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Gum arabic nanoemulsion coating for shelf life extension of tomato (*Solanum lycopersicum* L.) fruit under ambient storage

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ABSTRACT

In the present study efficacy of the gum arabic nanoemulsion coating for shelf life extension of tomato fruit was evaluated. Nanoemulsion coating was synthesised using gum arabic (0.5, 1.0, 1.5%), glycerol (0.5, 0.75, 1.0%) and sodium benzoate (1.0, 1.5, 2.0%). A stability study of synthesised gum arabic nanoemulsions was carried out for 30 days under ambient storage by analysing their mean particle size, polydispersity index, count rate and zeta potential. Nanoemulsion, containing 1% gum arabic, 0.5% glycerol and 1.5% sodium benzoate, was the most stable. Hence, freshly harvested, breaker tomato fruits were coated by selected gum arabic nanoemulsion and gum arabic microemulsion with five dipping times (1, 2, 3, 4, 5 min) followed by ambient storage. Tomato fruits coated with gum arabic nanoemulsion and 4 min dipping had maximum shelf life (24 days) with an advantage of 15 days over the control. In contrast, fruits coated with gum arabic microemulsion and 4 min dipping had a shelf life of 15 days when stored under ambient condition. Furthermore, the gum arabic nanoemulsion coating retained the quality attributes of fruits during extended storage. Hence, coating with gum arabic nanoemulsion can significantly improve the quality and shelf life of fruits and vegetables compared to gum arabic microemulsion.

Keywords: Coating, Gum arabic, Nanoemulsion, Shelf life

INTRODUCTION

Gum arabic a mixture of polysaccharides and glycoproteins, is obtained from trees of the Acacia genus. It is a soluble fibre having properties of a glue and binder. It has been recognised as one of the safest nutritional fibres by the American Food and Drug Administration (Babiker *et al*., 4). Patel and Goyal (10) reported that due to desirable emulsifying, stabilizing, binding and shelf-life enhancing properties of gum arabic, it has numerous applications in many foods and drugs.

In recent years, gum arabic edible films and coatings has emerged as a new, effective and environment friendly alternative mean to extend the shelf-life of fresh fruits and vegetables. Gum arabic has emulsifying property due to minor, relatively protein-rich components. Furthermore, oil in water emulsion is preferred for producing edible coatings, since they allow the incorporation of different lipophilic substances with antioxidant and antimicrobial effects into a hydrophilic polymeric matrix.

In relation with extension of shelf life of horticultural products, nanotechnology is helpful as the edible coating. In nanotechnology, gum arabic has ability to disperse and stabilize nanoparticles in aqueous solutions along with enhancing biocompatibility, film forming ability with desirable polar properties, reduces surface energy, improves the tensile strength of starch film and enhances biomolecular attachment of magnetic nanoparticles (Patel and Goyal, 10). Moreover, distinct morphologies of nanosystems that modify the characteristics of edible coating offer several advantages over conventional emulsions in different ways. Ultrasonication and high pressure homogenization are widely used technologies to obtain the nanometer size of an emulsion.

Patel and Goyal (10) summarised that gum arabic has a significant potential in formulation of stable nanoemulsion. Although there are few researches on the application of gum arabic and its complexes, the application of gum arabic nanoemulsion is not been explored to edible coating of fruits and vegetables for shelf life extension. Thus, scientific study was undertaken to study the effect of gum arabic based nanoemulsion coating on extending the shelf life of tomato fruits with the objectives; (a) synthesis, characterization and stability study of gum arabic nanoemulsion under ambient storage and (b) to evaluate the effect of gum arabic nanoemulsion coating on the shelf-life and physico-chemical properties of tomato fruits during ambient storage.

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MATERIALS AND METHODS

For conducting experiments, tomato fruits of 'GAT-5', an early variety, were grown at Main Vegetable Research Centre, Anand Agricultural University, Anand, Gujarat, under continuous supervision of experts to avoid cross variety contamination. Round, uniform sized mature tomato fruits were picked from the fields at the breaker stage on the first appearance of external pink red or tannish yellow colour. Harvested fruits were brought to the Department of Post Harvest Engineering and Technology, College of Food Processing Technology and Bio-Energy and were sorted on the basis of size, colour, and absence of external injuries for further studies.

Gum arabic powder (density: 1.35 kg/L) was procured from Fisher Scientific of Thermo Fisher Scientific India Pvt. Ltd. Other chemicals i.e. glycerol, sodium benzoate, oleic acid and tween 20 used in experimentation for preparation of nanoemulsion were of analytical grade and obtained from commercial manufacturers.

Gum arabic (GA) based nanoemulsion was prepared according to the method described by Ali *et al*. (1) with modifications. Firstly, to prepare the microemulsion (Oil-in-water), 0.5, 1.0, and 1.5 g of gum arabic exudates were dissolved in 100 mL double distilled water. The solution was homogenized by stirring at 800 rpm and 40°C temperature for 60 min using a magnetic stirrer. Gum arabic was added slowly to avoid lump formation in the water. An antifungal agent, sodium benzoate (SB; accurately weighed to 1, 1.5, 2 g) was added into the gum arabic solution. Then plasticizer, glycerol (G; 0.5, 0.75, 1.0%) was added to improve the strength and flexibility of the coating solutions. Finally, emulsifier tween20 (0.2%) was added and mixed well for adequate strength and wettability of the coating solutions and to that 0.75% of oleic acid was added as a lipid phase in each formulation of emulsion. Glycerol, tween20 and oleic acid were added drop wise, which produced translucent coarse microemulsion. The formulated microemulsions were subjected to the ultrasonication using ultrasonicator (Model: Qsonica Q500, Make: Qsonica L.L.C, Newtown, CT) for 20 min at 500 W and 20 kHz to convert it into the nanoemulsion. The two main differences between conventional microemulsions and synthesised nanoemulsions observed were particle size (nanoemulsion: 5-200 nm, whereas microemulsions: 1-100 µm) and shape of the particles in the continuous phase (microemulsions: roughly spherical droplets whereas nanoemulsion: various structures i.e. droplet like swollen micelles and bicontinuous structure). Hence, synthesized gum arabic nanoemulsions were characterized and stored in glass vials for one month under ambient condition to determine their stability. Experimental coding of the synthesised gum arabic nanoemulsions are shown in Table 1.

