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Amelioration of Noodles' Nutritional Values via Nano-Encapsulation of Extracted Lycopene from Tomato Waste

Nahla M.M. Hassan, Mohammad, F.M. Abdulla, Amira M.A. Abd El- Salam and Sahar S. El-Gohery

Bread and Pastry Research Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt

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ABSTRACT

The by-product of tomato processing contains seeds and peels. Tomato lycopene is a potential antioxidant sensitive to heat and light and protects against chronic diseases like cancer and heart disease when applied to a food additive. This problem can be addressed by extraction with SCF-CO_2 and encapsulation using sodium alginate. This study aimed to evaluate the effect of adding an extract and encapsulating lycopene extract from tomato waste on noodles' antioxidant properties and sensory acceptability. The sensory and physicochemical characteristics of the dried noodles were evaluated. Total phenols, flavonoids, FRAP, ABTS scavenging, and DPPH radical scavenging activities were used to determine antioxidant activities in extracted lycopene and nano-encapsulated. Lycopene nano-encapsulated had the highest level of FRAP content (459.33 µg/mg) and extracted lycopene had the lowest level (349 µg/mg), respectively. The encapsulated lycopene sample improves sensory qualities particularly the color of the noodles. The sample that contained nano-encapsulated lycopene had the highest sensory score for color, 9.23, whereas the sample that contained extracted lycopene scored 9.02 and the control sample scored 8.72. This shows that the processing did not negatively affect the encapsulated sample. These results indicate that the produced nano-capsules may be used in the food industry as potential ingredients in developing functional foods to improve health benefits. Thus, tomato waste powder may be a cheap source of functional noodles and food items.

Keywords: tomato wastes, lycopene, encapsulation, sodium alginate, sensory attributes, antioxidant properties

1. Introduction

Globally, tomatoes are the most widely grown fruit and vegetable crop. (Nayik and Gull, 2020). Tomatoes are rich in phytochemicals and vitamins (Encyclopedia Britannica, 2018). The high quantity of bioactive chemicals in tomatoes, especially ascorbic acid, phenolic compounds, β-carotene and lycopene makes them beneficial for human consumption (Palestina *et al.,* 2021). Lycopene is one of the important compounds found in tomatoes. The increased use of tomato products means that tomatoes provide more than 85% of the required lycopene (Amiri-Rigi and Abbasi, 2016).

Tomatoes' rich red color is a result of lycopene. According to several studies, consuming tomatoes may improve human health (Unlu *et al.,* 2007), reduce the risk of various cancers, especially those of the prostate and breast (Kapała *et al.,* 2022), and potentially prevent cardiovascular diseases (Mordente *et al.,* 2011). Most bioactive compounds such as lycopene easily break down in the presence of heat, light, oxygen, and other environmental factors. Although lycopene's sensitivity to light and heat (Jatau *et al.,* 2017), encapsulation can help with this problem (Silva *et al.,* 2014 and Doronio *et al.,* 2022). Green chemistry using nanotechnology can encapsulate the material with less harmful chemicals, which makes it environmentally friendly.

Lycopene's stability and effectiveness can be improved by encapsulating it to protect it from extreme environmental (Sarong *et al.,* 2020 and Eugenio *et al.,* 2021).

Corresponding Author: Nahla M.M. Bread and Pastry Research Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt.

Noodles are the main source of carbohydrates and a good option for wheat products in many Asian diets. For this reason, noodles might be a great way to encapsulate nutrients such as bioactive compounds and dietary fiber like carotenoids, and phenolics absent in wheat flour.

Fruit processing residues, such as seeds, peels, and pomace, are enriched in phytochemicals that can be added to food to provide functional benefits (Marcillo-Parra *et al.* (2021), Islam *et al.* (2021) and Dinani and Van Der Goot, (2022)). Therefore, encapsulated tomato peel powder for making functional wheat-based noodles can be an alternative to ensure that an individual's diet contains an acceptable amount of bioactive components. Many bioactive food ingredients would have a longer shelf life due to the encapsulation method, allowing for the controlled distribution of functional compounds. (Gharsallaoui *et al.,* 2007).

This study aims to evaluate the possible use of encapsulating tomato waste-derived lycopene pigment, a naturally occurring source of bioactive components, in the creation of functional noodles. As a result, the quality factors for the produced noodles, including their sensory evaluation, antioxidant activity, and cooking properties, were also evaluated.

2. Materials and Methods

2.1. Materials

The tomato fruits were purchased from a local market in 6th October City, Giza, Egypt. Wheat flour 72% was commercially taken from Company South Giza Mills, 6th October City, Egypt. All other chemicals chosen were of high-quality analytical grade.

