceutical and functional food industries. Fruits with a waxy skin, such as blueberries (Vaccinium myrtillus L.), cranberries (Vaccinium macrocarpon Ait.), and cherry tomatoes (Lycopersicon esculentum Mill.) are the focus of this discussion. These fruits have each been implicated to offer health benefits beyond basic nutritional requirements, and may require special pretreatment(s) to reduce the impermeability of their skin to moisture movement. A system which minimizes exposure to light, oxidation and heat, (i.e. high heat (70°C) and shorter time duration) may help conserve critical bioactive compounds. This review focuses upon conventional and new drying technologies and pre-treatment methods based upon drying efficiency, quality preservation, and cost effectiveness.

Keywords. Berries, tomatoes, pretreatment methods, drying, functional foods, nutraceuticals

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INTRODUCTION

The preservation of fruit, through drying, dates back many centuries and is based upon sun and solar drying techniques (Van Arsdel et al. 1973). The limited application of sun drying in temperate climates and the possibility of product contamination has led to the development of alternate drying technologies. This review will concentrate solely on drying methods specifically applicable to small waxy skinned fruits, such as cranberries (Vaccinium macrocarpon Ait.), blueberries (Vaccinium myrtillus L.), and tomatoes (Lycopersicon esculentum Mill.). The most applicable methods include: freeze, vacuum, osmotic, cabinet or tray, fluidized bed, spouted bed, and microwave drying, and combinations thereof.

Pre-treatment methods and drying may contribute to the deterioration of both the eating quality and the nutritive value of a food product (Crapiste 2000). Biologically active (bio-active) compounds offering demonstrated physiological benefits for consumers have been identified in plants and plant-based food products (Oomah and Mazza 2000). Bio-active compounds such as anthocyanins in cranberries and blueberries and lycopene in tomatoes have been implicated in offering health benefits over and above basic nutritional requirements. These compounds among many others are used as ingredients in the manufacture of functional foods and nutraceuticals. The effectiveness and uniformity of these products is dependent upon the preservation of bioactive compounds throughout the value-added chain.

Advances in drying technology and standardization techniques in compound analysis allow for the possibility of using drying for the development of functional foods and nutraceuticals. The selection of the type of dryer or drying system used for a specific situation is based upon the product’s characteristics and drying behaviour, as well as the end product required (Barbosa-Cánovas and Vega-Mercado 1996). The purpose of this paper is to review the development of technologies and methods applicable to the drying of small waxy skinned fruit serving as foods and nutraceuticals.
Evaluation Parameters

The research reviewed in this paper is representative of that performed on the drying of waxy skinned fruit. The results from these research projects cannot be directly compared due to the variability in experimental procedure, fruit variety, dryers tested, and the parameters upon which effectiveness of drying was based. The results, however, provide a good indication of where research is being focused, technologies that may have potential, and the problem areas which exist. This review is divided into sections based upon pre-treatment methods and various drying techniques from an effectiveness, quality, and energy efficiency standpoint.

Traditional quality parameters used when assessing dryers include physical aspects such as: colour, taste, bulk density, shearing and puncture strength, and rehydration ratio (Beaudry et al. 2003; Feng and Tang 2003; Feng et al. 1999; Grabowski and Marcotte 2003; Grabowski et al. 2002; Kim and Toledo 1987). With advances in standardization techniques for measuring levels of vitamins, minerals, and bioactive compounds, research assessing these parameters is beginning to appear, albeit in a small number (Grabowski et al. 2002; Yang and Atallah 1985). Most of the papers assessed the drying systems on a number of the traditional parameters, whereas, Grabowski et al. (2002) looked at levels of anthocyanins (cranberries), and Yang and Atallah (1985) measured levels of vitamins and minerals. Grabowski et al. (2002) also performed an energy efficiency evaluation, another parameter which was not common between all research studies.

