Effects of the Inlet Temperature and Maltodextrin on the Physicochemical Properties and Vitamin C Content of Microencapsulated Tomato (*Solanum lycopersicum* L.) Powder

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Abstract

The research was carried out to investigate the physicochemical characteristics and concentration of Vitamin C of the microencapsulated tomato powder (MTP) as affected by these two factors and their level: inlet temperature (1) and maltodextrin concentration (2). Results showed that as the concentration of maltodextrin increases, Vitamin C content and encapsulation efficiency also increase. However, as the inlet temperature increases, encapsulation efficiency also decreases. Both factors lowered the moisture level and water activity of the powders, and their interaction influenced flowability, cohesion, and wettability time. Treatment 4 had the highest percentage yield (13.5 %) and encapsulation efficiency (71.12 %). The powder was also found to retain have a Vitamin C content of 124.16 mg/100 g along with excellent flowability and lower cohesion capacity. The said powder also had low water activity and moisture level, suggesting good storage stability. The predicted best powder treatment (Treatment 4) possessed considerable Vitamin C stability over time. These findings suggest that microencapsulated tomato powder could be a Vitamin C-rich ingredient with tailored functional properties for several food products.

***Keywords**:* inlet temperature, maltodextrin, tomato, vitamin C

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a good source of Vitamin C and bioactive minerals (Ali *et al*., 2020). It is the second most important fruit vegetable in the Philippines and one of its most profitable crops (Gorme *et al*., 2017; Altoveros & Borromeo, 2007). This highly valued crop is largely grown for its fruits which are eaten fresh or made into food products such as juice and ketchup. Moreover, the Philippine Statistics Authority (PSA) (2023) reported that Northern Mindanao produced 76.2 % of the country's total production, highlighting its economic significance.

However, post-harvest losses limit agricultural production in densely populated Southeast Asian countries (Mopera, 2016). Mopera (2016) reported that up to 50% of the crops were lost from the initial harvesting to storage and distribution to the consumers. Nuevo and Apaga (2010) added that tomatoes lose 11-38% of their value after harvest. One practical solution to reduce packaging, storage, transportation, and post-harvest losses is the microencapsulation of fruits and vegetables into juices and powders.

Microencapsulation through spray drying is the most cost-effective dehydration approach due to its low overhead costs (Shishir & Chen, 2017). Spray drying chemically sensitive substances to produce powdered juices has also been studied. This method concentrates active compounds in a polymeric matrix to prevent the oxidation of unstable molecules such as Vitamin C in tomatoes (Santos *et al.*, 2018). Besides, powders made up of extracts from fruits and vegetables can last for months and even years, with proper packaging conditions (Chauhan & Patil, 2013; Henríquez *et al.*, 2013; Pua *et al.*, 2008).

Spray drying is typically performed with maltodextrin and gum Arabic as an encapsulating agent to improve efficiency. Maltodextrin is the most commonly used carrier agent since it is able to encapsulate heat sensitive bioactive compounds. This material is also cheaper, readily found in the local market, and has an acceptable product quality for large-scale and practical applications (Park *et al.*, 2023; Tran & Nguyen, 2018; Kha *et al.*, 2010).

Although there were already studies on microencapsulated tomato powder (MTP), little information is available on the interactive effect of spray drying temperature and maltodextrin concentration on the physicochemical and vitamin C characteristics of the powder. Also, this study aimed to monitor the Vitamin C stability of the predicted desirable MTP during prolonged storage, thereby filling a major knowledge gap.

Based on the above reasons, the study developed MTP and studied the effect of inlet temperature and maltodextrin concentrations on their physicochemical properties and Vitamin C content. Farmers will be guided by the study to lessen post-harvest losses. It will also contribute to addressing malnutrition and Vitamin C deficiencies in the country.

2. Methodology

2.1 Materials

Fresh tomatoes were procured from the local market in Valencia City, Bukidnon, Philippines. The maltodextrin utilized as a carrier material for spray drying was procured from a reputable supplier. Additionally, the reagents required for Vitamin C analysis, including Potassium Iodide (ACS Grade, Scharlab S.L., Spain), Iodine Pearl-Resublimed (ACS Grade, Scharlab S.L., Spain), Soluble Starch (Synthesis Grade, Scharlab S.L., Spain), and Ascorbic Acid (AR Grade, Laboratory Reagents and Fine Chemicals, India), were procured from Merteflor Enterprises.

2.2 Experimental Design

The study employed a 2^2-factorial design to evaluate both the main and interaction effects between the independent factors and the dependent factors. The independent factors considered were the inlet temperature (180 ºC and 200 ºC) and maltodextrin concentration (12 % and 15%) (Table 1). The high and low levels of both factors were selected based on the results of the preliminary experiments.

Table 1. A 2^2 factorial design matrix with levels of medium components

Treatment	Inlet Temperature (ºC)	Maltodextrin (%)
1	180	12
2	200	12
3	180	15
4	200	15

2.3 Preparation of Tomato Extract for Spray Drying

Fresh tomatoes were soaked in water overnight and thoroughly washed. The cleaned tomatoes were then blended using a heavy-duty food processor (ET-QS806, ETON, China) for two minutes to obtain a uniform mixture. The resulting juice was extracted and filtered through a muslin cloth.

2.4 Spray Drying if Tomato Extract

The juice extracts were combined with maltodextrin (12 % and 15 % w/w) and spray-dried in a high-speed centrifugal spray dryer (LPG-5, Unbranded, China) at two inlet temperatures (180 ºC and 200 ºC), selected based on the results of preliminary experiments. The outlet temperature was controlled by adjusting the exhaust pipeline aperture. The other operating conditions were as follows: atomization speed of 23,160 rpm and feed flow rate of 23 mL/min. Afterward, the obtained MTPs were cooled and packed in a stand-up pouch with an aluminum foil lining (Figure 1).

