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**POPULAR ARTICLE**

## Extensive uses and composition of sunflower crop

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### Introduction and intricacies of the topic

Sunflower is one of the most versatile and economically important oilseed crops, with wide-ranging applications in nutrition, medicine, livestock feeding, bioenergy, environmental sustainability, industry, and ornamental horticulture. Almost every part of the sunflower plant contains valuable biochemical constituents and possesses significant economic utility. This article aims to comprehensively highlight the detailed uses, biochemical composition, and multifaceted importance of the sunflower crop for researchers, breeders, students, and stakeholders working in the field of agriculture and plant sciences.

| **Category** | **Detailed uses and composition of sunflower crop** |
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| **Plant and botanical importance** | Sunflower (*Helianthus annuus* L.) is a multipurpose oilseed crop widely cultivated for edible oil, food, feed, industrial raw materials, ornamental purposes, and environmental applications. The crop produces high green biomass (35–50 t/ha), dry biomass (5–8 t/ha), plant height (1–4 m), head diameter (10–40 cm), and deep root systems extending up to 1.5–3.0 m. The plant contains cellulose (25–35%), hemicellulose (18–25%), lignin (15–22%), and substantial organic matter useful for bioenergy and soil enrichment. |
| **Seed composition and uses** | Sunflower seeds contain oil (35–50%), protein (20–25%), carbohydrates (15–20%), crude fiber (8–12%), moisture (4–8%), ash (2–4%), and energy value (550–620 kcal/100 g). Seeds are rich in vitamin E/tocopherol (35–70 mg/100 g), thiamine (1.0–2.0 mg/100 g), niacin (6–10 mg/100 g), folate (200–250 µg/100 g), and antioxidants. Mineral composition includes magnesium (300–390 mg/100 g), phosphorus (600–700 mg/100 g), potassium (600–850 mg/100 g), calcium (70–120 mg/100 g), sulfur (250–400 mg/100 g), iron (4–8 mg/100 g), zinc (4–7 mg/100 g), copper (1.0–2.0 mg/100 g), manganese (1.5–3.0 mg/100 g), selenium (50–70 µg/100 g), sodium (2–10 mg/100 g), chlorine (20–60 mg/100 g), boron (1–3 mg/kg), molybdenum (0.1–0.5 mg/kg), cobalt (0.01–0.05 mg/kg), and nickel (0.1–0.5 mg/kg). Seeds are used for edible oil extraction, roasted snacks, bakery products, confectioneries, breakfast cereals, sunflower butter, health foods, sprouts, bird feed, pet feed, and nutraceutical products. |
| **Sunflower oil composition and uses** | Sunflower oil contains total lipids (99–100%), unsaturated fatty acids (85–91%), linoleic acid (48–74%), oleic acid (14–40%), palmitic acid (4–9%), stearic acid (1–7%), tocopherols/vitamin E (40–70 mg/100 g), phytosterols (200–500 mg/100 g), lecithin (0.5–1.0%), carotenoids (1–2 mg/100 g), and low saturated fats (8–12%). The oil is cholesterol-free and highly digestible. It is extensively used for cooking, frying, salad dressings, margarine production, processed foods, bakery industries, baby foods, pharmaceuticals, cosmetics, soaps, detergents, lubricants, |

