



Review Paper

Effect of natural and synthetic dyes on human health

Naseem Zahra^{1,2*}, Imran Kalim¹, Muhammad Khalid Saeed¹, Zilwa Mumtaz³, Naima Amjad³, Alim-un-Nisa¹, Sajila Hina¹, Shahid Masood¹, Ijaz Ahmed¹ and Muhammad Ashraf¹

¹Pakistan Council of Scientific and Industrial Research Laboratories Complex, Ferozepur Road, Lahore, 54600, Pakistan

²College of Earth and Environmental Sciences, University of the Punjab, Lahore

³Institute of Biochemistry and Biotechnology, University of the Punjab, Lahore
naseem.zahra1981@gmail.com

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Abstract

Food dyes are added to enhance the quality perception of the food. Dyes are of two categories natural dyes and artificial dyes. Natural dyes are extracted from the plants or animal source. So they are quite expensive and not available in large quantity. Artificial dyes are petroleum based products and constitutes aromatic rings. Dyes are extensively used in food items like candies, bakery, confectionery, drinks, rice, cooked as well as processed foods. Despite of its extensive use the ill-health situations caused by over-dosed use of dyes must not be underlooked. Multiple disorders are related to the toxicity of the artificial dyes. Dyes are potentially mutagenic either directly or indirectly.

Keywords: Synthetic dyes, Natural dyes, Purpose of dyes, Toxicity of dyes, Permissible limits.

Introduction

Dyes are in human use for many centuries, either synthetic or natural. People prefer fresh looking and vibrant food. They always keep aside fade colored food and considered it stale. While using dyes in food important question raises is either the dye which we are using in food is safe or not. Therefore, a permissible limit has been devised by food authorities for every dye used in food whereas; black or brown synthetic dye has been completely banned due to harmful ingredients in them. Use of food color had its origin in Egyptian times, those people used to extract color from plant source but with the increasing population and its demands trend went towards the use of synthetic dyes. Synthetic dyes are highly carcinogenic and also causes hyperactivity in many children whereas, it is a cause of many diseases like asthma, organ damage and estrogen enhancers.

Therefore, many synthetic dyes have been banned in many countries and people are moving towards use of natural dyes which are safe in every way but also have some limitations such as low yield, are expensive and also colors obtained are dull and not so vibrant. Research is still needed in this perspective in order to improve results obtained and problems faced while extracting natural dyes.

Synthetic dyes

Synthetic dyes are a non-nutritional, chemically active component that gives color or pigmentation to either processed or cooked food products, this practice is termed as food coloring. Synthetic dyes impart a secondary color to the food

items. Colors are defined as the “food additives” under 1958 Food, Drug, and Cosmetics Act. Use of synthetic colors is very common in Pakistan and other countries. Food coloring improves the quality perception and gives an appetizing look to the food and vendors take advantage of making more sale. Food additives are generally chemicals or coal-tar based components. Color is added in innumerable food items like confectionary, soft drinks, bakery, sweets and candies. Adding the dyes in the form of powder, pastes or semi fluid form improves the sight of the food¹.

Purpose of food dye

Synthetic dyes are added due to a number of reasons like to overcome loss of color owing to light and air exposure, temperature extremes, moisture and storage conditions. To perceive a more natural color of the processed food, to enhance colors that occur naturally, for slow spoilage. To prevent fats and oils from becoming rancid, it is better to avoid cutting fruits from turning brown, imparting color to colorless foods to make them more appetizing and attractive². To corroborate colors which are already present in food but are less intensive than the expectations of consumers.

For restoration of the original appearance of food whose color is affected during processing. To give colors to food such as ice lollies, soft drinks and sugar confectionery which are otherwise colorless in real³.

Food colorants have been widely used despite of its unfavorable effects on health. Among human population adults are found to be less affected by the adversities of food colorants than the children⁴.

History of synthetic dyes

Dyes in food have been popular since far back in time, where food additives were made a part of drinks especially wine. Smoke and aloe extract was used as a coloring agent. Use of harmful chemicals and inorganic salts such as mercuric sulphide (vermillion), lead chromate and copper sulphate was also prevalent in jams, desserts, milk, jellies, cheese, confectionery and butter. At the mid of 18th century the first synthetic dye was prepared by William Perkin, that is "aniline purple" or "mauve", from coal tar. After this milestone a number of organic based dyes were produced and replaced toxic salts⁵.

Types of synthetic dyes

Synthetic dyes are of many types and are used in different food stuff as per requirement⁶. Some artificial food dyes have been mentioned.