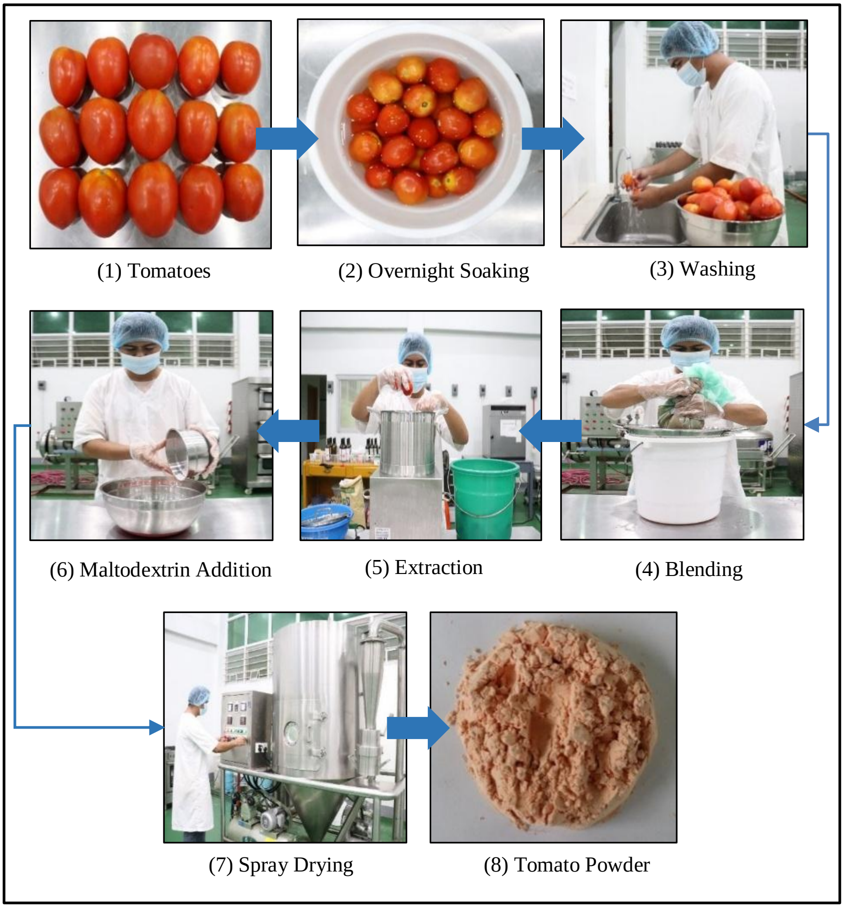

Figure 1. Spray drying process for the production of MTP

2.5 Percentage yield

The percentage yield of MTP was evaluated as the proportion of the weight of the obtained MTP to the initial solid content in the feed solution. The initial solid content was calculated as the combined weight of the tomato juice extract solids and the maltodextrin added as a carrier agent prior to drying (Equation 1) (Alissa *et al.*, 2020).

$$\%\,Percentage\;Yield = \frac{weight\;of\;spray\text{–}dried\;powder}{weight\;of\;initial\;solids\;in\;the\;feed\;solution}\;x\;100 \quad (1)$$

2.6 Vitamin C Content Analysis

The iodometric titration method described by Abushusha and Sayed (2017) was used with slight modifications to determine the Vitamin C content of fresh extracts and MTP. In detail, a standard iodine solution was prepared by carefully dissolving 50 grams of potassium iodide (ACS Grade, Scharlab S.L., Spain) with 400 mL of distilled water. Approximately 1.3 grams of resublimed iodine pearls (ACS Grade, Scharlab S.L., Spain) were then added and dissolved in the same solution, and the volume was raised to the 500 mL mark with distilled water. Meanwhile, the starch indicator was prepared by dissolving 1 gram of soluble starch (Synthesis Grade, Scharlab S.L., Spain) with 100 mL distilled water. The solution was agitated thoroughly, heated for one minute at 100°C, and cooled at room temperature. Then, a standard Vitamin C solution was prepared by dissolving 10 mg L-ascorbic acid (AR Grade, Laboratory Reagents and Fine Chemicals, India) with 10 mL distilled water.

A 10 mL aliquot of the juice was added with a 1 mL starch indicator for the Vitamin C analysis of fresh juice extracts. In the meantime, 10 grams of MTP were added with 50 mL of distilled water for the Vitamin C analysis of spray-dried powders. Then, a 10 mL aliquot was added with a 1 mL starch indicator.

The resulting solutions were titrated with the gradual addition of a standard iodine mixture approaching the endpoint. The samples' Vitamin C content was computed based on the volume of titrant (standard iodine mixture) used for the standard Vitamin C solution and the samples (Equation 2).

$$\frac{mL\;of\;iodine\;solution\;used\;for\;vitamin\;C\;standard\;solution}{mL\;of\;iodine\;solution\;used\;for\;juice\;samples} = \frac{10\;mg\;vitamin\;C}{X\;mg\;vitamin\;C} \quad (2)$$

where X = unknown and is the Vitamin C concentration in milligrams as determined for the samples after calculation.

2.7 Encapsulation Efficiency (%EE) Determination

The encapsulation efficiency was determined using the approach described by Busch *et al*. (2017). In detail, %EE was calculated by the ratio of the Vitamin C concentration in the MTP (x) to the Vitamin C concentration of the fresh tomato extracts (y), as illustrated in Equation 3.

$$\%EE = \frac{x}{y}\, x\, 100 \qquad (3)$$

2.8 Physicochemical Properties

2.8.1 Moisture Content (%)

The products' moisture content was analyzed following the protocol of Alissa *et al*. (2020) with slight modifications. In detail, MTP samples (5 grams) were analyzed using a rapid moisture analyzer (Radwag MAX2.A, Poland), which automatically measured the powder's moisture content.

2.8.2 Water Activity (Aw)

The products' water activity was assessed employing the protocol of Alissa *et al*. (2020) with minor changes. Specifically, the obtained MTP samples (1-gram) were set up in a water activity meter (WA-160A, Power TX, China) at ambient temperature for five minutes.

2.8.3 Flowability (CI) and Cohesion (HR)

The products' flowability and cohesion were calculated by measuring the bulk and tapped density according to the protocol outlined by Gierczynski *et al*. (2011), as cited by Drozłowska *et al*. (2023), with minor changes. Specifically, a 5-gram sample of MTP was introduced into a 10 mL graduated cylinder instead of a 25 mL cylinder. The tapped density was measured following twenty taps of the cylinder, whereas the bulk density was assessed before tapping the cylinder. Subsequently, the flowability (Carr Index) and cohesion (Hausner Ratio) of the obtained MTP were totaled using the formulas devised by Carr and Hausner, respectively. The Carr and Hausner indices (Table 2) were calculated employing Equation 4 and 5.

$$CI = (\rho T - \rho B) / (\rho T) \tag{4}$$

$$HR = \rho T / \rho B \tag{5}$$

Table 2. Characterization of granular materials' flowability and cohesion (Seo, 2022)

CI	Flowability	HR	Cohesion
Less than 15	Very Good	Less than 1.2	Low
15 to 20	Good	1.2 to 1.4	Intermediate
20 to 35	Fair	Greater than 1.4	High
35 to 45	Bad		
Greater than 45	Very Bad		

2.8.4 Solubility

The solubility of MTP was determined utilizing the protocol outlined by Seth *et al*. (2017) with minor changes. Specifically, the solubility was quantified gravimetrically and reported as a percentage of undissolved residues. The MTP sample weighing 1 gram was diluted with 100 mL distilled water for 1 minute and agitated at 1000 rpm using a magnetic stirrer (1000 rpm) (SP88857107, Thermo Scientific, China). The diluted samples were then filtered utilizing a dried and pre-weighed Whatman filter paper. Subsequently, the filter paper containing residues was dried at 105ºC for 2 hours in a laboratory oven (UNB 100, Memmert, Germany). The dried samples were cooled in the desiccator for 15 minutes and weighed. The percentage solubility was calculated employing Equation 6.

$$(Mass\ of\ sample - Mass\ of\ Residue)/Mass\ of\ sample\ x\ (100) \tag{6}$$

2.8.5 Wettability

The wettability of the MTP was assessed according to the protocol outlined by Jinapong *et al*. (2008), as cited by Seth *et al*. (2017), with minor changes. Wettability was defined as the period of time necessary for 1 g of solids (instead of 0.1g) placed on the fluid surface to be entirely submerged in 400 mL (instead of 100 mL) of distilled water at ambient temperature.

