The present investigation entitled “Studies on extraction, degradation and utilization of lycopene from watermelon” has been carried on the physicochemical changes during development stages and post harvest storage of fruits, juice concentration and preparation of powder, dehydration of pomace, optimization of pigment extraction, preparation, antioxidant properties and bioavailability of coloring, preparation of lycopene crystals and their application into food products.

Watermelon cultivars (‘Namdhari-95’, ‘Namdhari-450’, ‘Sugar Baby’) were studied for physicochemical changes during four development stages i.e. white, white-pink, pink and red-ripe. The soluble solids, ascorbic acid and sugars content increased up to the red ripe stage while moisture content and acidity decreased. Significant changes in physical constituents, composition and pigment content were observed during different development stages. Total carotenoids, lycopene and β-carotene content of cultivar ‘Namdhari-450’ were 7.30, 6.53 and 0.17 mg/100g respectively followed by ‘Namdhari-95’ and ‘Sugar baby’ cultivars at red ripe stage. The rate of pigment biosynthesis in watermelon was the highest at red ripe stage resulting in 50.2-57.5% increase in lycopene content with respect to pink stage. Lycopene content was highly correlated with ripening parameters using power regression with coefficient of determination of 0.835-0.998.

Concentration of watermelon juice is essential to increase its utilization in food products. Watermelon juice yield of ‘Namdhari-95’, ‘Namdhari-450’ and ‘Sugar baby’ cultivars was 42.9, 49.6 and 48.6 g/100g while soluble solids content of juice was 6.0, 5.1 and 8.9 g/100g respectively. Juice concentrate with soluble solids content of 70 g/100g had total solids, titrable acidity and total sugars contents of 77.1-77.3, 0.34-0.35 and 44.7-53.8 g/100g respectively. Total carotenoids of watermelon juice concentrate with soluble solids content of 70 g/100g varied from to 34.9 to 86.7 mg/100g whereas lycopene content from 33.12 to 84.42 mg/100g for three cultivars. Hunter ‘L’, ‘a’ and ‘b’ value of watermelon juice increased as soluble solids varied from control to 20 g/100g but then decreased with further increase in soluble solids. Watermelon juice concentrates behaved like Non-Newtonian pseudoplastic fluid and apparent viscosity varied from 0.001-0.117, 0.001-0.284 and 0.001-0.220 Pa.s for ‘Namdhari-95’, ‘Namdhari-450’ and ‘Sugar baby’ cultivars, respectively. Soluble solids had
exponential relationship with consistency index (k) but linear relation with lycopene content.

The effect of spray/freeze drying and maltodextrin concentration (3, 5, 7 and 10%) on pigment retention of watermelon juice powder from three cultivars was investigated. Incorporation of maltodextrin in watermelon juice yielded freely flowable powder. Maltodextrin was an effective drying aid which helped in reducing stickiness and altered the physicochemical properties of watermelon powder. With increase in maltodextrin concentration, the moisture content of the spray and freeze dried powder decreased while time for reconstitution and sugar content increased. The spray dried powder had less moisture content, low water activity, high dissolution value and less reducing sugar content as compared to freeze dried powder. Lycopene content of fresh watermelon juice was 4.58-6.53mg/100g on wet basis (wb) which increased up to 56.4mg/100g (wb) in spray dried powder and 62.3mg/100g (wb) in freeze dried powder. The visual color analysis showed that watermelon powder lost its redness with increase in maltodextrin above 5% in spray drying. Lycopene loss in spray drying was influenced by high air temperature and intensive exposure to oxygen causing degradation of pigment. The freeze dried powder retained more pigment but powder had high water activity, limited shelf life, low flowability and was hygroscopic in nature. Good correlation between colorimetric values and lycopene content was observed in spray dried powder.

Watermelon pomace being the concentrated source of lycopene can be used in dried form to obtain the value added products. Drying kinetics and lycopene retention in watermelon pomace during drying was investigated in fluidized-bed and cabinet dryer at 50-70°C using 2-6 kg/m² tray loads. Page’s model described the drying behaviour of watermelon pomace better than other models with high coefficient of determination (≥0.96), lower standard error (≤0.03) and scattered residual plot. Effective moisture diffusivity of pomace during drying varied from 0.880×10⁻⁸ to 3.541×10⁻⁸ m²/sec for fluidized bed and 0.347×10⁻⁸ to 0.868×10⁻⁸ m²/sec for cabinet dryers. Arrhenius’s equation adequately explained the relationship between the drying rate constant/effective moisture diffusivity and drying air temperature. Lycopene content of watermelon pomace dried in fluidized-bed dryer was 5.67-9.86 mg/100g on dry basis (d.b.) (‘Sugar baby’) and 11.0-17.3 mg/100g (d.b.) (‘Namdhari-450’) whereas in cabinet dryer the values were 4.82-8.12mg/100g (d.b.) (‘Sugar baby’) and 9.3-15.4 mg/100g (d.b.) (‘Namdhari-450’) under experimental conditions. Fluidized bed dryer
can be employed preferably over cabinet dryer to stabilize the watermelon pomace with higher lycopene retention.

Degradation kinetics of lycopene in watermelon pomace followed first order model over 50-90°C. Thermal degradation showed higher lycopene retention than drying under similar conditions of temperature and time indicating that circulating air increased the rate of lycopene degradation. Lycopene loss during drying of watermelon pomace was 19.02-60.57% whereas 7.46-43.28% was observed during thermal treatment of watermelon pomace.

