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STRATEGIES TO RETAIN VOLATILE COMPOUNDS DURING CONVECTIVE DRYING OF VEGETABLES

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Abstract
Vegetables are processed into dried powders to prolong their shelf-life and to be applied as ingredient. However, the vegetable powders currently available in the market often have a poor flavour profile after drying. Therefore, this review aims to illustrate recent advances and challenges in the development of high-quality vegetable powders. Two main topics are discussed: the effects of process conditions in hot air drying on flavour retention and the role of encapsulation agents during spray drying of vegetable juice concentrates.

***Keywords**: Vegetables; Encapsulation; Hot air drying; Spray drying, Flavour*

1. Introduction

Drying of vegetables is common practice for preservation purposes and enhances more efficient transportation. However, physicochemical properties of vegetables are strongly altered upon drying. The physical quality is often decreased by phenomena such as shrinkage, crystallization, puffing, colour changes and reduced rehydration capacity (Karam *et al.*, 2016). In addition, the nutritional quality and flavour (taste and aroma) are found to be significantly lower in dried vegetables compared to fresh (Nijhuis *et al.*, 1998; Sablani, 2007). Flavour profile of vegetable powders is an important quality indicator when the powders are applied into food products. To compensate for the flavour losses during drying, flavouring agents are frequently added to food products. In general, consumers have a negative attitude towards the use of food additives based on the perception that food additives are unnatural and could even be harmful to human's health (Eiser, Coulson and Eiser, 2002; Shim *et al.*, 2011; Bearth, Cousin and Siegrist, 2014). Thus, there is an interest in the development of strategies to retain flavour compounds during vegetable drying to produce natural ingredients. This review aims to illustrate recent advances and challenges in the development of dried vegetable ingredients with preserved flavour profile. First, we will discuss the concepts of hot air and spray drying for drying whole vegetable pieces and vegetable concentrates, respectively. Subsequently, we will discuss the influences of drying temperature and sample thickness on flavour retention during drying of vegetable pieces. Finally, flavour retention during spray drying of vegetable concentrates will be discussed.

2. Drying methods

The most common drying technologies for vegetable drying in industry are hot air drying and spray drying. While hot air drying is carried out for vegetable pieces, spray drying is used to dry concentrated vegetable juice, and both strategies can yield a vegetable powder (see Figure 1).

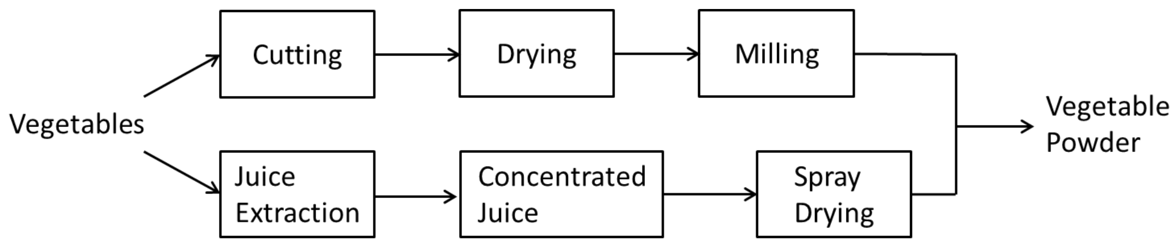

Figure 1 Different approaches for drying of vegetables.

Hot air drying (HAD) is the most frequently used drying method in the food industry due to its simplicity and low cost. A vegetable powder can be produced by milling dried vegetable pieces. The HAD process can be either performed batch-wise in the form of a tray dryer or as a continuous process with a belt-dryer for example. HAD usually involves high temperatures and long drying times, consequently the quality of the final products is rather poor. The drying kinetics of vegetables during HAD has been widely studied to understand how product quality is degrading during drying. For most food products, the drying curve can be divided in two periods, first the constant rate period which is followed by a falling rate period. Once the internal resistance for moisture transfer becomes the limiting factor the falling rate period will start (Srikiatden and Roberts, 2007). The review of Onwude *et al.* (2016) described that most vegetables are dried with a short constant rate and an extended falling rate period. The falling rate period is usually responsible for two-third of the total drying time (Karam *et al.*, 2016). During the falling rate period the moisture removal rate decreases and product temperature increases. The increase of temperature in this period has negative influences on product quality. Therefore, it is interesting to carry out a two-step process, i.e., the drying temperature can be lower in the second step, which may benefit the preservation of product quality. More specifically, during constant rate drying, the air temperature can be very high as the product temperature will settle at the wet bulb temperature, while at the falling rate the air temperature is decreased until an acceptable level that minimizes a large negative influence on product quality.

