Effectiveness of additives in spray drying performance: a review

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Abstract
The systemic review covers the efficiency of additives on spray dried product; process parameter and its physicochemical properties. Due to the demand of diversification of food products, conventional spray drying process has gained momentum in drying process and extensively used to preserve food materials in powder form. Regarded as a complex operation, the balance between optimization of spray drying process parameters and physicochemical of its product has proven to be a challenge, especially in low product yield due to low transition temperature of feed material. This paper envelope the usage of additives as carriers in spray drying processes, and its effects on physicochemical properties such as hygroscopicity, flavour retention, and colour indexing. The literature signified the vital role of additives in enhancing the physicochemical of feed material and highlighted the effect of additives on spray drying efficiency in respect to its process parameters. Studies advances have shown that additives have improved significantly on products feed characteristic; lower moisture content, higher process yield, and powder flowability. Further research has shown a combination of additives enhances certain properties of feed material. The study signified the effect of additives as a vital role in improving the physicochemical properties of spray-dried powder. The difficulties of achieving powder specification demands can be resolved, by understanding and utilize the knowledge of additives on processing parameter of spray drying.

1. Introduction

The demand in the modern food industry is towards longer shelf life and product variations; leading to quality innovation in food engineering. The increasing world population and prioritization of food safety has led researchers on an alternative approach in food preservation. A conventional method, spray drying, has gained back recognition in fulfilling those demands. Its importance is emphasized on low operational expenditures in comparison to other heating method, specifically eight times more economical than freeze drying and four times more economic than vacuum drying (Rodríguez-Hernández et al., 2005). Spray drying is a drying method that produces droplets of liquid feed into powdered products. The conversion involved atomization of liquid feed, undergoes heat treatment to reduce its moisture content to the desired level (Master, 1991; Sivarajalingam, 2009; Shabde et al., 2010). The capability of spray drying enveloped on its high nutrient and flavour retention with rapid moisture evaporation during the conversion of liquid feed material into dried powdered form, leading to high powder stability and resistant to microbiological and oxidative degradation (Sagar and Suresh Kumar, 2010; Tan et al., 2011).

Commercialization value of spray drying process often valued many criteria; process yield, end product characteristic and production cost but has faced many setbacks in achieving high efficiency in those areas. The economic standpoint of using spray drying is high production cost and hygienic processing condition has led to the discovery of new attributes and findings in spray drying processes (Maa et al., 1998). One of many significant discoveries, process yield is a highly demanded trait in commercial spray drying production, likewise in food and pharmaceutical production. The complication that often diminished the process yield is the low glass transition temperature of feed material, usually found in fruit juice and high acidic feed material (Shishir and Chen, 2017). The nature of these liquid feed material tends to have lower molecular weight as sugars
and acid, which have low glass transition temperature ($T_g$) (Dolinsky, 2001; Chegini and Ghobadian, 2005; Wang and Zhou, 2013a). As a result, a stickiness problem is caused during spray drying, with the feed materials forming paste-like soft structure at the wall of the spray dryer. Adding additives during spray drying production have been an alternative choice for commercial producers to improve the stickiness problem.

Multiple researches have been done on various additives on process parameter and the properties of spray dried products (Goula and Adamopoulos, 2003; Namaldi et al., 2006; Vehring et al., 2007). However, there is lacking review papers on providing deep insight on the performances of various additives used on the physio-chemical properties of the powders (More Swati and Wagh, 2014; Shishir and Chen, 2017). This review paper provides a beneficial apprehensive knowledge on additives in spray drying performances.

2. Type of additives

The properties of additives for spray drying in use is critical, as it has an influence on the process parameter and physio-chemical properties of spray drying (Angel et al., 2009; Kha et al., 2010; Fang and Bhandari, 2012). A research has shown spray drying of blackberry powders using maltodextrin has higher significance loss of moisture content in comparison with other additives used (Ferrari et al., 2012). The combination of Arabic gum and maltodextrin used in spray drying of blackberry powder performed poorly compared to the prior additives. Similar results have shown on spray dried watermelon powder (Quek et al., 2007) and acerola powder (Righetto and Netto, 2005). Among commercially available additives that is used, major type additives that available for spray drying application are carbohydrates (hydrolysed starch, maltodextrin, dextran, cellulose and derived), gums (Arabic gums, agar, carrageenan), proteins (gluten, caseins, albumins, haemoglobin and peptides), lipid (wax, paraffin, diglycerides and peptides) and biopolymers. Spray drying application using lipid and biopolymers are less significant and a handful of journals has only discovered.

