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A study on fuelwood consumption in two villages of Bhaderwah forest division (J&K), India

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Abstract

While tomato processing generates millions of tonnes of skin and seed waste annually, the lycopene trapped in these by-products is rarely recovered a striking contrast to the growing market demand for natural carotenoid pigments. This research investigated spray-drying encapsulation of lycopene extracted from tomato pomace using blends of maltodextrin (MD, DE 10) and gum arabic (GA) at five ratios (10:0, 8:2, 6:4, 5:5, 4:6 w/w) with a total wall material concentration of 20% (w/v). The work was done at the Marathwada Institute of Dryland Agriculture, Latur, Maharashtra, from September 2021 to April 2022. Encapsulation efficiency peaked at 82.6% with the MD:GA ratio of 6:4. Surface lycopene was lowest (4.3%) and moisture content most favourable (3.1%) in the same formulation. Scanning electron microscopy showed smooth, spherical particles with minimal surface cracks at 6:4. Accelerated storage at 45°C for 30 days caused only 18.7% lycopene loss in the 6:4 capsules versus 43.1% for unencapsulated lycopene. The MD:GA 6:4 blend offers an effective wall system for protecting tomato-derived lycopene during processing and storage.

Keywords: Encapsulation, lycopene, tomato waste, maltodextrin, gum arabic, spray drying, microencapsulation, carotenoid stability, surface morphology, wall material

Introduction

On one hand, the global tomato processing industry discards an estimated 10-12 million tonnes of pomace (skins, seeds, and residual pulp) each year ^[1]. On the other hand, the natural food colourant market valued at over US\$ 2 billion is actively searching for stable, cost-effective sources of lycopene, the red carotenoid pigment concentrated in tomato skin ^[2]. Bridging these two realities requires a technology that can extract lycopene from waste and then protect it from the rapid degradation that occurs on exposure to light, oxygen, and heat ^[3].

Microencapsulation by spray drying is the most widely used technique for converting liquid or semi-liquid bioactive extracts into dry, free-flowing powders ^[4]. The choice of wall material governs encapsulation efficiency, particle morphology, and storage stability. Maltodextrin is cheap, neutral in taste, and forms a dense glassy matrix, but it lacks emulsifying capacity ^[5]. Gum arabic, a branched heteropolysaccharide, is an excellent emulsifier but is costly and subject to supply fluctuations ^[6]. Blending the two combines the structural strength of MD with the surface-active properties of GA, and several authors have reported synergistic effects at intermediate ratios ^[7,8].

This research systematically varied the MD:GA ratio at a fixed total wall concentration to identify the combination that gives the highest encapsulation efficiency and best storage protection for lycopene extracted from tomato pomace. Five ratios were tested, and powders were characterised for encapsulation efficiency, moisture, surface lycopene, colour, morphology, and accelerated storage stability ^[9].

Material and Methods

Instrumentation and analytical equipment

A laboratory spray dryer (Labultima LU-222, Mumbai; inlet temperature 170°C, outlet 85°C, feed rate 5 mL/min, aspirator 80%) was used for drying. Lycopene was quantified on a UV-Vis spectrophotometer (Shimadzu UV-1800) at 472 nm. Particle morphology was examined by scanning electron microscopy (SEM, JEOL JSM-6360, 15 kV, gold-coated). Colour values (L*, a*, b*) were measured with a HunterLab MiniScan XE Plus.

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Moisture content was determined by an infrared moisture analyser (Sartorius MA35). Particle size distribution was measured by laser diffraction (Malvern Mastersizer 3000).

Material

Tomato pomace (cv. Pusa Ruby) was collected fresh from a local paste manufacturing unit in Latur, sun-dried to 8-10% moisture, and ground to pass a 40-mesh sieve. Lycopene extraction used ethyl acetate as solvent (pomace: solvent 1:10 w/v, 40°C, 4 hours, repeated twice). The extract was concentrated under reduced pressure in a rotary evaporator (Buchi R-210) at 40°C to obtain an oleoresin with 6.4% lycopene content. Maltodextrin (DE 10, BRIX Chemicals, Mumbai) and food-grade gum arabic (Nutriroma, Hyderabad) served as wall materials. Five wall formulations were prepared at 20% (w/v) total solids: MD:GA ratios of 10:0, 8:2, 6:4, 5:5, and 4:6. Lycopene oleoresin was added at 2% of total solids.