On the other hand, spray drying is often applied for drying of vegetable juice concentrates on a larger industrial scale. During spray drying, the liquid is atomized into small droplets and introduced to a drying chamber where the droplets come in contact with hot air. Similar to HAD, moisture evaporation during spray drying takes place at a constant rate followed by a falling rate (Verma and Vir Singh, 2015). For flavour encapsulation in vegetable powders, the falling rate period is of particular importance for the retention of volatiles in the droplets, due to the decrease in diffusion coefficients in this period. Thijssen (1971) found that the loss of volatile flavours is fully controlled by the migration rate of those compounds to the surface of the droplets and is independent of their relative volatility. Furthermore, the results showed that the diffusion coefficients of flavour components decrease much more steeply than the diffusion coefficient of water when the water concentration in the droplets decreases (i.e., the selective diffusion concept). As a result, quick drying of the droplets is a promising method to encapsulate aromas. In addition, Coumans, Kerkhof and Ruin (1994) stated that the selective diffusion concept is most effective at a surface water concentration below 15 wt% (the critical concentration), which is the concentration where the interface becomes impermeable to volatile compounds but still permeable to water. Hence, it is hypothesized that the selective diffusion concept may facilitate aroma retention up to 100% for quick drying, i.e. spray drying times much shorter than 1 s.

In Table 1 a selection of studies on the drying of vegetables is reported. The table describes the applied drying method and the quality parameters (e.g. colour and nutritional components) evaluated in these studies. Different drying methods are compared in only few studies of which two studies made a comparison between tray drying and novel drying technologies in terms of physical quality and the retention of volatiles and ascorbic acid . Nine out of ten studies evaluated the chemical properties of the dried vegetables by measuring the presence of flavour compounds, nutritional components (i.e. ascorbic acid, anthocyanin) or volatile compounds.

Table 1 Selective studies on the drying of various vegetables

Vegetable	Drying method	Quality parameters	Reference
Asian white radish	Hot air drying	Flavour	Coogan and Wills, 2002
Asparagus	Tray drying; freeze drying; spouted bed drying; microwave and spouted bed drying; refractance window drying	Colour, nutritional components	Nindo *et al.*, 2003
Bell pepper	Hot air drying	Colour, microstructure, nutritional components	Vega-Gálvez *et al.*, 2008
Black carrot	Spray drying; freeze drying	Colour, microstructure, nutritional components	Murali *et al.*, 2014
Broccoli	Hot air drying	Microstructure, nutritional components	Jin *et al.*, 2011, 2014
Onion	Vacuum drying	Colour, flavour	Mitra, Shrivastava and Rao, 2015
Purple sweet potato	Spray drying	Colour, nutritional components, microstructure	Ahmed *et al.*, 2010
Shiitake mushrooms	Hot air drying; vacuum drying; microwave drying; microwave vacuum drying	Colour, free amino acids, volatile compounds, microstructure	Tian *et al.*, 2016
Tomato	Hot air drying	Volatile compounds	Narain *et al.*, 2010
Tomato	Spray drying	Density, particle size	Goula and Adamopoulos, 2007

3. Effects of drying conditions on flavour retention during drying of vegetable pieces

Drying times are dependent on product size and drying conditions such as drying temperature (Onwude *et al.*, 2016). Drying at high temperatures can accelerate the drying process but have negative effects on the quality properties of the final product such as flavour retention.

Different studies investigated the effects of drying methods and drying temperature on the flavour retention in vegetables. Coogan and Wills (2002) investigated the influence of drying temperature during hot air drying on the retention of volatile compounds in Asian white radish. They found that the amount of one primary volatile compound, 4-methylthio-3-trans-butenyl isothiocyanate (MTBITC), substantially decreased when a higher drying temperature was used: MTBITC loss was 46 ± 13 % w/w at 40 °C, while the loss increased to 90 ± 12 % w/w at 70 °C. Moreover, in the work of Mitra, Shrivastava and Rao (2015) the drying temperature and the sample thickness of onion slices were related to the loss of thiosulphinate during vacuum drying. The onion slices were dried until a constant weight was achieved. Consequently, the duration of drying was determined by the temperature (50, 60 and 70 °C) and the sample thickness (1, 3 or 5 mm). It was found that the onion slices of 5 mm thickness dried at 50 °C retained most of the thiosulphinate, even though they experienced the longest drying time (385 min) of all samples. In addition, it was found that the slice thickness had a greater impact on the flavour loss than the drying temperature.