2.8.6 Vitamin C Stability Assessment of the Most Desirable Treatment

The Vitamin C stability of the most desirable treatment of MTP was evaluated following the methods of Garcia *et al*. (2020) with some modifications. The identified desirable MTP was packed in aluminum-coated packaging and stored at room temperature. The Vitamin C content was determined and monitored every week for seven (7) weeks.

2.9 Statistical Analysis

The study used the Design Expert version 11 and SPSS version 23 (Trial versions) software for the statistical analysis. Specifically, the obtained results were evaluated by means of analysis of variance (ANOVA) to determine whether the identified factors significantly influence the different attributes of the product developed. Tukey's HSD test was applied to evaluate if the variances between the parameters of the samples were significant. Plots were also overlaid to identify the most desirable treatment of the developed product.

3. Results and Discussion

3.1 Results of the Preliminary Experiment

As calculated in Equation 2, Figure 2 shows that MTP produced at 180 °C, 190 °C, and 200 °C exhibited the highest concentrations of Vitamin C, with values of 119.76 mg/100g, 124.43 mg/100 g, and 123.64 mg/100 g, respectively. Statistical analysis indicates that the Vitamin C contents at 190 °C and 200 °C are not significantly different from each other but are significantly higher than those at 180 °C at the 5% significance level.

Additionally, as calculated in Equation 3, the encapsulation efficiency was maximized at 180 °C, 190 °C, and 200 °C (71.3–71.4%) (Figure 3). Statistical analysis further reveals that the encapsulation efficiencies at these temperatures are not significantly different from each other, but are significantly higher than at 160 °C and 170 °C.

Thus, based on statistical findings and treatment ranking (Figures 2 and 3), inlet temperatures of 180 °C and 200 °C are most desirable for achieving optimal retention of Vitamin C and encapsulation efficiency in spray-dried tomato powder.

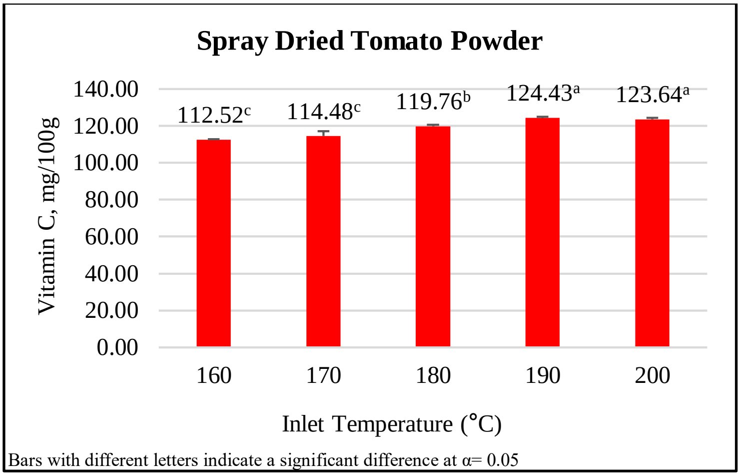

Figure 2. Vitamin C content of the microencapsulated tomato powders spray dried at various inlet temperatures at constant maltodextrin concentration (15%)

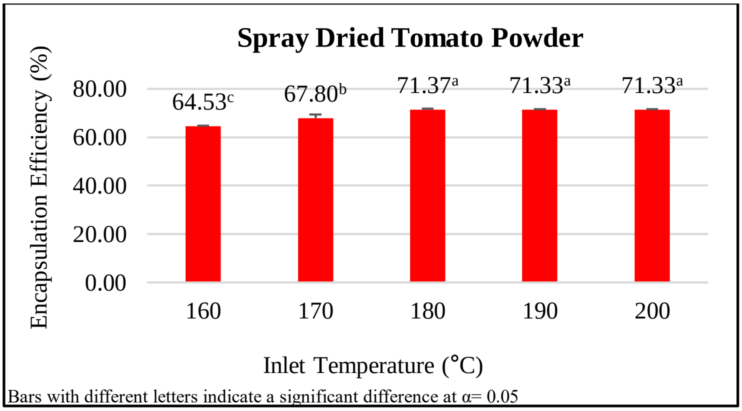

Figure 3. Encapsulation efficiency of the Vitamin C content of the microencapsulated tomato powders spray dried at various inlet temperatures at constant maltodextrin concentration (15%)

3.2 Percentage Yield

MTP had a percentage yield that ranged from 11.1% (Treatment 2) to 13.5% (Treatments 3 and 4), as calculated in Equation 1. Further, a statistically significant difference among treatments was detected at the 5% significance level (Table 3). Likewise, the statistical results revealed that the maltodextrin concentration (B) exerted a positive influence on the percentage yield of the resulting powders.

The addition of maltodextrin to the juice extract positively affected the percentage yield of the resulting MTP, which means that the higher the maltodextrin concentration, the higher the yield. Technically, maltodextrin improves the yield of the powder by preventing adhesion and increasing product yield, as reported in tamarind juice (Cynthia *et al.*, 2015), black mulberry extract (Fazaeli *et al.*, 2016), persimmon puree (Du *et al.*, 2014), and sugarcane extract (Largo Avila *et al.*, 2015). Chuaychan and Benjakul (2016) also reported that maltodextrin is excellent at enhancing moisture retention because it is hydrophilic which means it attracts water molecules. This maximizes powder structure and minimizes agglomeration, leading to better drying and higher overall yield of the powder.

3.3 Vitamin C content and Encapsulation Efficiency

Table 3 illustrates that MTP had a Vitamin C content varying from 112.49 mg/100g (Treatment 2) to 130.91 mg/100g (Treatment 1), as calculated in Equation 2. Further, a statistically significant difference among treatments was detected at the 5% significance level. Likewise, the statistical results revealed that inlet temperature (A) exerted a negative influence on the Vitamin C content of the resulting MTP. Meanwhile, the interaction of the factors (inlet temperature and maltodextrin) exerted a positive influence on the powder's Vitamin C content.

Table 3. Percentage yield, Vitamin C, and encapsulation efficiency of the microencapsulated tomato powders

Treatment	Inlet Temperature (°C)	Maltodextrin Concentration (%)	Percentage Yield (%)	Vitamin C (mg/100g)	Encapsulation Efficiency (%)
1	180	12	11.8 ± 0.10^{b}	130.91 ± 1.01^{a}	63.73 ± 0.69^{b}
2	200	12	11.1 ± 0.10^{c}	112.49 ± 1.03^{b}	51.54 ± 1.15^{c}
3	180	15	13.5 ± 0.10^{a}	121.26 ± 1.07^{ab}	69.45 ± 1.34^{a}
4	200	15	13.5 ± 0.10^{a}	124.16 ± 0.99^{a}	71.12 ± 1.01^{a}

*Results are presented as average ± standard deviation (n=3). Data within a column sharing similar letter superscript are not significantly comparable (p-value is greater than 0.05).

Based on the results presented in Table 3, MTPs were able to achieve encapsulation efficiency varying from 51.54% (Treatment 2) to 71.12% (Treatment 4), as calculated in Equation 3. In addition, a statistically significant difference among treatments was detected at the 5% level. Also, the results of statistical analysis showed that maltodextrin (B) and the interaction of factors (inlet temperature and maltodextrin) positively affected the encapsulation efficiency of the powder. Meanwhile, the inlet temperature (A) has a negative effect on the encapsulation efficiency of MTP.

