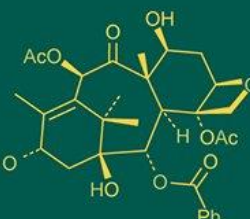
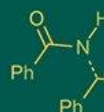
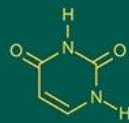


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Pranoti A Lad

Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth (MPKV), Ahilyanagar, Maharashtra, India

Dr. Vikram P Kad

Professor (CAS), Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth (MPKV), Ahilyanagar, Maharashtra, India

Dr. Kailas J Kamble

Professor and Head, Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth (MPKV), Ahilyanagar, Maharashtra, India

Dr. Govind B Yenge

Scientist (Junior Research Officer), Regional Sugarcane and Jaggery Research Station, Mahatma Phule Krishi Vidyapeeth (MPKV), Kolhapur, Maharashtra, India

Dr. Ganesh N Shelke

Assistant Professor, Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth (MPKV), Ahilyanagar, Maharashtra, India

Ganesh M Chavan

Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth (MPKV), Ahilyanagar, Maharashtra, India

Corresponding Author:**Pranoti A Lad**

Department of Agricultural Process Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth (MPKV), Ahilyanagar, Maharashtra, India

Development of spray-dried mixed berry juice powder

Pranoti A Lad, Vikram P Kad, Kailas J Kamble, Govind B Yenge, Ganesh N Shelke and Ganesh M Chavan

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Abstract

This study comprehensively evaluated the effects of juice concentration, carrier concentration and inlet air temperature on the physicochemical properties of spray-dried mixed berry juice powder, demonstrating that all three parameters significantly influenced powder yield, moisture content and total anthocyanin retention. The inlet air temperature significantly affected physicochemical characteristics, with powder yield increasing from 48.62% at 130°C to 62.76% at 180°C due to rapid moisture evaporation and reduced stickiness, moisture content decreasing from 5.82% to 2.18% due to enhanced heat transfer, but anthocyanin content declining from 198.45 mg/100 g to 128.76 mg/100 g due to thermal degradation of heat-sensitive bioactive pigments. Juice concentration played a critical role in determining powder recovery, moisture level, and anthocyanin retention, where moderate concentration (15°Brix) yielded optimal powder recovery (61.78%) with acceptable moisture (3.95%), while higher concentrations (25°Brix) increased anthocyanin content (219.86 mg/100 g) but reduced powder yield (51.12%) due to increased feed viscosity and wall deposition. Similarly, carrier concentration significantly affected all measured properties, with powder yield increasing progressively from 54.22% at 10% CC to 61.13% at 30% CC, moisture content decreasing from 4.48% to 2.00%, but anthocyanin content declining from 198.67 mg/100 g to 165.71 mg/100 g due to the dilution effect of carrier agents on berry solids. An optimal carrier concentration of 20% CC was identified, providing balanced properties of acceptable powder yield (59.97%), low moisture content (2.35%) and good anthocyanin retention (182.76 mg/100 g). These findings collectively indicate that process optimization requires careful balancing of powder recovery, moisture stability and bioactive compound retention, recommending moderate operational conditions of 15°Brix juice concentration, 20% carrier concentration and optimized inlet air temperature (160°C) for producing high-quality mixed berry juice powder with enhanced physicochemical properties and maximum anthocyanin retention for industrial applications and commercial production.

Keywords: Maltodextrin, spray drying, powder yield, juice concentration and mixed juice berries

Introduction

Blueberries and raspberries are important berry fruit for high nutritional and functional value due to their nutritional values, functional value due to the presence of anthocyanin, flavonoids, phenolic acids, vitamins and dietary fibre (Skrovankova *et al.*, 2015) [17] and these barriers strong possess antioxidant, antimicrobial, anti-inflammatory and anticancer properties which contribute significantly to human health promotion (Nile *et al.*, 2014) [11]. Fresh berries contain high moisture content ranging from 80-90% making them highly perishable and susceptible to microbial spoilage and physio-chemical deterioration during storage (Shishir and Chen, 2017). Due to their high moisture content and perishable nature, preservation of berries through drying technique is essential to extent shelf life and maintain nutritional quality of berry products (Pateiro *et al.*, 2022).