Furthermore, it should be noted that drying will not only result in loss of volatiles, but could also lead to the formation of other volatiles by different mechanisms. In the study of Tian *et al.* (2016) the effects of different drying methods on the volatile compounds of whole shiitake mushrooms were assessed. Among the drying methods, HAD and vacuum drying (VD) were evaluated. For the HAD, the mushrooms were dried at an air temperature of 60°C and 70°C in an electric thermal heater (Tian *et al.*, 2012). The mushrooms in the vacuum dryer were dried in 90 kPa at 60°C for 15 h. Surprisingly, all dried shiitake mushrooms increased in total number and the total amount of volatile compounds compared to the fresh. In particular, the sulphur compounds increased significantly. The formation of sulphur compounds could be explained by induced thermal fragmentation of precursors which resulted in sulphur volatiles or via Maillard reactions, involving Strecker degradation, where amino acid degradation products are formed (Tressl, Holzer and Apetz, 1977; Nijhuis *et al.*, 1998).

Overall, it can be concluded that the choice of drying conditions influences the degree of flavour retention. Upon drying not only aromas will be lost, but also other aromas are generated during thermally-induced reactions.

4. Flavour retention during drying of vegetable concentrates by encapsulation

The addition of encapsulation agents to the food matrix can ease the spray drying process as well as promoting retention of aroma compounds (Madene *et al.*, 2006). The role of these encapsulation agents on flavour retention has been extensively studied. Glass transition is important for the spray drying process and the stability of food products after drying. The glass transition temperature (T_g) is determined by the molecular weight of the proteins and carbohydrates and by the presence of water. Low molecular weight molecules generally have a lower glass transition temperature than high molecular weight molecules. For example, the anhydrous glass transition temperature of maltodextrin with a dextrose equivalent (DE) 5 is equal to 180°C, whereas a shorter chain maltodextrin like DE 10 shows an anhydrous T_g of 138°C (Avaltroni, Bouquerand and Normand, 2004). Usually, a vegetable juice needs to be extracted first and then concentrated before drying. This is because the solid concentration of the juice is low and a concentration step is necessary to make spray drying economically feasible. However, the concentrated vegetable juices are often rich in small sugars which have low glass transition temperatures and will cause stickiness of the powder at the end of the spray drying operation. To prevent stickiness, an additive or so-called carrier matrix is required to increase the glass transition temperature of the drying materials.

In addition, the usage of carriers during spray drying could enhance the retention of volatiles. Flavour compounds may be successfully retained when formulated with carbohydrates in the glassy state (Ubbink and Krüger, 2006). However, suitable conditions are required to retain the volatiles upon storage, which include a low water activity environment and a temperature below T_g. Once the structure of the glassy matrix collapses or crystallization of the carbohydrates occurs, aroma losses are observed (Bonazzi and Dumoulin, 2011). Both the glass transition, as well as the selective diffusion concept introduced earlier, are considered important mechanisms to control the release of aroma compounds during drying. Moreover, studies on other drying techniques than spray drying also confirmed that flavour encapsulation increased with the addition of starch-based carriers. For example, Narain *et al.* (2010) studied the air drying of tomato juice at 60 °C, and the main volatile compounds were better retained in the dried tomato powder when 5 % maltodextrin and 5 % tapioca flour were added as the carriers.

To select a suitable carrier, different aspects need to be considered. First of all, the carrier needs to be an approved additive for food products. In terms of flavour retention, it is important to define whether the key odour compounds are hydrophilic or lipophilic to select the best applicable carrier. For example, hydrolysed starches, such as maltodextrin, are suitable carriers for the encapsulation of hydrophilic volatiles (Reineccius, 2004). Bangs and Reineccius (1982) found that the DE of maltodextrins was inversely related to the volatile retention and therefore high molecular weight maltodextrins as DE 10 or 15 are preferred. On the other hand, for the retention of lipophilic volatiles, the emulsification ability of the carrier is important (Reineccius, 2004). Cyclodextrins, which are formed by enzymatic modification of partially hydrolysed starches, can be used as an encapsulating agent. The inner part of the cyclodextrin is lipophilic, thus the aroma molecules can attach via the molecular inclusion process which involves hydrophobic interactions (Zuidam and Heinrich, 2010). Although cyclodextrin presents excellent encapsulation properties, it is relatively expensive and not all derivatives possess data on the toxicity (Wang, Yuan and Yue, 2015). Other encapsulates for lipophilic volatiles retention are proteins, which provide good emulsification and film-forming properties since they rapidly adsorb on the oil-water interface (Madene *et al.*, 2006).

