***Review Article***

**Investigating Green Solvents for Sustainable Pigment Extraction from Floral Sources: A review**

 **ABSTRACT**

The study of extracting colorants from flowers appeals to researchers because flowers generate visually appealing results while offering health benefits and industrial utility in food production and medical fields. The usage of modern extraction systems which require toxic organic solvents creates both environmental risks and health concerns. This study evaluates the effectiveness of natural deep eutectic solvents (NADES), ionic liquids, and supercritical fluids as eco-friendly alternatives to toxic solvent systems used for pigment extraction. The solvent systems meet green chemistry protocols while providing more effective solutions that protect health and the environment. Pigment quality remains stable while output increases thanks to extraction methods combined with sonication, microwave and enzyme technologies. New research on carotenoids, anthocyanins and betalains with updated extraction techniques shows how green solvents fulfill their potential role in pigment extraction. The current laboratory evidence shows limitations as scientist struggle to scale up production volumes for profitable operation methods which also adhere to industrial specifications. Making sustainable industrial methods effective for floriculture needs the resolution of both technical and commercial obstacles.

**Keywords:** Pigment extraction, Green solvents, Deep eutectic solvents (NADES), Sustainable methods, Industrial scalability

**INTRODUCTION**

The things which play importance in both aesthetic and industrial application are the natural pigments e.g. carotenoids, anthocyanins and betalains. These compounds create a very good visual representation of flowers but also have proven health benefits and are making their way into food, cosmetics and pharmaceutical use. Carotenoids are vital for photosynthesis and antioxidant properties and play a role in human health, (Nabi *et al*., 2023). They are widely used in food industry for color and health effects, as well as in cosmetics for their protective effects of photooxidation. Anthocyanins are important for their rich colors and health benefits, such as anti-inflammatory and anti-cancer properties(Sousa, 2022). The applications of these colorants are in food, cosmetics and textiles, especially in accordance with preference of consumer for natural colorants (Nabi *et al*., 2023).Betalains are naturally red-violet and yellow pigments gaining attention for their effect on health (Qaisar *et al*., 2019). Although the effects of these natural pigments are known; there are difficulties standardizing extraction methods and quality control over the various applications that may restrict their wider use in industries. Environmental problems arising from traditional extraction methods are addressed through the exploration of green solvents for their extraction.

**GREEN SOLVENTS**

Green solvents are environmentally friendly alternatives to conventional solvents used in chemical processes (Bubalo *et al*., 2015). Their main target is minimizing the environmental impact, health hazards and associated safety risks of solvent use in industrial production (Capello *et al.* 2007). Water, ionic liquids, supercritical CO2, biosolvents, organic carbonates and deep eutectic mixtures are some of the green solvents. Selection of green solvents involves their physical properties, chemical reactivity and environmental impact across its entire life cycle (Reichardt, *et al* 1988; Capello, *et al*, 2007). In general, simple alcohols such as methanol and ethanol or alkanes such as heptane or hexane are regarded as environmentally favourable solvents (Capello *et al*., 2007). Green chemistry embraces new rules for the development of sustainable and environmentally benign chemical processes, in which one of the important aspects is the use of green solvents (Bubalo *et al*., 2015)

**PRINCIPLES OF GREEN CHEMISTRY**

Green chemistry is an approach of chemical processes and products which produces and minimises the use and generation of hazardous substances (Abdussalam-Mohammed *et al*., 2020; Ivanković *et al*., 2017). It is founded on several principles that shape the design of environmentally benign substances and processes in their entire life cycle. Preventing waste, maximizing atom economy, using safer chemicals, designing energy efficient processes, incorporating renewable feed stocks, and reducing derivatives are these principles (Abdussalam-Mohammed *et al*. 2020). Applications of green chemistry range from organic, inorganic, biochemistry and polymer chemistry. Catalysis, biocatalysis, and the use of alternative renewable feedstocks, reaction media, and conditions are important key trends in green chemstry (Ivanković *et al*., 2017). Formation of green chemistry principles is related to achieving both economical and environmental protection and this is meant to achieve sustainable development and tackling the global challenges (Mammino, 2022; Hassan & Saleh, 2021).