Preparation of tomato waste (skin and seeds) powder

Tomatoes were cleaned with tap water to get rid of dust and other unwanted particles from the surface. The tomatoes were blanched in warm water (80°C, 15 min) to facilitate the removal of the peel. The peels and seeds were removed manually, sun-dried (32°C) to constant weight, milled in a hammer mill, separately packaged in plastic bags, and kept in a cool and clean place until used.

2.2. Methods

Tomato waste supercritical fluid carbon dioxide extracts (TWSCF-CO_2)

The lycopene extracts sample (fig.1) from tomato waste were prepared using a laboratory-scale equipment at the National Research Center (Speed TM SFE-2/4, Applied separations, developed in association with the USDA1-USA) at 50°C and 250 bar of pressure, respectively. and according to (Azza *et al.,* 2023). 150 grams of tomato waste powder was added to the container and closed well to prevent gas leakage. After being pumped into the reactor, which was supported by two 300 vessels, the CO_2 was left in place for 30 minutes to allow for full contact and ensure the pressure and temperature within the reactor were stabilized. The mass flow rate of CO_2 was 1.0 g/min. To recover the deposited extract, the samples were collected and the process line rinsed with used ethanol. The global extract yield can be calculated as Xo (%) (Extraction + cleaning process) to the initial mass of raw material (dry basis).

At the end of the extraction methods, the tomato waste yield was obtained and calculated as follows:

$$\text{Yield (\%)} = ((W1/W2) \times 100) \qquad (1)$$

Where: W1 is the weight (in grams) of the tomato waste extracts, and W2 is the weight (in grams) of the dried raw tomato waste powder.

Preparation of Nano-encapsulation

The extract of bioactive compounds from tomato waste obtained using SCF-CO_2 was encapsulated in sodium alginate using nanotechnology. By dissolving 3 grams of sodium alginate powder in 100 milliliters of deionized water, a 3% solution of sodium alginate was obtained according to the method of Eman *et al.* (2023) with continuous stirring using a magnetic stirrer for 60 minutes at 2000 rpm and stored at 4 degrees Celsius in a refrigerator. For 12 hours to form a gel state and swelling. Nanoemulsions were prepared using an oil-in-water system, and 1.5 ml of deionized water was added to each 1.4 g of sample extract (approximately 1:1 w/v ratio) and 1% emulsion (Tween 20). The mixture was made by adding water gradually to prevent air bubbles during homogenization at room temperature with a magnetic stirrer running at 2000 rpm until complete dissolution and then subjecting the mixture to a high-speed homogenizer for 20 minutes at 20,000 rpm (Model: 400 ELPC, PRO Scientific Inc., 01- 02411ELPC Homogenizer, USA American) in an ice water bath to lower the mixture's temperature, and all samples were kept for a full day at 4°C before being packaged.

To make nanocapsules, the previously made nanoemulsion was progressively mixed with 25 milliliters of 3% sodium alginate solution. Stirring was done using an ultra-high-speed homogenizer at 20,000 rpm for 15 minutes. The mixture was applied using an ultrasonic probe (MTI Corporation, model UD150SH3.8LQ, USA) for 20 min. At 30°C. Then keep it in tightly closed brown containers at a temperature of 4 degrees Celsius until needed (Fig.1).

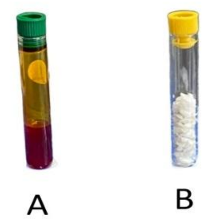

Fig. 1: Extraction and Nano-encapsulation results.

(A): Lycopene extract obtained from tomato waste. (B): nano-encapsulation of extract.

Identification of lycopene by HPLC analysis

High-performance liquid chromatography in reversed-phase with UV detection set at 475 nm was used for analyzing lycopene. Chromatographic conditions: Using a Supelcosil LC-18 analytical column measuring 3µm by 150× 4.6 mm (Supelco, USA), the mobile phase was supplied at a flow rate of 1.0 ml /min and contains methanol, acetonitrile, and tetrahydrofuran (70:25:5, % v/v). Before being used, the mobile phase was sonicated to get rid of any gas. The injection needle was cleaned with the blank solution in between each sample. Astaxanthin and lycopene had retention durations of 14.2 and 3.0 minutes, respectively **(Udayakiran *et al.*, 2009).**

Chemical properties

Total phenolic content (TPC)

The method of Folin–Ciocalteau was used to specify the total phenolic content as reported by Singh *et al*. (2002). The following ingredients were combined: 2.0 ml of H_2O, 1.0 ml of 15% Na_2CO_3 solution, 0.2 ml of Folin-Ciocalteu reagent, and 100 ml of tomato waste extract. Using a Jenway 6300 spectrophotometer, the color was measured at 765 nm after two hours of storage at room temperature. The standard curve of gallic acid was prepared and then the total phenolic concentration was measured. Total phenol content is expressed in the gallic acid equivalent (GAE mg/g of extracted compounds).