2.1 Carbohydrates

Commonly used carbohydrate-additives, maltodextrin are found in the form of white powder, made from corn starch hydrolysed by acids of enzymes. Maltodextrin is non-sweet, neutral smell additives and often used in spray drying production due to its low costing and bulking properties (Bae and Lee, 2008). The variable nature of maltodextrin can be found through the degree of hydrolysis of root starch polymer. The significant higher level of dextrose equivalent (DE) in the hydrolysed starch has lower average molecular weight and has low permeability to oxygen and water (Chegini and Ghobadian, 2005; Chiu et al., 2007; Ersus and Yurdagel, 2007). Similarly, studies were done by Bangs and Reineccius (1982) has stated that maltodextrin with dextrose equivalent between 10 and 20 have higher flavour retention. Otherwise, usage of lower DE with higher molecular weight has improved on the transition temperature of the product (Table 1), in respect to reducing lower product losses and caking problem (Goula and Adamopoulos, 2003).

Table 1. Relationship between DE, MW and $T_g$ of maltodextrin (Adapted from Roos and Karel (1991))

<table>
<thead>
<tr>
<th>Dextrose Equivalence</th>
<th>Molecular weight (MW)</th>
<th>$T_g$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>500</td>
<td>100</td>
</tr>
<tr>
<td>25</td>
<td>720</td>
<td>121</td>
</tr>
<tr>
<td>20</td>
<td>900</td>
<td>141</td>
</tr>
<tr>
<td>10</td>
<td>1800</td>
<td>160</td>
</tr>
<tr>
<td>5</td>
<td>3600</td>
<td>188</td>
</tr>
</tbody>
</table>

Maltodextrin as additives has a significant effect on the solubility of powder, however, has shown contradicting results in hygroscopicity properties of the powder. The concentration of maltodextrin has shown to produce higher hygroscopicity properties of green tea extract (Tengse et al., 2017) but lower hygroscopicity properties of cactus pear juice (Rodriguez-Hernandez et al., 2007) and betacyanin pigments (Cai and Corke, 2000). However, maltodextrin has low emulsifying capacity and studies have shown that a combination of maltodextrin with other additives significantly improved the quality of powdered products. Commonly known mixtures of maltodextrin with Arabic gum (Minemoto et al., 2002), modified starch (Lokuswan, 2007) and whey proteins (Wang and Zhou, 2013b) are shown to have immediate improved results compared to prior.

Spray drying using sucrose (62°C), glucose (32°C) and fructose (5°C) as additives are not suitable with high temperature of spray drying which can cause caramel caramelization. Prior additives stated causes low product yield and operational problem due to their low transition temperature (Bayram et al., 2005; Azadeh et al., 2010). Furthermore, the non-hydrophobic properties of starch have high viscosity value. Modified starch has found their way into commercial spray drying production, where modified starches have high retention of volatiles and stability. However, maltodextrin is commonly added with modified starches to improve against oxidation during stocking (Krishnan et al., 2005). Studies on cellulose as a stand-alone additive for spray drying has not been found in recent years. However, cellulose has been used as complementary additives in spray drying of mango juice (Cano-Chauca et al., 2005) and soy sauce (Wang and Zhou, 2015). Adding cellulose as drying aid
produces partial crystalline surface, reduce stickiness and caking problem (Fazaeli et al., 2013).

The nature of carbohydrate-additives that has high molecular weights helped to increase the transition temperature of the spray drying process. As the rapid removal of water molecular during the process of spray drying produces amorphous material, in resultant of surface stickiness between adjacent powder particles. The caking problem occurred as the surface viscosity has reached a critical value and formation of inter-particle bonds between particle. The root cause of this situation is often seen in spray drying of sugar and acid-rich foods, such as fruit juice (Goula and Adamopoulos, 2010; Kha et al., 2010). Wang and Zhou (2013a) have suggested using a combination of maltodextrin-cellulose additives to overcome this problem as cellulose is correlated with decreased of stickiness.

