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Research article

Extraction of organic pigments from tomato (*Solanum lycopersicum* L.), turmeric (*Curcuma longa* L.) and red amaranth (*Amaranthus tricolor* L.) for safe use in agro-products

Md Shariful Islam [a,*], Md Sharifur Rahman [b,c], Muslima Khatun [a], Majid Hajibeigy [d], Md Nizam Uddin [a], Mst Moriom Khatun [e]

[a] Department of Agricultural Chemistry, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh
[b] Department of Food Technology and Engineering, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh
[c] Department of Grain Science and Industry, Kansas State University, Manhattan, KS, 66506, USA
[d] Canadian Pacifico Seaweeds, British Columbia, Canada
[e] Lecturer, S.B. Railway Colony School and College, Sirajganj, Bangladesh

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ABSTRACT

The utilization of synthetic dyes in food industries is a great concern for food safety and health issues. So, natural pigments can be an excellent substitute for synthetic dyes and also health-friendly for consumers. In the experiment, natural pigments were extracted from tomato (*Solanum lycopersicum* L.), turmeric (*Curcuma longa* L.) and red amaranth (*Amaranthus tricolor* L.). Then the stability and consumer acceptance of the extracted pigments were examined. The highest amount of pigment was extracted from turmeric (2.14 ± 0.30 %) with ethanol solvent, followed by tomato (0.67 ± 0.06 %) with hexane: acetone (1:1) solvent, and red amaranth (0.78 ± 0.05 %) with acetone solvent. Turmeric pigment showed the highest stability in high temperatures and light exposure. All of the pigments were highly stable in a neutral environment; however, tomato pigment showed the highest stability index (84.33 ± 2.52) at pH 3.0, but turmeric pigment showed the highest stability (91.67 ± 1.53) at pH 5.0. The simple preference test revealed that the use of turmeric pigment in boiled rice had the highest acceptance rate, and in terms of taste and flavor, red amaranth pigments in ice cream. So turmeric pigment can be utilized in high-temperature processing and/or acidic foods, but tomato and red amaranth pigments might be in low-temperature processing foods such as the ice-cream and soft drinks processing industry.

1. Introduction

Color is one of the most vital attributes of food considering quality indicators and acceptability [1–3]. Consumers' acceptability largely depends on the color, flavor, and taste of products [4]. Presently, coloring food products with natural pigments has attracted the favor of consumers [5]. These products have received much interest from consumers in the aesthetic, nutritional, and safety aspects of food [6,7]. The common practice for coloring food is to use synthetic azo-dye, which is considered low in cost and high in stability. Recent research revealed that food colored with synthetic dyes is associated with numerous health effects, especially hyperactivity in

* Corresponding author.
E-mail addresses: sharifacm@pstu.ac.bd, sharifulpstu@yhaoo.com (M.S. Islam).

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children [3,8,9]. Numerous studies have highlighted the health advantages associated with natural pigments, particularly anthocyanins, and carotenoids [10,11]. In recent years, the importance of investigating and increasing the use of natural pigments in novel and attractive food matrices has become evident [3,12,13]. Plant-based natural pigments such as anthocyanins, carotenoids, and chlorophylls not only add attractive colors to food products, but also provide consumers with therapeutic effects, such as antioxidant, antimicrobial, anticancer, and anti-inflammatory activities [3,7]. These pigments have been extensively investigated for their antioxidant properties, which offer protection against harmful free radicals and can help lower the risk of cancer and heart disease [14,15]. Consequently, there has been a growing trend among individuals to avoid synthetic colorants and choose natural pigments instead, as they are perceived to be safe or even beneficial to health [16,17]. The extraction of organic pigments from plant samples will help to meet the demand for natural colorants.

Food adulteration is now a burning issue in developing countries including Bangladesh [18]. The millers are using different textile and inorganic dyes as coloring material for different processed foods. These textile dyes are highly carcinogenic for human health and highly hazardous for children [9,19]. On the other hand, plant-based pigments are very healthy because they contain vitamins, antioxidants, and anti-carcinogens [16,20]. It is hypothesized that stable organic pigments will be extracted from plant materials in Bangladesh that will be used in safe and healthy agro-product processing and development. So, the current research is designed to produce low-cost extraction of healthy coloring materials from available plants/fruits in Bangladesh like tomato, red amaranth, and turmeric and application of plant-based organic pigments for low and high-temperature agro-products processing. This will help farmers to get the benefit in pick season. During pick season, the prices of tomato or red amaranth are very low and the over-ripe tomato is very perishable. Pigments extracted from these plant species will help to ensure the price of tomato and red amaranth to farmers. After extraction of pigment, the remaining parts of the tomato can be used to produce jam, jelly, or drinks, the red amaranth by-product can be used for producing fry products and the turmeric by-product can also be used as a spice. So, this pigment extraction will help to produce safe processed food production and the farmer will also be financially benefited.