Total flavonoids content (TFC)

The estimation of the flavonoids content overall was made by Kumaran and Karunakaran, (2007). Glacial acetic acid was added to ethanol to dissolve aluminum trichloride. Using quercetin as a standard, the absorbance of all working and standard solutions was measured at 415 nm against a methanol blank. The quercetin standard calibration curve was used to assess the flavonoid concentration of the extracts. The flavonoid values were expressed as mg of quercetin equivalent per g of extracted compounds.

Antioxidant activity

DPPH radical scavenging activity

The 2,2-diphenyl-2-picryl-hydrazyl (DPPH) method was used to assess the free radical scavenging activity according to Alachaher *et al.* (2018). Ten µL of the extract was combined with 1ml of 0.1mol/L DPPH in methanol. Following a 30-minute dark incubation period at room temperature, a spectrophotometer was used to measure the mixture's absorbance at 517 nm. (Shimadzu model 1601, Japan).

Scavenging Activity of ABTS Radical

The activity of ABTS radical scavenging was measured by Re *et al.* (1999). A reaction between 140 m M potassium persulfate solution and a 7 mM ABTS stock solution produced the radical cation ABTS. Before being used, this solution was kept at room temperature in the dark for 12 hours. After six minutes, 10 µl of extract aliquot absorbance was measured at 734 nm with 1 ml of ABTS solution.

Ferric-reducing antioxidant power (FRAP)

The FRAP assay was carried out according to agreement with Athamena *et al.* (2019). Labeled Eppendorf tubes were filled with 40 ml of the sample, 50 ml of 10% trichloroacetic acid, 50 ml 1% of potassium ferricyanide ($K_3Fe (CN)_6$), and 50 ml (0.2 mol /L) of sodium phosphate dihydrate (Na_2HPO_4. $2H_2O$) buffer. The mixture was centrifuged for ten minutes at 3,000 rpm. Following centrifugation, 166.66 milliliters of each sample's supernatant and 33.3 milliliters of ferric chloride (1% $FeCl_3$) were put to 96-well plates. Using a microtiter plate reader (Biotek ELX800; Biotek, Winooski, VT, USA), readings were obtained at 630 nm. Ascorbic acid (1 mg/ml) served as the positive control, while DMSO served as the negative control. Ascorbic acid equivalent (AAE), or µg/mg of extract, is used to express the results.

Preparation of noodles

The noodles were prepared using 72% ext. wheat flour with extracted and encapsulated lycopene by Park *et al.* (2004). The ingredient list for the noodles was 100 g of wheat flour combined with the needed amount of water. Noodles samples were made by replacing wheat flour with lycopene that had been extracted and encapsulated such as 0% (control), 1% non-encapsulated lycopene, and 1% Nano-encapsulated lycopene. The mixing process took 8 minutes after adding all of the water. The pre-mixed dough was put in the Demaco molder's vacuum mixer (Demaco, De Francis machine corporation, Germany) at 25°C and 21 rpm. The noodles were steamed for 3-4 min.

Nutritional analysis

Crude fiber, protein, fat, moisture, and ash content were measured using the technique in A.O.A.C. (2016). The total carbohydrate content was calculated using a difference in dry weight.
- Minerals content (Ca, Mg, Na, K, Fe, Zn, and Mn) was determined. Microwave Plasma - Atomic Emission Spectroscopy, or MPAES4210 (Agilent, Mulgrave, Victoria, Australia) was used as a microwave digester (Multi-wave GO Plus 50 HZ) before the spectrophotometric assessment of the samples according to Agilent Technologies, Inc. (2021).

Cooking Quality

Noodle sample were analyzed for cooking loss as estimated by A.A.C.C. (2000). After cooling, the cooked noodles were weighed again. Grams were used to calculate the cooked weight, as Kamble *et al.* (2018).

Noodle and tomato waste color analysis

Using the CIE L*a*b* system, we used a Chroma-meter (Minolta, Tokyo, Japan) with a D65 illuminant to assess the color of the dry noodle sheets and the optimally cooked noodle samples. The lightness, redness, and yellowness were measured using the L*, a*, and b* measurements obtained directly from the instrument. Every measurement was taken out three times (Lee *et al.,* 2013).