Pretreatment methods

In addition to their potential role in the battle against certain illnesses and degenerative diseases, blueberries, cranberries, and tomatoes also share a unique characteristic, a waxy outer skin. This outer layer offers benefits such as protection to the fruit from environmental and external factors (i.e. parasites) (Grabowski and Marcotte 2003). The waxy layer also affects the flow of moisture from inside the fruit to its surface, a crucial process in drying. Pre-treatment methods employing chemical dipping, mechanical methods, and thermal treatments have been used to overcome the wax barrier in several applications (Azoubel and Murr 2003; Feng et al. 1999; Grabowski et al. 2002; Grabowski and Marcotte 2003; Yang et al. 1987).
Mechanical treatments Based on an overall assessment of moisture removal and taste acceptability, halving cranberries provided the most practical pre-treatment method prior to osmotic drying as compared to chemical and thermal methods (Grabowski and Marcotte 2003). Mechanical cutting of blueberries and tomatoes is not possible due to the softness of these fruit. Another mechanical pre-treatment, perforating the skin, had been tested on cranberries and on cherry tomatoes (Azoubel and Murr 2003; Grabowski and Marcotte 2003). Grabowski and Marcotte (2003) had determined that the perforations should represent 20 to 30% of the total surface area of the cranberries for this method to be effective. Azoubel and Murr (2003) washed and perforated cherry tomatoes with needles (1 mm in diameter) to a pin hole density of 16 holes/cm², prior to osmotic and air drying.

Chemical treatments Dipping in a high temperature chemical solution (i.e. NaOH and ethyl oleate in boiling water), provided the best rates of moisture removal in cranberries and blueberries (Feng et al. 1999; Grabowski and Marcotte 2003). When combined with osmotic drying, the low temperature (20°C), chemically processed cranberries provided the lowest value of taste acceptability (Grabowski and Marcotte 2003). Also in this study it was determined that by raising the temperature (100°C) of the dipping solution, a medium level of taste acceptability was achieved. Hot dipping processes are sensitive to treatment duration resulting in destruction of texture due to over-processing, and insufficient treatment effects due to under-processing (Grabowski and Marcotte 2003).

Thermal treatments A post-harvest technique used to preserve the freshness of blueberries can also be used as a pre-treatment method. Freezing the berries with the individual quick frozen (IQF) method directly after harvest, is the method by which the berries are frozen in a thin layer in temperatures of ~40°C, packaged and maintained at that temperature until required (Yang and Atallah 1985). Slow defrost for at least five hours in a 4°C refrigerator resulted in a preserved berry with slight changes in skin permeability. This slight breakdown of the waxy skin layer may be enough to increase the rate of drying without extra pre-treatment applications (Yang et al. 1987). Cost may be a limiting factor to this process.
Comparison of drying technologies

Detailed drying values and parameter measurements have been omitted from this discussion due to the inability to compare research using different methodologies, equipment, operating conditions, fruit variety, and evaluation parameters. This discussion is sectioned into two parts, convective air drying technologies such as cabinet or tray, fluidized bed, spouted bed, and microwave/spouted bed (MWSB) and those employing other technologies (freeze, vacuum, microwave, and osmosis).

Convective air drying technologies

Tray drying, fluidized bed, and spouted bed provided similar ratings for colour, anthocyanins content, taste, and rehydration of halved cranberries (Grabowski et al. 2002). The fluidized systems including the spouted bed, reduced drying times over tray drying, thus increasing energy efficiency of the system (Grabowski et al. 2002). Adding a pulsation or vibration feature to the fluidized and spouted bed drying systems increased product movement and exposure to air, enabling a decrease in air velocity and as a result, a further decrease in energy consumption as compared to the basic fluidized bed dryer. Excessive berry hardening and shrinkage occurred at temperatures of 100 and 110°C, therefore 90°C had been selected as the suitable drying temperature (Grabowski et al. 2002). Preliminary tests showed that quality was similar for products dried at 80°C, however, drying time was 50% longer than that at 90°C. Airflows ranged from 0.9 m/s (cabinet dryer) to 1.4 m/s (pulsated fluidized bed systems), and 1.8 m/s (fluidized bed dryer).