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| | biodiesel, paints, varnishes, surfactants, and industrial emulsifiers. |
| **Sunflower cake and meal composition and uses** | Sunflower cake and de-oiled meal contain crude protein (28–50%), carbohydrates (20–30%), crude fiber (12–18%), residual oil (1–10%), ash (5–7%), calcium (0.2–0.4%), phosphorus (0.8–1.2%), potassium (1–2%), sulfur-containing amino acids, and metabolizable energy (1800–2500 kcal/kg). The meal is rich in methionine and cysteine. It is utilized as protein-rich livestock feed, poultry feed, dairy feed, fish feed, aquaculture feed ingredient, organic manure, compost, and biofertilizer substrate. |
| **Hull and husk composition and uses** | Sunflower hulls and husks contain crude fiber (40–60%), cellulose (25–30%), hemicellulose (18–25%), lignin (20–25%), silica (1–3%), ash (2–5%), and calorific energy value (16–18 MJ/kg). Hulls are used for biomass fuel, briquettes, pellets, particleboard, fiberboard, paper pulp, compost production, mushroom cultivation substrate, industrial absorbents, activated carbon, and insulation materials. |
| **Leaf composition and uses** | Sunflower leaves contain crude protein (12–18%), chlorophyll (1.5–3.0%), potassium (2–4%), calcium (1–2%), magnesium (0.3–0.8%), phenolic compounds, flavonoids, and antioxidants. Leaves are used as green fodder, compost material, organic manure, medicinal extracts, and livestock feed supplements. |
| **Stem and stalk composition and uses** | Sunflower stalks contain cellulose (35–45%), hemicellulose (20–30%), lignin (15–22%), crude fiber (30–45%), silica (1–3%), and moisture (10–15%). Stalks are utilized for fuel, paper pulp, fiberboard manufacturing, biodegradable packaging material, composting, biomass energy generation, and rural construction material. |
| **Flower composition and uses** | Sunflower flowers contain pigments including carotenoids and xanthophylls (5–20 mg/100 g), flavonoids, anthocyanins, essential oils, nectar sugars (35–60%), pollen proteins (15–25%), and antioxidants. Flowers are used in ornamental horticulture, floriculture, cut flower industries, medicinal extracts, natural dyes, and pollinator attraction. |
| **Nutritional importance** | Sunflower products provide high-quality protein (20–25%), essential fatty acids (linoleic acid 48–74%), dietary fiber (8–12%), vitamin E (35–70 mg/100 g), antioxidants, phytosterols, selenium (50–70 µg/100 g), magnesium (300–390 mg/100 g), and zinc (4–7 mg/100 g). These nutrients contribute to cardiovascular protection, cholesterol reduction, immunity enhancement, antioxidant defense, anti-inflammatory activity, improved metabolism, and cellular protection. |
| **Medicinal and pharmaceutical uses** | Sunflower contains bioactive compounds such as tocopherols (40–70 mg/100 g), phytosterols (200–500 mg/100 g), flavonoids, phenolics, chlorogenic acid, caffeic acid, and lecithin (0.5–1.0%). These compounds possess antimicrobial, antioxidant, anti-inflammatory, cardioprotective, wound-healing, and cholesterol-lowering properties. Sunflower oil and extracts are used in therapeutic oils, ointments, cosmetics, nutraceuticals, and pharmaceutical formulations. |
| **Industrial uses** | Sunflower oil and biomass are utilized in biodiesel production (85–95% conversion efficiency), Sunflower industrial products are primarily derived from sunflower oil, seed proteins, husks, stalk biomass, and associated biochemical constituents. Refined sunflower oil obtained from seeds containing oil (35–50%) and total fatty acids (85–91%) is extensively utilized in soap manufacturing due to its high linoleic acid (48–74%), oleic acid (14–40%), palmitic acid (4–9%), and stearic acid (1–7%) composition. The same fatty acid-rich oil fractions along with phospholipids (0.5–1.5%) and lecithin (0.5–1.0%) are used in detergent and surfactant production because of their emulsification and cleansing properties. High-oleic sunflower oil containing oleic acid levels up to 70–90% is particularly valuable for industrial lubricants due to improved oxidative stability and viscosity |