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \text{……………………..…………………}(2)$$

where, in respect to parameters at time zero, the variations of the a* coordinate are denoted by Δa*, b* by Δb*, and L* by ΔL*.

Noodle Texture Analysis

The texture method (Steven Farnell QTS 25 Texture Analyse) was used to measure the hardness of each product. According to Diwakar *et al.* (2016), the glossiness was evaluated using the Pro Glass Version 1.0 Model PRO-6 and PRO-3, Hunter Associates Laboratory (Virginia, USA).

Water Activity

The water activity (aw) of the dried samples was measured by using the Rotronic Hygrolab 3CH-8303, (Switzerland) aw meter followed by Cadden (1988). All measurements were conducted in triplicate.

Sensory evaluation of noodles

Ten panelists from the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt's Bread and Pastry team evaluated the cooked noodles' sensory qualities for (appearance, color, taste, texture and odor) (Watts *et al.,* 1989) until otherwise stated.

Statistical Analysis

The statistical software package, SPSS version 25.0 (IBM Corp., Armonk, NY), was used for all statistical analyses. ANOVA and means comparisons between the two groups were used to compare means. $P < 0.05$ was considered the threshold for statistical significance. Standard deviation (SD) ± mean ($n = 3$) is used to express the data by Snedecor and Cochran (1980).

3. Results and discussion

3.1. Physicochemical characterization of fresh and tomato waste

Table (1) shows the color and moisture level of fresh tomatoes and also the tomato waste. Results showed that the fresh tomato had a 91.32% moisture content. According to Celma *et al.* (2012), who reported that high moisture contents vary from 63.3% to 92.7%. While the color values (a*, b*) of the tomato waste showed a significant decrease in comparison to the fresh tomato, the L* value of the tomato waste was the greatest.

Table 1: Physiochemical properties of fresh and waste tomatoes from local tomatoes.

Tomato samples	Moisture content (%)	Color value			
		L*	a*	b*	Δ E*
Fresh tomato	91.32 ± 0.02	35.93 ± 0.01	25.52 ± 0.02	23.75 ± 0.05	23.27 ± 0.02
Tomato waste	6.57 ± 0.01	55.43 ± 0.03	17.39 ± 0.07	15.36 ± 0.05	14.66 ± 0.04

Color is another important indicator of quality; drying affects it, making the color lighter and less highly red. Additionally, 40% of the seeds and 60% of the skin (epidermis) make up the industrial by-product of dried tomatoes, which is comparable to other tomato by-products from Tunisia (35% and 65%) and Brazil (38.5 and 61.5%) (Silva *et al.,* 2019 and Kehili *et al.,* 2019).

The mineral content of tomato waste powder is shown in Table (2). Tomato waste is a good source of some minerals and antioxidants. Potassium had the highest concentration of macro elements (40120 mg/kg), followed by magnesium (1597 mg/kg) and calcium (1304.39 mg/kg).

Table 2: Mineral content of tomato waste (mg/kg) *

Sample	Ca	Mg	Na	K	Fe	Zn	Mn
Tomato waste powder	1304.39	1597	3220	40120	93.41	32.22	12.2

* calculated on a dry weight basis.

In addition, the waste from tomatoes contains trace elements including iron, manganese, and zinc. These elements function as cofactors for antioxidant enzymes and help in the defense mechanisms by scavenging free radicals. These findings corroborated those of González *et al.* (2011), who found that K, Mg, Ca, and Na are the main elements found in tomato peels. According to these findings, tomato peels are a great source of antioxidant minerals, particularly calcium, zinc, and manganese, which support antioxidant enzymes in vivo and help in the body's defense against cancer.

3.2. Identification of lycopene in tomato waste by High-performance Liqued Chromatography (HPLC)

The HPLC separation and identification of lycopene pigments obtained from tomato waste are displayed in Figure (2). The lycopene is true carotenoid, was identified by HPLC separation as having a represented value of 14.22 µg/ml. The results are in agreement with the conclusions reached by Rizk *et al.* (2014). They demonstrated that whereas phytoene and β-carotene were concentrated, lycopene accounted for the majority of pigments in tomato waste (86.13%).