Drying is one of the most widely used preservation methods for fruits and vegetables because it reduces the water activity, inhibit the microbial growth, extends shelf life (Nwankwo *et al.*, 2021). Among different drying technologies, spray drying is one of the most efficient and commercially important methods for converting fruit juices into stable powders because it provides rapid drying, reduced storage volume, ease of transportation and improved product stability (Shishir and Chen, 2017) [12, 13, 16].

Spray drying also offers better retention of heat-sensitive compound compared to conventional drying methods due to the shorter drying time involved (Ferrari *et al.*, 2012) [5]. Fruits juice rich in sugar and organic acids generally exhibit stickiness during spray drying due to their low glass transition temperature resulting in wall deposition and low powder recovery (Rahman *et al.*, 2024) [10]. To overcome the challenges carrier agents are commonly incorporated in to feed solution to improve drying efficiency and powder stability (Kumari *et al.*, 2024) [9]. Although several studies have been conducted on spray drying of individual fruit juice limited information is available on the development of spray drying of mix berries. Therefore present investigation was undertaken to develop spray-dried mix berries juice powder using spray drying.

Materials and Methods

Raw Materials

Fresh blueberries and raspberries were procured from the market. Maltodextrin was used as carrier material for spray drying.

Preparation of Mixed Berries Juice

Blueberries and raspberries were washed thoroughly with potable water to remove dirt and impurities. The fruits were crushed separately using a mixer grinder and the juice was extracted by filtration through muslin cloth. The extracted blueberry and raspberry juices were blended in a 1:1 ratio to prepare mixed berry juice. A mixed berry juice (blueberry and raspberry) with a total soluble solids content of 12.13°Brix was prepared at the Post-Harvest Technology Center of Mahatma Phule Krishi Vidyapeeth, Rahuri, India. The mixtures were completely combined at 1,000 rpm for 20 minutes using a magnetic stirrer (2MLH, Remi Sales and Engineering Ltd., Mumbai, India), resulting in a homogenous and well-blended solution. The prepared mixed berry juice was stored in dark glass bottles for further treatment. Initially, the inlet air temperature was varied from 130 to 180°C while maintaining the carrier agent concentration at 15% w/v and the juice concentration at 12°Brix. Thereafter, the juice concentration was varied at 12, 15, 20, and 25°Brix while keeping the carrier agent concentration constant at 15% w/v and the inlet air temperature constant. Finally, the carrier agent concentration was varied at 10, 15, 20, 25, and 30% w/v while maintaining the juice concentration and inlet air temperature constant throughout the experiment. The produced powder was collected immediately after spray drying and packed in moisture-proof containers for further analysis and storage studies.

Spray Drying Process

Spray drying of mixed berries juice was carried out using a laboratory-scale spray dryer (LH,222, Labultima Pvt. Ltd Mumbai). The feeding solution was placed in the drying chamber. Operating element remained steady during the process, with a feeding rate of 10 mL/min, an inlet air flow rate of 63 m³/h, an outlet air temperature of 80°C and an inlet air temperature of 160°C, methodology given by (Shelke *et al.*, 2023) [15]. A sample was taken from the cyclone collector and kept in a sealed container with desiccant at 20°C to maintain low humidity until further analysis.