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| | characteristics.<br><br>Sunflower oil also functions as an important raw material in paints, varnishes, and printing inks because of its high unsaturated fatty acid content (85–91%), linoleic acid concentration (48–74%), triglycerides (95–98%), and iodine value (110–145), which support oxidative drying and film formation. In cosmetic industries, sunflower oil, tocopherols/vitamin E (40–70 mg/100 g), phytosterols (200–500 mg/100 g), lecithin (0.5–1.0%), and essential fatty acids are used in creams, lotions, moisturizers, massage oils, and skincare formulations owing to their antioxidant and skin-conditioning properties.<br><br>Sunflower lecithin and phospholipids serve as industrial emulsifiers due to the presence of phosphatidylcholine and phosphatidylethanolamine compounds. Protein isolates derived from seeds containing protein (20–25%) are utilized in adhesive and bio-polymer formulations. Industrial chemicals and oleochemicals are produced from sunflower oil fatty acids (85–91%), glycerol generated during biodiesel production (8–12%), and lignocellulosic biomass components including cellulose (25–45%) and lignin (15–25%).<br><br>Biodegradable plastics and bio-based products are prepared using sunflower stalk cellulose (25–45%), hemicellulose (18–30%), lignin (15–25%), crude fiber (20–40%), triglycerides (95–98%), seed proteins (20–25%), and husk biomass. Sunflower oil containing oil content (35–50%) is also widely used for biodiesel production with methyl ester conversion efficiency ranging between 85–95%. Stalks and husks rich in cellulose (35–45%), hemicellulose (20–30%), lignin (15–22%), and crude fiber (30–45%) are employed in paper pulp, fiberboard, particleboard, packaging material, and bioenergy industries. Seed husks and biomass residues containing carbon content (40–55%) and crude fiber (40–60%) are further utilized for activated carbon preparation and industrial absorbents. Additionally, compost and organic amendments are produced from leaves, stalks, husks, and cake residues containing organic carbon (35–45%), nitrogen (1–3%), potassium (1–3%), and phosphorus (0.1–0.5%). |
| **Ornamental and decorative uses** | Sunflower plants produce large attractive inflorescences/flower (10–40 cm diameter), colorful petals, and tall stems (1–4 m), making them valuable for landscaping, parks, gardens, floriculture, bouquet preparation, decorative arrangements, and agro-tourism. |
| **Ecological and environmental uses** | Sunflower possesses high phytoremediation capacity for heavy metals such as lead, cadmium, uranium, arsenic, chromium, and nickel. The crop improves soil structure, enhances carbon sequestration, reduces soil erosion, supports biodiversity, conserves pollinators, and assists in wastewater remediation. Biomass accumulation may reach 35–50 t/ha. |
| **Apicultural importance** | Sunflower flowers produce abundant nectar with sugar concentration (35–60%) and protein-rich pollen (15–25%), supporting honeybee activity, honey production (25–75 kg/ha), pollinator conservation, and improved agricultural pollination efficiency. |
| **Livestock and fodder uses** | Green biomass contains crude protein (8–16%), digestible nutrients (55–65%), moisture (70–80%), calcium (0.5–1.2%), phosphorus (0.2–0.5%), and metabolizable energy suitable for silage, hay, green fodder, and livestock feed supplements. |
| **Bioenergy uses** | Sunflower oil (35–50%) is used for biodiesel production, while stalks and residues provide biomass energy (16–18 MJ/kg). Crop residues are also used for biogas, bioethanol, briquettes, pellets, and renewable energy generation. |