The moisture adsorption isotherms of dehydrated watermelon pomace waste were obtained over a range of water activities and temperature varying from 0.113 to 0.920 at 20-50°C respectively. The adsorption power of dried pomace decreased with increase in temperature at constant water activity. Chung & Pfost model was the most efficient model among Type I models for both cultivars with coefficient of determination ($R^2$) of 0.973-0.990, standard error (SE) of 0.082-0.096 and scattered residual plots. Among Type II models, Modified Henderson model gave best results with $R^2$ of 0.967-0.982, SE of 0.167-0.234 and scattered residual plots. The variation of net isosteric heat of sorption for dried pomace of both cultivars, estimated using the Clausius-Clapeyron equation, was 41.69-0.2 kJ/mol at 3-30% moisture content on dry basis. The moisture adsorption isotherms of dehydrated watermelon pomace waste at different temperatures and relative humidity values showed sigmoid curve.

Pigment extraction was optimized from watermelon pulp waste using response surface methodology using independent variables namely solvent/meal ratio (4:1 to 12:1 v/w), number of extractions (1 to 5), temperature (20 to 60°C) and extraction time (4 to 20 min). Watermelon pulp waste contained 59.95 mg lycopene/100g (wb). The experimental values of lycopene with selected combinations of independent variables were 8.20-59.17 mg/100g (wb). The second order model obtained revealed a $R^2$ of 0.986, the SE of 0.04, the root mean square error of 0.02 and a scattered plot between experimental and predicted values. The optimum solvent/meal ratio, number of extractions, temperature and extraction time were 10:1 v/w, four, 50°C and 16 min respectively. The optimum conditions of lycopene extraction were confirmed experimentally.

The watermelon coloring prepared from the watermelon pulp was studied for pigment degradation and loss of antioxidant activity at 20, 40, 60 and 80°C up to 9 days of thermal heat treatment and under the effect of light and oxygen. The results showed

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that there was a significant (p≤0.05) decrease in the total carotenoids, lycopene and antioxidant activity at all temperatures after 9 days of incubation period. The total carotenoids content reduced from 417.2 to 84.3 mg/100ml, lycopene content reduced from 302.92 to 27.75 mg/100ml and the antioxidant activity was reduced from 87.3 to 15.67% when held at 20 to 80°C for 9 days of incubation. Effect of light (50,000 lux) and oxygen resulted into 80-90% and 27-32% loss of bioactive compounds and antioxidant activity in the watermelon coloring respectively. The first order kinetics model explained well the degradation behavior of total carotenoids content, lycopene content and antioxidant activity with R² of 0.911-0.993, 0.975-0.995 and 0.976-0.986, respectively. The dependence of degradation rate constant of total carotenoids, lycopene and antioxidant activity on temperature was adequately explained by Arrhenius equation and the activation energy obtained for total carotenoids, lycopene and antioxidant activity was 6.36, 4.50 and 14.64 kJ/mol respectively. The antioxidant activity of watermelon coloring showed higher degree of heat sensitiveness. The degradation kinetics showed that with decrease in the total carotenoids/lycopene content at higher temperature there was decrease in antioxidant activity in the watermelon coloring. The watermelon coloring with unique antioxidant activity and pigment composition could be used as a food additive, functional foods and nutritional supplements.

Lycopene enriched diets were prepared by mixing watermelon coloring with other ingredients and fed to albino rats to study in vivo bioavailability of lycopene. The rats were initially fed with control diet only for a week followed by lycopene rich diet (5-50 mg lycopene/100g feed sample) along with control diet for next week and finally with control diet for one week. The body weight of each group of albino rats significantly (p≤0.05) increased during feeding trial which showed that rats were in healthy condition during the treatment. The daily lycopene intake from test diets varied from 0.82-2.30mg during seven days trial which decreased to 0.07-0.27mg during seven days of feeding with control diet. The lycopene absorbed by different groups of rats varied from 0.13-0.33mg/100g body weight during treatment period. Lycopene absorption increased and became stationary during treatment period and then decreased during post treatment period.

The watermelon coloring was utilized to make lycopene crystals which were incorporated into mayonnaise, ice-cream and butter at the rate of 2.5, 5, 7.5 mg lycopene/100 g product. The products were evaluated for quality characteristics during
three months storage. Lycopene containing foods showed less peroxide and free fatty acid values as compared to market samples because lycopene acts as the oxygen quencher and decreased the rate of oxidation process and hence prevented rancidity in the products. Non-significant changes were observed in hunter color values of lycopene containing foods. Organoleptic evaluation results revealed higher sensory scores for color in the lycopene enriched foods as compared to market samples. Thus, lycopene containing food had an appealing color along with antioxidant properties.

The findings of the studies can be concluded as follows:

- Study of fruit during development stages provides valuable information to understand synthesis of pigments to harvest at the best time.
- Watermelon juice concentrates behaved like Non-Newtonian pseudoplastic fluid.
- The freeze dried powder retained more pigment as compared to spray dried powder.
- Fluidized bed dryer can be employed preferably over cabinet dryer to stabilize the watermelon pomace with higher lycopene retention.
- Moisture content of watermelon pomace at different temperature and relative humidity can be predicted by modified Henderson model.
- Optimization study provides the valuable data which can be utilized in process design and industrial scale-up operations.
- Watermelon coloring is less stable under heat, light and oxygen.
- The lycopene acts as an excellent bio-color with antioxidant properties in mayonnaise, ice-cream and butter.

**Recommendation for further studies**

The study on watermelon was carried out with a focus on the pigment extraction and characterization which can be extended in following area by other researchers in future:

a) The rind of the watermelon can be utilized to extract the citrulline component.

b) The watermelon powder may be incorporated into different food formulations.

c) Anticancer activity of watermelon coloring can be studied.

d) The present research data can be used for development of non destructive quality analysis of fresh watermelon.