Process Flow Diagram

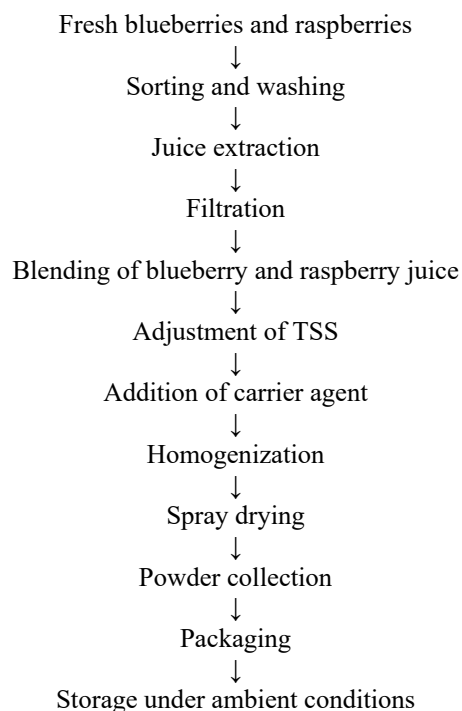


Fig 1: Process flow chart for preparation of mixed berry juice

Powder yield: The powder yield was determined by the method described by Karaca *et al.*, (2016) [8]. The powder yield was calculated as mass of powder dry matter collected after drying to the weight of total solids in the feed

$$\text{Powder yield (\%)} = \frac{\text{Dry solids collected}}{\text{Total solids in feed}} \times 100$$

Moisture content: Moisture content was obtained by following procedure given by AOAC, (2005) [11]. A 5 g mixed berry powder was measured and dehydrated in a vacuum dryer at 70°C for 24 h, or till the constant weight was achieved, maintaining a vacuum between 85 and 100 mm of Hg, following drying process, the samples were collected from the oven, let to cool in a sealed container with desiccant. Repeated the procedure until consistent weight was reached. Moisture content was computed in triplicate, and the averages of three values were evaluated according to the specified formula.

$$\text{MC\% (d. b)} = \frac{W1 - W2}{W2} \times 100$$

where, W1 = Initial powder quantity of mixed berry powder (by weight), g, W2 = Final powder quantity of mixed berry powder (by weight), g.

Total anthocyanin content: Total anthocyanin content (TAC) was assessed using the pH differential technique outlined by Shelke *et al.* (2023) [15], which involves two buffer systems: potassium chloride buffer at pH 1.0(0.025M) and a sodium acetate buffer at pH 4.5(0.4M). Specifically, 1g of juice was mixed with 24 ml of each buffer solution and absorbance was measured at 510 and 700nm with water as blank. The optical density was measured using formula,

$$A = (A510 - A700) \text{ pH}1.0 - (A510 - A700) \text{ pH}4.5$$

TAC was denoted in milligrams of cyaniding of 3-glucoside per 100 ml, calculated by,

$$\text{TAC} = \frac{AX \text{ MWX DF X100} \text{ MA}}{\text{MA}}$$

Where 'A' denoted optical density, 'MW' represented molecular weight of cyaniding 3-glucoside (449.2), 'DF' denoted as the dilution factor (25) and 'MA' denoted molar extinction coefficient of cyaniding 3- glucoside (26,900).

Statistical analysis

Each formulation was measured in triplicate to ensure statistical validity. Analysis was done using SAS software, version 9. A one-way ANOVA utilized to determined significant difference along treatment group.

Result and discussions

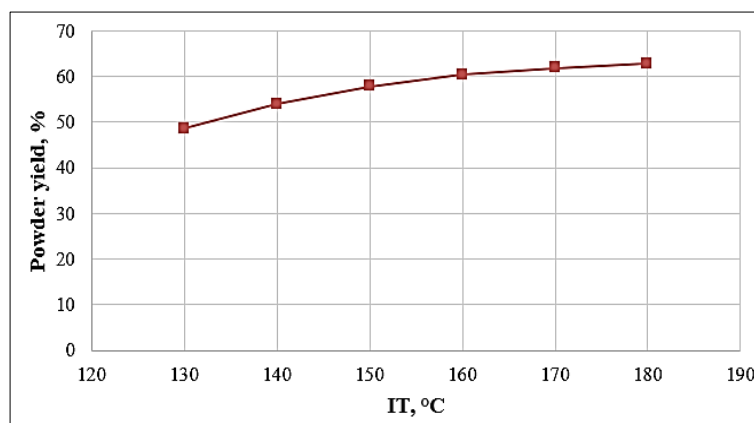
Powder yield, Moisture content and total anthocyanin content at different inlet air temperatures