Synthesized gum arabic nanoemulsions of different formulations were characterized by the particle size (nm), polydispersity index (PDI), count rate (kcps) and zeta potential using dynamic light scattering device (DLS; Model: Zetasizer Nano ZS90; Make: Malvern Panalytical Ltd, UK) equipped with a zetasizer laser diffractometer, at the Department of Nanotechnology and Centre for Advanced Research in Plant Tissue Culture, Anand Agricultural University, Anand, Gujarat. In order to find out the particle size and other characteristics of the synthesized gum arabic nanoemulsion, 1 mL of the suspension was taken in the cuvette and measurements were conducted at 25°C. The instrument uses dynamic light scattering at a scattering angle of 90° to measure particle size. This technique measures the diffusion of particles moving under Brownian motion and converts this to size and a size distribution using the Stokes-Einstein relationship. In addition, laser doppler micro-electrophoresis technique is used to measure zeta potential, where, an electric field is applied to a solution of molecules or a dispersion of particles, which will then move with a velocity related to their zeta potential. This velocity is measured using a laser interferometric technique called M3-PALS (Phase Analysis Light Scattering).

Table 1. Experimental coding of the synthesised gum arabic nanoemulsions

Nano emulsion	GA: G: SB (%)	Nano emulsion	GA: G: SB (%)
T1	0.5: 0.50: 1.0	T15	1.0: 0.75: 2.0
T2	0.5: 0.50: 1.5	T16	1.0: 1.00: 1.0
T3	0.5: 0.50: 2.0	T17	1.0: 1.00: 1.5
T4	0.5: 0.75: 1.0	T18	1.0: 1.00: 2.0
T5	0.5: 0.75: 1.5	T19	1.5: 0.50: 1.0
T6	0.5: 0.75: 2.0	T20	1.5: 0.50: 1.5
T7	0.5: 1.00: 1.0	T21	1.5: 0.50: 2.0
T8	0.5: 1.00: 1.5	T22	1.5: 0.75: 1.0
T9	0.5: 1.00: 2.0	T23	1.5: 0.75: 1.5
T10	1.0: 0.50: 1.0	T24	1.5: 0.75: 2.0
T11	1.0: 0.50: 1.5	T25	1.5: 1.00: 1.0
T12	1.0: 0.50: 2.0	T26	1.5: 1.00: 1.5
T13	1.0: 0.75: 1.0	T27	1.5: 1.00: 2.0
T14	1.0: 0.75: 1.5		

GA: Gum arabic; G: Glycerol; SB: sodium benzoate

Characterized gum arabic nanoemulsions were stored in glass vials for 30 days to determine their stability. Stirred samples were evaluated for the particle size (nm), polydispersity index (PDI), count rate (kcps) and zeta potential at 10 days interval to check stability throughout storage. At the end of 30 days storage study, the most stable nanoemulsion having lowest particle size was selected for coating on tomato fruits.

Freshly harvested tomato fruits were washed and allowed to air dry at room temperature. An adequate quantity of selected most stable gum arabic nanoemulsion and microemulsion of the same formulation (prepared using the same method as of preparation of nanoemulsion except ultrasonication treatment) were prepared. Tomato fruits were treated with the selected gum arabic nanoemulsion and its microemulsion by dipping into the emulsions for 1, 2, 3, 4, and 5 min (Figure 1). The excess coating was drained and the coated tomato fruits were kept for surface drying under natural convection for 6 hrs. Tomato fruits dipped in distilled water served as a control. For each treatment three replications, each containing 30 fruits were treated and stored in crates for storage study at ambient condition. Details of experimental coding of the selected gum arabic emulsions for coating of tomato fruits are shown in Table 2.

In the first phase, stored tomato fruits were analysed at three days interval to determine the spoilage and physiological loss in weight (PLW), thereby shelf life, as per methods described by Patel *et al*. (9). In the second phase, synthesised coating which resulted into maximum shelf life of the fruits was selected to study its effect on the physico-chemical changes during storage.

Table 2. Experimental coding of selected gum arabic emulsions for coating of tomato fruits

Experimental code	Treatment details
C1	1 min dipping into nanoemulsion
C2	2 min dipping into nanoemulsion
C3	3 min dipping into nanoemulsion
C4	4 min dipping into nanoemulsion
C5	5 min dipping into nanoemulsion
C6	1 min dipping into microemulsion
C7	2 min dipping into microemulsion
C8	3 min dipping into microemulsion
C9	4 min dipping into microemulsion
C10	5 min dipping into microemulsion
C	Control- without any treatment

Proximate composition (moisture content, protein, crude fat, ash, and crude fibre content) of freshly harvested tomato fruit were estimated using standard analytical methods (AOAC, 2). Differential method was used to calculate carbohydrate content (Sulieman *et al*., 11). Stored tomato fruit samples were periodically analysed for physico-chemical changes viz. physiological loss in weight (PLW), spoilage, firmness, shelf life, total soluble solids (TSS), acidity and lycopene content as per methods described by Patel *et al*. (9), rate of respiration (Patel *et al*., 8) and tomato skin colour (L*, a*, b*, measured using Lovibond colorimeter RT850i) at every three days interval. All the analysis were carried out in triplicate and mean values recorded.