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| **Biomass composition and uses** | Sunflower biomass includes leaves, stalks, stems, heads, husks, roots, and post-harvest residues. Total green biomass production ranges from 35–50 t/ha, while dry biomass ranges from 5–12 t/ha depending on genotype and environmental conditions. Biomass contains moisture (60–80%), cellulose (25–45%), hemicellulose (18–30%), lignin (15–25%), crude fiber (20–40%), ash (2–8%), silica (1–3%), crude protein (5–16%), carbohydrates (20–35%), and organic carbon (35–45%). Mineral composition includes potassium (1–3%), calcium (0.5–2.0%), magnesium (0.2–0.8%), phosphorus (0.1–0.5%), sulfur (0.1–0.4%), iron (50–250 ppm), manganese (20–100 ppm), zinc (15–60 ppm), copper (5–20 ppm), boron (10–40 ppm), and sodium (0.05–0.2%). Biomass energy value ranges between 15–18 MJ/kg. |
| **Stem/stalk biomass** | Stem and stalk biomass constitute approximately 40–60% of total plant dry matter and contain cellulose (35–45%), hemicellulose (20–30%), lignin (15–22%), crude fiber (30–45%), silica (1–3%), ash (2–5%), and moisture (10–15%). Stalks are used for briquettes, pellets, bioethanol production, paper pulp, fiberboard, biodegradable materials, fuel, and composting. |
| **Leaf biomass** | Leaves contribute 10–20% of plant biomass and contain crude protein (12–18%), chlorophyll (1.5–3.0%), crude fiber (10–18%), carbohydrates (15–25%), calcium (1–2%), potassium (2–4%), magnesium (0.3–0.8%), iron (80–200 ppm), and phenolic compounds. Leaves are used as green fodder, silage material, compost, organic manure, and medicinal extracts. |
| **Head/receptacle biomass** | The sunflower head and receptacle contain carbohydrates (25–40%), crude fiber (15–25%), pectin (3–8%), cellulose (20–30%), and residual oil (2–8%). These residues are utilized in animal feed, composting, bioenergy production, and organic amendments. |
| **Root biomass** | Roots contribute 5–10% of total biomass and contain cellulose (20–30%), lignin (10–18%), carbohydrates (15–25%), and minerals including calcium, phosphorus, potassium, and sulfur. Deep root systems improve soil structure, nutrient recycling, carbon sequestration, and phytoremediation efficiency. |
| **Husk biomass** | Husk biomass contains crude fiber (40–60%), cellulose (25–30%), lignin (20–25%), silica (1–3%), ash (2–5%), and calorific value (16–18 MJ/kg). Husks are utilized for biomass fuel, briquettes, activated carbon, mushroom substrate, insulation materials, and industrial absorbents. |
| **Bioenergy potential of biomass** | Sunflower biomass has high renewable energy potential with biodiesel yield from oil (35–50%), biomass calorific value (15–18 MJ/kg), methane generation potential (180–300 $m^3$/ton biomass), and bioethanol production capacity due to high cellulose and carbohydrate content. Biomass is widely used for briquettes, pellets, biogas, bioethanol, and thermal energy generation. |
| **Economic importance** | Sunflower contributes significantly to edible oil security, livestock feed industries, pharmaceutical industries, renewable energy sectors, agro-industrial development, export earnings, employment generation, and farmer income due to its high oil recovery (35–50%), multiple by-products, and industrial versatility. |

## Recent unknown uses of sunflower crop with global examples

| Emerging use | Description with global examples |
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| **Biostimulant production from sunflower residues** | Sunflower stalks, husks, and processing residues contain phenolic compounds (2–8 mg GAE/g DW), soluble carbohydrates (18–32%), amino acids (3–7%), and antioxidant metabolites. Residue-derived extracts improved seed germination and salt tolerance by 15–40% in horticultural crops. In France and Italy, sunflower biomass hydrolysates are utilized in sustainable biostimulant |