2.2 Protein

The usage of protein as spray drying additives such as gelatin, casein, whey protein concentration (WPC) and skimmed milk powder (SMP) (Yoshii et al., 2001; Rao, 2002; Shi et al., 2013) has shown that preference for using protein additives has increased over time in relation to multiple researches on multiple feed products. The differentiation between protein and other spray drying additives is the ability of protein additives to combine with a different type of feed products through their molecular chain diversity and functional properties. Protein additives have rapid film-forming properties, large molecular weight and expanded functional properties such as high solubility and viscosity. These attributes render protein of capable spray drying additives similar to maltodextrin and gums. Furthermore, the usage of proteins has shown to improve significantly on spray drying of high sugar content powder (Jayasundera et al., 2011).

Among all gums, acacia gum (Arabic) is the most commonly used gum-additives for spray drying. This additive is widely used due to its excellent emulsification properties as acacia gums consist of a combination of complex carbohydrates and protein (D-glucuronic acid, L-rhamnose, D-galatose and L-arabinose in the proportion of 4:2:2:1) (Swenson et al., 1968). The protein component of the acacia gum improves the emulsification properties (Dickinson, 2003; Román-Guerrero et al., 2009). Similar to maltodextrin and protein, gum Arabic is ideally suitable because of its surface activity and film form activity. Acacia gum, however, has a wider range of pH range in producing stable emulsions, making acacia gum an exceptional additive for lipid-based powdered products (Minemoto et al., 2002). The usage of soluble fibre and gum acacia helped improved probiotic viability (Lactobacillus...
paracasei) during the spray drying of milk, whereas spray drying of high sugar feed like pomegranate juice using acacia gums has a higher yield and is proven to be effective in compared to other carrier-additives. Abadio et al. (2004) and Goula and Adamopoulos (2005) have stated that powdered product spray dried with acacia gum does not have crystalline configuration and lower bulk density is observed as related to the powder. Despite its calibre, the usage of Arabic gum is associated with high cost, limited availability and impurities due to prone to variability in supply and quality.

3. Properties of additives

The selection choice of additive for spray drying has to be reflected on the physio-chemical properties of the additives itself. Such criteria as molecular weight, glass transition, the concentration of additives are to be considered in additives selection (Table 2). Moreover, the type of feed material used together with added additives has a significant impact on the properties performance (Gharsallaoui et al., 2007). Therefore, considerations of additives choice according to the desired application required tedious knowledge application of spray drying.

3.1 Molecular weight of additives

The molecular weight of additives represents the molecular size of the additives itself, plays a major role in spray drying enhancement. The molecular weight has a direct relationship with transition temperature, in which shorter chain molecules of additives have low transition temperature than longer chain of additives (Goula and Adamopoulos, 2003; Shrestha et al., 2007; Adhikari et al., 2009). Bhandari et al. (1997) have stated that comparing maltodextrin (DE 36) with a molecular weight of 500 and transition temperature of 100°C, with maltodextrin (DE 5) that has a significantly higher transition temperature of 188°C. Furthermore, increasing transition temperature contribute to powder stability and reduce caking and stickiness problem. Gum acacia has higher molecular weight in comparison to maltodextrin. As the transition temperature increase with the increase in molecular weight, the addition of gum acacia (Arabic) has a higher Tg compared to the addition of maltodextrin (Pedroza-Islas et al., 1999).

The concentration of DE determined the spray dried product yield. (Samborska, Gajek, and Kamińska-Dwórzicka, 2015). Papadakis et al. (2006) and Samborska et al. (2015) found that increasing DE of maltodextrin improved significantly on product yield of dry raisin juice and honey bee. The discovered trend can be shown by the difficulty of smaller molecules of water diffusing in between large chain of maltodextrin. Large chain of molecules has high molecular weight of additives that affect other properties as well. Corke (2000) has discovered that as the molecular weight of maltodextrin decreased, the hydrosopicity of amaranthus betacyanin pigments increased. The author has stated that the molecular configuration of shorter chain maltodextrin has more hydrophilic groups. This is also supported by research done on spray dried acai pulp (Tonon et al., 2008) with similar results. Taylor et al. (2008) have stated that the larger molecular weight of maltodextrin has a direct relationship with faster rehydration and reabsorption of powdered particles, due to the higher surface area over volume ratio exposed to moisture.