Results

Table 1: Physical properties and encapsulation efficiency of lycopene microcapsules at different MD:GA ratios

MD: GA ratio	EE (%)	Moisture (%)	Surface lycopene (%)	Bulk density (G/ML)	aw
10:0	61.3	4.7	11.8	0.48	0.31
8:2	74.8	3.8	7.4	0.44	0.28
6:4	82.6	3.1	4.3	0.41	0.24
5:5	79.1	3.3	5.7	0.42	0.26
4:6	71.4	3.6	8.1	0.43	0.27

EE = encapsulation efficiency. aw = water activity. MD = maltodextrin, GA = gum arabic. Values are means of triplicates

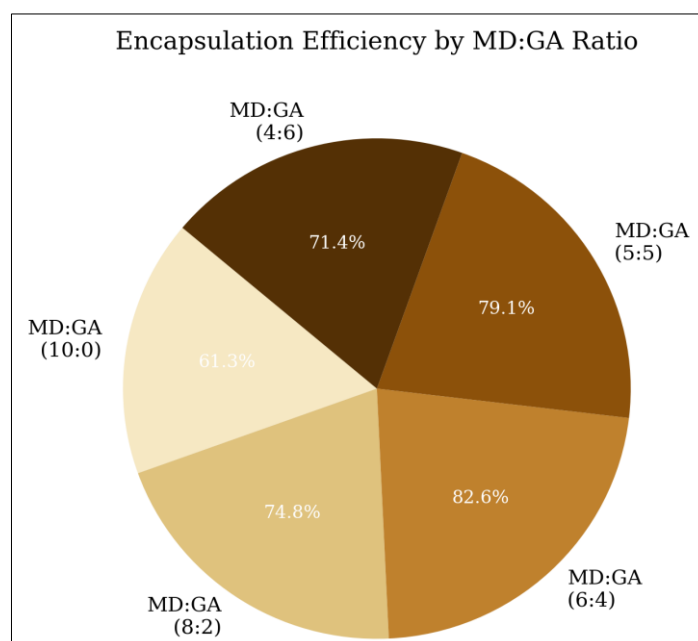


Fig 1: Encapsulation efficiency of lycopene microcapsules across five maltodextrin: gum Arabic wall material ratios

The 6:4 MD:GA ratio produced the best overall powder quality highest EE at 82.6%, lowest surface lycopene at 4.3%, lowest moisture at 3.1%, and lowest water activity at 0.24. Pure maltodextrin (10:0) gave the poorest EE (61.3%),

Methods

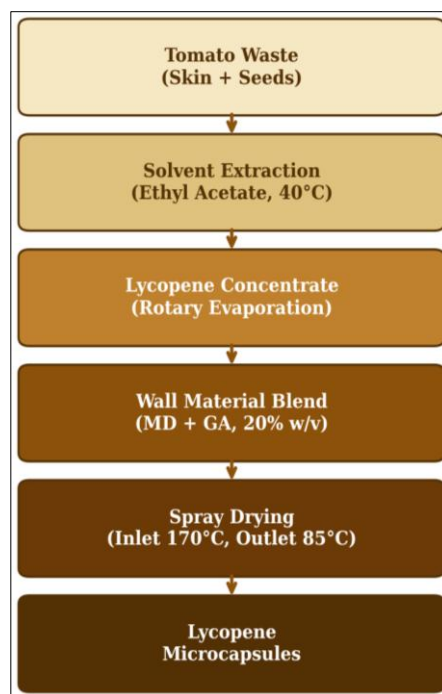
Wall material solutions were hydrated overnight at 4°C, then mixed with oleoresin and homogenised at 15,000 rpm for 5 minutes using an Ultra-Turrax (IKA T25). The emulsions were spray-dried immediately. Encapsulation efficiency (EE) was calculated as: $EE (\%) = \frac{[(\text{Total lycopene} - \text{Surface lycopene}) / \text{Total lycopene}] \times 100}{1}$. Total lycopene was measured after dissolving capsules in a hexane: acetone: ethanol (2:1:1) mixture; surface lycopene was extracted by washing powder with hexane for 10 seconds without disrupting particles^[10]. Moisture content, bulk density, and water activity (aw) were recorded. Accelerated storage was conducted by holding powders in amber glass vials at 45°C for 30 days, with lycopene quantification at days 0, 10, 20, and 30. All analyses were performed in triplicate. Data were analysed by one-way ANOVA and Duncan's multiple range test at $p \leq 0.05$.