**SOLVENT SELECTION GUIDE**

Prat *et al*. (2016) has prepared CHEM21 selection guide, which offers a complete ranking of classical and less common solvents according to a safety, health and environmental criteria consistent with global regulations. This work expands on existing efforts, including Sanofi's solvent selection guide that ranks solvents according to four classes, from 'recommended' to 'banned' just like GlaxoSmithKline developed an expanded solvent selection guide of 110 solvents with process safety factors and life cycle assessments (Henderson *et al*., 2011). The objective of these guides is to assist chemists to choose sustainable solvents for the pharmaceutical and chemical processing. Literature reviewing the ecological and economic significance, and application in commercial or academic practice, of green solvents further stress the relevance of such solvents (Nelson, 2003). Taken together, these selection guides constitute an essential first step towards less carbon intensive chemical processes in industrial sectors.

**TYPES OF GREEN SOLVENTS**

Green solvents are environmentally friendly alternatives to petrochemical solvents being developed in accord with green chemistry principles (Benvenuti & Santos, 2021). According to Naziri Mehrabani *et al*. (2022) they are categorized into several types, such as bio sourced solvents, water, ionic liquids, deep eutectic solvents, green synthetic organic solvents and supercritical fluids. This is because these solvents are easily accessible, low toxicity, and possibly reusable (Talele&Shahare, 2020). Green solvents have been employed in various technological fields (e.g. remediation technologies, polymeric membrane fabrication, pharmaceuticals, Benvenuti & Santos, 2021; Talele & Shahare, 2020), and the list is growing with the pressing need for restoration and environmental sustainability. The physicochemical properties of the green solvents have been modeled and classified using the COSMO-RS approach to facilitate the selection of appropriate green solvents in comparison with conventional solvents (Moity*et al*., 2012). In this classification, the possible other solvents listed alongside questionable solvents are identified as potential candidates, while new green solvents should be developed in areas where the alternatives are not shown.

Boiling point is extremely important when choosing green solvents for pigment extraction since these polar, sensitive compounds must be protected. The low boiling points make the extraction process less intensive because it is accomplished at milder temperatures, so the extraction step occurs at lower temperatures than can be used to extract the volatile and thermolabile pigments like carotenoids and chlorophylls. The extraction by novel green chemistry principles promotes safer and more efficient extraction methods as solvents having boiling below about 80°C minimize the loss of volatile compounds during extraction

thereby resulting in high yields of sensitive pigments(Ozel &Göğüş, 2014). For example, supercritical fluids and subcritical water extraction preserve the quality of extracted pigments and run at lower temperatures. Selective pigment extraction can be accomplished with solvents of lower boiling points compared with solvents of higher boiling points ensuring extraction of the desired pigment without accompanying unwanted compounds (Yoshikatsu *et al*., 1980). It has been noted in pigment extraction from microalgae, but in this case the solvents are boiling below 150 °C in order to achieve the simultaneous isolation of chlorophyll and carotenoids (Yoshikatsu *et al*., 1980). Often green solvents with low boiling points are less toxic and environmentally less harmful than traditional organic solvents which is in line with sustainability goals (Viñas-Ospino *et al*., 2023). This transition to these solvents cuts back on exposure to volatile organic compounds (VOCs). However, low boiling points are a virtue but they may impede extraction of high boiling compounds, and a judicious selection of solvents may be needed to achieve a joint optimization of the recovery of compounds and product quality.