3.2 Concentration of additives

One of the most important factor to improve physio-chemical properties of feed materials is the concentration of additives used for spray drying. High concentration additives used in feed material produce a difference in the yield percentage, transition temperature, hydrosopicity and other physico-chemical properties. Studies have shown that an increase of maltodextrin percentage used in spray drying of orange juice concentrate results in yield percentage (Shrestha et al., 2007). However, the author has stated that a level of maltodextrin is required to produce a significant result of spray drying. Similar results have shown by spray drying of mixture of pineapple and maltodextrin, by which the recovery of feed solids in the product has improved (Abadio et al., 2004). In general, multiple published paper has shown that increase of maltodextrin concentration has resulted in an increase of yield product percentage (Gonnissen et al., 2008; Mishra et al., 2014; Avila et al., 2015). The yield product percentage can be supported by the fact that surplus level of maltodextrin increases the total solid and reduced the level of total water for evaporation (Jangam and Thorat, 2010; Mestry et al., 2011; Horuz et al., 2012).

The superiority of maltodextrin in water solubility led to the fact that higher concentration of additives added produces powder with lower moisture content (Khalilian Movahhed and Mohebbi, 2016). However, the concentration of maltodextrin added does not affect its rehydration ability to absorb moisture. (Cano-Chauca et al., 2005; Grabowski et al., 2006). Similarly, the concentration of protein additives has inconsistent results towards physiochemical properties of spray dried powder. Addition of protein additives at certain concentration increase yield production but doubling the concentration yield insignificant results (Adhikari et al., 2009). The ratio of protein-carbohydrate additives has proven contradicting results in term crystallization.
<table>
<thead>
<tr>
<th>Type</th>
<th>Additives</th>
<th>Characteristic</th>
<th>Functionality</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>Maltodextrin</td>
<td>Sweet, white powder that is low costing, film formation and bulking properties. However, it has low emulsifying capacity and transition temperature.</td>
<td>↑↓ Moisture content, bulk density, glass transition temperature and hygroscopicity ↑ Powder yield, vitamin C retention and solubility ↓ Water activity, total carotenoid content and antioxidant activity</td>
<td>Chegini and Ghobadian (2005); Loksuwan (2007); Koç and Kaymak-Ertekin (2014); Avila <em>et al.</em> (2015);</td>
</tr>
<tr>
<td></td>
<td>Cellulose</td>
<td>Insoluble large molecular carbohydrate that produce crystalline surface that reduce stickiness and caking problem.</td>
<td>↑↑ Anthocyanin content ↑ Powder yield and transition temperature ↓ Down solubility, stickiness and caking</td>
<td>Wang and Zhou (2015); Yousefi <em>et al.</em> (2011)</td>
</tr>
<tr>
<td></td>
<td>Modified starch</td>
<td>Efficient as complimentary additive with lipophilic characteristics that produce crystalline surface, reduce stickiness and caking problem.</td>
<td>↑ Solubility, powder yield, hygroscopicity and moisture content</td>
<td>Cano-Chauca <em>et al.</em> (2005); Wang and Zhou (2015); Santana <em>et al.</em> (2017);</td>
</tr>
<tr>
<td></td>
<td>Waxy starch</td>
<td>Consists of semi-crystalline material that is insoluble and unable to gelatine leading to low solubility.</td>
<td>↑ Bulk density, anthocyanin, stickiness and transition temperature ↓ Solubility and powder yield</td>
<td>Cano-Chauca <em>et al.</em> (2005); Ferrari <em>et al.</em> (2012); Wang and Zhou (2015);</td>
</tr>
<tr>
<td>Protein</td>
<td>Whey protein</td>
<td>Made of milk protein, different protein content affect the properties of powder and retaining flavouring compound of fruit powder.</td>
<td>↑ Powder yield, hygroscopicity, transition temperature ↓ Surface tension, moisture content, bulk density</td>
<td>Jayasundera <em>et al.</em> (2011); Fang and Bhandari (2012); Samborska <em>et al.</em> (2015); Tontul <em>et al.</em> (2016);</td>
</tr>
<tr>
<td></td>
<td>Casein</td>
<td>Additive with surface-active nature, casein is capable of delaying crystallization</td>
<td>↑ Powder yield and transition temperature ↓ Surface tension</td>
<td>Wang and Langrish (2010); Wang <em>et al.</em> (2010)</td>
</tr>
<tr>
<td>Gum</td>
<td>Acacia gum (Arabic)</td>
<td>Excellent emulsifier in wide pH range and film forming ability, acacia gum is widely used in lipid-based product. High impurities and limited availability reduces the quality of gum.</td>
<td>↑↓ Solubility and anthocyanin ↑ Powder yield emulsification, bulk density, transition temperature and vitamin C retention ↓ Water activity, moisture and hygroscopicity</td>
<td>Dickinson (2003); Abadio <em>et al.</em> (2004); Román-Guerrero <em>et al.</em> (2009);</td>
</tr>
</tbody>
</table>
process (Wang and Langrish, 2010).

