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Storage stability and anti-caking agents in spray-dried fruit powders: A review

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Abstract:
Fruit powders possess numerous benefits compared to fresh raw materials, i.e., extended shelf-life, convenient transportation and storage, a wide range of applications, etc. Nonetheless, the storage time of fruit powders depends on such factors as storage conditions, packaging, etc.
This review suggests a comprehensive analysis of articles, reviews, reports, and books indexed in Scopus, Web of Science, and eLIBRARY.RU, as well as reported at conference proceedings and other scholarly resources in 2005–2022.
Due to their high hygroscopicity, powders tend to absorb moisture from the environment and become prone to caking. Anti-caking agents can prevent powders from this process. Different packaging materials also affect the compounds and properties of fruit powders. Accelerated degradation and temperature models can predict shelfp-life. This review featured the effectiveness of different anti-caking agents, as well as the impact of various packaging methods on the storage of powders. Calcium phosphate demonstrated excellent anti-caking properties, reduced hygroscopicity, and enhanced flowability. Aluminum laminated packaging proved effective in protecting powders during storage. As the storage time increased, powders demonstrated only a slight increase in moisture content. Their L^* value (light to dark) and b^* value (yellow to blue) decreased while the a^* value (green to red) and the total color change increased. Caking increased as the flowability, pigment content, and antioxidant content went down.
The review has practical implications for developing new technologies aimed at prolonging the storage time of spray-dried fruit powders.

Keywords: Fruit powder, physico-chemical properties, anti-caking agents, kinetics, packaging, shelf-life, spray-dried products

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INTRODUCTION

Stickiness and caking of food powders are one of the most important problems that the modern food industry has to solve [1]. Spray-dried powder has many water-soluble amorphous substances that are prone to caking [2, 3]. Caking can be caused by such factors as inter-particle forces that develop under moisture absorption, increased temperature, or pressure during processing, transportation, and storage [4]. Humidity caking is the most common caking phenomenon that damagees food powder. It usually occurs as bridging, agglomeration, compaction, or liquefaction [5].

Caking happens when amorphous food powders turn into an undesirable sticky material [2]. Anti-caking agents are substances that can prevent caking, clumping, and aggregation of hygroscopic powders by improving their flowability [2, 6]. An anti-caking agent competes with the host powder for moisture and acts as a moisture-protective barrier [5]. Anti-caking agents improve the powder flowability. They inhibit caking by acting as a physical surface barrier between particles. As a result, they increase the glass transition temperature (Tg) of the amorphous phase, thus or creating a moisture-protective barrier on the surface of hygroscopic particles [2]. In addition, anti-caking agents also decrease inter-particle forces and reduce stickiness [6].

Anti-caking agents are extremely important components of food production because they make it possible to obtain non-sticky and free-flowing powders [5]. Calcium phosphate, silicon dioxide, silicates, phosphates, stearic acid salts, and modified carbohydrates resolve the stickiness problem and increase the spray-dried powder yield [7]. Anti-caking agents must be effective at low concentrations, e.g., 3%. As a rule, their allowable concentration is restricted to a very low level [8]. In practice, the percentage of anti-caking agents does not exceed 1% [6, 9].

Packaging means that a product is placed in a protective container or wrapped for storage and transport [10]. Package has a three-fold function: it protects the product against heat, light, moisture, and oxygen, inhibits evaporation, and prevents microbial contamination [11]. The right selection of packaging materials is essential to maintain product quality and freshness during distribution [12]. Packaging materials affect the physicochemical profile and quality of the final product, which the consumer acceptability depends on [13].

Dehydrated fruits serve either as food or ingredients for bakery products, soups, and instant fruit powders. Spray-drying converts fruits into powder, which is a more stable product [14, 15]. Spray-drying can be applied to such exotic fruits as pineapple, papaya, *cempedak* (*Artocarpus integer* Thunb), and *terung asam* (*Solanum ferox*) [16–20]. Powder requires protection against moisture and oxygen, as well as against the loss of volatile flavorings and color [21]. High humidity and temperature conditions are not favorable for powder storage: powder starts to melt and solidify, thus decreasing in quality [4]. As a consequence, food products lose consumer attraction.