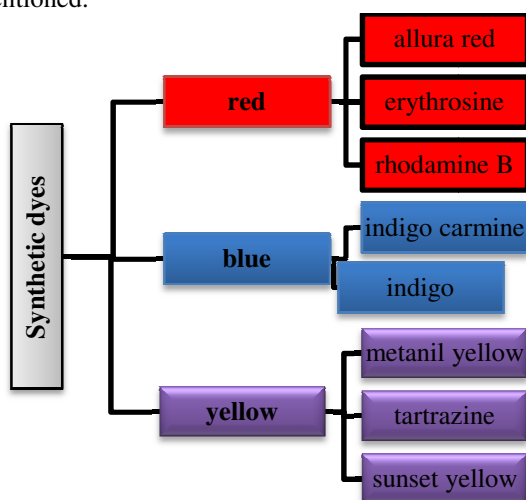


Figure-1: Artificial food dyes.

- i. *Allura red (Red 40)*; A red color imparting azo dye used as coloring agent in confectionary, beverages, candies, drugs, syrups, soda and cosmetics. Azo dyes are electroactive⁷.
- ii. *Erythrosine (Red3)*; It gives a cherry-pink color. It belongs to the organoiodide group of compound. It is added in baked items, candies, oral medication, sausages and maraschino cherries⁸.
- iii. *Rhodamine B* it is a cationic, basic dye. It gives a fluorescent pink color^{9,10}.
- iv. *Indigo carmine*; used for as a colorant in pet food, candies, beverages and other foods
- v. *Amaranth*; it is a strongly water soluble azo dye.
- vi. *Lead chromate (Yellow)*; also known as chrome yellow. It is bright yellowish dye and added in turmeric powder.
- vii. *Tartrazine (Yellow5)*; it is a synthetic azo dye, added in bakery goods, pet foods, beverages, candies, dessert powders, gelatin desserts, cereals and many other foods commodities, as well as cosmetics and pharmaceuticals. It is readily and very soluble in water.

- viii. *Sunset Yellow (Yellow 6)*; added for yellow color in confectionary, gelatin deserts, sausage and drugs. It is an azo dye.
- ix. *Food Brown 1*; it imparts brown color to the food. It is basically a mixture of azo dyes and very miscible in water. It is used in fish products¹¹.
- x. *Green (fast green 3)*; Personal care products, drugs, cosmetic products except for eyes, ingested drugs, sorbet, beverages, candies, ice cream, lipsticks and externally applied cosmetics^{12,13}.

Permissible limits

Maintaining a border line concentration of any food additive is compulsory. A permissible limit of any food additive is set that states to the health safety upon consumption. Food dyes are categorized as permitted and non-permitted food dyes. Addition of non-permitted or non-food substance to increase the quantity and quality of the food is termed as adulteration. USA permits seven food colors while European Union (EU) allows the use of sixteen synthetic dyes. The use of Black and Brown dyes is completely banned in the developed countries as they contain harmful ingredients. The maximum limit of permissible colour to be added in any food shall be 0.1 gram per Kg of food as consumed¹⁴.

FDA (Food and drug administration) and many other food quality administration agencies sets permissible limits of synthetic dyes added in food. European Food Safety Authority (EFSA) under its newly set strategies approved a daily intake of Allura red AC, according to which acceptable daily intake is 7mg/kg body weight¹⁵. According to FDA food dyes can be bifurcated into "certified" and "non-certified" categories¹⁶. Black and brown dye owing to their toxicity is banned in many countries like USA. The maximum limit of permissible colors to be added must be 0.1 g/Kg of food. The ADI (acceptable daily intake) of erythrosine was alleviated from 2.5 to 0.1 mg kg⁻¹ body-weight. The maximum permissible level of food color that can be added either in pure or in blend form is 100 parts per million (ppm or ug/g) except in canned food where the level of 200 ppm is allowed. It has been found that food products from rural and local markets exceed the permissible level of the additive dye. ADI levels recommended by the joint FAO/WHO Expert Committee for amaranth and allura red are 0.5 and 7mg/kg. Use of amaranth is banned in USA.

Natural dyes: Within a biological system, a pigment which is synthesized, accumulated or excreted from the living cells is called natural pigment.

Natural colorants verses artificial colorants: Artificial colorants are commonly referred as food dyes or coal tar dyes are of great importance for many years in replacing natural colorants that are destroyed during the processing of food. Demand of artificial colorants has been reduced in recent years due to their hazardous effects on health. Therefore, scientists are

paying more attention towards production of natural colorants due to high consumer pressure on having such food products which are based on completely natural ingredients. Natural colorants are more expensive, lower tinctorial power, less stability, low yield and color instability than synthetic colorants.