The mean values generated from the analysis of each of the quality attributes, obtained from

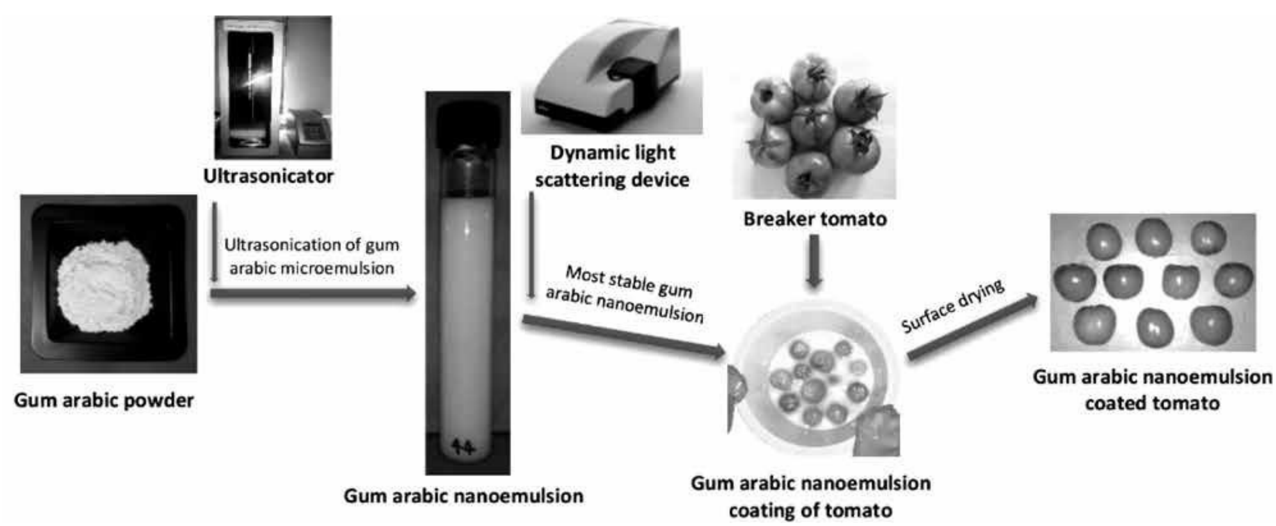

Fig. 1. Gum arabic nanoemulsion coatings on tomato fruits

three replications during the experimentation were subjected to statistical analysis using a completely randomized design (CRD). ANOVA tables were prepared and the significance of the influence of gum arabic nanoemulsion coating on extension of shelf life of tomato fruits was tested at 5% significance level.

RESULTS AND DISCUSSION

In present investigation, from the nanoemulsion characterization it was observed that due to conversion of microparticles of the solute into the nanoparticles by ultrasonication, the colour of emulsion changed from translucent to milky white as particle size reduced. DLS analysis of synthesized gum arabic nanoemulsions was performed for their characterization and stability study based on particle size distribution, polydispersity index (PDI), count rate and zeta potential. The data of mean particle size of the synthesised gum arabic nanoemulsions are presented in Table 3. From the result, it was observed that the synthesised gum arabic nanoemulsions had particles of nano sized and the mean particle size was 69.83 nm. The minimum particle size obtained was 41.75 nm (T11) followed by 44.21 nm (T1), whereas the maximum mean particle size was 193.70 nm (T6).

The uniformity of particle size in gum arabic nanoemulsions is specified by PDI where higher PDI represents the lower uniformity of particle size in nanoemulsions and vice-versa. Hence, smaller the PDI, the particles are distributed more uniformly within the formulation and vice versa. In addition, it provides a clue on the rate of sedimentation of a heterogeneous liquid system. The PDI can range from 0 to 1 (Gurpreet and Singh, 7). In all the combinations of the synthesised gum arabic nanoemulsions, the PDI was ranged from 0.275 to 0.457 as shown in Table 3. PDI was lower than 0.5 in each combination representing stable nanoemulsions. The lower PDI of nanoemulsion indicated the efficacy of the ultrasound emulsification method in preparation of a nanoemulsion with homogenous size distribution.

Count rate shows the number of nano particles present in the nanoemulsion which results into the scattering of the light, detected using the DLS device. In general, count rate of nano systems ranges from 250 to 350 kcps. The results of count rates of synthesised gum arabic nanoemulsions are shown in Table 3. From all the combination of gum arabic nanoemulsion, highest count rate of 417.6 kcps was obtained for the T6 and lowest count rate of 269.4 kcps was observed in T11.

In Table 3, zeta potential values of gum arabic nanoemulsion were also reported. According to Das *et al*. (5) nanoemulsion particles with high zeta potential are electrically stabilized whereas low zeta potential in nanoemulsion tends to undergo flocculation and coagulation. Synthesized gum arabic nanoemulsion had mean zeta potential -30.92 mV while it remained in the range of -39.3 to -26. The electrostatic repulsive force between particles of nanoemulsion produced by negatively charged surface is responsible for the stability of the emulsion. Zeta potential of ±30 mV is considered to be sufficient for ensuring physical stability of nanoemulsion (Gurpreet and Singh, 7).