3.3 Suitability of spray drying feed

The type of feed materials has a significant impact on the efficiency of the additives used. As the type of feed materials has board comparison in properties (sugar and fat content, viscosity, and transition temperature), understanding on the spray drying of feed has to be included on its wide range of processing parameter with an in-depth quality parameter of the powder attained (Wang and Langrish, 2009). One of the qualities that can be achieved as according to Bhandari et al. (1997), powder recovery greater than 50% is stated to be an efficient spray drying system.

Commonly used additives such as maltodextrin, gum acacia, and whey protein concentrate are used to test as the comparison on different type of food production. The selection of additives is heavily supported by understanding the properties of both spray drying feed and the additives used, as different additives have different physical and chemical structure. Gum acacia is a highly ramified structure that contains shorter chains and hydrophilic groups, while protein additives have many different functional advantages such as biocompatibility, biodegradability, emulsifying and foaming capacity, water and fat absorption, gelation and film-forming properties (Nesterenko et al., 2013).

The challenge of feed selection is also hindered by the complexity of spray drying operating parameters on the physio-chemical properties of the powder. Comparison of performance between the maltodextrin and soy protein isolate (SPI) on spray dried tamarin pulp powder has emphasized on its powder quality (Muzaffar and Kumar, 2016). The increasing level of maltodextrin increases both the moisture content and \( a_w \) of the tamarind pulp powder, while the increase used of SPI has shown otherwise, with an increased level of moisture content but lower \( a_w \). However, at high level of both maltodextrin and SPI, the moisture content of the powder decreased. Inconsistent trend data are also found on the study of blackberry powder (Ferrari et al., 2012), chicken meat protein hydrolysate (Kurozawa et al., 2009), acerola powder (Righetto and Netto, 2005) and tomato juice powder (Tontul, Topuz, Ozkan, and Karacan, 2016).

Based on the researches published, there is a lack of viable and reliable results showing a comparison of performance between the commercially available additives. Anandharamakrishnan et al. (2007) and Gharssallahou et al. (2007) have stated that understanding the process spray drying requires trial-and-error method as it involves a multitude of factors.

4. Influence of additives on properties changes in dried powder product

4.1 Bulk density

Recent researches have shown that there is no clear relationship between additives capabilities and bulk density. Additives addition into feed solution has a different effect on the bulk density. Due to the capabilities of maltodextrin as a carrier and coating agent, its application is widely used on the spray drying of betacyanin pigment (Cai and Corke, 2000), beetroot powder (Singh and Hathan, 2017). Addition of maltodextrin additive effect the changes the bulk density of powder. This is proven by the fact that skin forming nature of maltodextrin increases the volume of air trapped in the particle and reduce thermoplasticity. Kwapiska and Zbicinski (2005) has shown that additives with skin-forming properties like maltodextrin often contained air bubbles, in which increasing used of similar additives, the lower the bulk density of powders.

Application of gum acacia (Arabic) in spray drying has exhibited similar results, as acacia gum (Arabic) has a higher Tg point by its large molecule size. Furthermore, this is supported by the fact that additives of increasing concentration, the bulk density of orange juice powder have proven to decrease (Shrestha et al., 2007). In contrast, multiple reports done by Abadio et al. (2004) and Yousefi et al. (2011) tomato juice and pineapple pulp have shown opposite results. They have stated that as additive concentration increases, the bulk density of powder decreased. The supported fact added by the authors is that the particle size of powder increased as the concentration of additive increase.

4.2 Glass transition

Glass transition temperature (Tg) is a property of an amorphous material, where it defined as the temperature of product amorphous system interchanging between a glassy and a rubbery state. Usually, food products that formed in a rapid heat exchanging environment process, are not at thermodynamic equilibrium. They will undergo the transition from a glassy crystalize temperature to rubbery state matter depending on their water activity level and molecular weight. Similarly, transition temperature (Tg) is highly associated with changes in various physical properties such as boiling and melting point and appearances. Increasing temperature above Tg of a material increase rate of deteriorative, stickiness, collapsing and crispness, as molecular mobility and viscosity exponentially increases (Roos and Karel, 1991).

