



## The Colour Code of Vegetables: What Pigments Tell You About Nutrition

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### INTRODUCTION

The colours of vegetables have long attracted human attention and influenced food preferences across cultures. Beyond their visual appeal, these colours represent complex biochemical compounds that play critical roles in both plant survival and human nutrition. Vegetable pigments are natural phytochemicals that contribute to photosynthesis, pollinator attraction, stress tolerance and protection against environmental damage. When consumed, many of these compounds exhibit antioxidant, anti-inflammatory and disease-preventive properties. Modern nutritional science increasingly emphasizes the importance of consuming a diverse range of coloured vegetables. Dietary recommendations often encourage people to eat a rainbow of vegetables because different colours generally indicate different classes of beneficial phytochemicals. This approach reflects the understanding that no single vegetable can provide all necessary nutrients and protective compounds.

Pigments such as chlorophylls, carotenoids and anthocyanins are associated with vitamins, minerals and antioxidants that influence human health. These compounds help reduce oxidative stress, improve immune function and lower the risk of chronic diseases, including cardiovascular disorders, diabetes and certain cancers. Advances in plant biochemistry and nutritional genomics have improved scientific understanding of the relationship between vegetable colour and nutritional composition. Researchers now recognize that pigmentation patterns can serve as indicators of nutrient density and functional food value.

## Pigments in Vegetables and Their Biological Functions

Plant pigments are specialized molecules that absorb and reflect specific wavelengths of light, thereby producing characteristic colours. These pigments are synthesized through complex metabolic pathways and perform essential physiological functions within plant tissues. In plants, pigments are involved in photosynthesis, photoprotection, antioxidant defence and signalling. Chlorophyll captures light energy for photosynthesis, while carotenoids protect photosynthetic tissues from oxidative damage. Anthocyanins and flavonoids protect plants against ultraviolet radiation, pathogens and environmental stress.

Pigments also influence ecological interactions. Brightly colored fruits and flowers attract pollinators and seed dispersers, while certain pigments act as chemical deterrents against herbivores and pathogens. For humans, vegetable pigments provide important nutritional and therapeutic benefits. Many pigments function as antioxidants that neutralize free radicals and reduce cellular damage. Others act as precursors to essential vitamins or influence metabolic pathways related to immunity and inflammation. The relationship between pigmentation and

nutrition highlights the importance of dietary diversity. Consuming vegetables of different colours ensures exposure to a broad spectrum of bioactive compounds.

## Chlorophyll and Green Vegetables

Chlorophyll is the primary pigment responsible for the green colouration of vegetables such as spinach, broccoli, kale and lettuce. It plays a central role in photosynthesis by capturing solar energy and converting it into chemical energy. Chemically, chlorophyll molecules contain magnesium at their core and share structural similarities with haemoglobin. Green vegetables rich in chlorophyll are often excellent sources of folate, iron, calcium and dietary fibre. Chlorophyll exhibits antioxidant and detoxification properties. Research suggests that chlorophyll derivatives may help reduce oxidative stress and support liver function by binding certain toxic compounds. Green vegetables are also associated with high concentrations of lutein and zeaxanthin, carotenoid pigments that contribute to eye health and reduce the risk of age-related macular degeneration. Dark green leafy vegetables are among the most nutrient-dense foods available and contribute significantly to micronutrient intake in healthy diets.

**Table 1:** Examples of Green Vegetables and Their Major Nutrients

Vegetable	Major Pigment	Key Nutrients	Health Benefits
Spinach	Chlorophyll	Iron, folate, vitamin K	Blood health and bone support
Broccoli	Chlorophyll	Vitamin C, fibre	Immune support
Kale	Chlorophyll	Calcium, antioxidants	Bone and heart health
Lettuce	Chlorophyll	Fibre, folate	Digestive support

## Carotenoids and Yellow Orange Vegetables

- ❖ Carotenoids are lipid-soluble pigments responsible for yellow, orange and some red colours in vegetables. Common carotenoids include beta carotene, lutein, zeaxanthin and lycopene.
- ❖ Carrots, pumpkins, sweet potatoes and yellow peppers are rich sources of carotenoids. Beta carotene is particularly important because it functions as a precursor to vitamin A, which supports vision, immunity and skin health.

- ❖ Carotenoids possess strong antioxidant activity and help protect cells against oxidative damage. Epidemiological studies associate high carotenoid intake with reduced risks of certain cancers and cardiovascular diseases.
- ❖ Unlike chlorophyll, carotenoids become more bioavailable after cooking because heat softens plant cell walls and improves pigment release. Small amounts of dietary fat also enhance carotenoid absorption.

- ❖ Lycopene, found abundantly in tomatoes and red peppers, has attracted considerable scientific interest due to its potential role in reducing prostate cancer risk and improving cardiovascular health.