Medicinal properties of natural food colorants: There are many natural food colorants that have medicinal importance such as natural colorants have some nutraceutical properties. Carotenoids are helpful in treatment of arthritis and cancer. Anthocyanins are used to treat coronary heart diseases and to treat hyper tension and liver disorders. Betalains are antimicrobial, anti-viral and anti-carcinogenic. Monascus pigments are anti tumorigenic and antimutagenic.

Importance of natural food colorants

Caramels are most widely used food colorants which are manufactured by different methods. It is used as an adulterant agent. Turmeric is used as a coloring agent in meat, cheese and bakery products. Curcumin is obtained from turmeric and legislation of both depends on the geographical region. Cochineal and carmine pigments are obtained from cochineal i.e. *Dactylopius coccus*. Monascus pigments are obtained from the fungi i.e. *Monascus* spp. These are produced by solid state fermentation and are not allowed by U.S. FDA. These colorants have got great importance because of their stability and clarity as compared to other natural colors.

Disadvantages of natural dyes

In spite of many advantages of natural dyes they also have some limitations such as production of low color, relatively higher cost and tedious extraction. Some natural dyes also need mordant to enhance the fastness properties of dyes but some mordants are hazardous. Also there are problems regarding collection of plants and extraction and dyeing techniques. It has been observed that consumption of synthetic dyes results in hyperactivity in children. So, most of the food products containing high amount of synthetic dyes in it also contains a warning label on them. A trend towards use of natural dyes is increasing slowly all over the world. Many food companies are looking at the feasibility to convert fully to such foods based on natural ingredients only. Whereas, according to an estimation food dye costs can increase to ten folds if companies convert from synthetic to natural dyes.

Applications of natural dyes

Natural dyes are also used in pH indicator, histological staining, UV protective clothing, textile coloration, dye sensitized solar cells and functional finishing of textiles.

Characterization of dyes

A dye molecule consists of mainly two chemical groups i.e. auxochromes and chromophores. Chromophore is usually an

aromatic ring which is associated with the coloring property. It consists of unsaturated bonds i.e. $-N=O$, $=C=O$, $-C-S$, $-N=N-$, $=C-NH$, $-CH=N-$, and $-C=C$, whose number determines the intensity of the color. Whereas, auxochrome helps dye molecules to combine with substrate and thus imparting its color.

Chemistry of natural dyes: Dyes are classified into different groups based on their source, method of application, chemical structure and color.

Natural colorants obtained from minerals

Ocher: Ocher is a dye obtained from an impure earthy ore of iron or ferruginous clay, usually red (hematite) or yellow (limonite). In addition to being the principal ore of iron, hematite is a constituent of a number of abrasives and pigments. There are many natural colorants which are obtained from mineral ores such as ocher. Ocher is red or yellow (hematite and limonite) dye obtained from impure earthy ore of ferruginous clay or iron.

Natural colorants obtained from animals

Cochineal: Cochineal is a very brilliant red dye which is extracted from an insect i.e. cochineal bug that lives on the cactus plant. This property of the cochineal bug was discovered for the first time by pre Columbian of India who dried female cochineal bug and then finely ground it to obtain a fine and rich red powder. When this powder was dissolved in water it produced a very vibrant deep red color. It is still harvested in some parts of the world in order to obtain vibrant red color. However, many cherries have a deep red color which is due to the presence of carmine which is obtained from cochineal bug.

On the basis of their structure they are classified as: i. Carotenoids, ii. Chlorophyllin, iii. Anthocyanins, iv. Betanin.

These are the four main categories of plant pigments that are used as food colorants. Derivatives of these colorants include; i. Annatto is a reddish orange dye which is made from the seed of achiote, ii. Caramel is made from the caramelized sugar, iii. Carmine is a red dye which is derived from the cochineal insect, *Dactylopius coccus*, iv. Elderberry is used as a colorant in juice, v. Indigo dye is obtained from plant *tinctoria L.* and is one of the most important dye, vi. Anthraquinone dyes are red colored dyes obtained from both plants and insects. Anthraquinone dyes have good fastness to light because of the formation of complexes with metal salts, vii. Alpha-hydroxy naphthoquinones or henna is the most important member of this class of dye, viii. Flavones are the most commonly and abundantly used yellow dyes which are the hydroxy and methoxy derivatives of both flavones and isoflavones, ix. Dihydropyrans dyes have closely related chemical structure to flavones, x. Carotenoids color is due to the presence of long conjugated double bonds. Saffron and annatto are the main example. xi. Anthocyanins have properties such as