The prepared gum arabic nanoemulsions were kept without agitation for 30 days to determine its stability at ambient condition. From Table 3, it was observed that during storage the mean particle size of gum arabic nanoemulsions increased. In contrast, PDI and zeta potential decreased. Based on particle size at the end of 30 days storage, T11 was found to be the most stable emulsion with least droplet size of 44.09 nm, having PDI 0.331, count rate 274.2 kcps and zeta potential -27.3 mV. Hence, to study the effect of gum arabic nanoemulsion coating on extension of shelf life of tomato fruits, nanoemulsion T11, containing gum arabic 1%, glycerol 0.5%, sodium benzoate 1.5%, oleic acid 0.75% and tween20 0.2%, was selected for coating on tomato fruits.

Tomato fruits grown throughout the world are different in their physical properties and chemical composition. Correct and accurate assessment of the characteristics for the variety under study was of utmost importance. Hence, physico-chemical properties of freshly harvested tomato fruits were determined. In accordance, tomato fruits harvested at breaker stage were analysed to determine the major and minor diameter, weight of a fruit, sphericity, bulk and true density, firmness, moisture, protein, crude fat, carbohydrate, ash, crude fibre content, pH, total soluble solid, titratable acidity and lycopene content, in triplicate, and mean values were reported in Table 4.

Tomato fruits coated with selected gum arabic emulsions (nano and micro) as per Table 2 and stored under ambient condition were evaluated visually to determine the spoilage and results are presented in Table 5. It was noted that spoilage of both gum arabic coated and uncoated tomato fruits increased gradually with storage period. Various types of spoilage; fungal growth on the tip, black spots and shrinkage of the fruit skin were observed during storage under ambient condition. However, in this experiment, delayed ripening and senescence was observed in gum arabic nanoemulsion and microemulsion coated fruits. This resulted into reduced decay in gum arabic emulsions coated fruits compared to control fruits ($P<0.05$). In this

Table 3. Experimental coding and characteristics of synthesised gum arabic nanoemulsions

Gum arabic nanoemulsions	Mean particle size (nm) ± SD		PDI ± SD		Count rate (kcps) ± SD		Zeta potential (mV) ± SD	
	0 day	30 days	0 day	30 days	0 day	30 days	0 day	30 days
T1	44.21±0.68	56.51±0.52	0.367±0.01	0.355±0.03	294.8±0.76	306.4±0.65	-37.20±1.68	-38.20±1.33
T2	59.61±0.66	65.30±0.15	0.406±0.01	0.282±0.06	326.4±0.96	322.7±0.30	-35.30±2.10	-36.60±0.79
T3	54.01±1.19	60.63±0.52	0.319±0.02	0.288±0.03	300.2±0.12	297.4±2.19	-30.00±2.55	-27.30±3.99
T4	46.59±0.76	65.30±0.94	0.382±0.01	0.282±0.06	304.5±2.20	322.7±0.30	-35.30±2.10	-36.60±0.79
T5	50.70±0.48	54.85±2.68	0.275±0.05	0.268±0.05	294.0±1.13	280.0±8.74	-32.90±2.04	-32.20±1.18
T6	126.50±2.45	138.30±1.52	0.357±0.05	0.340±0.06	417.6±2.03	431.2±3.44	-30.20±5.19	-32.60±4.20
T7	44.82±1.28	53.40±1.06	0.360±0.01	0.317±0.03	291.3±0.60	299.3±0.17	-39.30±0.78	-35.90±1.86
T8	56.11±0.29	59.67±2.17	0.283±0.05	0.332±0.03	301.7±0.10	306.4±1.42	-32.50±1.99	-34.70±1.10
T9	88.77±0.66	92.15±3.29	0.286±0.06	0.239±0.08	342.9±0.55	351.8±0.87	-34.50±4.65	-30.10±3.41
T10	114.60±1.01	120.90±0.59	0.457±0.02	0.318±0.08	425.3±1.71	394.2±1.27	-30.40±0.51	-28.20±1.06
T11	41.75±0.30	44.09±1.56	0.299±0.04	0.331±0.02	269.4±1.14	274.2±2.28	-34.40±1.62	-33.60±1.25
T12	57.60±0.81	64.69±0.69	0.348±0.02	0.343±0.03	283.7±2.38	300.0±1.48	-30.10±3.36	-30.40±3.68
T13	74.18±2.75	62.00±1.32	0.415±0.02	0.283±0.08	332.0±1.97	301.5±0.31	-31.40±1.27	-34.20±0.64
T14	62.72±1.38	69.16±7.56	0.407±0.01	0.397±0.02	320.6±0.35	320.2±1.13	-29.70±0.93	-28.90±0.96
T15	193.70±4.02	273.30±0.96	0.399±0.05	0.274±0.10	458.6±4.30	471.0±1.90	-26.70±3.61	-29.50±3.28
T16	66.08±0.31	68.81±1.27	0.407±0.02	0.382±0.02	323.9±2.43	321.4±2.27	-31.10±1.02	-29.80±0.30
T17	65.22±0.32	64.06±1.19	0.414±0.01	0.370±0.02	306.5±3.91	308.1±1.49	-30.60±1.31	-31.20±1.36
T18	80.68±1.53	89.20±1.86	0.413±0.03	0.438±0.02	336.2±2.00	335.9±0.32	-30.20±4.55	-28.00±3.54
T19	55.76±0.41	66.95±0.92	0.390±0.01	0.334±0.04	288.9±1.41	287.2±1.25	-29.50±1.25	-29.60±0.72
T20	48.19±1.62	62.40±1.63	0.378±0.03	0.356±0.03	298.7±0.26	292.4±0.92	-27.10±1.27	-28.20±1.16
T21	77.38±0.42	85.16±1.61	0.428±0.02	0.345±0.05	313.9±1.59	337.3±1.21	-27.60±3.18	-25.10±2.87
T22	74.18±2.75	109.10±1.00	0.415±0.02	0.296±0.10	332.0±1.97	329.6±0.15	-28.20±1.31	-30.00±1.05
T23	60.40±0.43	62.49±1.03	0.285±0.04	0.358±0.02	222.9±1.55	283.5±0.95	-27.20±1.75	-27.80±1.68
T24	53.52±0.54	69.40±1.44	0.360±0.02	0.336±0.05	284.5±2.20	295.8±0.45	-26.00±3.07	-25.80±3.63
T25	47.29±0.42	66.13±1.17	0.398±0.01	0.335±0.04	279.4±0.87	279.6±2.08	-29.80±1.31	-29.20±1.05
T26	65.22±0.32	75.58±2.60	0.414±0.001	0.398±0.02	306.5±3.91	306.4±0.35	-31.20±0.45	-29.00±1.66
T27	75.57±1.75	87.27±2.60	0.364±0.04	0.331±0.05	317.7±0.46	328.2±2.35	-26.50±3.92	-25.80±2.35
S.Em.	GAxGxSB = 0.82	GAxGxSB = 1.19	GAxGxSB = 1.67	GAxGxSB = 2.94	GAxGxSB = 1.12	GAxGxSB = 1.27	GAxGxSB = 1.46	GAxGxSB = 1.28
C.D. (p≤0.05)	GAxGxSB = 2.34	GAxGxSB = 3.38	GAxGxSB = 4.74	GAxGxSB = NS	GAxGxSB = 3.17	GAxGxSB = 3.61	GAxGxSB = NS	GAxGxSB = NS
C.V., %	2.02	2.51	7.33	13.57	0.61	0.68	-7.64	-6.81