**Table 2: Major Carotenoid-Rich Vegetables and Nutritional Functions**

Vegetable	Dominant Pigment	Associated Nutrient	Physiological Role
Carrot	Beta carotene	Vitamin A precursor	Vision and immunity
Pumpkin	Beta carotene	Antioxidants	Cellular protection
Tomato	Lycopene	Antioxidants	Cardiovascular health
Yellow pepper	Lutein	Eye protective compounds	Eye health

### Anthocyanins and Purple Blue Vegetables

- ❖ Anthocyanins are water-soluble pigments that produce red, purple and blue colours in vegetables such as purple cabbage, eggplant and purple sweet potato.
- ❖ These pigments belong to the flavonoid family and exhibit strong antioxidant and anti-inflammatory properties. Anthocyanins protect plant tissues from ultraviolet radiation and environmental stress while contributing to vibrant colouration.
- ❖ In human nutrition, anthocyanins have been associated with reduced risks of cardiovascular disease, cognitive decline and metabolic disorders. Their antioxidant capacity helps neutralize reactive oxygen species that contribute to cellular ageing.
- ❖ Purple vegetables often contain higher antioxidant activity than lighter coloured varieties of the same species. For example, purple cabbage contains significantly greater anthocyanin concentrations compared with green cabbage.
- ❖ Anthocyanins are sensitive to pH changes and temperature. Cooking methods influence pigment stability and may alter colour intensity.

### Betalains and Red Vegetables

- ❖ Betalains are nitrogen-containing pigments found mainly in beetroot and certain cactus species. These pigments are classified into betacyanins, which produce red violet colours, and betaxanthins, which produce yellow orange colours.
- ❖ Beetroot pigments are associated with antioxidant, anti-inflammatory and

detoxification effects. Betalains may support cardiovascular health by improving blood flow and reducing oxidative stress.

- ❖ Beetroot is also rich in dietary nitrates that enhance nitric oxide production and improve vascular function. Athletes often consume beetroot products to improve endurance and exercise performance.
- ❖ Compared with anthocyanins, betalains exhibit greater stability across a wider pH range, although they remain sensitive to prolonged heat exposure.

### White and Brown Vegetables

- ❖ White and brown vegetables are frequently underestimated because they lack bright pigmentation. However, these vegetables contain valuable phytochemicals and sulfur compounds with important health benefits.
- ❖ Garlic, onion, cauliflower and mushrooms contain flavonoids, sulfur compounds and phenolic substances associated with antimicrobial and anticancer effects.
- ❖ Allicin, a sulfur containing compound found in garlic, exhibits antimicrobial and cardioprotective activity. Quercetin in onions functions as a potent antioxidant and anti-inflammatory compound.
- ❖ Mushrooms contain ergothioneine and beta-glucans that support immune function and oxidative stress reduction.
- ❖ White vegetables demonstrate that nutritional value cannot always be judged solely by colour intensity.

**Table:** Nutritional Importance of White and Brown Vegetables

Vegetable	Key Compound	Nutritional Role
Garlic	Allicin	Antimicrobial activity
Onion	Quercetin	Anti-inflammatory effects
Cauliflower	Glucosinolates	Cancer protective properties
Mushroom	Beta glucans	Immune support

### Relationship Between Vegetable Colour and Antioxidant Capacity

Oxidative stress occurs when reactive oxygen species accumulate faster than the body can neutralize them. Antioxidants protect cells by stabilizing these reactive molecules. Many vegetable pigments function as antioxidants. Anthocyanins, carotenoids and flavonoids are particularly effective in reducing oxidative damage.

Generally, deeply coloured vegetables exhibit higher antioxidant activity compared with pale varieties. Purple, red and dark green vegetables often contain concentrated phytochemical profiles. However, antioxidant effectiveness depends not only on concentration but also on bioavailability, synergistic interactions and metabolic factors. Dietary diversity remains important because different antioxidants function through distinct mechanisms.

### Influence of Cooking and Processing on Pigments

Cooking methods significantly affect pigment stability and nutrient retention.

Chlorophyll degrades during prolonged heating, producing olive brown compounds that reduce visual appeal. Rapid cooking methods, such as steaming, preserve chlorophyll more effectively than boiling. Carotenoids often become more bioavailable after cooking. Tomato processing increases lycopene availability, while cooking carrots improves beta carotene absorption.

Anthocyanins are relatively unstable and may degrade under high temperatures or alkaline conditions. Minimal water cooking methods help preserve pigment content. Food processing can either enhance or reduce nutritional quality depending on the pigment type and preparation technique.