Table 1 and Fig 1 presents the effect of inlet air temperature on powder yield, moisture content, and total anthocyanin content of mixed berry juice powder. During the study, the juice concentration was kept constant at 12 °Brix and carrier concentration was maintained at 15% to evaluate the individual effect of juice concentration on powder characteristics. The powder yield increased significantly from 48.62% at 130°C to 62.76% at 180°C. The increase in powder yield at higher temperatures may be attributed to rapid moisture evaporation, which reduced stickiness and minimized wall deposition of powder particles inside the

drying chamber, thereby improving powder recovery. Higher drying temperatures facilitate the formation of dry particle surfaces more rapidly, reducing adhesion to the dryer wall (Bhandari *et al.*, 1997). Similar findings were reported by Quek *et al.* (2007) during spray drying of watermelon juice and by Tonon *et al.* (2010) for açai powder. Shishir and Chen (2017)^[3, 14, 16, 18], stated that drying temperature is one of the most critical parameters influencing the quality attributes of spray-dried fruit powders. In contrast, the moisture content decreased from 5.82% at 130°C to 2.18% at 180°C. The reduction in moisture content may be due to enhanced heat transfer and accelerated drying rates at higher inlet air temperatures, resulting in efficient removal of water from feed droplets. Goula and Adamopoulos (2004)^[6] also reported that increasing inlet air temperature significantly reduced the moisture content of spray-dried tomato pulp powder. Similar trends were observed by Ferrari *et al.* (2012) in blackberry powder production. The total anthocyanin content decreased from 198.45 mg/100 g at 130°C to 128.76 mg/100 g at 180°C. The reduction in anthocyanin content may be attributed to thermal degradation of anthocyanins, as these bioactive pigments are highly sensitive to heat during spray drying. High temperatures can accelerate oxidation and structural breakdown of anthocyanin compounds, leading to reduced retention in the final powder (Wang *et al.*, 2010), Ferrari *et al.* (2012) and Tonon *et al.* (2010)^[5, 18, 21] also reported significant losses of anthocyanins and antioxidant compounds at elevated drying temperatures during spray drying of berry juices. Among the different inlet air temperatures studied, 160°C was found to be the most suitable for spray drying of mixed berry juice powder, as it provided a desirable balance between powder yield, moisture content and anthocyanin retention.

Table 1: Effect of inlet air temperature (IT) on the physico-chemical properties of mix berries juice powder

Treatments	IT, °C	Powder yield,%	Moisture content,%	Total anthocyanin content, mg/100g
T1	130	48.62	5.82	198.45
T2	140	53.94	5.11	186.12
T3	150	57.86	4.52	179.38
T4	160	60.43	3.79	156.89
T5	170	61.92	3.45	142.54
T6	180	62.76	2.18	128.76
SE(m)		0.01	0.04	1.23
CD @ 5%		0.03	0.11	3.82
C.V		0.03	1.55	1.28