2. Materials and methodology

2.1. Sample collection and preparation

Ripped tomato (BINA Tomato-6), turmeric rhizome, and young red amaranth (BARI Lalshak-1) were purchased for pigment extraction. All of the collected raw materials were rinsed with distilled water to remove dirt and air-dried at room temperature. The samples were chopped into small pieces, packed in airtight zip lock packets, and preserved in a freezer for easy disruption of the cell wall.

2.2. Pigment extraction

Pigments were extracted from three samples with different solvent(s). The procedures are given below:

2.2.1. Tomato

Two hundred grams of chopped tomato was dissolved with 400 mL acetone, hexane: acetone (1:1), and hexane: ethanol (1:1) solvents separately. The mixtures were kept in a flask wrapped with aluminum foil and shaken vigorously at room temperature in a mechanical shaker (MaxQ HP Tabletop Orbital Shaker, China) for 2 h followed by vacuum filtration in a Buchner funnel using a filter paper (Whatman No. 5). The filtrates were then collected and the residues were re-extracted in the same manner until the solvent became colorless. The filtrates were combined and transferred to a separatory funnel, washed with 2.5 % sodium chloride solution to initiate the separation and formation of two layers [21]. The lower aqueous layer was run off, and the red upper layer was collected and evaporated to dryness in a rotary evaporator (Buchi, Switzerland) under vacuum at 35–40 °C. Then the concentrated pigment solution was kept in different vials in a refrigerator (4 °C) for the assessment of the stability of the pigments in response to heat, light, pH, chemical analysis, and for a sensory test.

2.2.2. Turmeric

The sliced turmeric was dried with a vacuum oven drier for 6 h at 50 °C to remove water and ground to get turmeric powder. It was dissolved in ethanol (1:3) and heated at 50 °C in a water bath for 1 h. The solution was then vacuum filtered and the filtrate was put in a vacuum rotary evaporator (at 90 °C) to remove excess ethanol in the filtrate. Finally, curcumin gel was obtained [22]. Then the concentrated pigment solution was kept in different vials in a refrigerator (4 °C) for further chemical analysis and assessment.

2.2.3. Red amaranth

Two hundred grams of chopped red amaranth was dissolved with 400 mL distilled water (1:2) and acetone (1:2) solvents separately. Blanching was done for water extraction at 80 °C for 5 min and immediately placed in an ice bath to cool down to room temperature. Red amaranth was removed and an extracted solution was obtained. In the case of acetone extraction, the mixtures were kept in a flask wrapped with aluminum foil and shaken vigorously at room temperature in a mechanical shaker for 2 h followed by vacuum filtration in a Buchner funnel using a filter paper (Whatman No. 5). Then the purified solution was concentrated by using a rotary evaporator. The concentrated pigment solution was kept in different vials in a refrigerator (4 °C) for the assessment of the stability of the pigments in response to heat, light, pH, chemical analysis, and for a sensory test. All extractions were carried out at room temperature.

2.3. Chemical analysis

2.3.1. Total carotenoids determination

The carotenoid content of the various extracts of tomato was determined and expressed as lycopene by diluting the extracted pigment in hexane and measuring the absorbance of the solution in a double beam UV-VIS spectrophotometer (UV-1900, Shimadzu, Japan) at 470 nm which is the maximum absorption peak for lycopene, the major carotenoid in the extract. The total carotenoid content in milligrams (mg) was calculated using the equation [i] [23].

$$\text{carotenoid} = \frac{\text{AD}}{100\text{dE}_{1\text{ cm}}^{1\%}} \times 1000 \quad \text{[i]}$$

where, A = Absorbance at 470 nm for lycopene.

D = Dilution volume (mL).

d = Cell path length (1 cm).

$E_{1cm}^{1\%}$ = 3450 for lycopene

The pigment (carotenoid) yield as a mean of three replicates was expressed as mg/kg fresh tomato. The total amounts of carotenoid concentration in red amaranth extract were estimated using equation [ii] given by Ref. [24].

$$\text{Carotenoids} = \frac{1000A_{470} - 3.27Ca - 104Cb}{229} \quad \text{[ii]}$$

where, Ca (Chlorophyll *a*) = $12.21A_{663} - 2.81A_{646}$

Cb (Chlorophyll *b*) = $20.13A_{646} - 5.03A_{663}$

A_{663}, A_{646}, and A_{470} = Absorbance at 663, 646, and 470 nm, respectively.