After the selection of the suitable carrier, the required amount to be added to the vegetable juice should be defined. As a rule of thumb to prevent stickiness, the temperatures of the dried particles at the outlet of the spray dryer should not exceed more than 10-20°C above the glass transition temperature (Vega and Roos, 2006). Furthermore, highly volatile compounds are better retained at a higher initial solids concentration. However, there is an optimum in solids concentration since a too high solids content could result in non-dissolved material and an increased viscosity. Consequently, film formation of the droplets upon drying could be slowed down and aroma losses are promoted (Zuidam and Heinrich, 2010).

In summary, (partially) hydrolysed starches or proteins are frequently added to the food matrix to act as encapsulation agents and to increase the glass transition temperature of the product. The role of encapsulates in the field of spray drying is well-established, for other drying technologies results are promising.

5. Conclusions

The retention of flavour compounds after drying presents a challenge since these volatile compounds get easily lost upon heating. The selection of the hot air drying conditions has often large influence on the flavour profile of the final product. Furthermore, the addition of an encapsulation agent, such as maltodextrin, can improve flavour retention during spray drying of vegetable concentrates.

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References

Ahmed, M., Akter, M. S., Lee, J.-C., & Eun, J.-B. (2010). Encapsulation by spray drying of bioactive components, physicochemical and morphological properties from purple sweet potato. *LWT - Food Science and Technology*, *43*(9), 1307–1312.

Avaltroni, F., Bouquerand, P. E., & Normand, V. (2004). Maltodextrin molecular weight distribution influence on the glass transition temperature and viscosity in aqueous solutions. *Carbohydrate Polymers*, *58*(3), 323–334.

Bangs, W. E., & Reineccius, G. A. (1982). Influence of Dryer Infeed Matrices on the Retention of Volatile Flavor Compounds During Spray Drying. *Journal of Food Science*, *47*(1), 254–259.

Bearth, A., Cousin, M.-E., & Siegrist, M. (2014). The consumer's perception of artificial food additives: Influences on acceptance, risk and benefit perceptions. *Food Quality and Preference, 38*, 14–23.

Bonazzi, C., & Dumoulin, E. (2011). Quality Changes in Food Materials as Influenced by Drying Processes. In *Modern Drying Technology: Product Quality and Formulation* (pp. 1–20).

Coogan, R. . C., & Wills, R. B. . B. H. Effect of drying and salting on the flavour compound of Asian white radish, 77 Food Chemistry § (2002).

Coumans, W. J., Kerkhof, P. J. A. M., & Ruin, S. (1994). Theoretical and practical aspects of aroma retention in spray drying and freeze drying. *Drying Technology, 12*(1–2), 99–149.

Eiser, J. R., Coulson, N. S., & Eiser, C. (2002). Adolescents' perceptions of the costs and benefits of food additives and their presence in different foods.

Goula, A. M., & Adamopoulos, K. G. (2007). Drying Technology An International Journal Spray Drying of Tomato Pulp: Effect of Feed Concentration.

Jin, X., Van Der Sman, R. G. M., Gerkema, E., Vergeldt, F. J., Van As, H., Van Straten, G., Van Boxtel, A. J. B. (2011). *Investigation on the influence of pre-treatments on drying behaviour of broccoli by MRI experiments*.

Jin, X., van der Sman, R. G. M., van Straten, G., Boom, R. M., & van Boxtel, A. J. B. (2014). Energy efficient drying strategies to retain nutritional components in broccoli (Brassica oleracea var. italica). *Journal of Food Engineering*, *123*, 172–178.