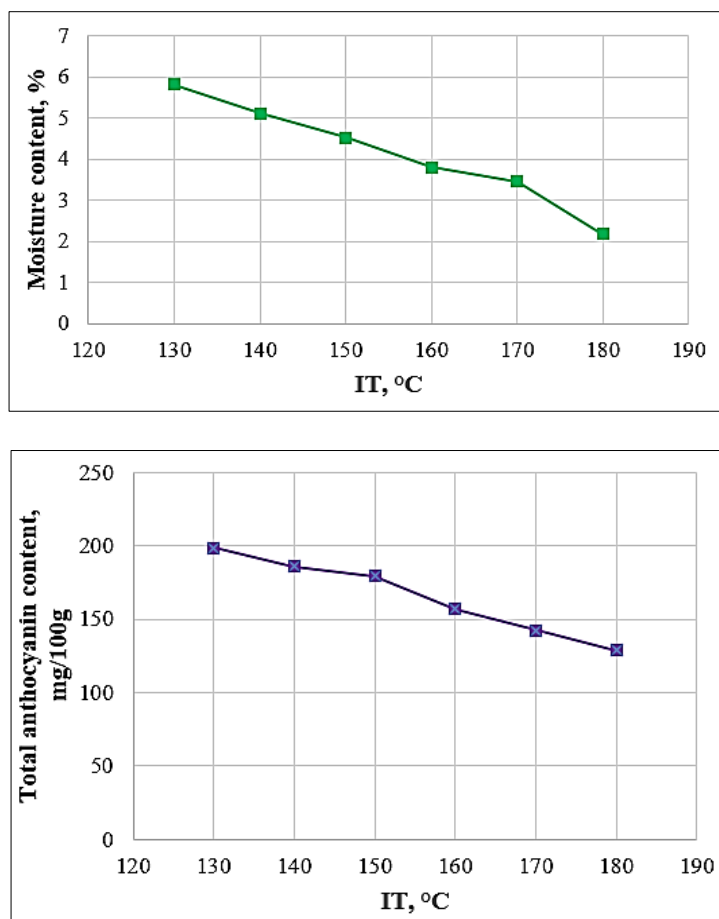


Fig 2: Effect of inlet air temperature (IT) on the powder yield, moisture content and anthocyanin content of mix berries juice powder

Powder yield, Moisture content and total anthocyanin content at different juice concentration

Table 2 presents the effect of juice concentration on powder yield, moisture content and total anthocyanin content of mixed berry juice powder. The results indicated that juice concentration significantly affected the physicochemical properties of the spray-dried powder. Effect of juice concentration (JC) on the powder yield, moisture content and anthocyanin content of mix berries juice powder is shown in Fig 2. During the study, the inlet air temperature was kept constant at 160°C and carrier concentration was maintained at 15% to evaluate the individual effect of juice concentration on powder characteristics. The powder yields initially increased from 60.43% at 12°Brix to 61.78% at 15°Brix and thereafter decreased to 51.12% at 25°Brix. The higher powder yield observed at moderate juice concentration may be attributed to improved solid content and efficient drying behaviour (Kumari et al., 2024) [9]. However, at higher juice concentrations, the feed viscosity increased, resulting in greater stickiness and wall deposition inside the drying

chamber, thereby reducing powder recovery. The moisture content increased from 3.79% at 12°Brix to 4.91% at 25°Brix (Tonon *et al.*, 2010; Pui *et al.*, 2024) [18]. This increase may be due to the higher solid concentration and increased viscosity of the feed solution, which reduced the rate of moisture evaporation during spray drying (Ferrari *et al.*, 2012). The total anthocyanin content increased significantly from 156.89 mg/100 g at 12°Brix to 219.86 mg/100 g at 25°Brix. The increase in anthocyanin content may be attributed to the higher concentration of berry solids and pigments present in the feed solution at elevated °Brix levels (Ferrari *et al.*, 2012) [5]. Overall, juice concentration played an important role in determining powder recovery, moisture level and retention of anthocyanins in the mixed berry juice powder. Among the various juice concentration evaluated, 15°Brix was considered the optimum juice concentration for spray drying of mixed berry juice powder, as it achieved a balanced combination of higher powder yield, lower moisture content and better retention of anthocyanins.

Table 2: Effect of juice concentration (JC) on the physico-chemical properties of mix berries juice powder

Treatments	JC, °Brix	Powder yield,%	Moisture content,%	Total anthocyanin content, mg/100 g
T1	12 °Brix	60.43	3.79	156.89
T2	15 °Brix	61.78	3.95	171.90
T3	20 °Brix	56.33	4.28	198.89
T4	25 °Brix	51.12	4.91	219.86
SE(m)		0.33	0.04	1.35
CD @ 5%		1.08	0.12	4.47
C.V		0.99	1.48	1.25