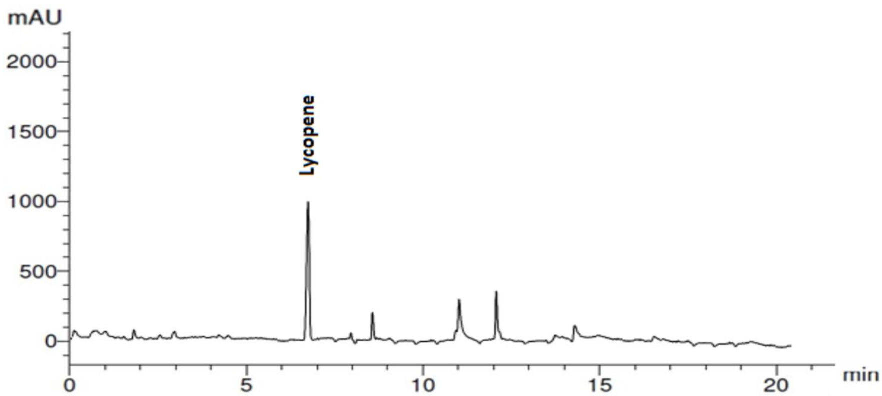

Fig. 2: Identification of lycopene pigment extracted from tomato waste.

3.3. Proximate chemical composition

The proximate compositions of wheat flour, tomato waste powder, and noodles with control, extracted lycopene, and encapsulated lycopene were presented in Table (3). The largest percentage of ash was found in tomato waste powder (4.88%), while the lowest rate was found in wheat flour (0.56%). As a result, lycopene encapsulation in noodles increased the ash content of the noodles by 1.1%, 1.4%, and 1.6% with control, extracted, and encapsulated lycopene, respectively. The quantity of minerals in the sample can be attributed to the ash content (Ismail, 2017). As a result, the improved noodles' lycopene addition may have increased their mineral content. The samples' total protein contents varied from 9.93% to 17.28%. The amount of protein in tomato waste powder and wheat flour is essential as it affects the cooking quality of noodles (Feillet and Fabr, 1988). Therefore, adding lycopene to the produced noodles can increase their protein content. As expected, the study found that the noodles prepared with non-encapsulated lycopene had a higher protein level (10.05%) than the control noodles (9.93%). The lycopene-encapsulated noodles had a slightly higher fat content than the control. This might be due to lycopene having (2.29%) more fat than wheat flour, which has (0.84%). From a nutritional perspective, noodles with a high-fat content are beneficial, and tomato peel oil has the potential to be an excellent edible plant oil that benefits human health because of its phenolic components and fatty acid composition (Del *et al.,* 2019). However, it could not be desired due to fat rancidities during storage, which could give to the final product an unpleasant taste and flavor (Gotoh *et al*., 2007). Notably, Interestingly, the highest percentage of crude fiber (51.42%) was found in tomato waste powder. This was to be expected as lycopene encapsulation in the noodle formulation improved the rate of fiber in noodles produced with non-encapsulated lycopene (0.93%), nano-encapsulated lycopene (0.81%), and control (0.68%). Additionally, consuming fiber has been associated with a decreased risk of diabetes, inflammation, and colorectal cancer (Riva *et al.,* 2019). The lycopene-encapsulated noodles had an 87.14% carbohydrate content, which was lower than that of the control group (87.31%), which was followed by the non-encapsulated lycopene (86.78%). In this study, the lycopene-encapsulated noodles supply a moderate quantity of carbs. Thus, for potential health benefits, people with diabetes can include lycopene-encapsulated noodles in their meals.

Table 3: Chemical composition of raw materials, and noodle samples (%on dry weight basis) .

Samples	Chemical composition (%)				
	Protein	Fat	Ash	Fiber	Total carbohydrate
			Raw materials		
Wheat flour (72%)	10.63 ± 0.03	0.84 ± 0.01	0.56±0.03	0.44±0.03	87.53 ±0.03
Tomato waste powder	17.28 ± 0.02	2.29 ± 0.01	4.88±0.02	51.42±0.01	24.13 ±0.02
			Noodle samples		
Noodle (control)	9.93[c] ± 0.02	0.87[a] ± 0.02	1.11[b]±0.01	0.68[c]±0.05	87.41[a]±0.01
Noodle with extracted lycopene	10.05[b] ± 0.03	0.90[a] ± 0.10	1.14[ab]±0.03	0.93[b]±0.01	86.98[c]±0.01
Noodle with lycopene nano-encapsulate	9.98[a] ± 0.01	0.91[a]±0.01	1.16[a]±0.01	0.81[a]±0.03	87.14[b]±0.01

Data are presented as mean ±SD.
Any two means with the same letters at the same column are not significant at $P \leq 0.05$

3.4. Color value of dried noodles

Dried noodle color is an important quality characteristic that directly affects customer acceptance Aranibar *et al.* (2018). It is dependent on the raw material's properties and the processing method Zardetto and Dalla Rosa, (2009). The color of the noodles in this study was influenced by the raw ingredient that was added. Noodle color parameters are shown in Figure (3) as L* (lightness), a* (redness–greenness), b* (yellowness–blueness), and (ΔE*) (total color difference). The incorporation of both extracted and encapsulated lycopene had a significant effect on the color of dried noodles. As expected, with the addition of these extracts, the color of the noodles became darker, and their level of redness and yellowness increased. Compared to extracts contained in nanoparticles, free extracts had a stronger effect on the color of the noodles.