All values are mean values of three replications

study, the significant effect ($p<0.05$) of dipping time on spoilage of tomato fruits was observed. Over a period of time, fruits treated with 5 min dipping in gum arabic nanoemulsion had significantly low ($p<0.05$) spoilage (11.11%) compared to 1 min (36.66%). Similar results were obtained for gum arabic microemulsion. Moreover, gum arabic nanoemulsion treated fruits had significantly slow ($p<0.05$) spoilage rate than its microemulsion. In accordance to this, the nanoemulsion treatment C4 had decay 41.11% on 24 days while the same amount of decay resulted in 15 days of storage for microemulsion coated fruits by same dipping time (treatment C9). Gum arabic nanocomposite coating had extensive efficacy compared to its microemulsion coating due to structural integrity and enhanced effect of its structural components. Hence, low microbial decay was observed in gum arabic nanoemulsion coated fruits compared to its microemulsion coated and uncoated (control) tomato fruits. Similar findings were reported by Gardesh *et al*. (6) who concluded that nanochitosan coating improved the quality and shelf life of apples significantly compared to the fruits coated with conventional chitosan. Breaker tomato ripens in 5 days at temperature above 25°C and thereafter losses cellular or tissue integrity which makes it more vulnerable to pathogenic infection. Therefore, spoilage of control fruits (C) was increased to 43.33% within 9 days of storage.

Physiological loss in weight (PLW) of stored fruit occurs due to migration of the water from the fruit to the surrounding environment. This is associated with respiration and transpiration of the stored commodity. In this study, about 10% physiological loss in weight was considered as end of shelf life of tomato fruits (Patel *et al*., 9). In accordance, the weight loss of stored tomato fruits over a period of time is reported in Table 6. Although, PLW of both gum arabic coated and uncoated fruits was increased under ambient storage, the use of nano and micro emulsion of gum arabic significantly reduced ($p<0.05$) PLW of fruits. Over a period of 9 days ambient storage, lowest weight loss (3.78%) was observed in C4 treatment fruits, 4 min dipping in gum arabic nanoemulsion, and highest weight loss (8.12%) recorded in control fruits. The result could be attributed to the barrier formed between tomato surface and its surrounding environment due to gum arabic coating. PLW of gum arabic

Table 4. Physico-chemical properties of freshly harvested tomato fruits

	Property	Mean value ± SD
Physical properties	Major diameter (mm)	60.57±4.37
	Minor diameter (mm)	52.21±3.41
	Fruit weight (g)	94.4±10.4
	Sphericity	0.87± 0.08
	Bulk density (g/cm^3)	0.58±0.03
	True density (g/cm^3)	0.83±0.04
	Firmness (g)	547.25±129.91
Chemical properties	Moisture (%)	94.6±0.33
	Protein (%)	1.03±0.03
	Fat (%)	1.79±0.13
	Crude fiber (%)	0.7±0.15
	Carbohydrate (%)	1.7
	Ash (%)	0.18±0.02
	pH	3.5±0.03
	Total soluble solids (°brix)	3.5±0.18
	Acidity (%)	0.2983±0.04
	Lycopene content (mg/100 g)	0.5±0.05

All values are mean values of three replications

Table 5. Effect of different gum arabic coatings on spoilage (%) of tomato fruits