### Pigments and Disease Prevention

Numerous epidemiological studies associate high vegetable consumption with reduced risks of chronic diseases. Carotenoids support immune regulation and visual health, while anthocyanins contribute to cardiovascular protection and cognitive maintenance. Glucosinolates in cruciferous vegetables are linked to reduced cancer risk through detoxification pathways. Polyphenolic pigments may influence gut microbiota composition, inflammation and metabolic regulation.

Although individual compounds show promising effects, whole vegetable consumption remains more beneficial than isolated supplements due to synergistic interactions among nutrients and phytochemicals.

### Agricultural and Environmental Factors Affecting Pigmentation

Vegetable pigmentation is influenced by genetics, environmental conditions and agricultural practices. Light exposure strongly affects pigment synthesis. Increased sunlight often enhances anthocyanin and carotenoid production. Temperature stress may alter pigmentation patterns. Cool temperatures intensify anthocyanin accumulation in certain vegetables.

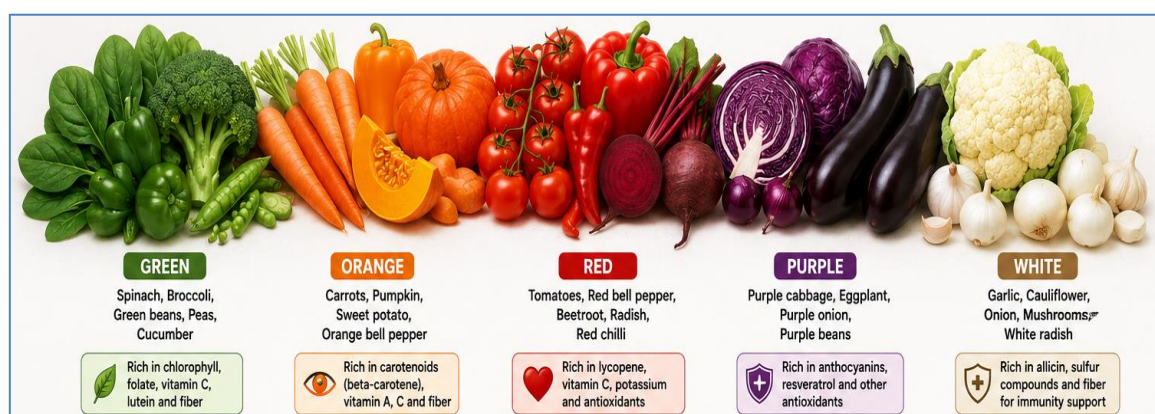
Soil fertility, irrigation practices and harvesting stage also affect pigment concentration. Plant breeders increasingly develop vegetable varieties with enhanced pigmentation and nutritional value. Purple carrots, black tomatoes and biofortified orange sweet potatoes are examples of nutritionally enhanced crops.

### The Importance of Eating a Rainbow Diet

The concept of eating a rainbow diet encourages the consumption of vegetables

from multiple colour groups to maximize nutrient diversity. Each colour category contributes unique phytochemicals and physiological benefits. Combining green, orange, red, purple and white vegetables supports balanced nutrition and broad antioxidant protection. Public health

campaigns increasingly use colour-based dietary guidance because it provides a simple and visually understandable framework for healthy eating. A rainbow diet also promotes culinary diversity and encourages greater vegetable intake overall.



**Figure 1.** Diversity of vegetable pigments is represented through different colour groups, illustrating the relationship between vegetable colouration and nutritional phytochemicals.

### Future Perspectives in Nutritional Pigment Research

- ❖ Advances in nutritional genomics, metabolomics and food science are expanding understanding of vegetable pigments and human health.
- ❖ Researchers are investigating interactions between phytochemicals and the gut microbiome, personalized nutrition approaches and biofortification strategies.
- ❖ Gene editing technologies may further enhance pigment concentration and nutritional quality in future crops.
- ❖ Functional foods and nutraceutical products derived from vegetable pigments are also attracting commercial and scientific interest.
- ❖ As consumer awareness grows, vegetable pigmentation may become an increasingly important criterion in agricultural breeding and dietary planning.

### CONCLUSION

Vegetable colours represent far more than visual diversity. They reflect complex biochemical systems that provide essential

nutritional and health-promoting functions. Chlorophylls, carotenoids, anthocyanins, betalains and sulfur compounds each contribute distinct physiological benefits and support disease prevention through antioxidant and metabolic mechanisms. Scientific evidence strongly supports the importance of consuming a diverse range of coloured vegetables as part of a balanced diet. The concept of eating a rainbow diet provides a practical strategy for improving nutritional intake and promoting long-term health. Understanding the relationship between vegetable pigments and nutrition enhances both consumer awareness and agricultural innovation. As research continues to uncover new functions of plant pigments, the colour code of vegetables will remain central to discussions of food quality, health promotion and sustainable nutrition.

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