The noodles with free extracts had far lower ΔE* values than the extracts that were encapsulated. The extracted lycopene sample shows lower lightness (L*) values than the control sample, but it has higher redness (a*) and yellowness (b*) values. The color differences between the control and enriched samples are defined by the color differential index (ΔE*) (Ozgoren and Yapar, 2019). Noodles' ΔE* values increase when lycopene supplementation levels increased. The color differential indexes for the dried noodles varied from 16.79 to 17.67.

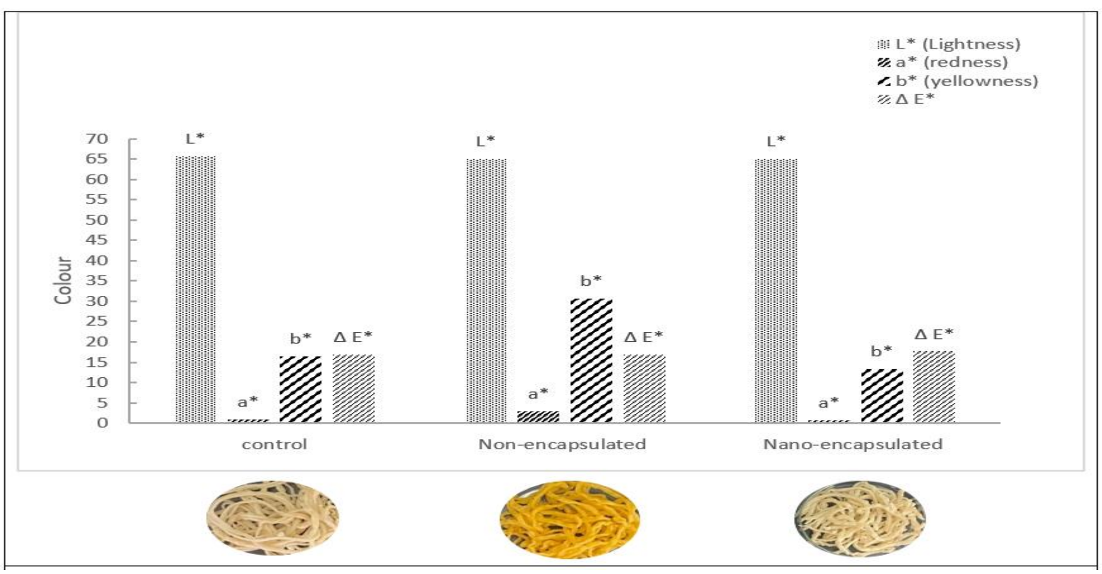

Fig. 3: Color value of dried noodles.

During cooking, the Maillard reaction occurs between reducing sugars and proteins may be the cause of the redness and yellowness that significantly increased with non-encapsulated lycopene and then gradually decreased with encapsulated lycopene (Mohamed *et al.,* 2010).

3.5. Physical and technical characterization of fresh noodles

Table (4) presents the physicochemical properties and indicators of these noodle formulations' quality. The formulations' water activity (aw) levels matched those of fresh noodles. Foods naturally include water activity, which prevents microbiological growth (Armellini *et al.,* 2018). Noodles with Nano-capsulated lycopene have lower water activity values (aw) than the other components in the control.

The water absorption in noodles was decreased in the presence of lycopene encapsulation (Table 4). After cooking, the control sample showed the highest water absorption percentage (%), followed by the Nano-encapsulated lycopene and oil Non-encapsulated noodles, respectively. The lycopene-enriched noodles' decreased water absorption (%) can be caused by a variety of factors. Lycopene-enriched noodles, for example, can produce a higher protein network that inhibits the starch granules' ability to absorb water and, as a result, prevents them from swelling (S¨ozer and Kaya, 2003).