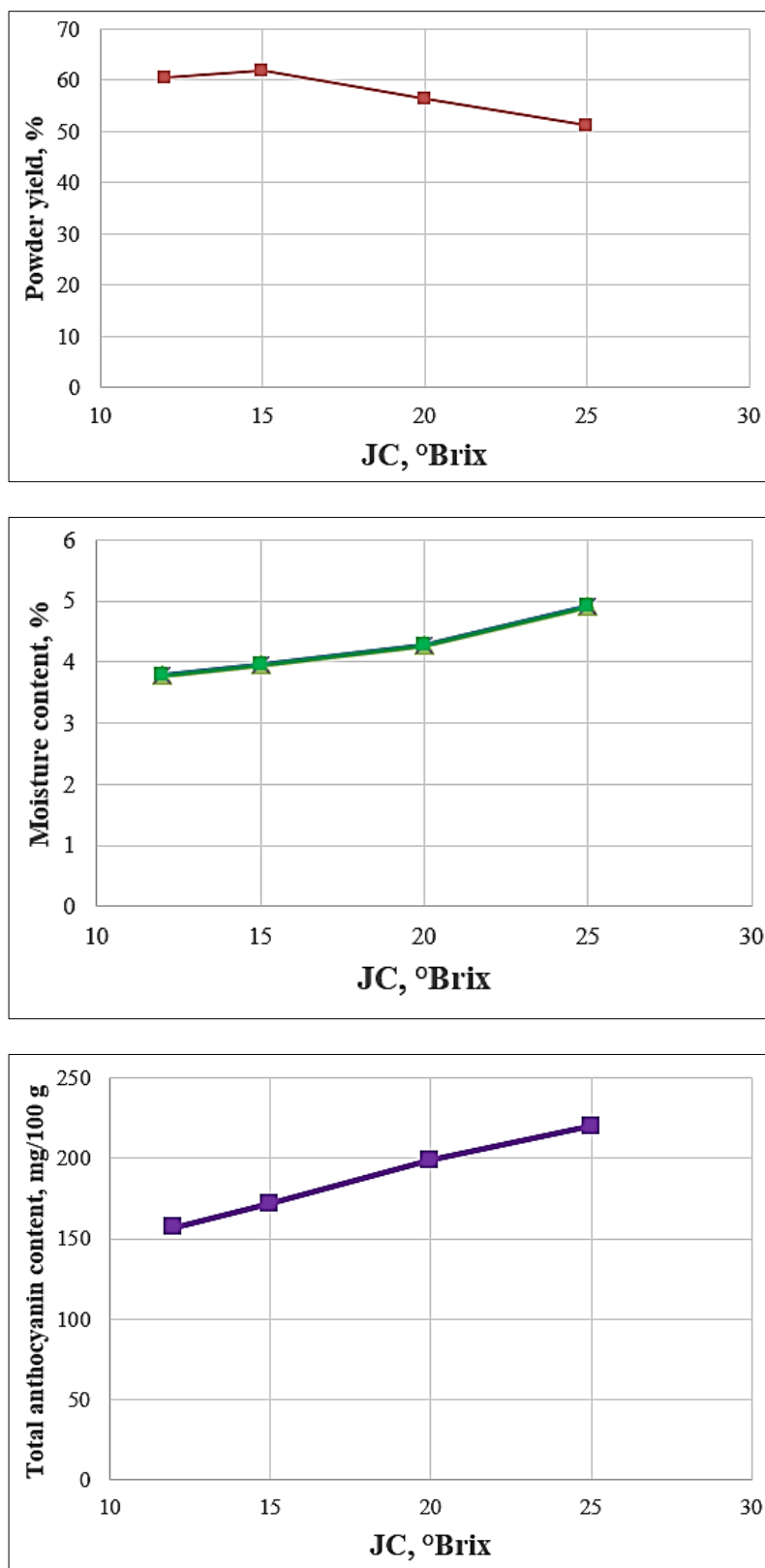


Fig 3: Effect of juice concentration (JC) on the powder yield, moisture content and anthocyanin content of mix berries juice powder

Powder yield, Moisture content and total anthocyanin content at different carrier concentration