Other studies confirm these conclusions. A spouted bed dryer accelerated moisture removal in blueberries (V. corymbosum) by about five times that of tray drying to 3.3 hours at a temperature of 70°C (Feng et al. 1999). The blueberries were pre-dipped in a dipping solution, rinsed and dried to a moisture content of 12.9% (wb) in a spouted bed dryer at 70°C with an air velocity of 2.1 m/s. The pre-dipping in chemical solution may have influenced the increase in drying rate for the spouted bed dryer. The fluidization of blueberries had not been reported to crush or damage the berries during the drying process. Of the convective drying technologies, spouted bed yielded the best quality next to the freeze and vacuum drying technologies (Feng et al. 1999).
Other drying technologies Freeze drying, provided the highest quality of all dryers tested (freeze drying, convective air, vacuum oven, and micro-convection) with regards to retention of vitamins C and A and niacin, colour, high rehydration rate, and low bulk density in lowbush blueberries (*V. angustifolium*) (Yang and Atallah 1985). In another study comparing numerous dryers (i.e. vacuum, fluid bed, pulsed fluid bed, vibrated fluid bed, and freeze dryer), freeze drying rendered the best product quality (cranberries) quantified in terms of colour, taste, rehydration capacity, and anthocyanin content (Grabowski et al. 2002).

Vacuum drying provided a high quality blueberry (*V. angustifolium*) (i.e. fruit approaching that provided by freeze drying), but resulted in a lower processing cost and shorter processing time than freeze drying (Yang and Atallah 1985). This drying method also, however, produced similar quality results (i.e. anthocyanin content, rehydration, colour, and taste) in cranberries compared to other direct heating methods such as fluidized bed, spouted bed, and tray drying. The energy and capital costs related to this technology combined with the quality achieved make it an impractical choice in large-scale production of commodity (Grabowski et al. 2002). Except for one study that recommended further research into a freeze-vacuum dryer combination, most researchers have deemed freeze drying and vacuum drying to be too costly for large-scale production of a commodity (Azoubel and Murr 2003; Grabowski et al. 2002; Yang and Atallah 1985).

Microwave drying can reduce drying time but may reduce product quality. Drying efficiency may have to be sacrificed in order to gain on quality. The power level and cycling period are the aspects that can be varied within a microwave (Beaudry et al. 2003). Generally, higher the power, faster the drying rate, and lower the power, higher the quality. Results from a sensory evaluation (i.e. taste and appearance) of microwave dried cranberries showed clear appreciation for cranberries dried at 0.75 W/g with 30 s On / 30 s Off as compared to those dried at 1.25 W/g with cycling period of 30 s On / 30 s Off. These lower sensory scores for the higher power level could have been due to the occurrence of burned berries, resulting in a blackened surface colour and unpalatable flavour (Beaudry et al. 2003).
Osmotic drying caused a reduction in anthocyanins in cranberries due to leaching in the syrup (Grabowski et al. 2002). In this study, osmosis also added five hours to 50-60 minutes convective drying time as compared to a three hour drying time for untreated berries. This change in dehydration behaviour is caused by alterations that occur within the berry due to uptake of the ionic sugar solution (Grabowski et al. 2002). Osmotic drying could be beneficial from two standpoints: 1) a large percentage of water (i.e. 75%) is removed non-thermally which translates into energy savings, and 2) a solute, such as sugar or salt can be added to a product to enhance market quality (i.e. sweetened cranberries such as Craisins, salted dried tomatoes) (Grabowski et al. 2002). In general, the weight loss in osmosed fruit is increased by increasing solute concentration of the osmotic solution, immersion time, temperature, and solution/fruit ratio (Azoubel and Murr 2003). Cranberries halved and pretreated in a standard osmotic syrup at 50 °C for five hours with a 1:5 fruit-to-syrup mass ratio provided high taste acceptability (Grabowski et al. 2002). In a study on blueberries (V. angustifolium), a sugar:berry ratio of 3:1 or 4:1 resulted in a better product when followed by freeze drying than did berries in a 2:1 ratio (Yang et al. 1987). The 2:1 (sugar to berry ratio) berries had experienced greater weight loss but were sticky and had an increased drying time of 24 hours compared to 18 hours (3:1 ratio) and 15 hours (4:1 ratio) (Yang et al. 1987).