The result also indicated that increasing the inlet temperature in the drying process could reduce the encapsulation efficiency, leading to a similar decrease in the Vitamin C concentration of the tomato powder. This is due to the heat-sensitive character of Vitamin C, where it gets destroyed due to high drying temperatures, as observed in ripe palm juice and guava powder (Mohanty *et al*., 2021; Patil *et al*., 2014).

The finding that maltodextrin has a significant positive effect on the encapsulation efficiency of MTP indicates that increasing the amount of maltodextrin may improve the encapsulation efficiency of the powder's Vitamin C. This is because maltodextrin has a protective effect that is due to the generation of protein-polysaccharide complexes which can encapsulate bioactive as well as sensitive molecules (Phan *et al*., 2021). Maltodextrin can also be a good carrier for water-soluble vitamins and minerals due to its hydrophilic character, which may also help improve their stability and bioavailability (Coelho *et al*., 2022). Studies identified that the use of maltodextrin is effective for retaining Vitamin C due to the strong attraction of Vitamin C with maltodextrin. The reason for this strong attraction is due to the presence of OH compounds (Cortés *et al*., 2017).

In addition, the positive influence of the interaction of factors (inlet temperature and maltodextrin concentration) increases the efficient encapsulation of Vitamin C by balancing the need for rapid water removal, thereby minimizing prolonged heat exposure, while ensuring sufficient carrier material for Vitamin C protection. In general, higher inlet temperature increases the rate of Vitamin C degradation. However, the effect of the elevated drying can be counteracted in the presence of higher maltodextrin concentration that facilitates rapid drying and forms a protective glassy matrix around Vitamin C molecules through hydrogen bonding and protein-polysaccharide complexation, limiting heat exposure and improving Vitamin C encapsulation and retention (Phan *et al*., 2021). Similar observation was also reported by Mohanty *et al*. (2021) wherein tomato powder's Vitamin C content and encapsulation efficiency are well encapsulated and less influenced by higher temperatures in the presence of more carriers.

3.4 Physicochemical Properties

3.4.1 Moisture Content

Table 4 shows that MTP had a moisture content that ranged from 2.21% (Treatment 4) to 3.39% (Treatment 2), wherein a significant difference between treatments was distinguished at a 5% significance level. Additionally, statistical analysis results showed that the inlet temperature (A), amount of maltodextrin (B), and the interaction of the factors (inlet temperature and maltodextrin) negatively affected the moisture content of MTP.

Table 4. Physicochemical characteristics of the microencapsulated tomato powders

Treatment	Inlet Temperature (°C)	Maltodextrin Concentration (%)	Moisture Content (%)	Water Activity (Aw)	Flowability (CI)
1	180	12	3.11 ± 0.05^{b}	0.40 ± 0.02^{a}	8.69 ± 1.06^{c}
2	200	12	3.39 ± 0.17^{a}	0.41 ± 0.01^{a}	14.9 ± 2.08^{a}
3	180	15	2.92 ± 0.04^{b}	0.40 ± 0.01^{a}	13.0 ± 0.53^{ab}
4	200	15	2.21 ± 0.02^{c}	0.34 ± 0.01^{b}	11.3 ± 0.84^{bc}

*Results are presented as average ± standard deviation (n=3). Data within a column sharing similar letter superscript are not significantly comparable (p-value is greater than 0.05).

Treatment	Inlet Temperature (°C)	Maltodextrin Concentration (%)	Cohesion (HR)	Solubility $(\%)^{ns}$	Wettability (sec)
1	180	12	1.10 ± 0.01^{c}	96.17 ± 0.96	1128 ± 1.55^{b}
2	200	12	1.18 ± 0.03^{a}	97.01 ± 0.45	1113 ± 1.58^{b}
3	180	15	1.15 ± 0.01^{ab}	97.32 ± 0.68	1233 ± 1.20^{a}
4	200	15	1.13 ± 0.01^{bc}	94.68 ± 0.67	1133 ± 1.18^{b}

*Results are presented as average ± standard deviation (n=3). Data within a column sharing similar letter superscript are not significantly comparable (p-value is greater than 0.05).
ns denotes not significant

The adverse effect of the inlet temperature and maltodextrin concentration on the moisture level of MTP suggests that increasing any of these parameters directly leads to a reduction in the moisture level of the formed MTP. Mohanty *et al*. (2021) also reported the same observation in the extracted ripe palm juice. This is because when the inlet air temperature was increased, the heat transfer occurred at a faster rate throughout the product and the air temperature, ultimately elevating the thermal energy of both the material and its surroundings. This increase in temperature could also increase the kinetic energy of water molecules, making them more capable to break the attractive forces that bind them to the substance more efficiently, thus augmenting evaporation and reducing moisture content.

Meanwhile, a higher level of maltodextrin in the feed solution prior to spray drying results in an increased total solids content, which in turn reduces the quantity of water that can be evaporated, leading to a lower moisture content in the powders (Shadordizadeh *et al*., 2023). According to Chuaychan and Benjakul (2016), maltodextrin is hygroscopic, meaning it has a strong attraction for moisture. Maltodextrin also decreases the availability of water to other components in a feed mix, when incorporated into the feed mix, hence reducing the moisture content of the final product.

Also, the interaction of the factors (inlet temperature and maltodextrin) has a negative effect on the moisture content of the powder. Meroni and Raikos (2018) state that this could be due to the hydrophobic nature of the tomato lycopene. According to O'Callaghan and Hogan (2013), due to the unencapsulated fat molecules in the powders during the spray drying process, these molecules migrate to the surface of these powder particles, because fat molecules are attracted to powder surfaces due to their hydrophobic properties. Given that, the end-product will have less moisture content because the fat molecules are less hydrophilic (water-loving), and these molecules will inhibit moisture absorption by the particles during the drying process.

In this study, the moisture content of the MTP was found to be less than 5%. According to Abdullah *et al*. (2020) and Tontul and Topuz (2017), the moisture content of spray-dried products should not exceed 5% to ensure microbiological safety and storage stability.

3.4.2 Water Activity

According to Table 4, the water activity of MTP ranged from 0.34 (Treatment 4) to 0.41 (Treatment 2). Moreover, a significant difference among treatments was found at the 5% level of significance. The water activity of the powder was significantly reduced due to the inlet temperature (A), maltodextrin concentration (B), and their interaction, according to the results of statistical analysis.

When the inlet temperature was raised to 200°C and the maltodextrin concentration to 15%, a negative effect was observed. This means that the level increases the evaporation of water, resulting in less water being free in the powder. According to Tran and Nguyen (2018), when the inlet temperature is higher, the extraction of water is faster which reduces the water activity of the powder. The results were also reported in spray-dried avocado powder (Karthik Nayaka *et al*., 2020) and extracted ripe palm juice (Mohanty *et al*., 2021). Accordingly, water activity (aw) determines the availability of free water for microbial growth and chemical reactions (Tarlak, 2023; Barbosa *et al*., 2022). Based on this, the low water activity of microencapsulated tomato powders points to a reduced risk of microbial spoilage and chemical degradation, and increased shelf life.