antioxidants, chemoprotective and stability. These dyes are obtained from red potatoes, red cabbage, purple sweet potatoes and radishes¹⁷. xii. Betacyanin is a red-purple pigment which is extracted from *Opuntia stricta*. Glucose syrup was used to aid drying process. More than 98% color was retained during drying process. This powdered color showed good strength and stability when stored at room temperature for one month whereas, this colour was very attractive for consumers when it was successfully applied in two food products such as soft drinks and yogurt and even after a month there was no observable change in its color¹⁸.

Blue colors are especially rare colors. In the case of Brilliant Blue, bacteria brought blue back with a punch thanks to an extract from the Cyanobacteria spirulina is the source of blue color as this color is rare among all other colors. There is an increasing demand to use this cyanobacterium to extract blue color¹⁹. Yield of natural food colors depends on raw material used. Researches have used fungi in order to produce colorants in high amount. However a detailed study and chemotaxonomic tools are required to carry out successful screening using fungal metabolites. In future, there would be the use of metabolic engineering to create microbial cell factories in order to produce food colors²⁰.

Technology for production and analysis of natural colorants

Technologies which are mainly used for the production of natural dyes are mainly dependent on the required purity. On the basis of required purity simple to complicated solvent extraction, supercritical fluid extraction are used whereas for drying freeze drying or vacuum can be used. There are also such technologies which are used to enhance the yield of colorants in plants. Techniques which are used to analyze natural food colorants in food are capillary electrophoresis, thin layer chromatography, high performance liquid chromatography, gas chromatography. Best technique among these is capillary electrophoresis. It has several advantages i.e. low capillary as well as operating cost, very small sample amounts, less time consuming and production of waste is quite low²¹.

Detection of synthetic food colorants: Different techniques are used for the detection of synthetic food colorants including thin layer liquid chromatography, traditional column chromatography, high performance thin layer chromatography, high performance liquid chromatography which includes ion pair chromatography, reverse phase chromatography and high performance ion chromatography.

Certification of food colors: There are nine synthetic dyes approved by U.S. FDA along with many natural food colorants such as turmeric, carrot oi paprika. Red color is obtained from tomato lycopene extract which is used in strawberry ice creams and many other red colored products. Most of the synthetic dyes which have been used by American food supply for more than

50 years are obtained from petroleum or are chemically derived. One of the main problems which have been faced by chemists and biotechnologists regarding natural colorants is the production of less attractive colors which are not appealing towards customers, obviously customers will not prefer to buy an anemic or greener strawberry though it have natural colorants and will prefer a vibrant and nice looking strawberry. Another problem with natural dyes is use of high dosage dye and is more expensive as compared to synthetic dyes whereas it is not much stable when subjected to heat and light. Synthetic dyes require certification before being used in the food products. Synthetic colors are of high demand because of their intense and uniform color, blend easily to impart variety of colors and above all are less expensive. The certified food colors don't add undesirable flavors to food. Natural colors are exempt from certification as they are obtained from natural sources such as animals, plants and minerals. They are more expensive and also adds flavors to food.

Harmful effects of synthetic dyes

At the advent of synthetic dyes production, the raw material use was originally obtained from unrefined petroleum products such as coal tar. These petroleum derived dyes are used in thousands of foods particularly cereals, candy, oral tablets and drinks²².

Damage to organs: Auramine, a yellow dye and rhodamine damages and dysfunctions kidney, liver and retards growth. Rhodamine is also eminent is the breakdown of red blood cells. Non-Permitted Food Colors in Edibles Lead chromate when used abusively causes anemia, abdominal pain, neurological disorders, hypertension and lead poisoning. Metanil yellow affects reproductive organs i.e. ovaries and testis. It has been also reported in the degeneration of liver, kidney and stomach. It also makes the skin cell deficient of oxygen leading to discoloration of the skin due to inadequate oxygenation of blood causing methaemoglobinaemia in adult within 2-4 hours after the consumption of rice colored by it. DNA damage in the glands of stomach, colon and urinary bladder is induced by dyes like amaranth, allura Red, tartrazine, erythrosine, phloxine and rose Bengal. Amaranth and Tartrazine have been tested and reported to induce immunosuppressive effects²³.