	Storage Period (S), days								
Treatment (T)	3	6	9	12	15	18	21	24	Mean
C1	13.33	26.66	36.66	41.11					29.44
C2	8.88	23.33	30.00	42.22					26.11
C3	5.55	15.55	26.66	36.66	41.11				25.11
C4	0.00	3.33	5.55	8.88	15.55	25.55	33.33	41.11	16.66
C5	1.11	5.55	11.11	16.66	21.11	30.00	42.22		18.25
C6	13.33	30.00	43.33						28.89
C7	10.00	26.66	36.66	43.33					29.16
C8	8.88	21.11	33.33	43.33					26.66
C9	6.66	20.00	28.88	31.11	43.33				26.00
C10	6.66	16.66	26.66	33.33	41.11				24.88
C	11.11	30.00	43.33						28.15
Mean	7.77	19.90	29.29	32.96	32.44	27.78	37.78	41.11	
S.Em.		S × T = 1.37							
C.D. (P≤0.05)		S × T = 3.85							
C.V. = 10.71%									

All above values are average of three replications

Table 6. Effect of different gum arabic coatings on PLW (%) of tomato fruits

	Storage Period (S), days								
Treatment (T)	3	6	9	12	15	18	21	24	Mean
C1	2.36	4.41	6.10	8.15					5.25
C2	2.34	4.28	6.07	8.06					5.19
C3	2.50	3.66	5.70	7.19	8.42				5.49
C4	1.80	2.93	3.78	5.50	6.29	6.94	8.61	9.51	5.67
C5	1.87	3.01	4.43	5.88	6.89	7.72	8.84	9.86	6.06
C6	3.11	5.20	7.61						5.30
C7	2.71	4.32	6.92	8.43					5.60
C8	2.54	4.37	7.26	8.28					5.61
C9	1.77	3.79	6.57	7.45	8.92				5.70
C10	1.80	3.68	6.16	7.13	8.63				5.48
C	3.51	5.38	8.12						5.67
Mean	2.39	4.09	6.25	7.34	7.83	7.33	8.72	9.68	
S.Em.	S × T = 0.05								
C.D. (P≤0.05)	S × T = 0.15								
C.V. = 2.01%									

All above values are average of three replications

microemulsion coating for 4 min (C9) increased to 8.92% in 15 days, whereas for the same storage period and dipping time, nanoemulsion coated fruits had PLW of 6.29%. The findings of this experiment show the effectiveness of gum arabic nanoemulsion over microemulsion due to enhanced structural conjugation and integrity of nanoemulsion coating. PLW of C4 treatment fruits was 9.51%, significantly lower ($p<0.05$) than PLW of all other treatments at the end of their respective shelf life. Therefore, gum arabic coating retarded dehydration and shrinkage of tomato fruits during ambient storage.

The data pertaining to the shelf life of tomato fruits as influenced by different treatments of gum arabic coatings, followed by storage at ambient condition are depicted in Figure 2. When 40% of fruits showed symptoms of spoilage during this experimental study, the fruits were considered to have reached end of the shelf life (Patel *et al*., 9). Results of shelf life study revealed that gum arabic nanoemulsion coating (treatment C4) extended shelf life up to 24 days. The minimum shelf life of 9 days was observed in control (C) and treatment C6. The synergetic effect of gum arabic nanoemulsion coating

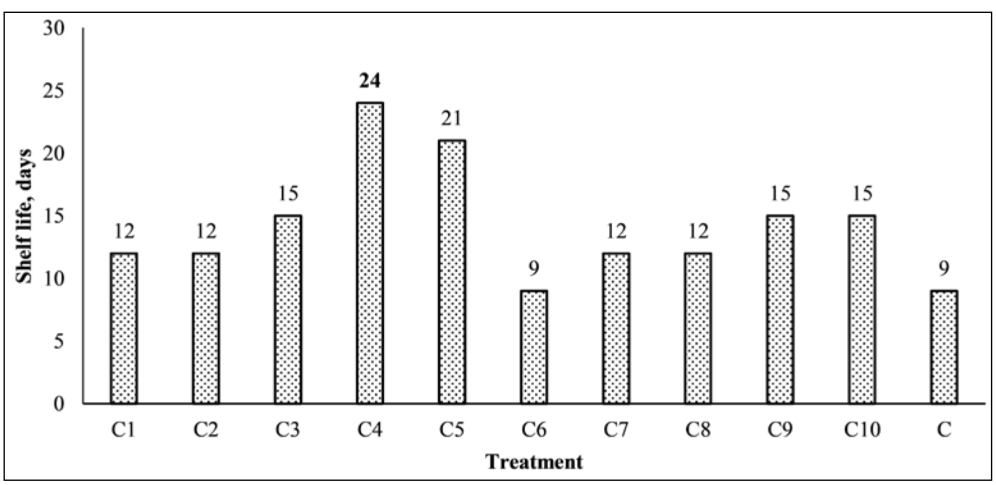

Fig. 2. Effect of different gum arabic coatings on shelf life of tomato fruits

and harvesting stage of tomato (breaker) contributed to the extension of shelf life of coated tomato fruits to 15 days over control. Furthermore, it was observed that the coated tomato fruits were visually same as control, but the surface glossiness of coated tomato fruits increased, giving high consumer acceptance. Ali *et al*. (1) have reported 20 days shelf life of 10% gum arabic coated breaker stage tomatoes stored at 20°C without any spoilage and off-flavour. Moreover, edible coating reduced decay without affecting product quality and extend shelf-life without causing anaerobic respiration. Hence, to study the physico-chemical changes in the gum arabic nanoemulsion coated tomato fruits during storage, fresh tomato fruit sample, coated with 4 min dipping in gum arabic nanoemulsion (treatment C4) was prepared and stored at ambient condition for 24 days along with the control sample.