Table (4) shows the results for the lycopene-enriched noodles' cooking quality (weight and cooking loss). The cooked weight of the lycopene-encapsulated noodles (32.30) is less than that of the control noodles (38.50). The lycopene-enriched noodles showed a significantly higher cooking loss in comparison to the control sample. The increased cooking loss of the encapsulated noodles could be caused by a number of variables, such as modifications to the noodles' water-holding capacity, gluten-protein network, and carbohydrate and fiber content. For example, Kim *et al.* (2016) discovered that the addition of fiber in pasta raised cooking loss by affecting the water's diffusion and weakening gluten networks. According to this study (Fu, 2008), cooking loss of 12% or less is seen to be indicative of high-quality pasta. This finding was supported by the decrease in the cooked weight of the noodles caused by the increase in cooking loss. Therefore, the lycopene non- encapsulated and lycopene-encapsulated noodles showed a cooking loss of 8.14 and 8.55%, respectively. They can thus be considered as high-quality noodles.

Hardness is measured instrumentally as the peak force of compression. Noodles of the highest quality should be extremely hard (Udachan and Sahoo, 2017). In this study, the addition of lycopene resulted in a decrease in the hardness values of the samples; however, no significant difference was found in all three types. Nochai and Pongjanta, (2013) found that when the lycopene content in the wheat noodle sample increased, the hardness decreased.

Table 4: Cooking quality of cooked dried noodles with tomato lycopene supplement

Noodle samples	aw	Cooking time (min.)	Water Absorption (%)	Cooking Loss (%)	Cooked Weight (g)	Hardness (N)
Control	$0.931^{a} \pm 0.001$	$6.12^{a}\pm0.02$	$150.44^{a}\pm0.02$	$7.91^{c}\pm0.01$	$38.50^{a}\pm0.50$	$3.24^{a}\pm0.01$
Oil lycopene Non-encapsulate	$0.926^{a}\pm0.004$	$6.15^{a}\pm0.05$	$116.74^{c}\pm0.04$	$8.14^{b}\pm0.02$	$32.84^{b}\pm0.02$	$2.21^{b}\pm0.01$
Nano-encapsulated lycopene	$0.910^{b}\pm0.010$	$6.20^{a}\pm0.20$	$122.14^{b}\pm0.04$	$8.55^{a}\pm0.05$	$32.30^{b}\pm0.10$	$3.30^{a}\pm0.20$

Data are presented as mean ±SD.
Any two means with the same letters at the same column are not significant at $P \leq 0.05$

3.6. Antioxidant activity

Total phenolic contents, total flavonoids, DPPH radical scavenging activity, FRAP and ABTS scavenging (%) of tomato waste powder, oil extract (non-encapsulated), and nano-encapsulated lycopene were presented in Table (5). The tomato waste powder was found to have a high total flavonoid content of 5.31 mg QE/g, a good total phenolic content of 10.85 mg GAE/g, and a great free radical scavenging activity (DPPH) of 38.22%. The levels of total phenolic were 2.40 mg/g on a dry weight basis, according to Ammar and Aboalfa (2017).

Table 5: Phytochemical properties of tomato powder, oil extract, and their nano-encapsulated

Samples	DPPH radical scavenging activity (%)	FRAP (equivalent (AAE) µg/mg of Sample)	ABTS Scavenging (%)	Total phenols contents (mg GAE/g)	Total Flavonoid (mg QE / g)
Tomato waste powder	38.22^{c} ±0.10	186.22^{c} ±0.02	18.26^{c} ±0.02	10.85^{c} ±0.05	5.31^{a} ±0.01
Oil extract	66.9^{a} ±0.40	349.0^{b} ±1.00	83.1^{a} ±0.10	19.86^{a} ±0.04	11.48^{a} ±0.02
lycopene nano-encapsulated	57.7^{b} ±0.20	459.33^{a} ±0.03	45.1^{b} ±0.10	12.45^{b} ±0.05	9.54^{b} ±0.04

Any two means with the same letters at the same column are not significant at $P \leq 0.05$

The total phenols content of extracted lycopene and encapsulated lycopene extract were 19.86 mg GAE/g extract and 12.45 mg GAE/g sample, respectively, as shown in Table (5). Tomato variety and maturity level, postharvest method, storage conditions, drying process, extraction method, type of solvent, and other factors all affect the total phenol concentration of lycopene extract. Varieties may affect a substance's chemical composition, rheology, hardness, and structure (Ghasemzadeh *et al.,* 2018). The encapsulation method and the ratio of coating to core material had an effect on the total phenol content of the encapsulated lycopene.