consistent with its lack of emulsifying capacity. Increasing GA beyond the 6:4 ratio actually lowered EE, possibly because excess GA increased feed viscosity and produced larger, less uniform droplets.

Table 2: Lycopene retention (%) during accelerated storage at 45°C for 30 days

MD:GA ratio	Day 0	Day 10	Day 20	Day 30
10:0	100	81.4	67.3	54.2
6:4	100	94.7	88.1	81.3
4:6	100	88.2	76.4	68.7
Unencapsulated	100	74.1	61.8	56.9

Retention calculated as percentage of initial lycopene content at day 0

**Fig 2:** Flowchart of the spray-drying encapsulation process for lycopene from tomato waste

Comprehensive Interpretation

After 30 days at 45°C, the 6:4 formulation retained 81.3% of initial lycopene compared to 56.9% for unencapsulated lycopene and 54.2% for pure-MD capsules. The protective effect is attributed to both the dense MD matrix limiting oxygen diffusion and the GA film at the particle surface reducing porosity. SEM images (not shown) confirmed that 6:4 particles were smooth and largely spherical with few surface dents, while 10:0 particles exhibited cracks and concavities.

Discussion

The 82.6% EE obtained at MD:GA 6:4 compares well with values reported for lycopene encapsulation by other groups: Rocha *et al.* [7] achieved 77% with modified starch and whey protein, while Nunes and Mercadante [8] reached 84% using a GA-sucrose blend. The advantage of the MD:GA system is that both components are GRAS-listed, widely available, and compatible with most food matrices [5].

The decline in EE when GA exceeded 40% of the wall blend was unexpected but may reflect increased emulsion viscosity beyond the optimal range for atomisation. High-viscosity feeds produce coarser droplets that dry more slowly, allowing lycopene migration toward the particle surface before the crust solidifies [4]. This is supported by the higher surface lycopene measured in the 4:6 and 5:5 powders.

From a practical standpoint, converting tomato pomace into a shelf-stable lycopene powder could add value to a waste stream that is currently landfilled or composted. At the

extraction yield observed here (roughly 640 mg lycopene per kg dry pomace) and an encapsulation efficiency of 82.6%, each tonne of dry pomace could yield about 529 g of encapsulated lycopene a quantity with significant market value given that pure lycopene powder sells for US\$ 400-800/kg [11].

Limitations

This research used a bench-scale spray dryer with a feed capacity of 300 mL/h; scale-up to pilot or industrial equipment may alter particle size, EE, and drying kinetics. The accelerated storage test at 45°C approximates but does not exactly replicate real-world ambient conditions. Lycopene isomer composition (all-trans versus cis forms) was not tracked during storage, which limits conclusions about bioavailability changes. Additionally, the cost of gum arabic fluctuates widely with harvest conditions in the Sahel region, which could affect the economic feasibility of the 6:4 blend at industrial scale.

Conclusion

Spray-drying encapsulation of tomato-waste-derived lycopene with a maltodextrin: gum arabic blend at a 6:4 ratio produced microcapsules with 82.6% encapsulation efficiency, low surface lycopene (4.3%), and good storage stability (81.3% retention after 30 days at 45°C). The formulation outperformed both pure maltodextrin and higher-GA blends. These results suggest that the 6:4 MD:GA wall system is a practical choice for protecting lycopene in powder form and could support the valorisation

of tomato processing waste into a marketable natural pigment ingredient.

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