Shelf-life prediction usually relies on the data generated under accelerated storage conditions. The test measures the stability of the product under abusive storage conditions, such as high temperature and humidity [22]. The obtained data then help estimate the shelf-life value [23]. This method is fast and cheap, which makes it advantageous for food product development.

Food powders possess numerous advantages over fresh products: they have a longer shelf-life, they are easy to store and transport, and they have a wide range of application as food ingredients. However, the storage time of food powders depends on storage conditions and packaging. Thus, scientific community needs to improve storage technologies and gather data on storage conditions for food powders.

This research features different types of powders, their storage conditions, and packaging methods, with an emphasis on preventing caking and assessing their impact on the properties of spray-dried powders. The findings may aid in developing long-term storage technologies for spray-dried food powders.

STUDY OBJECTS AND METHODS

The research consisted of an exhaustive analysis that defined the anti-caking capabilities of spray-dried powders. It covered articles, reviews, reports, books, etc. published in Scopus, Web of Science, eLIBRARY.RU, conference proceedings, and other scholarly resources in 2005–2022. Such a protracted period provided a thorough comprehension of the subject matter represented in various studies, discoveries, and improvements in the field of spray-dried powder and its anti-caking properties. As a result, the review included findings and conclusions that were well-informed, reliable, and representative of the current body of knowledge on the subject.

RESULTS AND DISCUSSION

Types of anti-caking agents and their effect on powder properties. Table 1 shows different types of anti-caking agents that are incorporated into fruit powders. Calcium phosphate and calcium silicate proved to be the main anti-caking agents [9, 21]. The percentage range of anti-caking agents in food formulations was 0.05–0.25% [24, 25]. However, Lipasek *et al.* described some extreme cases when the share of an anti-caking agent was as high as 50% [26].

Fruit powder producers use different anti-caking agents. Pui *et al.* studied calcium silicate, silicon dioxide, and calcium phosphate incorporated into *cempedak* powder: 0.66% of calcium phosphate demonstrated the best results in hygroscopicity reduction [31]. On the other hand, Addo *et al.* reported calcium stearate to be the most effective anti-caking agent in improving the flowability of *jujube* powder, as compared to magnesium stearate and silicon dioxide [32].

Calcium phosphate. Calcium phosphate (E341) is a calcium salt of phosphoric acid. Its chalky texture makes it a useful free-flowing agent as it can take up to 10% of its weight in moisture [33]. Calcium phosphate inhibits

Table 1 Application of anti-caking agent in fruit and vegetable powders

Powder	Anti-caking agent	Concentration, %	References
Kokum (*Garcinia indica* L.)	Calcium phosphate	0.25	[25]
Guava and pineapple powder	Calcium phosphate, calcium silicate, calcium oxide	0.05, 0.1, and 0.15	[24]
Lemon	Powdered sugar	50	[27]
Lime	Silicon dioxide	10	[28]
Mango	Glycerol monostearate, calcium phosphate	1.5	[21]
Pineapple	Calcium phosphate, calcium silicate, calcium oxide	0.25	[9]
Powdered drink mix	Silicon dioxide	0.2	[29]
Strawberry	Calcium carbonate	–	[30]
Vitamin C	Calcium phosphate, calcium silicate, calcium stearate, corn starch	2.0; 50.0	[26]

caking in cases when a lot of multiwall bags are stacked on top of each other [34].

Jaya & Das reported the optimal requirement of 0.015 kg calcium phosphate and glycerol monostearate per 1 kg mango solid [7]. The degree of caking decreased when the concentration of the anti-caking agents increased. Calcium phosphate also proved effective in hygroscopicity reduction [7]. Nayak & Rastogi added 0.25% of calcium phosphate to *Garcinia indica* L. powder, while Phanindrakumar *et al.* incorporated the same concentration into pineapple powder [9, 25]. Tricalcium phosphate also reduced hygroscopicity in crystalline coconut sugar [35].

Calcium silicate. Calcium silicate (E552) is made from chalk, limestone, or diatomaceous earth. It serves as an anti-caking agent in dry products [8]. Due to its extensive surface area, calcium silicate can draw up quite a lot of moisture [34]. Phanindrakumar *et al.* incorporated 0.25% of calcium silicate into pineapple powder, while Lipasek *et al.* used as many as 2% in vitamin C powder [9, 26]. However, other studies reported a much lower concentration of calcium silicate in guava and pineapple powder, namely 0.05–0.15% [24].