Asthma: Dyes such as allura red and brown may cause allergic reactions. Brown dye and tartrazine is a histamine liberator and elevates asthma.

Carcinogens: Red 40, Yellow 5, and Yellow 6 contain benzidine, a potent carcinogen. Benzidine is present in the free form or in bounded form. The bounded form is detected to be in a greater concentration in the food dyes. Azo dyes follow three mechanisms to produce such a cancerogenic product. During its metabolism reactive electrophilic intermediate molecules are formed that associates covalently with the DNA²⁴. Benzidine ring present in azo dyes when is metabolized by the body by anaerobic intestinal microflora produces aromatic amines that

causes intestinal cancer²⁵. Azo dyes such as methyl orange, methyl red, methyl yellow, Ponceau, sunset yellow, tartrazine, acid yellow, and amaranth are widely used in food coloring as well as textile coloring. And the chances to contact with it in industrialized zone is much more, one of the reason for increased rate of cancer among population living in industrial area.

These colors are widely used in US in processed macaroni and cheese. In 1990 erythrosine is recognized as an agent of thyroid cancer by FDA. *p*-dimethylaminoazobenzene (butter yellow), an azo dye is an animal carcinogen. And two xanthene dyes, non azo dyes are thought to be mutagenic²⁶. Allura red after metabolizing in body produces a product that causes bladder cancer in animals. Some other synthetic dyes like auramine, metanil yellow, lead chromate, rohdamine, sudan-3 and malachite green are considered to be mutagenic. Sudan dyes are red, synthetic, fat-soluble azo-dyes which are not allowable for use as food colors due to health perilous effects²⁷.

Estrogen Enhancers

Excessive use of sunset yellow (Yellow 6) and tartrazine (Yellow 5) have been shown to mimic the estrogen in the body. Increase in the level of estrogen may contribute to breast cancer and may decrease male sex drive. Red 3 has been studied to have estrogen like growth stimulating capability, and is potentially genotoxic and stimulatory for breast cancer.

ADHD (attention deficit hyperactivity disorder)

ADHD is a multifactorial, quantitative disorder and its studies laid some genetic as well as environmental causes on occurrence in human population. Its symptoms includes hyperactivity, lose temperament, low frustration tolerance, impulsivity, and lack of attention. Consumption of food containing artificial cause is one of the causes of ADHD. Yellow 5 and allura red causes severe hypersensitivity reaction²⁸. In an experiment design, children under age of 5 were subjected to drinks containing artificial color upto 20mg/day and withdrawal after some regular exposures. The behavior of children observed, shows a significant hyperactivity during exposure to the synthetic color^{29,30}. In another study, 65% to 89% individuals react to produce a hyperactive behavior when supplied with 100 mg of artificial food colors. Tartrazine when present in combination with benzoate it implicit hyperactive³¹.

Scenario in Pakistan on the use of food dyes

Being a developing nation Pakistan is involved in commercial preparation of many food items. Manufacturing comprises both the national and international production of food items. Each industrial sector must comprise of quality check and controls for the maintenance of standard food. And to eliminate the ill practices leading to the sub-standard foods, that leads to food

intoxication. In Pakistan very less number of people are concerned about the health issues and lack of awareness is prevalent. No idealized premises are set to check the abusive use of harmful components in the food. Some national level producers follow permissible additives to some extent but the addition of non-permissible dyes in food products by local vendors is reported to be high. Pakistan Pure Food Rules (1965) approves eighteen synthetic and five natural food colors as permitted food dyes. According to which some of the permitted synthetic colors are Brown 4, indigo 10, sunset yellow, indanthrone, food blue, food violet, green red and food black. The use of non-permitted synthetic dyes by private food industries and local products is extravagant. And no required action is taken against it^{32,33}.

Conclusion

Use of dyes either natural or synthetic is both adverse in different aspects. Synthetic dyes are far more toxic as they are aromatic compounds or obtained from coal-tar and are mutagens. Natural dyes are expensive, unstable and rare. There is an ample and immediate need to highlight the toxicity of the use of non-permitted dyes. A public awareness campaign must be formed to create awareness at different levels to the harmful aspects of excessive use of non-permitted dyes. Nowadays people are more conscious about their health and they prefer food based on natural ingredients. Due to low pollution less side effects and non-toxic properties natural dyes are frequently used in our daily food. Investigation is being carried out to improve quality as well as quantity of natural dyes but is not used excessively because of lack of technical knowledge on extraction and dyeing techniques. One of the main problem regarding natural dyes is their higher cost which makes them less desirable for every customer.

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