2.3.2. Anthocyanin determination

Anthocyanin content was estimated in red amaranth extract as described by Ref. [25] using the equation [iii].

$$\text{Anthocyanin} = 0.08173A_{537} - 0.00697A_{647} - 0.002228A_{663} \quad \text{[iii]}$$

where, A_{663}, A_{647}, and A_{537} = Absorbance reading at 663, 647, and 537 nm, respectively.

2.3.3. Analysis of curcumin

Pure curcumin (CAS#458-37-7, 368.39 g/mol) was used to prepare a concentration of 100 μg/mL using methanol for standard stock solution. Then a series of standard like 0, 1, 2, 4, 8 μg/mL was prepared from the stock solution for preparation of standard curve. Spectrophotometric absorbance reading was taken using 425 nm wavelength with the help of a double beam UV-VIS spectrophotometer (UV-1900, Shimadzu, Japan) [26,27]. One milligram of curcumin extract was weighed accurately and transferred into a 100 mL volumetric flask and volume up to the mark with methanol and the resulting solution was used to determine the curcumin. Finally, the concentration of curcumin from the extracted sample was calculated from the standard curve [28]. All reagents and chemicals used were of analytical grade and HPLC grade quality.

2.3.4. Stability test

Pigment extract from all of the plant materials was used for evaluating the stability of the pigment to heat, light, and pH. The absorbance of the test sample calculated as a percent of its value at the beginning of the test was expressed as its Stability Index [21]. Stability tests were done for tomato, turmeric, and red amaranth pigment extracted by only hexane: acetone (1:1), ethanol, and acetone, respectively.

2.3.4.1. Thermal/heat stability. Five grams of the pigment extract were kept in closed vials at 30, 50, and 70 °C for a period of 5 d. One-gram sample from each vial was diluted in 45 mL of hexane and the visible absorbance at 470 nm was taken at one-day intervals to determine pigment concentration [21].

2.3.4.2. Light stability. Five grams of the pigment extract were kept in closed vials and exposed to the light of a 36-W fluorescent lamp in a wooden chamber 0.6 m × 1.5 m × 0.7 m for a period of 5 d. Absorbance was read at one-day intervals as above.

2.3.4.3. pH stability. Oil in water emulsion was prepared by mixing the pigment extract with water at a ratio of 30:70 (W/W) by adding an emulsifier. The mixture was then warmed to 60 °C in a water bath for 15 min and then homogenized to form an emulsion. The pH of the emulsion was corrected to 3 and 5 by adding HCl; a third homogenized sample with a pH of 7 was used as a control. The three samples were kept in the dark at 4 °C for 24 h, then a 20 mL aliquot from each was dissolved in 40 mL of hexane: acetone (1:1), and 1 mL sample from the hexane phase which contained the pigment was diluted with 45 mL of hexane and its absorbance was taken at 470 nm [21].

Table 1
Pigment extraction from tomato, turmeric, and red amaranth using different solvents (data indicates Mean ± SD, n = 3, ** and * indicated significant variation at the $p < 0.01$ and 0.05, respectively).

Sample	Sample and Solvent Ratio	Solvent	Extracted Pigment (%)	Anthocyanin (mg/100 g FW)	Total carotenoids (mg/100 g FW)	Curcumin (g/100 g FW)
Tomato	1:2	Acetone	0.29 ± 0.02	–	7.86 ± 0.32	–
		Hexane:Acetone (1:1)	*0.67 ± 0.06	–	11.38 ± 0.57	–
		Hexane:Ethanol (1:1)	*0.49 ± 0.05	–	**10.01 ± 0.93	–
Red amaranth	1:2	Acetone	**0.78 ± 0.05	**233.88 ± 17.13	**44.26 ± 2.61	–
		Water	0.55 ± 0.03	165.37 ± 10.18	26.76 ± 2.25	–
Turmeric	1:3	Ethanol	**2.14 ± 0.30	–	–	1.33 ± 0.2
		Water	0.09 ± 0.02	–	–	0.09 ± 0.02