Silicon dioxide. Silicon dioxide (E551), also known as silica, is the oxide of silicon. It absorbs water and improves the flowability of dry products [8]. Silicon dioxide is known to attract and soak up moisture in seasoning blends. However, after silicon dioxide reached its moisture limit, it stopped inhibiting moisture caking [34].

Castro *et al.* applied 0.2% of silicon dioxide to a powder drink mix [29]. Nortuy *et al.* calculated the optimal percentage of 0.73% silicon dioxide for instant date powder [36]. On the other hand, Rostapour *et al.* came up with a much higher optimal concentration of 10% for lime powder [28]. The maximal limit of silicon dioxide was 2% because higher doses gave powder a sandy texture [8].

Packaging materials. Table 2 describes different storage packaging materials for different powders. Quite a few popular packaging materials can be applied to food powders, e.g., polyethylene and polypropylene. Pouches with a metalized barrier are another type of powder packaging, e.g., metalized co-extruded bi-axially-oriented polypropylene, metalized polyester polyethylene, and aluminum foil laminated polyethylene [37–40].

New powder packaging materials appear in scientific publications every day. For instance, Kardile *et al.* used low density polyethylene and coextruded laminated pouches to store instant *puran* powder [45]. Ding *et al.* studied black garlic powder stored in polyethylene tetraphtalate bottles, kraft paper bags, and aluminum laminated polyethylene bags [46]. Kuchi *et al.* determined the quality of *Burfi* banana packaged in aluminium foil, butter paper, and polyethylene film [47]. Varastegani *et al.* used low density polyethylene to store *Nigella sativa* instant beverage powder [48].

The thickness of these packaging is usually 90–100 μm [40, 41, 43]. However, metalized films of high barrier can be as thin as 50 μm; they are used as packaging for apple peel powder [41]. Rao *et al.* studied polyethylene and metalized polyester polyethylene with a thickness of 25 and 20 μm, respectively [39].

Aluminum is a good barrier to oxygen, water vapor, and light. Barrier properties can be measured by the oxygen and water vapor permeation [49]. However, the

Table 2 Different packaging material in storing various fruit powders

Sample	Packaging	Size, cm	Thickness, μm	Water vapor transmission rate, kg/m²day Pa	Oxygen transmission rate, L/m² day atm	References
Apple peel powder	High-density polyethylene (HDPE)	10×8	100	1900 cm³/m² day	5700 cm³/m² day	[41]
	Metalized films of high barrier (MFHB)	10×8	50	0.3 g/m² day	< 50 cm³/m² day bar	
Jackfruit powder	Aluminum laminated polyethylene (ALP)	10×15	89	1.2×10^{-6} kg/m² day	0.0197	[42]
	Metalized co-extruded bi-axially oriented polypropylene (BOPP/MCPP)	10×15	75	3.56×10^{-5} kg/m² day	0.0233	
Mango powder	Polyester polypropylene (PP)	18×13	40.2	–	–	[38]
	Metalized polyester polyethylene (MPP)	18×13	62.2	–	–	
Papaya	Aluminum laminated polyethylene (ALP)	15×18	117	6.44×10^{-8}	0.0213	[43]
	Polyamide/polyethylene (PA/PE)	15×18	90	2.25×10^{-7}	0.1200	
Pink quamachil aril powder	Polyethylene (PE)	14×12	25	–	–	[39]
	Metalized polyester polyethylene (MPE)	14×12	20	–	–	
Sour cherry powder	High barrier metalized polypropylene (Pet/PPmet/PE)	12×12	130	–	–	[44]
	Aluminum packaging (Pet/Al/PE)	12×12	106	–	–	

permeability of plastic films to gases and water vapor varies according to the type and thickness of the plastic used [50].