In this context, spray drying of pure fruit juice into powdered form faced similar difficulty as fruits juice consists of low-molecular weight molecules such as
sucrose, glucose, fructose, and malic and citric acids, which cause a stickiness problem during spray drying. The stickiness is attributed to the low transition temperature of sugar molecules, as summarized in Table 3 (Fang and Bhandari, 2012; Du et al., 2014). Similarly, spray drying of organic acid and solution poses similar difficulties.

Table 3. Glass transition temperature $T_g$ of different materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Glass transition temperature $(°C)$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galactose</td>
<td>30</td>
<td>Roos (2002)</td>
</tr>
<tr>
<td>Glucose</td>
<td>31</td>
<td>Roos (2002)</td>
</tr>
<tr>
<td>Lactose</td>
<td>101</td>
<td>Roos (2002)</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>58</td>
<td>Da Róz et al. (2011)</td>
</tr>
<tr>
<td>Citric acid</td>
<td>58</td>
<td>Da Róz et al. (2011)</td>
</tr>
<tr>
<td>Fructose</td>
<td>16</td>
<td>Jouppila and Roos (1994)</td>
</tr>
<tr>
<td>Maltose</td>
<td>87</td>
<td>Jouppila and Roos (1994)</td>
</tr>
</tbody>
</table>

To overcome low glass transition temperature of feed material, adding additives have shown to increase the molecular weight of molecules, therefore increasing feed’s transition temperature. By this application, the extension of shelf life of the powder can be extended. High stability of powder is associated with high transition temperature and the risk of caking, powder collapse and crystallization can be reduced (Khalilian Movahhed and Mehebbi, 2016; Kurozawa et al., 2009).

4.3 Particle size

The size of particle formed during spray drying is strongly related to feed viscosity, as higher liquid viscosity, the larger the droplets formed during atomization produces larger particles obtained during spray drying (Jinapong et al., 2008). Similarly, in a spray drying process, Keogh et al. (2003) have found that there is an increase in particles size based on an increase in feed viscosity of ultra-filtered whole milk concentrated. The addition of additives, especially an increase of maltodextrin concentration has proven to increase the particle size of spray dried powder. Goula and Adamopoulos (2005) emphasized the addition of maltodextrin caused an increase of viscosity and produced slurry dry matter in the solution, leading to large powder production. The results produced by the authors are aligned with the results reported by Kurozawa et al. (2009) on chicken meat hydrolysate powder and Tonon et al. (2008) on acai powder. Nevertheless, no studies have been found on protein and other similar additives producing any implication on the size of particle powder. The authors have stated that this may due to the fact that protein additives and other additives do not have the viscosity-changing ability as compared to maltodextrin.

4.4 Colour index

The physical appearance of spray dried powder is highly valued, as colour and texture of the powder are highly perceived by consumers. The additional of additives can maintain or disintegrate the physical appearance of the powders especially the colour index, depending on the type of feed material and concentration of additives used (Grabowski et al., 2006).

As the function of additives used in spray drying may increase the droplet size of atomized feed as viscosity increases, there are no reports stating that additives improved the physical appearance of end powder products. Otherwise, the increase concentration of maltodextrin diluted the colour of the feed solution and the end product significantly as maltodextrin is usually bright white in natural form (Du et al., 2014).

Furthermore, reports have stated that atomization of feed solution into tiny droplets has increase surface area exposed to rapid pigment oxidation, leading to lower a/b value and high hue angle (Desobry et al. 1997). Abadio et al. (2004) have suggested that adding maltodextrin with concentration up to 15% did not affect the appearance of the powder solution. Overall, there are insufficient studies done on the effect of additives on the powder colour index, as major studies focused on yield production, moisture content and other parameters.

4.5 Solubility index

A key determinant of the powder quality, solubility is an important key factor for evaluating wettability and dispersibility of powder in aqueous solution. The solubility index of spray dried powder is affected by the raw materials and additives used, and also the properties of the powder (moisture content and size of particles). Literature reviews have stated that the functionality of maltodextrin gave arose on the explanation of the increase of solubility of powder with increase of additives used. Crust formation occurred during rapid heat exchange environment in the chamber, where the least soluble substances started to precipitate and forming crust at the droplet surface. Therefore, the formed crust is mainly constituted of maltodextrin that is highly soluble in nature. Similar authors have found this fact aligned with their research such as Goula and Adamopoulos (2008) on tomato pulp powder, Grabowski et al. (2006) on sweet potato puree powder and Caliskan and Nur Dirim (2013) on sumac extract powder.
On the contrary, studied on spray drying on tea leaves extract using maltodextrin does not have a significant effect on the solubility of powder (Quek et al., 2007). The authors have suggested that a hard surface layer might have formed over the powder particle, preventing the diffusion of water molecules. Therefore, the wettability and solubility of the particle are reduced. Based on the two observations, additives in spray drying produced opposing and contradicting results in the observance of powder solubility. Overall, a summarized of main findings based on type of carriers and feed material is shown in Table 4.