**ADVANTAGES OF GREEN SOLVENTS FOR FLOWER PIGMENTS EXTRACTION**

Preserving the natural color and integrity of flower pigments has been demonstrated using green solvents. Natural deep eutectic solvents (NADES) are more stable for natural colorants than are water or ethanol solutions (Dai *et al*., 2014). There is a strong interaction between the natural colorants and the solvent. The flowers have been preserved using modified method which includes ethyl alcohol and polypropylene glycol, color and texture of which are naturally preserved for longer periods (Ito *et al*., 2010). The combination of green solvents like water, supercritical fluids, NADES and ionic liquids with various extraction techniques can optimally stabilise and increase the diversity of natural colorants such as carotenoids, anthocyanins and betalains (Tzanova*et al*., 2024). In addition to these traditional preservation methods using chemicals such as copper sulphate, formalin and silica gel, attempts have been tried to retain natural color pigments in botanical specimens using some chemicals (Verma, 2008). But green solvent approaches have environmentally friendly aspects that can help preserve flower pigments in their brilliance.

Lutein is high in marigold flower and the natural yellow-orange pigment is used as food coloring and nutrient supplement (Kashyap *et al*., 2022, Sowbhagya *et al* 2004). Traditionally, the solvents used for extraction include toxic ones like hexane; they leave residues not suitable for food use (Ballentine, 2020). Nevertheless, there has been research to develop non-toxic and greener extraction process to assure food safety and satisfy consumers' need for natural colorants (Aberoumand, 2011; Kashyap *et al*., 2022). the green solvent 2-methyltetrahydrofuran was shown to extract lutein with yield (2.56%) and purity (97.33%) superior to the conventional methods (Kashyap *et al*. 2022).

There have been recent research into eco friendly practices for pigment extraction from agricultural and floral waste. Recently, natural deep eutectic solvents (NADES) have been a sustainable alternative for the extraction of pigments and antioxidants from agri-processing waste (Kumar & Brooks, 2021). Although vegetable oils are another green solvent choice for carotenoid extraction, they possess food and environmental safety compared to product-based solvents (Tiwari *et al*., 2022). Sustainable carotenoid extraction is feasible through the use of innovative extraction technologies, including ultrasound, microwaves and enzyme assisted, combined with green solvents like ethyl lactate and ionic liquids (Morón-Ortiz *et al*., 2024). These ecofriendly methods also apply to microbial pigments, a new area of interest as possible alternatives to synthetic dyes. Recently, ultrasound assisted extraction and ionic liquid assisted extraction have been employed to extract efficiently and environmentally friendly pigment from microbial sources (Rajendran *et al*., 2023). Nevertheless, the scalability of these laboratory scale processes to industrial applications remains difficult.

Green solvents have been shown promising for preservation and stabilisation of natural pigments from flowers when stored. The various preservation techniques used in preserving natural color pigments in botanical specimens have included treatment with copper sulphate solutions and formalin based mixtures (Verma, 2008). Natural deep eutectic solvents (NADES) have been shown to stabilise pigment molecules of safflower more effectively than in water or ethanol solutions and this is attributed to strong hydrogen bonding interactions (Dai *et al*., 2014). Ethanol at 4–10% concentrations extended the vase life of bouquet flowers by up to 2 days, delaying the wilting and senescent of petals, and maintained higher chlorophyll fluorescence intensity (Hossain *et al*., 2008).