Pua *et al.* described the high-water vapor transmission rate and oxygen transmission rate of 3.56×10^{-5} kg/m^2 day Pa and 0.0233 L/m^2 day atm, respectively [42]. On the other hand, aluminum foil laminated polyethylene had a lower water vapor transmission rate of 1.58×10^{-8} kg/m^2 day Pa [51]. Udomkum *et al.* reported oxygen transmission rate value of 0.12 L/m^2 day atm for polyamide/polyethylene [43].

Aluminum laminated polyethylene. The barrier properties are the main requirement in choosing a high-performance packaging material. A good packaging material prevents oxygen, water, light, flavor, and grease from entering or leaving the package [49]. Aluminum foil laminates have a wide application in food packaging. Table 2 demonstrates quite clearly that aluminum laminated polyethylene is a better packaging material than aluminum foil laminated polyethylene in terms of water vapor permeability [37, 43, 51].

Powder packed in aluminum laminated polyethylene retains more nutrients and catches less moisture. Yu *et al.* reported that powder packaged in polyethylene terephthalate pouches gained more moisture than that in aluminum laminated polyethylene pouches [51]. Aluminum laminated polyethylene had a lower water vapor transmission rate than metalized co-extruded biaxially oriented polypropylene.

Pua *et al.* reported that jackfruit powder packaged in aluminum laminated polyethylene exhibited a lower moisture uptake and had a higher kinetic constant for the total color [42]. In addition, spray-dried bovine colostrum powder packaged in aluminum laminated polyethylene had a longer shelf-life than that packaged in polyethylene terephthalate pouches [51]. Zorić *et al.* studied *marasca* powder preserved with laminated packaging [52].

Loo & Pui reported that aluminum laminated polyethylene pouches were more effective than polyethylene terephthalate pouches in retaining moisture content, water solubility, carotenoid content, flowability, and hygroscopicity [53]. Dried carrots packaged in aluminum laminated pouches and stored under refrigerated conditions showed a minimal increase in moisture content, water activity, pH, and sugar. The carrots also retained the highest amounts of carotenoids, total phenolics, and antioxidants [54].

Phahom *et al.* also reported that aluminum laminated polyethylene was more effective that polyester poly in storing *Thunbergia laurifolia* L. leaves: it had a smaller decrease in hue angle and a smaller increase in total color difference [55]. Suhag & Nanda studied honey powder stored in aluminum laminated polyethylene [56]. The sample had better antioxidant properties and minimal hygroscopicity as compared to those stored in high-density polyethylene. According to Barooah *et al.*, spray-dried ripe banana powder stored in aluminum laminated polyethylene was sensory acceptable even after one year of storage, while metalized polyester pouches were able to preserve its qualities for three months only [57].

Accelerated storage of powder. Table 3 summarizes the storage conditions for different powders. Accelerated storage tests usually include high relative humidity and temperature. Accelerated storage at 90% relative humidity and 38 ± 1°C can be applied to model moisture adsorption and storage time relationships [58].

Some publications report models that predict variations in food quality and shelf-life, e.g., for aloe vera gel powder and apple peel powder [37, 41, 62]. Kinetic modeling based on the Arrhenius principle relates temperature to shelf-life. For dried products, their shelf-life can be calculated from their critical moisture content [63, 64].

Table 4 illustrates the effects of storage stability on the properties and shelf-life of powders. Generally, the moisture content in packaged powder increases together with storage time. Sornsomboonsuk *et al.* reported that extended storage under elevated temperature increased the water activity, moisture content, bulk density, and tapped density of *bael* fruit powder [65]. Apart from storage time, relative humidity, and temperature, the packaging material also affected the moisture gain in jackfruit powder because water vapor migrated from the storage environment into the packaging material [42].

An increased oisture content deteriorates the physical, chemical, and technological properties of the product [67]. Jaya & Das studied mango powder and reported that accelerated storage time decreased the flowability and increased caking [21].

Color is an important attribute as it is the first property noticed by the consumer [68]. Hence, color retention is a predictor of food deterioration rate [69]. Nonenzymatic browning during storage depends on temperature, moisture, water activity, oxygen, and chemical composition [70].

Table 3 shows that total color change increases together with storage period temperature and relative humidity, as well as the type of packaging. Kumar & Mishra studied the total color change in yogurt powder fortified with mango soy and stored under accelerated storage conditions [61]. Packaged powders lost their pigment content and total phenolic content (Table 4) under the effect of temperature, acidity, light, and oxygen exposure caused by the porosity of the packaging.