Moreover, the reduction in water activity because of the combined effect of higher inlet temperature and maltodextrin concentration follows a similar mechanism to that of the decrease in moisture content. As discussed, the interaction of these factors lowers the water activity of the powder because of the rapid water evaporation, as well as higher total soluble solids, and the maltodextrin's hygroscopic properties (Mohanty *et al*., 2021).

Overall, MTP's water activity (aw) was below 0.6, meeting spray-dried product safety standards (Alissa *et al*., 2020). Accordingly, microencapsulation improves the stability and safety of powdered products, resulting in microbiologically safe and chemically stable products with water activity <0.6.

3.4.3 Flowability (CI) and Cohesion (HR)

As shown in Table 4, MTP had flowability values ranging from 8.69 (Treatment 1) to 14.9 (Treatment 2), as calculated in Equation 4. In addition, a significant difference among treatments was found at the 5% significance level. Statistics also infer that the inlet temperature (A) had a positive effect on the flowability of the powder, while the interaction of factors (inlet temperature and maltodextrin) has a negative effect.

Moreover, Table 4 showed the cohesiveness of MTP ranging from 1.10 (Treatment 1) to 1.18 (Treatment 2), as calculated in Equation 5. Also, there was a statistically significant difference among treatments at 5% significance level of significance. The results of statistical tests further indicated that the inlet temperature (A) caused an increase in the cohesion of the powder, while the interaction of factors (inlet temperature and maltodextrin) caused a reduction in the cohesion of the powder.

The positive effect was noticed when a higher inlet temperature (200°C) was used. It shows that higher temperature increases the flowability and cohesiveness of the powder. A similar finding was reported in the research on oil palm milk powder (Samsu & Mohamad Zahir, 2020). Wang *et al*. (2015) explain that this is because of the higher evaporation rate at higher inlet temperature. In addition, this produces microcapsules or powders with finer sizes and smooth surfaces. Powder particles with finer in size and have a smoother texture have a wider contact surface area throughout the powder particle. This allows for the generation of intermolecular and frictional forces that can hinder its flow. The study of Fitzpatrick (2024) and Sathyashree and Ramachandra (2017) supplemented that smaller particle sizes are often affected by forces like Van der Waals that can also affect the flow of the powder.

Treatment 4 showed the adverse effect of the interaction of the inlet temperature and maltodextrin concentration. At the higher inlet temperature, the presence of higher maltodextrin concentration forms strong bonds between spray drying particles containing maltodextrin, leading to the agglomeration of the powder. This causes the production of larger particles. The flow of a powder improves as the size of the particle increases, and at one point, the powder will become free-flowing. Also, maltodextrin with higher dextrose equivalent (DE) spray-dried at an inlet temperature of 150 °C exhibited larger powder particle sizes with weak attraction. This means that the inlet temperature, carrier concentration, and dextrose equivalent are key variables affecting the morphology of the spray-dried particles (Qadri *et al*., 2023; Nadali *et al*., 2022; Medina-Torres *et al*., 2017).

Generally, according to the CI and HR index (Table 2), powders with a Carr index of less than 15 and Hausner Ratio of less than 1.2 are desirable powders that can be classified as having very good flowability and low cohesion. Accordingly, the MTP obtained in the study exhibited very good flowability and low cohesion, as the powders had low Hausner Ratio (HR) and Carr's Index.

3.4.4 Solubility

As shown in Table 4, MTP had a solubility level that ranged from 94.68% (Treatment 4) to 97.32% (Treatment 3), as calculated in Equation 6, with no significant difference observed between treatments at a 5% significance level. Statistical analysis further confirmed that inlet temperature, maltodextrin concentration, and their interaction did not significantly affect the solubility of the powder.

Nonetheless, the MTP's solubility exceeds the findings of the microencapsulated orange extract powder (84.66–93.33%) (Sathyashree *et al*., 2018) and pomegranate juice powder (90.19%–91.94%) (Hadree *et al*., 2023). High solubility is a desirable characteristic, primarily when the obtained powder is used as an additive to produce different products.

3.4.5 Wettability

As shown in Table 4, MTP had a wettability time that ranged from 1113 sec (Treatment 2) to 1233 sec (Treatment 3), with a significant difference between treatments distinguished at a 5% significance level. Additionally, statistical analysis results showed that the inlet temperature (A) and the interaction of factors (inlet temperature and maltodextrin) negatively affected the powder's wettability. Meanwhile, the amount of maltodextrin (A) positively affected the powder's wettability.

The significant positive impact of the maltodextrin on the powder's wettability suggests that increasing the concentration of maltodextrin in the juice extracts may increase the wettability time of MTP, as also evidenced in the study of the microencapsulated orange extract powder (Sathyashree *et al*., 2018) and microencapsulation of pineapple peel extract (Lourenço *et al*., 2020). Paiva *et al*. (2023) also asserted that the longer wettability time of the spray-dried powders using maltodextrin as an encapsulating agent can be explained by the poor wettability nature of the maltodextrin itself, resulting in the extended immersion time with the increase in the added concentration of the additive. According to Li *et al*. in 2020, maltodextrin can apparently build a hydrophobic zone in an aqueous solution that can alter the wettability duration of the powder and result in longer wettability period.

The adverse effect of the inlet temperature and the interaction of factors (inlet temperature and maltodextrin) on the wettability of tomato powders is also reported in the study of the microencapsulated fig powder (Megharaj *et al.*, 2023). The effect can also be explained similar to the mechanism with the powder's flowability and cohesion. Accordingly, at higher inlet temperature, the presence of higher maltodextrin concentration forms strong bonds between spray drying particles containing maltodextrin, leading to the agglomeration of the powder. This causes the production of larger particles. Then, these larger particles, due to the larger void sizes between the particles, the water can penetrate quickly. Thus, larger particles may show improved wettability behavior (Fitzpatrick *et al.*, 2017).

However, according to Sobulska and Zbicinski (2021), since the wettability time of the resulting MTP was greater than 120 seconds, this will require an application of agglomeration in a fluidized bed granulator.

3.5 Desirable Treatment Prediction

Numerical and graphical prediction on the Design Expert Software Version 11 (Trial version, Stat-Ease Inc., 2018) was employed to ascertain the best inlet temperature and maltodextrin concentration for the microencapsulation of tomato powders. Prediction criteria and primary goals were narrowed down to predict the desirable treatment, focusing on maximizing percentage yield, Vitamin C, encapsulation efficiency, while reducing flowability, cohesion, and wettability.

According to the numerical and graphical prediction results, the best inlet temperature and maltodextrin concentration for the microencapsulation of tomato powder is 200°C and 15% (Treatment 4), respectively, with a desirability of 0.739.

3.6 Vitamin C Stability

The Vitamin C stability of the most desirable MTP was evaluated and monitored over time. The data showed that an increase in weeks correlates with a reduction in Vitamin C content, as denoted by a negative beta coefficient (-1.816). This means that a one-week increase in storage duration correlates with an estimated reduction of around 1.816 units in Vitamin C, equivalent to 94.43 mg/100 g per year assuming a constant linear rate of degradation. Also, based on the regression model ($y=-1.816x + 125.6$), the predicted Vitamin C concentration after 52 weeks (1 year) was 31.17 mg/100g. Relative to the measured initial concentration (124.16 mg/100 g), this corresponds to a predicted cumulative loss of 92.99 mg/100 g (74.90% degradation), leaving 25.10% of the initial Vitamin C after one year. This reduction was less than that of acerola powder (91.3%) and greater than that of Camu-Camu powder (57.1%), as reported by Garcia *et al*. (2020).