2.3.5. Using extracted pigments in boiled rice, ice cream, and sensory test

The pigment extracts were added at the rate of 300 mg per kg rice and cooked boiled rice/khichuri. The same foods prepared without pigment addition were used as controls. Thirty-five semi-trained taste panelists (student and staff) were asked to evaluate the colored foods by indicating which product is preferred based on the color and flavor. 4.5, 3.0, and 0.5 mL of tomato, red amaranth, and turmeric pigment extract were used to prepare 300 mL of ice cream for different colors and flavors. Other ingredients for ice cream preparation like skim milk powder, gelatin, fresh cream, and sugar were purchased from a local market, and cow's fresh milk was obtained from a private farm. The ice cream preparation method included the required amount of skim milk powder were mixed with gelatin and sugar followed by added to the fresh milk and cream at 45–50 °C temperature under vigorous agitation, then the mixture was pasteurized at 80 °C for 10 min in a water bath and cooled at 4 °C in an ice bath [29]. The extracted pigments were added at the above rate and mixed homogeneously. Then the mixture was poured in a 100 mL cup and placed in a freezing cabinet at −18 °C for at least 24 h before evaluation. Control was maintained in all cases. Ten taste panelists were asked to evaluate the taste and flavor of each ice cream and rate this using a simple preference test questionnaire (Annex-I).

2.4. Statistical analysis

The results were presented as mean values accompanied by standard deviation (SD), and the experiments were conducted in triplicates. The statistical significance was determined through a *t*-test, and curve fitting analysis was performed using the Microsoft Excel software program.

3. Results and discussion

3.1. Pigment extraction and chemical analysis

Tomato, red amaranth, and turmeric were extracted with different solvents, and the amount of extracted pigments (%) with their quantification of total carotenoids, anthocyanin, and curcumin, respectively, were presented in Table 1. The one-way analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the impact of a specific solvent on the amount of extracted pigment. The amount of extracted pigment (%) from tomato was significantly different ($p < 0.05$) from solvent to solvent (0.29–0.67 %). The higher amount of pigment (0.67 ± 0.06) was extracted with hexane and acetone at a 1:1 ratio, followed by hexane:ethanol (0.49 ± 0.05) and acetone (0.29 ± 0.02) only (Table 2). There was a correlation between pigment extraction and the amount of carotenoid present in the extracted pigments, and the carotenoid content was also significantly different for the various solvents used ($p < 0.01$). The result revealed that the total carotenoid content in extracted pigment varied from 7.86 ± 0.32 to 11.38 ± 0.57 mg/100 g fresh weight (FW) of the tomato sample. It was noted that the highest pigment content was found by hexane and acetone-aided extraction (1:1) and the lowest by only acetone-aided extraction (Table 1). Rizk and his group extracted about 128 mg and 17.3 g total carotenoids from 100 g dry tomato peel and oily tomato peel extract, respectively, which is consistent with the findings of the current study [29]. Shi and Maguer also identified nine carotenoid pigment compounds including lycopene (major compound, 86.12 %), phytoene, phytofluene, β-carotene, *cis*-lycopene, and lutein. Lycopene is considered as a principal pigment for red color in ripe tomatoes [30].

The turmeric sample was examined with two different solvents to extract the pigment. A significantly higher percentage of pigment was extracted with ethanol (2.14 %) than with water (0.09 %). The amount of curcumin (g/100 g sample) was significantly different ($p < 0.001$) for the use of different solvents. The amount of curcumin pigment content varied from 0.09 ± 0.02 to 1.33 ± 0.2 % of the concentrated extract. The highest percentage of curcumin pigment was in the ethanol-aided extract (Table 1). Popuri and Pagala also got a higher percentage of curcumin extract with organic solvents rather than water [22].

The red amaranth sample was also studied with two different solvents acetone and water to extract the pigment. The amount of extracted pigment (%) was significantly different ($p < 0.01$) from one solvent to another. The pigment content varied from 0.55 ± 0.03 to 0.78 ± 0.05 % of fresh red amaranth. It was noted that the highest pigment content was extracted with the acetone solvent. The amount of anthocyanin and total carotenoid contents of the extracted pigments also varied considerably, higher in acetone-extracted than the water-extracted pigment (Table 1). Das et al. experimented with the influence of different parameters (like pH, solvents, and temperature) for betacyanin extraction from red amaranth and concluded that water and 4 °C were favorable to get more betacyanin [31].

The efficiency of pigment extraction relies on several factors, including the resistance of the cell wall, the penetrating power and solvation properties of the solvent, the duration of the extraction, and the utilization of mechanical disruption methods [32,33]. This is evident from the diverse range of solvents and mechanical techniques employed for pigment extraction. Mechanical disruption methods can vary from simple soaking to physical grinding and ultrasonic baths. The effectiveness of each method or a combination

Table 2
Simple preference test by using extracted tomato, turmeric, and red amaranth pigments in boiled rice (n = 35).