Gum arabic nanoemulsion coated tomato fruits stored under ambient condition were evaluated to determine the rate of respiration over a period of time and the results obtained are reported in Table 7. The results of this study indicated that even after harvest both treated and control tomatoes continued to respire to maintain their metabolic activities in accordance with the storage conditions. Tomato being climacteric fruit, increase in rate of respiration was observed due to ripening. However, on attaining ripening senescence decreasing trend was observed. Gum arabic nanoemulsion coated fruits had initial respiration rate 12.29 $mLCO_2$/kg/h which increased to a maximum of 25.86 $mLCO_2$/kg/h on the fifteenth day of storage. Thereafter, their respiration rate decreased to a minimum of 11.90 $mLCO_2$/kg/h at the end of shelf-life. Control tomato fruits had a consistent increase in respiration rate from 20.34 to 29.46 $mLCO_2$/kg/h in 9 days shelf life. Hence, gum arabic nanoemulsion coating effectively controlled respiration by partial or complete blockage of pores of the tomato skin through which gas exchange between fruit and atmosphere occurred. This is attributed to potential of edible coating to create an internal modified atmosphere, providing a barrier to oxygen and carbon dioxide. Significant difference ($p<0.05$) in rate of respiration was observed between control and treated tomatoes at the end of shelf life.

Results of firmness of gum arabic nanoemulsion coated and control tomato fruits are presented in Table 7. Firmness of both coated and control tomato fruits gradually decreased to varying degrees as storage period increased. The firmness of gum arabic nanoemulsion coated tomato fruits decreased from 547 N to 227.79 g at a significantly slower rate ($p<0.05$) as compared to control under ambient storage for 24 days. In contrast, firmness of control

Table 7. Physico-chemical changes during storage of freshly harvested gum arabic nanoemulsion coated tomato fruits

Storage interval	Firmness ± SD		Respiration rate ± SD		Colour						TSS ± SD		pH ± SD		Acidity ± SD		Lycopene ± SD	
					L* value ± SD		a* value ± SD		b* value ± SD									
	g		$mLCO_2$/kg/h								°Bx				%		mg/100 g	
	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C
Days																		
3	432.29 ± 41.90	380.66 ± 15.50	12.29 ± 0.03	20.34 ± 0.22	57.14 ± 1.65	50.96 ± 0.85	0.92 ± 0.02	3.88 ± 0.11	34.43 ± 0.47	27.73 ± 1.43	3.63 ± 0.14	3.76 ± 0.22	3.66 ± 0.07	3.73 ± 0.11	0.29 ± 0.01	0.29 ± 0.02	0.60 ± 0.10	0.76 ± 0.05
6	403.45 ± 48.54	269.70 ± 15.14	14.37 ± 0.13	28.10 ± 0.59	50.80 ± 0.38	43.17 ± 0.65	5.87 ± 0.11	14.37 ± 0.54	30.14 ± 0.76	20.73 ± 0.61	3.87 ± 0.09	4.14 ± 0.23	3.75 ± 0.07	3.82 ± 0.17	0.27 ± 0.02	0.22 ± 0.02	1.02 ± 0.14	2.18 ± 0.55
9	376.20 ± 20.10	222.26 ± 13.29	17.44 ± 0.33	29.46 ± 0.14	45.71 ± 1.23	30.79 ± 0.46	13.45 ± 0.53	27.08 ± 0.77	23.52 ± 1.61	18.45 ± 0.26	4.04 ± 0.14	4.85 ± 0.09	3.76 ± 0.08	4.07 ± 0.05	0.25 ± 0.04	0.17 ± 0.02	1.90 ± 0.13	4.82 ± 0.36
12	334.71 ± 25.27		23.97 ± 0.23		38.91 ± 0.73		21.36 ± 0.63		20.89 ± 0.85		4.26 ± 0.11		3.86 ± 0.04	0.21 ± 0.03	0.23 ± 0.03		2.80 ± 0.15	
15	284.73 ± 9.01		25.86 ± 0.12		35.26 ± 0.54		28.32 ± 0.71		19.22 ± 0.82		4.38 ± 0.04		3.92 ± 0.05	0.19 ± 0.05	4.00 ± 0.56			
18	268.67 ± 2.47		24.28 ± 0.01		34.03 ± 0.83		30.63 ± 0.94		18.30 ± 0.25		4.61 ± 0.25		3.97 ± 0.02	0.14 ± 0.01	4.46 ± 0.11			
21	246.63 ± 18.68		13.29 ± 0.40		34.04 ± 1.56		31.58 ± 0.60		17.35 ± 0.10		4.84 ± 0.10		4.11 ± 0.12	0.12 ± 0.00	5.37 ± 0.31			
24	227.79 ± 36.27		11.90 ± 0.16		32.60 ± 0.29		31.96 ± 0.79		17.27 ± 0.10		5.05 ± 0.08		4.19 ± 0.08		5.62 ± 0.31			

Abbreviations: NC, Gum arabic nanoemulsion coated fruits; C, Control fruits; SD, Standard deviation. All values are mean values of three replications tomato fruits rapidly declined from initial firmness of 547 to 222.26 g in 9 days. While for the same storage period, nanoemulsion coated tomato fruits retained firmness to 376.20 g. During the ambient storage of tomato fruits, degradation of the structural components necessary to strengthen the cell wall and the adhesion of cells caused softening of both coated and uncoated fruits. This is due to cell wall-modifying activity of several enzymes, including polygalacturonase, pectin-methyl-esterase, endo-β-mannase, α- and β-galactosidases, and β-glucanases (Athmaselvi *et al*., 3). However, gum arabic nanoemulsion coating of tomato fruits slowed down rate of respiration and thereby ripening of tomato fruits. Thus, retained firmness of the fruits for the extended shelf life. Earlier Athmaselvi *et al*. (3) concluded that the coating of fruits and vegetables was the most effective treatment to retard the softening compared to control.