Statistical analysis results indicated that the Vitamin C content had a significant change ($p < 0.05$) with respect to the products' storage duration. The r2 infers that around 83.5% of the variability in Vitamin C can be attributed to storage duration (Figure 4). The significant impact of the storage time on the Vitamin C stability of the obtained MTP can be attributed to the susceptibility of Vitamin C. As mentioned, Vitamin C is a thermolabile compound, indicating its susceptibility to heat and its degradation over time. Vitamin C degradation is also expedited by exposure to oxygen, transition metals, heat, alkaline conditions, and elevated temperatures and humidity during storage (Maurya *et al*., 2023; Yin *et al*., 2022; Herbig & Renard, 2017). Feszterová *et al*. (2023) also reported that storage time affected the reduction in Vitamin C levels in plant and vegetable juices, with prolonged storage resulting in greater losses.

Nevertheless, the findings indicate that the desirable MTP (Treatment 4) has a considerable degradation rate per year.

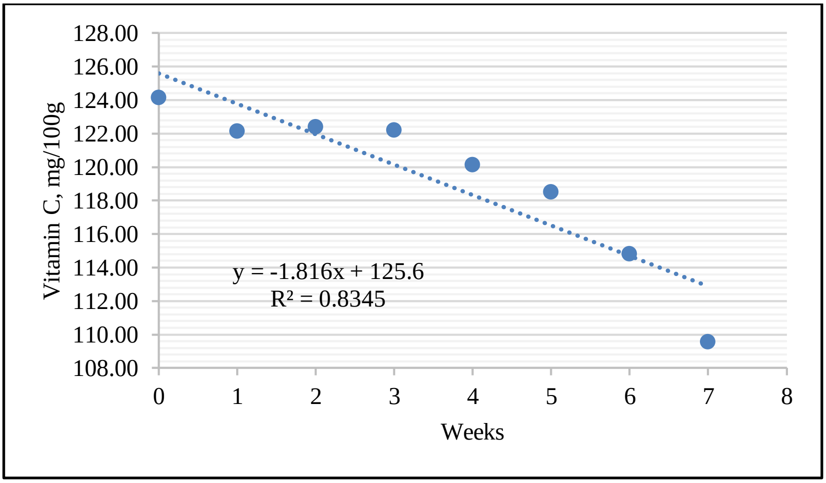

Figure 4. Linear regression graph of the Vitamin C content of the microencapsulated tomato powder over time

4. Conclusion and Recommendation

This study examines the effect of inlet temperature and maltodextrin concentration on the physicochemical properties and Vitamin C content of MTP. Overall, the results obtained in this study showed that higher maltodextrin concentration improved the yield and encapsulation efficiency, while higher inlet temperature reduced the encapsulation efficiency and increased the flowability and cohesion. In addition, the negative effect of the interaction of both factors resulted in powders with less moisture content and water activity, which also affected flowability, cohesion, and wettability time.

MTP also attained higher Vitamin C content and better physicochemical properties. Therefore, microencapsulation holds a good capacity for protecting nutrients and improving product functionality. The best formulation with the inlet temperature of 200 °C and having 15% maltodextrin was found to retain good stability of Vitamin C for an extended period of time.

The study also recommends further studies, specifically on the hygroscopicity and glass transition temperature of MTP to improve the stability, reconstitution feasibility, and flowability. Furthermore, stability studies should be carried out in real time at different storage conditions to assess the long-term stability of Vitamin C.

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6. References

Abdullah, Z., Taip, F.S., Kamal, S.M.M., & Rahman, R.Z.A. (2020). Nonlinear model-based inferential control of moisture content of spray dried coconut milk. *Foods, 9*(9), 1177. https://doi.org/10.3390/foods9091177

Abushusha, W.M.A., & Sayed, S.F. (2017). Comparative analysis of Vitamin C content of some locally available packed and fresh fruit juices by redox titration method. *International Journal of Advanced Research (IJAR), 5*(5), 1548-1554. http://dx.doi.org/10.21474/IJAR01/4281

Ali, M.Y., Sina, A.A.I., Khandker, S.S., Neesa, L., Tanvir, E.M., Kabir, A., ... & Gan, S.H. (2020). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods, 10*(1), 45. https://doi.org/10.3390/foods10010045

Alissa, K., Hung, Y.C., Hou, C.Y., Lim, G.C.W., & Ciou, J.Y. (2020). Developing new health material: The utilization of spray drying technology on avocado (Persea americana Mill.) seed powder. *Foods, 9*(2), 139. https://doi.org/10.3390/foods9020139

Altoveros, N.C. & Borromeo, T.H. (2007). Country Report on the State of Plant. Genetic Resources for Food and Agriculture Philippines. The State of the Plant Genetic Resources for Food and Agriculture of the Philippines (1997- 2006). Retrieved from http.www.fao.org/docrip/013/i1500e/Philippines.pdf

Barbosa, J.C., Almeida, D., Machado, D., Sousa, S., Freitas, A.C., Andrade, J.C., & Gomes, A.M. (2022). Spray-drying encapsulation of the live biotherapeutic candidate Akkermansia muciniphila DSM 22959 to survive aerobic storage. *Pharmaceuticals, 15*(5), 628. https://doi.org/10.3390/ph15050628

Busch, V.M., Pereyra-Gonzalez, A., Šegatin, N., Santagapita, P.R., Ulrih, N.P., & Buera, M.D.P. (2017). Propolis encapsulation by spray drying: Characterization and stability. *LWT - Food Science and Technology, 75*, 227-235. https://doi.org/10.1016/j.lwt.2016.08.055

Chauhan, A.K., & Patil, V. (2013). Effect of packaging material on storage ability of mango milk powder and the quality of reconstituted mango milk drink. *Powder Technology, 239*, 86-93. https://doi.org/10.1016/j.powtec.2013.01.055

Chuaychan, S., & Benjakul, S. (2016). Effect of maltodextrin on characteristics and antioxidative activity of spray-dried powder of gelatin and gelatin hydrolysate from scales of spotted golden goatfish. *Journal of Food Science and Technology, 53*(9), 3583-3592. https://doi.org/10.1007/s13197-016-2340-7

Coelho, S.C., Estevinho, B.N., & Rocha, F. (2022). Recent advances in water-soluble vitamins delivery systems prepared by mechanical processes (Electrospinning and spray-drying techniques) for food and nutraceuticals applications—A review. *Foods, 11*(9), 1271. https://doi.org/10.3390/foods11091271

Cortés, R.M., Hernández, G., & Estrada, E.M. (2017). Optimization of the spray drying process for obtaining cape gooseberry powder: An innovative and promising functional food. *Vitae, 24*(1), 59-67. https://doi.org/10.17533/udea.vitae.v24n1a07

Cynthia, S.J., Bosco, J.D., & Bhol, S. (2015). Physical and structural properties of spray dried tamarind (Tamarindus indica L.) pulp extract powder with encapsulating hydrocolloids. *International Journal of Food Properties, 18*(8), 1793-1800. https://doi.org/10.1080/10942912.2014.940536