Pigments	Number of agreeing judgments	Number of disagreeing judgments
Tomato	10	25
Turmeric	29	6
Red amaranth	13	22
Control	25	10

thereof, depends on their appropriate utilization. It is important to note that prolonged extraction periods can lead to increased formation of degradation products and isomerization of pigments [34]. Moreover, the heat generated during grinding and sonication can promote the production of degradation products and activate chlorophyllase activity [31,32].

3.2. Stability of the extracted pigment

3.2.1. Stability in heat/temperature

A one-way analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the impact of storage temperature on the stability of extracted pigments. There were three different samples kept at three different temperatures (i.e., 30, 50 and 70 °C) to examine the stability. There was no statistically significant difference ($p = 0.06$) among the stabilities depending on temperature. However, Fig. 1 showed that the extracted pigments were comparatively more stable at 30 °C temperature than the higher one, and color intensity decreased over time.

Again, a one-way analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the variation in the stability of extracted pigments among three samples. There was a statistically significant difference among the samples ($p < 0.001$). It was also observed that the stability of turmeric pigment (i.e., stability index 76.33 at 50 °C temperature on day 5, Fig. 1A) was comparatively higher than tomato (i.e., stability index 40.00 at 50 °C temperature on day 5, Fig. 1B) and red amaranth pigment (i.e., stability index 28.00 at 50 °C temperature on day 5, Fig. 1C). Post-hoc comparisons using the Tukey HSD test also indicated that the stability of the three pigments

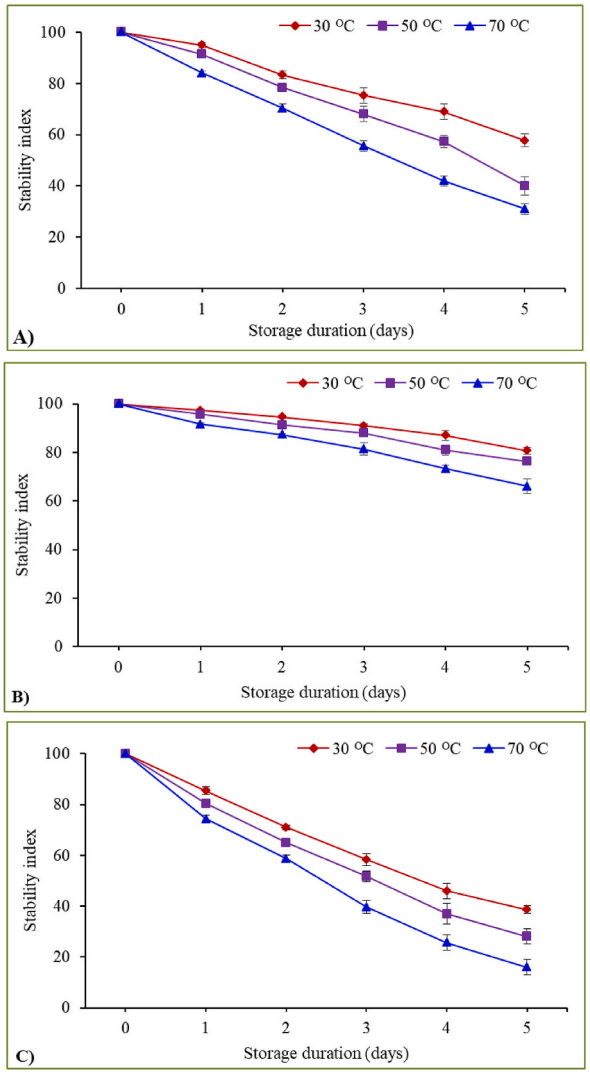

Fig. 1. Effect of storage duration at various temperatures on the stability of extracted pigments. A) Stability of tomato pigment extracted with hexane and acetone solvent mixture (1:1), B) Stability of turmeric pigment extracted with ethanol, and C) Stability of red amaranth pigment extracted with acetone.

was significantly different from each other, and turmeric pigments was more stable followed by tomato and red amaranth pigments (Fig. 1A–1C).

Carotenoids, in general, are highly vulnerable molecules and can degrade rapidly, particularly when exposed to reactive oxygen species, light, acidic pH, and high temperatures [35]. Previous studies have indicated that long periods of thermal processing can lead to carotenoid degradation but enhance their bioavailability. This phenomenon may be attributed to the fact that heating, combined with agitation during thermal processing, disrupts the cellular structure of the plant material, facilitating the release of lycopene and promoting the *trans*-to-cis isomerization process [36,37]. Das et al. [31] also found that degradation of betacyanin (extracted from red amaranth) was higher at ambient temperature (30 ± 2 °C) compared to 4 °C.