The effect of carrier concentrations (CC) on the physicochemical properties of spray-dried mixed berry juice powder, shows that carrier concentrations significantly influenced powder yield, moisture content and total anthocyanin content presented in Table 3. The experiment was conducted by maintaining a constant inlet air temperature of 160°C and juice concentration of 15°Brix in order to

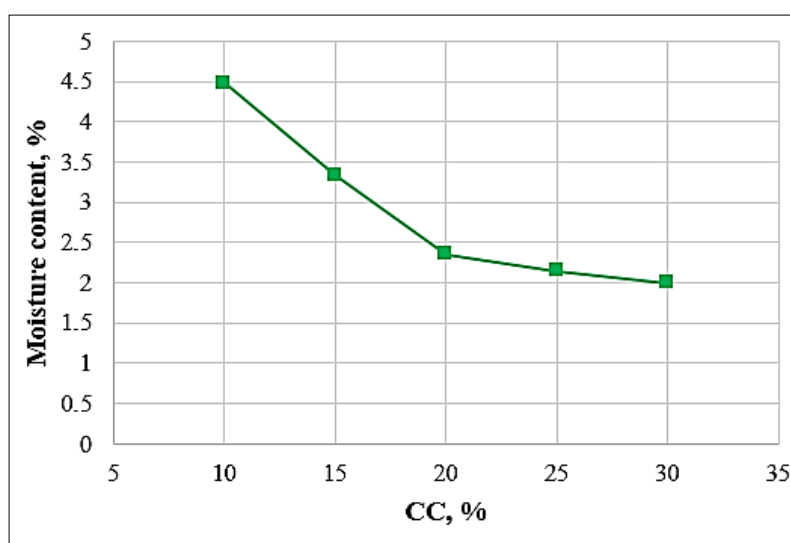
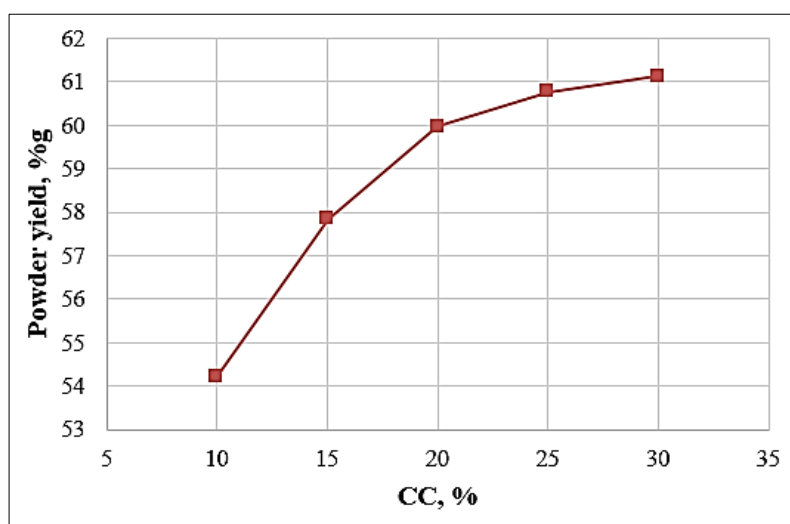
investigate the specific effect of carrier concentration on the characteristics of mixed berry juice powder. The powder yield increased from 54.22% at 10% (T1) to 61.13% at 30%(T5), which may be attributed to improved solid content and enhanced drying efficiency, leading to better powder recovery and reduced wall deposition in the drying chamber (Arebo *et al.*, 2023)^[2]. Fig 3 shows that, the moisture content decreased significantly from 4.48% at 10% CC (T1) to 2.00% at 30% CC (T5), as carrier agents act as drying aids by

reducing hygroscopicity and improving heat and mass transfer during spray drying; maltodextrin reduced moisture content due to the increment in feed solids and low amount of free water. This is in agreement with the results published by Fazaeli *et al.* (2012) and Quek *et al.*, (2007) [4, 14]. However, total anthocyanin content decreased significantly from 198.67 mg/100 g at 10% (T1) to 165.71 mg/100 g at 30% (T5), due to the dilution effect where higher carrier concentrations reduces the proportion of berries solids per unit weight of powder and the least amount of encapsulant compatible with desired anthocyanin protection should be