Drozłowska, E., Starowicz, M., Śmietana, N., Krupa-Kozak, U., & Łopusiewicz, Ł. (2023). Spray-Drying Impact the Physicochemical Properties and Formation of Maillard Reaction Products Contributing to Antioxidant Activity. *Antioxidants, 12*(4), 919. https://doi.org/10.3390/antiox12040919

Du, J., Ge, Z.Z., Xu, Z., Zou, B., Zhang, Y., & Li, C.M. (2014). Comparison of the efficiency of five different drying carriers on the spray drying of persimmon pulp powders. *Drying Technology, 32*(10), 1157-1166. https://doi.org/10.1080/07373937.2014.886259

Fazaeli, M., Emam-Djomeh, Z., & Yarmand, M.S. (2016). Influence of black mulberry juice addition and spray drying conditions on some physical properties of ice cream powder. *International Journal of Food Engineering, 12*(3), 277-285. https://doi.org/10.1515/ijfe-2015-0253

Feszterová, M., Kowalska, M., & Mišiaková, M. (2023). Stability of vitamin C content in plant and vegetable juices under different storing conditions. *Applied Sciences, 13*(19), 10640. https://doi.org/10.3390/app131910640

Fitzpatrick, J.J., Salmon, J., Ji, J., & Miao, S. (2017). Characterisation of the wetting behaviour of poor wetting food powders and the influence of temperature and film formation. *KONA Powder and Particle Journal, 34*, 282-289. https://doi.org/10.14356/kona.2017019

Fitzpatrick, J. (2024). Powder properties in food production systems. In: B. Bhandari, N. Bansal, M. Zhang, & P. Schuck (Eds.), Handbook of Food Powders (pp. 203–218). Woodhead Publishing. https://doi.org/10.1016/B978-0-323-98820-9.00071-5

Garcia, V.A.D.S., Borges, J.G., Vanin, F.M., & Carvalho, R.A.D. (2020). Vitamin C stability in Acerola and Camu-Camu powder obtained by spray drying. *Brazilian Journal of Food Technology, 23*. https://doi.org/10.1590/1981-6723.23719

Gierczynski, I., Guichard, E., & Laboure, H. (2011). Aroma perception in dairy products: The roles of texture, aroma release and consumer physiology. A review. *Flavour and Fragrance Journal*, *26*(3), 141-152. https://doi.org/10.1002/ffj.2036

Gorme, A.L.G., Gonzaga, Z.C., Capuno, O.B., Rom, J.C., McDougall, S., Goldwater, A.D., & Rogers, G.S. (2017). Growth and yield of Tomato (*Solanum lycopersicum*) as influenced by different soil organic amendments and types of cultivation. *Annals of Tropical Research*, 116-128. https://doi.org/10.32945/atr39sb9.2017

Hadree, J., Shahidi, F., Mohebbi, M., & Abbaspour, M. (2023). Evaluation of effects of spray drying conditions on physicochemical properties of pomegranate juice powder enriched with pomegranate peel phenolic compounds: modeling and optimization by RSM. *Foods, 12*(10), 2066. https://doi.org/10.3390/foods12102066

Henríquez, C., Córdova, A., Lutz, M., & Saavedra, J. (2013). Storage stability test of apple peel powder using two packaging materials: High-density polyethylene and metalized films of high barrier. *Industrial Crops and Products, 45*, 121-127. https://doi.org/10.1016/j.indcrop.2012.11.032

Herbig, A.L., & Renard, C.M. (2017). Factors that impact the stability of Vitamin C at intermediate temperatures in a food matrix. *Food Chemistry, 220*, 444-451. https://doi.org/10.1016/j.foodchem.2016.10.012

Jinapong, N., Suphantharika, M., & Jamnong, P. (2008). Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. *Journal of Food Engineering, 84*(2), 194-205. https://doi.org/10.1016/j.jfoodeng.2007.04.032

Karthik Nayaka, V.S., Azeez, S., Suresha, G.J., Tiwari, R.B., Prasanth, S.J., Karunakaran, G., & Suresha, K.B. (2020). Influence of intel drying temperature on the physical attributes of spray dried Avocado (*Persea americana* Mill) powder. *International Journal of Current Microbiology and Applied Sciences, 9*(12), 1761-1770. https://doi.org/10.20546/ijcmas.2020.912.208

Kha, T.C., Nguyen, M.H., & Roach, P.D. (2010). Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder. *Journal of Food Engineering, 98*(3), 385–392. https://doi.org/10.1016/j.jfoodeng.2010.01.016

Largo Avila, E., Cortes Rodríguez, M., & Ciro Velásquez, H.J. (2015). Influence of maltodextrin and spray drying process conditions on sugarcane juice powder quality. *Revista Facultad Nacional de Agronomía Medellín, 68*(1), 7509-7520. https://doi.org/10.15446/rfnam.v68n1.47839

Li, K., Pan, B., Ma, L., Miao, S., & Ji, J. (2020). Effect of dextrose equivalent on maltodextrin/whey protein spray-dried powder microcapsules and dynamic release of loaded flavor during storage and powder rehydration. *Foods, 9*(12), 1878. https://doi.org/10.3390/foods9121878

Lourenço, S.C., Moldão-Martins, M., & Alves, V.D. (2020). Microencapsulation of pineapple peel extract by spray drying using Maltodextrin, Inulin, and Arabic Gum as wall matrices. *Foods, 9*(6), 718. https://doi.org/10.3390/foods9060718

Maurya, V. K., Shakya, A., McClements, D. J., Srinivasan, R., Bashir, K., Ramesh, T., ... & Sathiyamoorthi, E. (2023). Vitamin C fortification: need and recent trends in encapsulation technologies. *Frontiers in Nutrition, 10*, 1229243. https://doi.org/10.3389/fnut.2023.1229243

Medina-Torres, L., Calderas, F., Nunez Ramírez, D.M., Herrera-Valencia, E.E., Bernad Bernad, M.J., & Manero, O. (2017). Spray drying egg using either maltodextrin or nopal mucilage as stabilizer agents. *Journal of Food Science and Technology, 54*(13), 4427-4435. https://doi.org/10.1007/s13197-017-2919-7

Megharaj, R., Roopa Bai, R.S., Beerappa, S. W., Raghavendra, P., & Udaykumar Nidoni, S.H. (2023). Effect of maltodextrin concentration and inlet air temperature on physical and reconstitution properties of spray dried fig (*Ficus carica*) powder. *The Pharma Innovation Journal, 12*(10), 14-21.