3.2.2. Stability in light

The samples were kept in light exposed for five successive days to examine the stability of the pigment and data represented in Fig. 2A. A one-way repeated measure analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the impact of light and storage duration (day) on the stability of extracted pigments. There was a statistically significant difference ($p < 0.01$) among the stabilities depending on storage duration. It was also observed that the stability decreased with storage time (for example, in the case of red amaranth, the stability index decreased to 55.67 ± 2.89 at 5 d). Post-hoc comparisons using the Tukey HSD test indicated that the stability of extracted pigments was significantly decreased ($p < 0.001$) each and every day.

Again, a one-way analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the variation in the stability of extracted pigments among three samples. There was a statistically significant difference among the samples ($p < 0.001$). It was also observed that the stability of tomato (stability index 63.33 ± 3.79 on day 5) and turmeric (stability index 72.33 ± 1.15 on day 5, Fig. 2A) pigments are comparatively higher than red amaranth. Post-hoc comparisons using the Tukey HSD test also indicated that the stability of pigments was significantly different ($p < 0.001$) from each other.

Etxabide et al. [38] examined that, the stability of curcumin pigment in temperature, pH, or light is comparatively higher than anthocyanin and carotenoid pigments. The storage ability of curcumin is also higher than those pigments. Anthocyanin-containing colorant had a broader color response over a wider pH range. Furthermore, color variations at different pH were dependent upon colorant type and concentration.

3.2.3. Stability in various pH

The samples were kept in three different pH solutions (pH 3, 5 and 7) to examine the stability of pigment in acidic to neutral

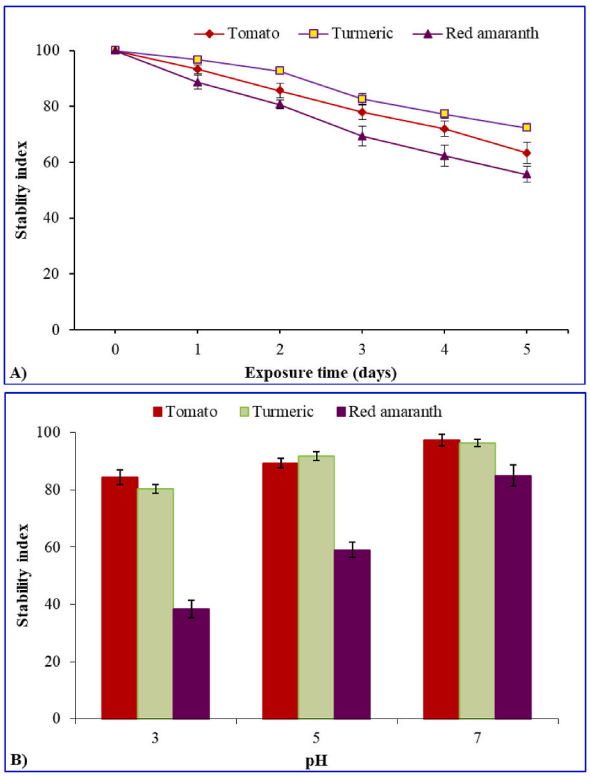

Fig. 2. Impact of light exposure and pH on the stability of tomato, turmeric, and red amaranth pigments. A) Stability of extracted pigments on light exposure. Stability was measured in 5 successive days, and B) Stability of extracted pigments in various pH levels. The stability index was measured after 24 h of exposure. Error bar indicates mean ± SD, n = 3.

conditions and data is shown in Fig. 2B. A one-way analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the impact of pH on the stability of extracted pigments. There was a statistically significant difference among the stabilities depending on pH ($p < 0.05$). It was also observed that the stability was decreased significantly for red amaranth pigment compared with other pigments with increasing acidity (pH 7 to 3). Post-hoc comparisons using the Tukey HSD test indicated that the stability of extracted pigments was significantly different ($p < 0.001$) from pH 3 and pH 7, but no significant difference between pH 3 and 5, or pH 5 and 7 (Fig. 2B).

Again, a one-way analysis of variance (ANOVA) was conducted ($\alpha = 0.05$) to explore the variation in the stability of extracted pigments among three samples. There was a statistically significant difference among the samples ($p < 0.01$). It was also observed that the stability of tomato (84.33 ± 2.52 at pH 3) and turmeric (i.e., 80.33 ± 1.53 at pH 3) pigments were comparatively higher than red amaranth (i.e., 38.33 ± 3.06 at pH 3). Post-hoc comparisons using the Tukey HSD test also indicated that the stability of red amaranth pigment was significantly lower ($p < 0.001$) than tomato and turmeric (Fig. 2B).