**Combination drying systems** such as: (MWSB; MWSB + dipping + osmotic dehydration; spouted bed + dipping; (tray drying, fluidized bed dryer, pulsed fluidized bed dryer, vibrated fluidized bed dryer, or freeze dryer) + osmotic drying + mechanical pre-treatment; microwave convection) were tested by Feng et al. (1999), Grabowski et al. (2002), and Yang and Atallah (1985). The number of combinations possible is vast and as technology continues to improve, more will be developed. Adding a microwave system to a spouted bed system combines the benefits offered by each technology; the microwave action increases drying time while the fluidization produced by the spouting system improves drying uniformity, thus reducing burning.

MWSB drying when compared to the SB + dipping, tray drying, and freeze drying resulted in a substantial reduction in drying time and improved product quality (i.e. low bulk density, high short-time rehydration ratio, and a more reddish and less blue colour) (Feng et al 1999). Pre-treatment using chemical dipping (i.e. 2.5% Ethyl Oleate and 0.2% NaOH) followed
by osmotic drying in a sugar solution prevented blueberries from bursting when microwaved, but resulted in high bulk density and low rehydration ratio (Feng et al. 1999). The change in colour from red/blue to more of a red was noticeable and could be represented by a loss of anthocyanins.

Taste testing had not been performed in this study and should be considered, to determine if the chemical dipping reduces the acceptability of the product.

A final question that should be considered is whether drying for the preservation of one compound versus many compounds or the whole fruit is a good idea. The benefits offered by these fruits may come from a complex combination of many compounds that act synergistically, complimentary or antagonistically with each other. Knowledge of how bio-active compounds interact with each other can provide valuable information to engineers in the design of drying technology for the functional food and nutraceutical industries.

**CONCLUSIONS**

This review focussed upon drying methods and evaluation parameters of systems for the dehydration of small waxy skinned fruit. The purpose for performing such a review was to determine the advances that have been achieved in this industry as well as to investigate the use of traditional drying methods for the development of functional foods and nutraceuticals. The following conclusions demonstrate the considerations that must be made when developing drying systems specifically for the manufacture of these value-added products.

- An optimal drying system for the preservation of quality, is cost effective, eliminates or reduces the exposure to light and oxygen, and shortens the drying time, thus causing minimal damage to the product.
- Pre-treatments such as chemical dipping, thermal treatments, and mechanical methods increase drying rates in waxy skinned fruit. Taste perception may affect use of chemical treatments especially at low temperatures (20°C).
• Drying rates using conventional convective drying methods can be improved through product fluidization (i.e. fluidized bed, spouted bed), increased drying temperatures (i.e. 70 to 90°C) and airflows (i.e. 1.8 to 2.1 m/s).
• Alternate drying technologies such as freeze and vacuum drying may be more applicable to the small-scale production of high valued crops (i.e. herbs) due to their associated high production costs.
• Microwave systems have good potential to decrease drying rates and incorporated with a spouted bed system can provide a uniformly dried quality product.
• Further research is required on the stability of various bioactive compounds during drying.
• Standardization techniques for the measurement of these compounds or markers should be established and implemented as quality tests in addition to those already in existence.

REFERENCES