Meroni, E., & Raikos, V. (2018). Lycopene in beverage emulsions: optimizing formulation design and processing effects for enhanced delivery. *Beverages, 4*(1), 14. https://doi.org/10.3390/beverages4010014

Mohanty, S., Mishra, S., & Pradhan, R.C. (2021). Development and process optimization of spray dried powder from enzymatically extracted ripe palm (*Borassus flabellifer*) juice. *Journal of Microbiology, Biotechnology and Food Sciences, 10*(6), e2539-e2539. https://doi.org/10.15414/jmbfs.2539

Mopera, L.E. (2016). Food loss in the food value chain: The Philippine agriculture scenario. *Journal of Developments in Sustainable Agriculture, 11*(1), 8-16. https://doi.org/10.11178/jdsa.11.8

Nadali, N., Pahlevanlo, A., Sarabi-Jamab, M., & Balandari, A. (2022). Effect of maltodextrin with different dextrose equivalents on the physicochemical properties of spray-dried barberry juice (*Berberis vulgaris* L.). *Journal of Food Science and Technology, 59*(7), 2855-2866. https://doi.org/10.1007/s13197-021-05308-w

Nuevo, P.A., & Apaga, A.R. (2010). Technology reducing postharvest losses and maintaining quality of fruits and vegetables (Philippines). In: 2010 AARDO Workshop on Technology on Reducing Post-harvest Losses and Maintaining Quality of Fruits and Vegetables, Philippines, 154-167

O'Callaghan, D.J., & Hogan, S.A. (2013). The physical nature of stickiness in the spray drying of dairy products—A review. *Dairy Science & Technology, 93*(4), 331-346. https://doi.org/10.1007/s13594-013-0114-9

Paiva, Y.F., Figueirêdo, R.M.F.D., Queiroz, A.J.D.M., Santos, F.S.D., Amadeu, L.T. S., Lima, A.G.B.D., ... & Leão, D.A.S. (2023). Maltodextrin as a drying adjuvant in the lyophilization of tropical red fruit blend. *Molecules, 28*(18), 6596. https://doi.org/10.3390/molecules28186596

Park, S. J., Lee, M. J., Choi, Y. J., Lee, M. A., Min, S. G., Seo, H. Y., ... & Park, S. H. (2023). Effect of the addition of maltodextrin on metabolites and microbial population during kimchi fermentation. *Journal of Food Science and Technology, 60*(8), 2153-2159. https://doi.org/10.1007/s13197-023-05742-y

Patil, V., Chauhan, A.K., & Singh, R.P. (2014). Optimization of the spray-drying process for developing guava powder using response surface methodology. *Powder Technology, 253*, 230-236. https://doi.org/10.1016/j.powtec.2013.11.033

Phan, A.D.T., Adiamo, O., Akter, S., Netzel, M.E., Cozzolino, D., & Sultanbawa, Y. (2021). Effects of drying methods and maltodextrin on Vitamin C and quality of *Terminalia ferdinandiana* fruit powder, an emerging Australian functional food ingredient. *Journal of the Science of Food and Agriculture, 101*(12), 5132-5141. https://doi.org/10.1002/jsfa.11159

Philippine Statistics Authority. (2023, January 15). Tomato. In Major Vegetables and Root Crops Quarterly Bulletin, July-September 2022. Retrieved from https://psa.gov.ph/vegetable-root-crops-main/tomato

Pua, C.K., Hamid, N.S.A., Tan, C.P., Mirhosseini, H., Rahman, R.A., & Rusul, G. (2008). Storage stability of jackfruit (*Artocarpus heterophyllus*) powder packaged in aluminium laminated polyethylene and metallized co-extruded biaxially oriented polypropylene during storage. *Journal of Food Engineering, 89*(4), 419-428. https://doi.org/10.1016/j.jfoodeng.2008.05.023

Qadri, T., Naik, H.R., Hussain, S.Z., Bhat, T.A., Naseer, B., Zargar, I., & Beigh, M.A. (2023). Impact of spray drying conditions on the reconstitution, efficiency and flow properties of spray dried apple powder-optimization, sensorial and rheological assessment. *Heliyon, 9*(8). https://doi.org/10.1016/j.heliyon.2023.e18527

Samsu, Z.A., & Mohamad Zahir, A.Z. (2020). Production of oil palm milk powder by spray drying technique. *Materials Today: Proceedings*, 31, 306-312. https://doi.org/10.1016/j.matpr.2020.06.015

Santos, D., Maurício, A.C., Sencadas, V., Santos, J.D., Fernandes, M.H., & Gomes, P.S. (2018). Spray drying: An overview. In R. Pignatello & T. Musumeci (Eds.), Biomaterials – Physics and chemistry: New edition. London, United Kingdom: IntechOpen. https://doi.org/10.5772/intechopen.72247

Sathyashree, H.S., & Ramachandra, C.T. (2017). Effect of spray drying conditions and feed composition on sweet orange juice powder. *International Journal of Agricultural Engineering, 10*(1), 191-198. https://doi.org/10.15740/HAS/IJAE/10.1/191-198

Sathyashree, H.S., Ramachandra, C.T., Nidoni, U., Mathad, P.F., & Naik, N. (2018). Rehydration properties of spray dried sweet orange juice. *Journal of Pharmacognosy and Phytochemistry, 7*(3), 120-124.

Seo, C.W. (2022). Improvements in the physical properties of agglomerated milk protein isolate/skim milk powder mixtures via fluidized bed agglomeration. *Journal of Dairy Science and Biotechnology, 40*(3), 134-142. https://doi.org/10.22424/jdsb.2022.40.3.134

Seth, D., Mishra, H.N., & Deka, S.C. (2017). Functional and reconstitution properties of spray-dried sweetened yogurt powder as influenced by processing conditions. *International Journal of Food Properties, 20*(7), 1603-1611. https://doi.org/10.1080/10942912.2016.1214965

Shadordizadeh, T., Mahdian, E., & Hesarinejad, M.A. (2023). Application of encapsulated *Indigofera tinctoria* extract as a natural antioxidant and colorant in ice cream. *Food Science & Nutrition, 11*(4), 1940-1951. https://doi.org/10.1002/fsn3.3228

Shishir, M.R.I., & Chen, W. (2017). Trends of spray drying: A critical review on drying of fruit and vegetable juices. *Trends in Food Science & Technology, 65*, 49-67. https://doi.org/10.1016/j.tifs.2017.05.006

Sobulska, M., & Zbicinski, I. (2021). Advances in spray drying of sugar-rich products. *Drying Technology, 39*(12), 1774-1799. https://doi.org/10.1080/07373937.2020.1832513

Stat-Ease, Inc. (2018). Design-Expert® Software (Version 11) (Computer software). Stat-Ease, Inc.

Tarlak, F. (2023). The use of predictive microbiology for the prediction of the shelf life of food products. *Foods, 12*(24), 4461. https://doi.org/10.3390/foods12244461

Tontul, I., & Topuz, A. (2017). Spray-drying of fruit and vegetable juices: Effect of drying conditions on the product yield and physical properties. *Trends in Food Science & Technology, 63*, 91-102. https://doi.org/10.1016/j.tifs.2017 .03.009

Tran, T.T., & Nguyen, H.V. (2018). Effects of spray-drying temperatures and carriers on physical and antioxidant properties of lemongrass leaf extract powder. *Beverages, 4*(4), 84. https://doi.org/10.3390/beverages40400 84

Wang, W., Dufour, C., & Zhou, W. (2015). Impacts of spray-drying conditions on the physicochemical properties of soy sauce powders using maltodextrin as auxiliary drying carrier. *CyTA-Journal of Food, 13*(4), 548-555. https://doi.org/10.1080/19476337.2015.1014430

Yin, X., Chen, K., Cheng, H., Chen, X., Feng, S., Song, Y., & Liang, L. (2022). Chemical stability of ascorbic acid integrated into commercial products: A review on bioactivity and delivery technology. *Antioxidants, 11*(1), 153. https://doi.org/10.3390/antiox11010153