The colors of anthocyanins are influenced by the pH of the environment. The structural characteristics of anthocyanins undergo changes depending on the pH and ionic strength of the aqueous solution. Under acidic conditions, specifically at pH 3 or below, anthocyanins exist as flavylium cations, displaying orange or red colors [39]. On the other hand, lycopene pigment is known to be unstable in alkaline solutions due to its chemical structure. Loss of this pigment is particularly evident at temperatures of 50 and 60 °C [40]. Cortez et al. and Zapata et al. concluded that yields of anthocyanins, chlorophylls, and/or carotenoids from plant species not only depend on the different extraction methods, but also consider the conditions that influence the stability of such natural pigments, namely temperature, pH, time, extractor solvent, and concentration, to avoid loss of functionality of these pigments in food processing [13,41].

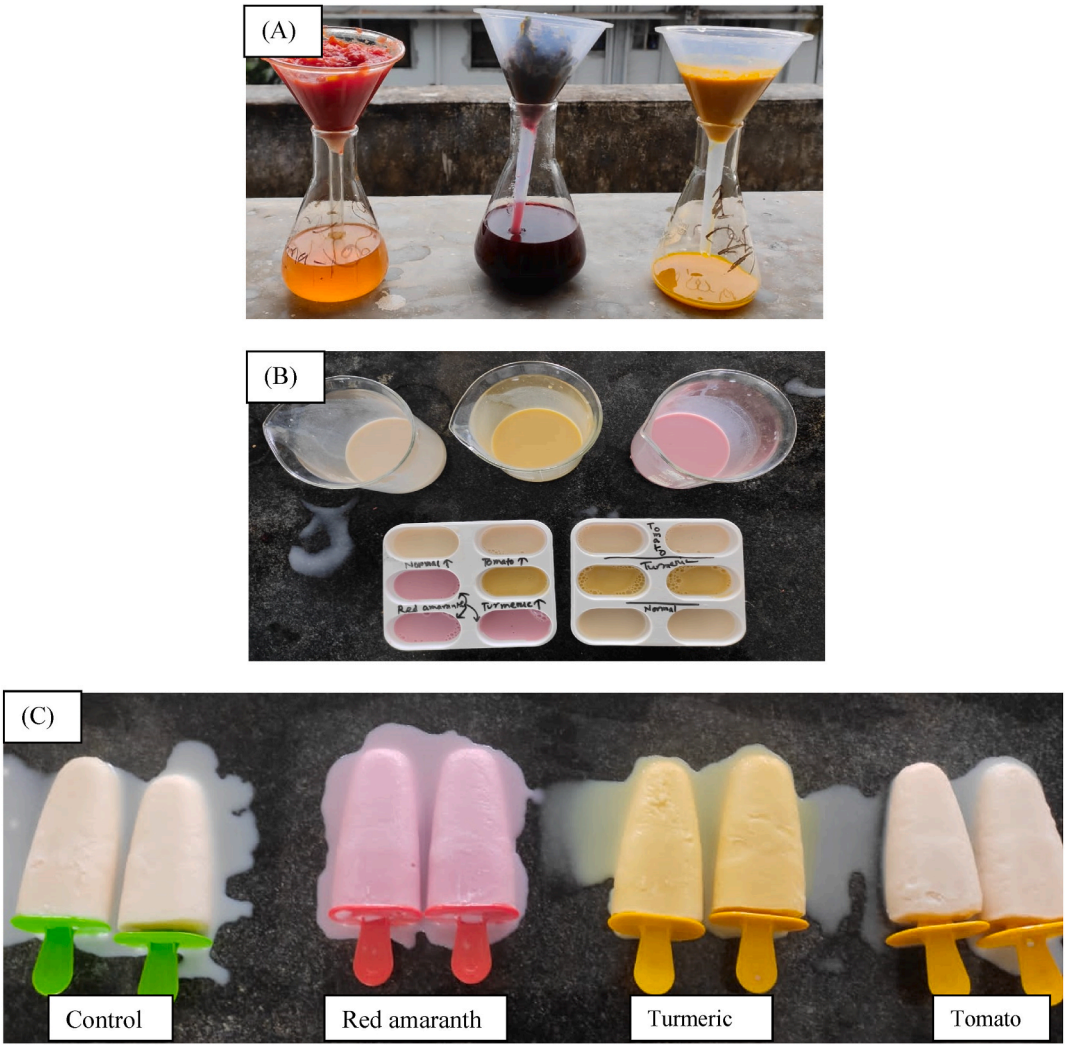

Fig. 3. Image A) shows a step of the extraction process, B) shows the mixing of pigments with ice cream, and C) shows the ice creams colored with extracted pigments.