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| | formulations within circular biorefinery systems. |
| **Nanotechnology-assisted biodiesel production** | Sunflower seed contains 35–50% oil, with 85–91% unsaturated fatty acids, primarily linoleic acid (48–74%) and oleic acid (14–40%). Nano-catalytic biodiesel systems using Fe3O4 magnetic nanoparticles (20–80 nm) achieved biodiesel conversion efficiencies of 85–95%. China and Turkey are developing reusable nano-catalyst systems that reduce transesterification waste generation by 30–50%. |
| **Sunflower-based nanomaterials** | Sunflower biomass including stalks, husks, and residues is increasingly utilized for synthesis of advanced nanomaterials. Sunflower-derived activated carbon exhibits surface areas of 150–1200 $m^2/g$ with adsorption efficiencies of 70–95% for dyes and heavy metals. Nanocellulose fibers isolated from sunflower stalks possess diameters of 5–50 nm and tensile strengths of 200–800 MPa suitable for biodegradable composites. Sunflower biochar contains stable carbon fractions of 40–55% with porosity values of 45–75%. Sunflower-based nanocomposites incorporating cellulose nanofibers improve mechanical strength by 20–60% in biodegradable materials. In India, China, Brazil, Germany, and Spain, sunflower waste biomass is used for water purification systems, supercapacitors, nano-fertilizers, biosensors, catalyst supports, biomedical carriers, and sustainable packaging technologies. |
| **Sunflower heads as microbial fermentation substrate** | Sunflower heads and capitulum residues contain cellulose (20–38%), hemicellulose (15–28%), soluble sugars (8–18%), proteins (6–12%), and lignin (12–22%), making them suitable substrates for microbial fermentation systems. Biodegraded sunflower head biomass supports fungal and bacterial growth efficiencies of 70–90% under controlled fermentation conditions. In China, India, and Brazil, sunflower head residues are utilized for production of biofertilizers, microbial enzymes, organic acids, compost inoculants, ethanol fermentation media, and soil biostimulants. |
| **Sunflower as a natural rubber source** | Wild *Helianthus* species contain natural rubber-like hydrocarbons and latex-associated compounds. Certain wild sunflower taxa accumulate polyisoprene-like hydrocarbons (2–8% dry biomass) and terpenoid metabolites useful for industrial biopolymer synthesis. Experimental studies reported rubber-yielding biomass production of 1–3 t/ha under controlled cultivation. Research programs in the United States, Argentina, and Russia are evaluating wild sunflower germplasm as alternative renewable sources for sustainable rubber, tire additives, industrial elastomers, and bio-based polymers. |
| **Sunflower in space biology research** | Due to rapid growth, heliotropism, and high biomass production, sunflower is being investigated in controlled-environment agriculture systems. Experimental studies reported biomass accumulation rates of 8–15 g/day/plant under optimized light systems. Research programs associated with NASA in the United States and European Space Agency in Europe are evaluating sunflower responses to artificial lighting, phototropism, oxygen recycling, and future space-based plant production systems. |
| **Biochar and carbon sequestration** | Sunflower stalks and husks converted into biochar contain stable carbon fractions of 40–55%, surface areas of 150–600 $m^2/g$, and significant water retention capacity. Application of sunflower biochar improved soil moisture retention by 10–35% and reduced greenhouse gas emissions in experimental systems. Australia and Brazil are investigating sunflower biochar for long-term carbon sequestration and climate-smart agriculture. |
| **Sunflower lecithin in advanced food technologies** | Sunflower lecithin constitutes approximately 0.5–1.5% of sunflower oil and contains phospholipids including phosphatidylcholine and phosphatidylethanolamine. It is increasingly replacing soy lecithin in allergen-free foods, chocolates, bakery products, infant formulas, and pharmaceutical encapsulation technologies throughout European Union countries. |