Karam, M. C., Petit, J., Zimmer, D., Baudelaire Djantou, E., & Scher, J. (2016). Effects of drying and grinding

in production of fruit and vegetable powders: A review. *Journal of Food Engineering*, *188*, 32–49.
Madene, A., Jacquot, M., Scher, J., & Desobry, S. (2006). Flavour encapsulation and controlled release - a review. *International Journal of Food Science and Technology*, *41*(1), 1–21.
Mitra, J., Shrivastava, S. L., & Rao, P. S. (2015). Non-enzymatic browning and flavour Kinetics of vacuum dried onion slices. *International Agrophysics*, *29*(1), 91–100.
Murali, S., Kar, A., Mohapatra, D., & Kalia, P. (2014). Encapsulation of black carrot juice using spray and freeze drying. *Food Science and Technology International*.
Narain, N., De Sousa Galvão, M., Letícia De Santana, K., De, J., Da, J., & Moreira, S. (2010). Volatile Compounds in Tomato-Based Dried Products. *Drying Technology*, *28*(2), 232–239.
Nijhuis, H. ., Torringa, H. ., Muresan, S., Yuksel, D., Leguijt, C., & Kloek, W. (1998). Approaches to improving the quality of dried fruit and vegetables. *Trends in Food Science & Technology*, *9*(1), 13–20.
Nindo, C. I., Sun, T., Wang, S. W., Tang, J., & Powers, J. R. (2003). Evaluation of drying technologies for retention of physical quality and antioxidants in asparagus (Asparagus officinalis, L.). *LWT - Food Science and Technology*, *36*(5), 507–516.
Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M., & Abdan, K. (2016). Modeling the Thin-Layer Drying of Fruits and Vegetables: A Review. *Comprehensive Reviews in Food Science and Food Safety*, *15*(3), 599–618.
Reineccius, G. A. (2004). The Spray Drying of Food Flavors, Drying Technology, *22*(6), 1289–1324.
Sablani, S. S. (2007). Drying Technology Drying of Fruits and Vegetables: Retention of Nutritional/Functional Quality.
Shim, S.-M., Seo, S. H., Lee, Y., Moon, G.-I., Kim, M.-S., & Park, J.-H. (2011). Consumers' knowledge and safety perceptions of food additives: Evaluation on the effectiveness of transmitting information on preservatives. *Food Control*, *22*(7), 1054–1060.
Srikiatden, J., & Roberts, J. S. (2007). Moisture Transfer in Solid Food Materials: A Review of Mechanisms, Models, and Measurements. *International Journal of Food Properties*, *10*(4), 739–777.
Thijssen, H. A. C. (1971). Flavour Retention in Drying Preconcentrated Food Liquids. *Journal of Applied Chemistry and Biotechnology*, *21*(12), 372–377.
Tian, Y., Zhang, Y., Zeng, S., Zheng, Y., Chen, F., Guo, Z., Zheng, B. (2012). Optimization of microwave vacuum drying of lotus (Nelumbo nucifera Gaertn.) seeds by response surface methodology. *Food Science and Technology International*.
Tian, Y., Zhao, Y., Huang, J., Zeng, H., & Zheng, B. (2016). Effects of different drying methods on the product quality and volatile compounds of whole shiitake mushrooms. *Food Chemistry*, *197*, 714–722.
Tressl, R., Holzer, M., & Apetz, M. (1977). Formation of Flavor Components in Asparagus. 1. Biosynthesis of Sulfur-Containing Acids in Asparagus. *Journal of Agricultural and Food Chemistry*, *25*(3), 455–459.
Ubbink, J., & Krüger, J. (2006). Physical approaches for the delivery of active ingredients in foods. *Trends in Food Science & Technology*, *17*(5), 244–254.
Vega-Gálvez, A., Lemus-Mondaca, R., Bilbao-Sáinz, C., Fito, P., & Andrés, A. (2008). Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo). *Journal of Food Engineering*, *85*(1), 42–50.
Vega, C., & Roos, Y. H. (2006). Invited Review: Spray-Dried Dairy and Dairy-Like Emulsions—Compositional Considerations. *Journal of Dairy Science*, *89*(2), 383–401.
Verma, A., & Vir Singh, S. (2015). Spray Drying of Fruit and Vegetable Juices-A Review. *Food Science and Nutrition*.
Wang, X., Yuan, Y., & Yue, T. (2015). The application of starch-based ingredients in flavor encapsulation. *Starch - Stärke*, *67*(3–4), 225–236.
Zuidam, N. J., & Heinrich, E. (2010). Encapsulation of Aroma. In *Encapsulation Technologies for Active Food Ingredients and Food Processing* (pp. 127–160).