3.3. Use of extracted pigments in agro-products

The simple preference test revealed that the turmeric pigment was most preferred by the consumer when it was added to boiled rice as a colorant. Among 35 panelists, more than 80 % of people accepted the colored with turmeric pigment sample than the controlled noncolored boiled rice sample (Table 2). But only less than 40 % of panelists accepted the boiled rice sample colored with the tomato or red amaranth pigment. This might be due to the degradation of tomato and red amaranth pigments and the stability of turmeric pigments in high temperatures (Fig. 1). That means tomato and red amaranth pigments can be used in cold processing/manufacturing agro-products [3,29]. So, these pigments were used for ice cream production to give its various color, taste, and flavor (Fig. 3A−3C). Here, Fig. 3(B−C) showed that red amaranth gives a very attractive color rather than tomato, turmeric, and control ice cream samples. Ten panelists (students and staff) were selected for evaluation of different tastes and flavors of ice cream made from these pigments. Data represented in Table 3 indicated that there were no significant differences in taste and flavor between the control and red amaranth-added ice cream (both like a lot by test panelists) though the red amaranth flavor rating is higher than the control. But taste and flavor ratings significantly decreased for turmeric ($P < 0.01$) and tomato ($P < 0.05$) compared to control (Table 3). It is concluded that red amaranth is a good and one of the cheapest sources of pigments that can be used for cold processing/manufacturing agro-products instead of synthetic pigment.

The use of natural pigments in food preparation is widely accepted, including anthocyanins derived from natural sources. These pigments like anthocyanins, chlorophyll and carotenoids recognized as E163, E1410 to E141 and E160a to E161b, respectively by the Codex Alimentarius Commission, FAO and WHO, are permitted for use as food colorants in various countries, including Japan, the United States, and many others, in a wide range of food and beverage applications [12,42]. Anthocyanin (E163) is permitted to use in soft drinks, confectionary, fruit preparations, dairy products such as cream cheese, milkshakes, fermented milk etc. [3,43,44].

4. Conclusion

It is concluded that different solvent extraction has different yield of pigments from plant species. In the study, hexane and acetone (1:1), acetone and ethanol solvent were found suitable for better pigment extraction from tomato, red amaranth and turmeric, respectively. It was observed that the extracted pigments have a capability to sustain in high temperature (30–70 °C), light intensity, and low to neutral pH, and have good consumer acceptance when added to two food products, one from high temperature processing (boiled rice) and other from low temperature processing (ice cream). So, there is an opportunity to utilize these natural pigments in various food industries according to the attributes of the pigments. Here turmeric can be used for high-temperature manufacturing/processing agro products (like bakery products, fried items, *Chips*, etc.) whereas red amaranth pigments can be used for low-temperature manufacturing/processing agro products (like ice cream, milkshake etc.) and tomato pigments for the preparation of acidic food (like soft drinks). The usage of these pigments will alleviate consumers' health risks and also add medicinal value to foods, and farmers will get their proper return.

Data availability statement

Data are available on reasonable request. All data are available in the manuscript and/or supplementary documents.

Declaration of Ethics

The study was approved by the Ethics Committee of Patuakhali Science and Technology University (PSTU) before conducting the research [Reference No. PSTU/IEC/2022/33 Dated: June 20, 2022, Approved by Professor Dr. Md. Golam Rabbani Akanda, Chairman, Institutional Ethical Committee (IEC)]. Consent was also taken from all participants in a proper way for sensory evaluation test.

Funding statement

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Table 3
Preference test by using extracted tomato, turmeric, and red amaranth pigments in ice cream. Data presented in mean ± sd (n = 10); *, ** indicated the significant variation at 5 % and 1 % level, respectively, compared to control].

Pigments	Taste rating (5)	Flavor rating (5)
Tomato	*4.17 ± 0.35	*3.89 ± 0.42
Turmeric	**3.50 ± 0.50	**3.39 ± 0.42
Red amaranth	4.67 ± 0.43	4.83 ± 0.35
Control	4.67 ± 0.43	4.44 ± 0.46

CRediT authorship contribution statement

Md Shariful Islam: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Md Sharifur Rahman:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Muslima Khatun:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Majid Hajibeigy:** Writing – review & editing, Writing – original draft. **Md Nizam Uddin:** Writing – original draft, Methodology, Data curation. **Mst Moriom Khatun:** Writing – review & editing, Writing – original draft, Methodology.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Md Shariful Islam reports financial support was provided by University Grants Commission of Bangladesh. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25278.

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