In addition, a higher moisture uptake eventually leads to degradation of phenolic compounds [71]. Li *et al.*, who studied plum powder, reported that phenolic components were stable for 40 days at room temperature and decreased slightly to 85% after 60 days of storage [72]. Pereira *et al.* managed to preserve the bioactive compounds in *juçara* powder for 103 days [73]. Zhang *et al.* reported that cranberry powder retained its phenolic content after 12 weeks of storage at 25°C [74]. Food quality requires a minimal retention of 50% initial phenolics. Loss of phenolics may result from the excessive gas permeability of the packing material [75].

Table 3 Storage condition for various powders

Powder	Packaging	Temperature, °C	Relative humidity, %	Time	References
Aloe vera gel powder	Aluminum laminated polyethylene (AF) Metalized co-extruded bi-axially oriented polypropylene (BOPP) Polypropylene (PP)	38	90	49 days (intervals of 7 days)	[37]
Aonla (Indian gooseberry)	High density polyethylene bag (HDPE) Polyethylene terephthalate (PET)	15	–	6 months (2, 4, and 6 months)	[59]
Apple peel powder	High-density polyethylene (HDPE) Metalized films of high barrier (MFHB)	4 10 25 38	– – – 90	120 days (30, 60, and 120 days)	[41]
Bovine colostrum powder	Aluminum laminated polyethylene (ALPE) Polyethylene terephthalate (PET)	4 25 50	40–70 50 20–50	90 days	[51]
Coconut milk powder	Aluminum foil laminated polyethylene (ALP)	38	90	49 days (intervals of 7 days)	[22]
Guava	High-density polyethylene (HDPE) Aluminum laminated polyethylene (ALPE) Coextruded pouches (COEX)	7 26	–	6 months	[60]
Jackfruit powder	Aluminum laminated polyethylene (ALP) Metalized co-extruded bi-axially oriented polypropylene (BOPP/MCPP)	28 38	50 90	12 weeks	[42]
Mango powder	Polyester poly (PP) Metalized polyester polyethylene (MPP)	27–32	–	6 months (0, 2, 4, and 6 months)	[38]
Mango soy fortified yogurt powder	High-density polypropylene (HDPE) Aluminum laminated polyethylene (ALP)	38	90	49 days (intervals of 7 days)	[61]
Papaya	Aluminum laminated polyethylene (ALP) Polyamide/polyethylene (PA/PE)	30	40–45	9 months	[43]
Pink quamachil aril powder	Polyethylene (PE) Metalized polyester polyethylene (MPE)	26	–	6 months (2, 4, and 6 months)	[39]
Pomegranate arils	Aluminum laminated polyethylene (ALP) High-density polypropylene (HDPP)	38	90	3 months	[40]
Sour cherry powder	High barrier metalized polypropylene (Pet/PPmet/PE) Aluminum packaging (Pet/Al /PE)	4 20 37	–	12 months	[44]

Kinetic modeling is essential to predict food changes during storage [62]. Most studies in Table 4 reported losses in food quality by zero or first-order degradation reaction kinetics [61, 76, 77].

According to Singh, the zero-order rate was useful in describing such reactions as enzymatic degradation, non-enzymic browning, and lipid oxidation, which cause rancidity [77]. On the other hand, food deterioration reactions showing first-order losses indicated vitamin and protein losses, as well as microbial growth.

Syamila *et al.* reported reaction kinetics and half-life based on carotenoid content for spray-dried spinach powder [78]. Muzzafar & Kumar assessed the storage stability of spray-dried tamarind powder [79]. They found that the color change followed the zero-order reaction kinetics. The zero-order kinetics was also observed for L^* and a^* parameters, moisture content, ascorbic acid, and total sugar in Khodifad *et al.*, who studied custard apple powder [80]. Similarly, Chang *et al.* reported that total color difference in *soursop* powder was also caused by a zero-order kinetic reaction [81].

Different specific models can predict product shelf-life [82]. The shelf-life of a food product ends when the product is no longer sensory stable or safe, or when its nutrients have degraded [83]. According to Entrup *et al.*, the actual shelf-life depends on the formulation, processing, packaging, and storage conditions [80].