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| **Protein-based meat alternatives** | Sunflower seed contains 20–25% protein, while sunflower meal after oil extraction contains 28–45% protein. Protein isolates with purity levels of 80–90% exhibit emulsification and water-holding properties useful in meat analogues. Israel, the United States, and Germany are utilizing sunflower proteins in vegan meat substitutes, dairy-free beverages, and high-protein food systems. |
| **Pharmaceutical and biomedical applications** | Sunflower bioactive compounds include chlorogenic acid (20–350 mg/kg), caffeic acid (15–120 mg/kg), tocopherols (40–70 mg/100 g oil), phytosterols (200–500 mg/100 g oil), and flavonoids with strong antioxidant activity. Extracts demonstrated antimicrobial inhibition zones of 8–22 mm against pathogenic bacteria and significant anti-inflammatory activity in experimental studies. The United States and United Kingdom are exploring sunflower-derived nutraceuticals, wound-healing formulations, and pharmaceutical antioxidants. |
| **Advanced phytoremediation systems** | Sunflower roots can accumulate heavy metals including uranium, cadmium, chromium, arsenic, and lead. Metal uptake efficiencies reported include cadmium (50–70%), lead (40–65%), and uranium removal from contaminated water by 60–95% under controlled systems. Following the Chernobyl disaster in Ukraine, sunflower plants were deployed for radioactive contaminant cleanup. Similar phytoremediation systems are now used in the United States and China for industrial wastewater remediation. |
| **Circular bioeconomy and waste valorization** | Sunflower processing generates substantial residues including husks (18–30% of seed weight), oil cake (35–45% after oil extraction), and stalk biomass. These residues are converted into activated carbon with adsorption capacities of 150–500 mg/g, compost, biofertilizers, and industrial biomaterials. Spain and Argentina utilize sunflower waste valorization to support circular bioeconomy systems and sustainable agriculture. |
| **Carbon-neutral bioenergy systems** | Sunflower biomass possesses calorific values of 15–18 MJ/kg, with stalk biomass yields reaching 4–9 t/ha dry matter. Combustion and pelletization systems generate renewable thermal energy with carbon emission reductions of 40–70% relative to fossil fuels. Sweden and Denmark integrate sunflower residues into decentralized biomass heating and renewable energy systems. |
| **Green nanoparticle synthesis** | Sunflower petals and leaves contain flavonoids (5–18 mg/g), phenolics (8–25 mg GAE/g), and antioxidant metabolites capable of reducing metal ions into nanoparticles. In India and Brazil, sunflower extracts are used to synthesize silver nanoparticles (10–70 nm) and zinc oxide nanoparticles (20–100 nm) for antimicrobial coatings, nano-fertilizers, biosensors, and crop protection systems. |
| **Biostimulant production from sunflower residues** | Sunflower stalks, husks, and processing residues contain phenolic compounds (2–8 mg GAE/g DW), soluble carbohydrates (18–32%), amino acids (3–7%), and antioxidant metabolites. Residue-derived extracts improved seed germination and salt tolerance by 15–40% in horticultural crops. In France and Italy, sunflower biomass hydrolysates are utilized in sustainable biostimulant formulations within circular biorefinery systems. |
| **Microplastic and environmental toxicology studies** | Sunflower is increasingly used as a model system to study nano- and microplastic toxicity. Exposure to polyethylene and polystyrene microplastics (50 nm–5 mm) caused reductions in chlorophyll content by 10–35%, root elongation by 15–45%, and photosynthetic efficiency by 12–28%. Japan and South Korea are investigating oxidative stress biomarkers and plastic accumulation in sunflower root tissues. |
| **Microbiome engineering and soil health** | Sunflower rhizosphere systems enhance beneficial microbial populations including Rhizobiaceae, Sphingomonas, Bacillus, and Pseudomonas spp. Root exudates containing sugars, flavonoids, and organic acids increase microbial |

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| | biomass carbon by 20–45% and soil enzyme activity by 18–38%. Studies in the United States and Australia reported improved nutrient cycling efficiency and enhanced phosphorus solubilization in sunflower-based cropping systems. |
| **Bioplastics, smart bio-based materials and biopolymer production** | Sunflower stalks contain cellulose (25–45%), hemicellulose (18–30%), and lignin (15–25%), while sunflower hulls contain cellulose (22–28%), lignin (26–40%), hemicellulose (18–25%), proteins (4–9%), and ash (2–5%). Sunflower fibers are incorporated into biodegradable composites at 10–60% reinforcement ratios. In Germany, Netherlands, Canada, Finland, and Norway, sunflower biomass-derived polymers are used in eco-friendly packaging, biodegradable insulation boards, renewable coatings, automotive interior panels, and lightweight construction composites with density reductions of 15–35% compared to petroleum plastics. |
| **Nanotechnology-assisted biodiesel production** | Sunflower seed contains 35–50% oil, with 85–91% unsaturated fatty acids, primarily linoleic acid (48–74%) and oleic acid (14–40%). Nano-catalytic biodiesel systems using $Fe_3O_4$ magnetic nanoparticles (20–80 nm) achieved biodiesel conversion efficiencies of 85–95%. China and Turkey are developing reusable nano-catalyst systems that reduce transesterification waste generation by 30–50%. |

Overall, sunflower represents one of the most versatile multipurpose crops of the future with immense potential to contribute toward nutritional security, renewable industrial raw materials, environmental sustainability, carbon-neutral agriculture, and global bioeconomy development. Understanding the diverse and emerging applications of sunflower will greatly assist researchers, breeders, policymakers, and industry stakeholders in designing strategic breeding programs aimed at developing high-value, climate-resilient, and industrially specialized sunflower cultivars for future agricultural systems.

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