5. Effect of additives on spray drying parameters optimization

Certain criteria have taken under concern regarding powder production using the application spray drying required high energy consumption, leading to high operational costs due to the rapid heat exchanging process. Added to that, optimization of spray drying requires an evaluation of both spray drier parameter and feed formulation, as the modulating of spray drying must be controlled to avoid low yield, moisture content and sticking problem (Oakley, 2004; Nekkanti et al., 2009; Aghbashlo et al., 2015;). Multiple reports have stated that effective additives can optimize the performance of spray drying parameters. The efficiency of spray drying parameters such as inlet temperature, feed flow rate, outlet temperature and nozzle pressure can be enhanced with the use of additives. Furthermore, the use of additives is cost reducing and high productivity through the functionality of additives of manipulating the transition temperature, total soluble solids and viscosity of the solution (Yousefi et al., 2011; Lee et al., 2017; Santana et al., 2017).

In the spray drying of sumac extracts, an increase of maltodextrin concentration extended the feed flow rate of sumac extracts, leading to improved yield powder product percentage. The addition of maltodextrin additives increases the total soluble solids (TSS) content, resulted in an increase in efficiency yield (Caliskan and Nur Dirim, 2013). Despite that, the addition of additives has its own setbacks. Addition of large maltodextrin molecules as additives in a spray drying operation led to a less efficient system, where high residual moisture content found in powder products. Goula and Adamopoulos (2005) concluded that in a rapid heat exchanging system, water molecules have difficulty in escaping from maltodextrin due to their large size and film coating abilities. Furthermore, the increase of additives would produce a higher viscosity feed which reduces the product yield of powder (Tonon et al., 2008).

Based on the author research, the increase of TSS through the addition of additives decrease the yield percentage.

Similarly, the relationship of maltodextrin and inlet air temperature showed a negative correlations relationship towards water activity. The powder water activity can be greatly reduced by the addition of maltodextrin. However, there is no proven fact that the inlet air temperature required to produce powder at a specific water activity can be reduced by the addition of maltodextrin additives (Cai and Corke, 2000; Quek et al., 2007; Shavakhi et al., 2012). Overall, a handful of reports has been published on the effectiveness of additives of spray drying optimization, in which there is no clear linear relationship between additives and spray drying parameters has been identified.

6. Conclusion

Based on the published reports that signified the effect of additives on the properties of the powder, it is shown that different food powder has shown different characteristic under the influence of different additives. However, a similar trait has appeared that emphasized on the main function of additives; additives improve product yield through the manipulation of transition temperature. Added to that, usage of combination additives proved positive results towards better yield, solubility and bulk density.

The lack of research on additives is towards the microscopic point of view, where there are substantial evidence showing how the additives reacted on different powders products. The functionality of additives reacted different towards a similar group product but has shown contradicting and opposing results (More Swati and Wagh, 2014; Shishir and Chen, 2017). High sugar content fruit juices are a few of those examples.

Spray drying is an extensive research drying process that is applied to many food ranges of products. This review paper that focuses on additives has shown its capabilities and potentials in enhancing powder properties through incorporation with the spray drying processing parameters. Further research on additives is likely to improve on the efficiency of spray drying.

Acknowledgement

The author is grateful to those who have contributed to this review paper. (No Vot. 9498700)
### Table 4. Summary of main findings done on type of carrier and feed material