Table (5) indicates that the lycopene extract's total flavonoid content was 11.48 mg QE/g extract. The encapsulated lycopene contained 9.54 mg QE/g of the sample. The location, climate, environmental factors, growing practices, harvesting period, and postharvest processing of the plant all affect the total flavonoid content of lycopene extract (Medisa and Anita Nugraheni, 2017). An often-used indicator of phenolic antioxidant activity, similar to reducing power, is the ferric reducing-antioxidant power (FRAP) (Dong *et al.,* 2014). The levels of both total phenolic compounds were highly associated with the antioxidant activity (FRAP and DPPH scavenging activity) of the raw materials before heat treatment. The amount of total phenolic compounds in the material during processing was the only factor influencing its antioxidant activity. The ability of lycopene to scavenge DPPH is influenced by its structure. Because the overlapping orbitals in its chromophore can produce a stable radical, lycopene's 11 conjugated double bonds have a considerable capacity to scavenge DPPH (Joshua *et al.,* 2024).

3.7. Sensory evaluation of cooked lycopene noodles

The sensory characteristics of cooked lycopene noodles, including appearance, color, taste, texture, odor, and overall acceptability, are shown in Table (6). The results showed that adding tomato lycopene had an important effect on the noodles' preference color. Additionally, there were no differences in the treatments' overall acceptance scores, taste, texture, odor, or appearance. On the other hand, the sample that contained tomato lycopene nano encapsulated in noodles had the highest acceptance scores (9.1). The sample (9.2), which was produced by adding encapsulated lycopene, scored higher on appearance in terms of sensory evaluation than the control noodle sample (8.5). Even the sample (8.7) which was prepared by incorporation of lycopene without encapsulation had a higher score for appearance than the control sample. This may be due to the likeness of the panel members toward the slightly reddish appearance of lycopene-added noodles.

The addition of extract and lycopene nano-encapsulated to the noodle formulation resulted in a significant reduction in the noodle samples' taste scores. On the noodles' texture score, however, it had no apparent effect. Also, Marinelli *et al.* (2015) observed that pasta enriched with polyphenol grape extract had a high level of sensory acceptability. According to Kazemi *et al.* (2017), the sensory acceptability of cooked noodles was not adversely affected by the addition of pomegranate peel extract.

Table 6: Effect of nano-encapsulated lycopene extract on sensory quality characteristics of noodle samples.

Noodle samples	Appearance	Color	Taste	Texture	Odor	Overall Acceptability
Control	$8.50^{b}\pm0.10$	$8.72^{c}\pm0.02$	$8.45^{a}\pm0.05$	$8.82^{a}\pm0.02$	$9.0^{a}\pm0.03$	$8.70^{c}\pm0.01$
Oil lycopene Non-encapsulate	$8.70^{b}\pm0.20$	$9.02^{b}\pm0.01$	$8.32^{b}\pm0.02$	$8.90^{a}\pm0.10$	$9.2^{a}\pm0.20$	$8.83^{b}\pm0.02$
lycopene nano-encapsulated	$9.20^{a}\pm0.20$	$9.23^{a}\pm0.03$	$8.35^{b}\pm0.05$	$8.85^{a}\pm0.05$	$9.70^{a}\pm0.10$	$9.1^{a}\pm0.10$

Data are presented as mean ±SD.
Any two means with the same letters at the same column are not significant at $P \leq 0.05$

When compared to noodles with extracted lycopene, noodles with lycopene nano-capsules scored significantly higher for taste and odor. Except for texture scores, there was no any significant difference between the noodles containing lycopene nano-capsules and control in all other sensory characteristic scores. Additionally, the results in the same table indicated that, noodles containing free lycopene obtained higher sensory scores than the control in all sensory properties, except taste (Mohammadi-Gouraji *et al.,* 2019).

4. Conclusions

This study was conducted to evaluate the effects of adding extract or encapsulated lycopene on the fresh noodles' quality characteristics (color, texture, cooking, and sensory aspects). The encapsulation technique protected against oxidation by keeping antioxidant qualities and making the noodles more stable. Future research may examine the influence on nutritional and sensory attributes. The water activity content of the lycopene nano capsule-containing noodles was slightly lower than that of the control. The color study of noodles containing lycopene extract or nanocapsules showed the encapsulation's different effect, particularly on the L* parameter. Furthermore, cooking loss was not significantly affected by the addition of extract or lycopene nano-capsules to noodles. Meanwhile, the cooked weight and water absorption values were lower than those of the control. According to the sensory evaluation score, encapsulation may typically result in a better degree of customer acceptability. Consequently, lycopene-enriched noodles serve as a great source of bioactive substances that promote a greater intake of lycopene for potential health benefits.

Conflict of Interest

The authors declare that there is no conflict of interest.

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