Table 4 shows that powders packaged in aluminum laminated polyethylene had a longer shelf-life, which ranged from 30.28 to 425.5 days. This shelf-life determination is commonly based on the free-flow properties of the powder. In Ramachandra & Rao, aloe vera

Table 4 Effects of storage stability on properties and shelf-life of various powders

Sample	Moisture/water activity	Hygroscopicity	Color *L**	Color *a**	Color *b**	Color difference	Caking	Flowability	Pigment content	Antioxidant/phenolic	Total soluble solids/sugar	Kinetic order	Shelf-life, days	References
Aloe vera powder	+ve	–	–ve	+ve	–ve	+ve	–	–	–	–	–	1 (color change)	33.87 (bi-axially-oriented polypropylene) 42.58 (polypropylene) 51.05 (aluminum laminated polyethylene) (free-flowing)	[37]
Apple peel powder	–	–	–	–	–	–	–	–	–	–	–	0 (phenolic content)	96 (high-density polyethylene) 120 (metalized films of high barrier)	[41]
Bovine colostrum powder	+ve	–	–	–	–	+ve	–	–	–	–	–	1 (Ig concentration)	425.5 (aluminum laminated polyethylene) 86.5 (polyethylene terephthalate)	[51]
Coconut milk powder	+ve	–	–	–	–	–	–	–	–	–	–	–	30.28 (aluminum foil laminated polyethylene)	[22]
Jackfruit powder	+ve	–	–ve	+ve	–ve	+ve	–	–	–	–	–	0 (color change)	–	[42]
Mango milk powder	–	–	+ve	+ve	–ve	–	–	–	–	–	–	–	10 months (free-flowing)	[66]
Mango powder	–	–ve	–	–	–	–	+ve	–ve	–	–	+ve	1 (color change)	114.68	[21]
Mango powder	+ve	–	–	–	–	–	–	–	–ve	–ve	+ve	–	–	[38]
Mango soy yoghurt	–	–	–	–	–	–	–	–	–	–	–	0	45 (high-density polypropylene) 54 (aluminum laminated polyethylene)	[61]
Papaya powder	+ve	–	–	–	–	–	–	–	–	–ve	–	1 (ascorbic acid)	8 months (aluminum laminated polyethylene) 6 months (polyamide/ polyethylene)	[43]
Quamachil aril	+ve	–	–	–	–	+ve	–	–	+ve		–	–	–	[39]
Pomegranate arils	+ve	–	–	–	–	+ve	–	–	–ve	–ve	+ve	0 (color change)	96 (high-density polypropylene) 187 (aluminum polyethylene)	[40]
Sour cherry	–	–	+ve	–ve	–ve	+ve	–	–	–ve	–ve	–	1 (anthocyanin)	12 months (polyphenol)	[44]

+ve = positive effect; –ve = negative effect; – = not reported

powder packaged in aluminum laminated polyethylene had a shelf-life of 51.05 days [37]. However, Kumar & Mishra reported a shelf-life of 54 days for mango soy yogurt powder packaged in aluminum laminated polyethylene [61].

Some powders have a shelf-life of 6–12 months when subjected to lower storage temperature, which is another basis for shelf-life determination, e.g., polyphenol content [44]. Instant *puran* powder had a predicted shelf-life of 13.41 months while the predicted shelf-life for *soursop* powder was 242 days [45, 85].

CONCLUSION

Prolonged storage time makes powders prone to caking. This review featured various anti-caking agents, e.g., calcium phosphate, calcium stearate, silicon dioxide, etc., in fruit powders, as well as different packaging materials used to preserve spray-dried powders. Aluminum laminated polyethylene, polypropylene, polyethylene, polyethylene terephthalate, and metalized films proved to be the most common packaging materials adopted for spray-dried powders. The review also included storage conditions for different fruit powders, as well as the effects of storage stability on their roperties and shelf-life. Most powders stored in aluminum laminated polyethylene followed zero- or first-order kinetics with predicted powder shelf-life ranging from 51 to 425 days, deding on the storage temperature.

CONTRIBUTION

All the authors were equally involved in the research analysis and manuscript writing.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this article.

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