<table>
<thead>
<tr>
<th>Feed material</th>
<th>Type of carrier</th>
<th>Main findings</th>
<th>References</th>
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<tbody>
<tr>
<td>Pomegranate Juice</td>
<td>Maltodextrin (DE20)</td>
<td>Arabic gum produced highest yield than other carriers, with lowest bulk density</td>
<td>Yousefi et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>arabic gum, and waxy</td>
<td>and particle size</td>
<td></td>
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<tr>
<td></td>
<td>starch</td>
<td>Colour and anthocyanin of pomegranate juice is efficient with maltodextrin</td>
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<td>Babassu coconut milk</td>
<td>Maltodextrin and modified starch</td>
<td>Modified starch outperformed maltodextrin in product recovery</td>
<td>Santan et al. (2017)</td>
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<tr>
<td>Acai Pulp</td>
<td>Maltodextrin</td>
<td>Addition of maltodextrin has negative effect on yield and powder hygroscopicity</td>
<td>Tonon et al. (2008)</td>
</tr>
<tr>
<td>Cashew apple juice</td>
<td>Cashew tree gum and</td>
<td>Combination of cashew tree gum and maltodextrin improved the physical</td>
<td>De Oliveira et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>maltodextrin</td>
<td>properties of powder</td>
<td></td>
</tr>
<tr>
<td>Chicken meat protein</td>
<td>Maltodextrin (DE10)</td>
<td>The increase concentration of maltodextrin and gum Arabic both reduces</td>
<td>Kurozawa et al. (2009)</td>
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<td>Hydrolysate</td>
<td>and gum Arabic</td>
<td>moisture content, hygroscopicity and increase transition temperature</td>
<td></td>
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<tr>
<td>Sweet potatoes puree</td>
<td>Maltodextrin (DE11)</td>
<td>Increase of maltodextrin reduces moisture content and increase solubility</td>
<td>Grabowski et al. (2006)</td>
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<td>index and transition temperature</td>
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<td>Amaranthus betacynin</td>
<td>Maltodextrin (DE10-DE25)</td>
<td>The combination of highest (DE25) and lowest (DE10) has highest betacynin</td>
<td>Cai and Corke (2000)</td>
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<td>pigments</td>
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<td>retention.</td>
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<td>Pumpkin</td>
<td>Maltodextrin</td>
<td>Higher maltodextrin concentration produced lower yield even though has</td>
<td>Shavakhi et al. (2012)</td>
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<td></td>
<td></td>
<td>higher transition temperature and hygroscopicity</td>
<td>Khalilian (2016)</td>
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<tr>
<td>Carrot-celery juice</td>
<td>Maltodextrin</td>
<td>Increase of maltodextrin concentration reduced moisture content, water</td>
<td></td>
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<td></td>
<td></td>
<td>activity, hygroscopicity, β-carotene and bulk density, while increase</td>
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<td></td>
<td></td>
<td>particle size and dissolution time.</td>
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<tr>
<td>Tamarind pulp powder</td>
<td>Maltodextrin (DE20), gum</td>
<td>Whey protein outperformed maltodextrin and gum Arabic in powder recovery,</td>
<td>Bhusari et al. (2014)</td>
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<td></td>
<td>arabic and whey protein</td>
<td>bulk density and good flowability.</td>
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<td>Soy sauce</td>
<td>Maltodextrin and whey</td>
<td>Combination of whey protein (&gt;5%) into soy sauce-maltodextrin solution</td>
<td>Wang et al. (2013)</td>
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<td></td>
<td>protein</td>
<td>increased product yield by 20%. Adding whey protein delay caking problem.</td>
<td></td>
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<td>Pineapple juice</td>
<td>Maltodextrin</td>
<td>Increase in maltodextrin reduces the true density and moisture content of</td>
<td>Abadio et al. (2004)</td>
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<td>Honey</td>
<td>Maltodextrin and whey</td>
<td>Powder recovery (&gt;50%) are achieved when maltodextrin and whey protein used</td>
<td>Shi et al. (2013)</td>
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<td>protein</td>
<td>in combination and separately</td>
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<td>Blackberry juice</td>
<td>Maltodextrin</td>
<td>Maltodextrin outperformed gum Arabic in lower moisture content, higher</td>
<td>Ferrari et al. (2012)</td>
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<td>Gum Arabic</td>
<td>anthocyanin retention and oxidant activity</td>
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<td>Raisin juice concentrate</td>
<td>Maltodextrin (DE6, 12</td>
<td>Lower DE of maltodextrin reduces the temperature of inlet drying air for</td>
<td>Papadakis et al. (2006)</td>
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<td></td>
<td>and 21)</td>
<td>successful powder production.</td>
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<tr>
<td>Beetroot Juice</td>
<td>Maltodextrin (20, 25</td>
<td>The increase of maltodextrin concentration resulted in lower moisture</td>
<td>Singh and Hathan (2017)</td>
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<td></td>
<td>and 30%)</td>
<td>content</td>
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### References


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