Tomato fruits harvested and treated at the breaker stage, which were green in colour. Storage of both treated and control tomato fruits resulted into change in colour from green to red. It is attributed to the ripening of the tomato fruit. During the ripening process green pigment (chlorophyll) degrades to chromoplasts and red carotenoid pigments are synthesised. The changes in colour of gum arabic nanoemulsion coated and control tomato fruits are shown in Table 7. The results showed gum arabic nanoemulsion coating delayed colour change and significant difference ($p<0.05$) in L*, a*and b* colour values of both coated and uncoated (control) tomato fruits was found. The L* value (lightness) of gum arabic nanoemulsion coated and control tomato fruits was decreased with the increase in storage period. Accordingly, b* value of both control and nanoemulsion coated tomato fruits decreased until the end of storage life. In contrast, a* value, represents greenness to redness of tomato fruits increased with the increase in storage period. In this study, significant increase in a* value was noted during first initial days of storage and then showed slow changes, as lycopene (red colour) and β-carotene (orange colour) achieved their peaks. This is due to gum arabic nanoemulsion coating which provided a barrier against gas exchange between inner and outer environments which delayed colour change. Rate of change of L*, a* and b* colour value of control fruits was double in comparison to gum arabic nanoemulsion coated fruits. These results are similar to the previous reports for coated tomato by Das *et al*. (5) and Athmaselvi *et al*. (3).

In the present investigation, gum arabic nanoemulsion showed significant effect on TSS of fruits when compared with control and the results are presented in Table 7. TSS of gum arabic coated tomato fruits changed from 3.63 to 5.05 °Bx on 24 days storage. However, control fruit had TSS of 4.85 °Bx within 9 days storage. Where at the 9 days, nanoemulsion coated tomato fruits were having TSS of 4.04 °Bx. TSS increased during the storage and ripening due to degradation of polysaccharides to simple sugars. Gum arabic coated fruits decreased rate of respiration, thereby slowed down the metabolic activity and hence resulted in lower TSS.

Change in acidity and pH of gum arabic coated and uncoated tomato fruits over a period of time is shown in Table 7. Acidity of both gum arabic nanoemulsion coated and control tomato fruits decreased throughout the shelf life. In contrast, pH of stored tomato fruits was increased. Minimum acidity of 0.12 and 0.17% were recorded on 24 and 9 days of storage in gum arabic nanoemulsion coated and control fruits, respectively. Control tomato fruits attained pH of 4.07 in 9 days, whereas, in gum arabic nanoemulsion coated tomato fruits had delayed catabolic activity and took 21 days to reach the pH of 4.11. The acidity was retained significantly higher ($P<0.05$) whereas pH was remained lower in gum arabic nanoemulsion treated fruits compared to the control. These results are attributed to high respiration rate of control fruits compared to coated fruits. Substrates for respiration are organic acids, such as malic or citric acid. Hence a rapid reduction in acidity and increase in pH is expected in highly respiring fruit.

Lycopene is the red colour pigment, synthesized during ripening of tomato fruits which represents 98% of carotenoid in tomato fruits giving the characteristic red colour. The results of influence of gum arabic nanoemulsion coating on lycopene content is presented in Table 7. There was a steady increase in the lycopene content of both control and gum arabic nanoemulsion coated tomato fruits throughout storage. In gum arabic nanoemulsion coated tomato fruits, lycopene content increased up to 5.62 mg/100 g till 24 days storage. However, the lycopene content of control fruits increased up to 4.82 mg/100 g during its shelf-life of 9 days. Rate of synthesis of lycopene was double in control as compared to treated fruits. Significant difference ($p<0.05$) in the lycopene content of both treated and untreated tomato fruits resembles to difference in their metabolic activity owing to gum arabic nanoemulsion coating.

It can be concluded from the present study that synthesised nanoemulsions contained 1% gum arabic, 0.5% glycerol, 1.5% sodium benzoate was found to be most stable at the end of 30 days ambient storage. Efficacy of nanoemulsion, prepared using most stable formulation, to extend the shelf life of the tomato fruits stored under ambient condition was determined. Gum arabic nanoemulsion was found to be the most effective coating for the prolonged storage of tomato fruits under ambient condition. Storage study revealed that extended shelf life of 24 days was obtained for tomato fruits coated by 4 min dipping in the gum arabic nanoemulsion, having advantage of 15 days over control. Furthermore, the gum arabic nanoemulsion coating delayed ripening and retained physico-chemical attributes of tomato fruits over extended shelf life. Hence, it can be concluded that the gum arabic nanoemulsion coating is a promising technology to retain the quality and to extend the shelf life of tomato fruits during ambient storage.

AUTHORS' CONTRIBUTION

Conceptualization of research (RFS); Designing of the experiments (KAV, RFS); Contribution of experimental materials (RFS, GBP); Execution of field/lab experiments and data collection (KAV, MCM); Analysis of data and interpretation (BBP); Preparation of the manuscript (BBP).

DECLARATION

The authors declare that they do not have any conflict of interest.

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