**Table 1 : INVESTIGATING GREEN SOLVENTS FOR SUSTAINABLE PIGMENT EXTRACTION FROM FLOWERS**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Flower** | **Pigment** | **Solvent Used** | **Extraction Method** | **Yield** | **Reference** |
| *Portulaca grandiflora* | Deep pink | Ethanol | Ultrasound-assisted extraction | 1.65% | Amir-Al Zumahi*et al*., 2020 |
| *Rosa ardsrovar* (Red Rose) | Anthocyanins (cyanidin, pelargonidin) | Ethanol | Ultrasound-assisted extraction | 6.79% | Amir-Al Zumahi*et al.,* 2020 |
| Pereskiableo (Desert Rose) | Orange | Ethanol | Ultrasound-assisted extraction | 3.3% | Amir-Al Zumahi*et al.,* 2020 |
| *Clitoria ternatea* L. | Anthocyanins (Ternatins) | Aqueous | Aqueous Extraction | TMAC: 7925.29±36.07 mg/L, Polymeric Color: 25.28±1.14% | Netravati *et al*., 2022 |
| *Carthamus tinctorius* | Red pigment (Carthamine) | Hydrogen Peroxide (H₂O₂) + Degassed Bicarbonate | Oxidant pretreatment + Degassed solvent extraction | Higher Yield: Effective for red carthamine pigment extraction. | Ghorbani *et al.*, 2015 |
| *Tagetes erecta* L. | Lutein | ChChl/glucose | No data | 80%369 mg/gFW | Dharani *et al.*, 2022 |
| *Gomphrena globosa* L  | Betalains  | Water | UAE; 500 W, 22 min; 5 g/L ratio | 161 mg/g DM | Roriz *et al.*, 2020 |
| *Hibiscus sabdariffa* | anthocyanins | Citric acid/ethylene glycol with a 1:4 M ratio | MAE; 550 W50% water (*v*/*v*), 180 s | 3 mg/g DW | Kurtulbas*et al*., 2020 |
| *Catharanthus roseus* | anthocyanins | Lactic acid–glucose1,2-propanediol–choline chloride | Stirring, 40 °C; 30 min | No data | Dai *et al.*, 2016 |
| *Hibiscus sabdariffa* L. | anthocyanins | 39.1% ethanol in water, *v*/*v* | UAE, 296.6 W, 26 min; 30–35 °C; 30 g/L ratio | 24 mg/g DM | Pinela *et al.*, 2019 |
| *Hibiscus sabdariffa* L. | anthocyanins | 15% acetic acid (*v*/*v*) | Stirring, 25 g/L ratio, ambient temp., 48 h | No data | Segura-Carretero *et al.*, 2008 |
| *Amaranthus hypochondricus*L*.* | Betalains  | Water | Solid-liquid extraction | 0.2–0.4 mg/g0.2–0.6 mg/g | Lopez *et al.*, 2023 |
| *Amaranth (A. cruentus)* | Betalains  | Water | Solid-liquid extraction | 4.8 mg/g | Howard *et al.*, 2022 |
| *Tagetes erecta* L*.* | Lutein | MeTHF, hexane, tetrahydrofuran, acetone, and 1,4- dioxane | CSE(Conventional Solvent Extraction) | 97.64% | Kashyap*et al.*, 2022 |
|

|  |
| --- |
| Dried Rose |

|  |
| --- |
|  |

 | Anthocyanins | LacticAcid:Choline Chloride (1:1) | Ultrasound-Assisted Extraction | 826.59 ± 17.35 mg/l |  Prakash *et al.,* 2024 |
| *Bougainvillea glabra* | Betalins | 1:1 Methanol:Water | Solvent extraction | Absorbance = **0.534** at 548 nm | Ibrahim*et al.,* 2019 |
| *Tagetes erecta L. (*Marigold*)* | Lutein | Choline chloride + glucose (ChCl+glucose) | Deep Eutectic Solvents (DES) | 368.64 g/kg | Dharani *et al***.** (2022) |
| *Ixora javanica* | Flavonoids, Anthocyanins | Choline chloride + propylene glycol (1:1) | Green ultrasound-assisted deep eutectic solvent extraction | 33 mg quercetin equivalent/g dried sample | Oktaviyanti, N. D., *et al*. (2019) |

**INTEGRATION WITH SUSTAINABLE EXTRACTION TECHIQUES**

Recent research has brought forward the growing demand for green extraction techniques of bioactive compounds due to environmental concern and a need for the sustainable practice (Muhammad Usman *et al*., 2023). Promising results have been demonstrated by various eco-friendly methods, such as supercritical fluid extraction, ultrasound assisted extraction or enzyme assisted extraction. Traditional solvents, such as deep eutectics solvents or bio based solvents, have shown promise to improve extraction efficiency (Muhammad Usman *et al*., 2023; Beshare Hashemi *et al*., 2022). Synergistic effects of various extraction techniques complementing each other have been combined e.g. ultrasound microwaved assisted extraction to get improved yields with short extraction times (Muhammad Usman *et al*., 2023; Manoj Kumar *et al*., 2023). When scaled up to industrial scale, these green approaches also present cost benefits and high purity potential (Manoj Kumar *et al*., 2023). However, the adoption of these gas detection techniques is hindered by standardization, selectivity and economic viability (Muhammad Usman *et al*., 2023; Naqvi *et al*., 2021).