used to maximize anthocyanin concentration in the encapsulating powder Janiszewska-Turak *et al.* (2019) [7]. Overall, carrier concentration played a critical role in determining physicochemical properties, where while higher carrier concentrations (25-30%) improved powder yield and reduced moisture content, they resulted in lower anthocyanin content, therefore an optimal carrier concentration of 20% (T3) may balance powder recovery (59.97%), moisture stability (2.35%) and bioactive compound retention (182.76 mg/100 g) as shows in Fig 4.

Table 3: Effect of carrier concentrations (CC) on the physico-chemical properties of mix berries juice powder

Treatments	CC,%	Powder yield,%	Moisture content,%	Total anthocyanin content, mg/100g
T1	10%	54.22	4.48	198.67
T2	15%	57.84	3.34	189.55
T3	20%	59.97	2.35	182.76
T4	25%	60.76	2.15	173.98
T5	30%	61.13	2.00	165.71
SE(m)		0.33	0.03	1.31
CD @ 5%		1.04	0.09	4.19
C.V		0.96	1.73	1.25



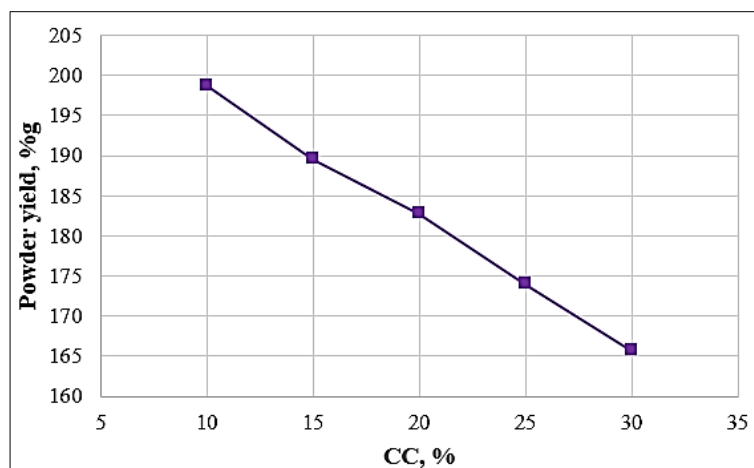


Fig 4: Effect of carrier concentrations (CC) on the powder yield, moisture content and anthocyanin content of mix berries juice powder

Conclusion

The present study investigated the effect of juice concentration, carrier concentration, and inlet air temperature on the physicochemical properties of spray-dried mixed berry juice powder. The results revealed that all processing parameters significantly influenced powder yield, moisture content and anthocyanin retention. Inlet air temperature significantly affected drying efficiency and bioactive compound retention. Higher temperatures improved powder yield and reduced moisture content due to rapid moisture evaporation, but excessive heat caused degradation of anthocyanins. Therefore, moderate drying temperature conditions were found to be more suitable for maintaining powder quality. Among the juice concentrations studied, 15°Brix showed optimum performance by providing higher powder yield with acceptable moisture content and good retention of bioactive compounds. Higher juice concentration increased anthocyanin content but reduced powder recovery due to increased feed viscosity and stickiness during drying. Carrier concentration also played a significant role in determining powder quality. Increasing carrier concentration improved powder recovery and reduced moisture content; however, excessive carrier addition diluted berry solids and reduced anthocyanin retention. A carrier concentration of 20% was found to be most suitable for achieving balanced physicochemical properties. Overall, the optimized conditions of 15°Brix juice concentration, 20% carrier concentration and 160°C inlet air temperature were found suitable for producing high-quality mixed berry juice powder with desirable physicochemical characteristics, improved storage stability and better retention of anthocyanins. The study demonstrated the importance of balancing drying efficiency and bioactive compound preservation for the commercial production of functional mixed berry juice powder.

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