One approach to reducing both solvent consumption and environmental impact in chemical process is by using green solvents. Compared to conventional solvents, containing and recycling them result in environmental contamination (Desimone, 2002). To overcome these issues, green solvents including ionic liquids, supercritical fluids and biosolvents are developed (Welton, 2015; Shanab*et al*., 2013). Nevertheless, both the technical and commercial performance (Welton, 2015) have to be considered for successful implementation of sustainable processes. Researchers have developed methods to calculate a 'greenness index' based on environmental parameters and solvent amounts (as measured in grams) in order to evaluate and compare solvent greenness (Stewart Slater &Savelski, 2007). With this approach, scientists and engineers can choose alternatives to greener solvents or processes. Solvent free processes and improved recycling protocols have been explored, however, they have limitations and further development and practical application of environmentally benign alternative solvents (Desimone, 2002; Shanab*et al*., 2013) is still required.

**ECONOMIC AND ENVIRONMENTAL IMPACTS**

Temple and floral industries discard flower waste posing environmental problems but they can be transformed into valuable products through green approaches. Several methods have been explored for exploitation of these wastes, such as through solid state fermentation for compost and bioethanol, biogas, dyes, and biosurfactants (biological surface active agents) (Bennurmath*et al*., 2021). The technique of ultra sonication of natural dye extraction has resulted in producing fabrics colors for fabric dyeing and the waste producing residue was further employed in vermicomposting and biochar production (Singh *et al*., 2017).

Sustainable practices in several industries including floriculture require green solvents. The motivation for these solvents is to decrease environmental pollution, energy consumption, and the hazard to health and surrounding environment suffered by traditional organic solvents (Clarke *et al*., 2018; Welton, 2015). As for sustainable solvent alternatives, water, supercritical carbon dioxide and ionic liquids, deep eutectic solvents, bio-derived solvents such as 2-methyltetrahydrofuran and glycerol (Kerton, 2016) are just some examples. The main advantage of these green solvents is that they have lower vapor pressure, reduced flammability and lower toxicity (Kerton, 2016). Moreover, the commercial performance has to be taken into account when environmentally sustainable processes are successfully implemented (Welton, 2015). Like many other properties, solvent free processes and more efficient recycling protocols have been developed, but this has certain limitations that have forced researchers to look for environmentally benign solvents (Desimone, 2002). In terms of chemical production processes, the selection of appropriate solvents can provide a substantial boost to the processes' sustainability and contribute to the more eco-friendly practices in any supply chain that involves floriculture (Clarke *et al*., 2018; Welton, 2015).

**APPLICATION OF FLOWER PIGMENTS EXTRACTED USING GREEN SOLVENTS**

In the textile industry, natural dyes are becoming more popular as eco friendly substitutes of synthetic dyes. Derived from plant sources these dyes are biodegradable, non toxic and ecologically friendly (Jordeva *et al*., 2020). Similar to other textile materials such as cotton, silk and wool, they can be used on most textile materials mordanting them in different ways to improve color fastness (Sanjeeda and Taiyaba, 2014; Gupta, 2019). The natural dyes provided a wide range of color shades and also show fair to excellent fastness properties in the studies (Iqbal & Ansari, 2014). Natural dyes often require mordants to fix, some of which may not be eco friendly (Gupta, 2019); their advantages are that they are non allergic and non carcinogenic. The challenge notwithstanding, use of natural dyes opens avenues for creating new markets and employment, supporting current environmental and economic concerns (Jordeva *et al*., 2020; Ado *et al*., 2015).Cosmetics, food and textiles are being explored to use colors obtained from plant such as anthocyanins, carotenoids, betalains.

**CHALLENGES IN ADOPTING GREEN SOLVENTS**

Different flower pigments are extracted differently depending on their solubility in different solvents. Carotenoids and chlorophylls absorb with characteristic curves in solvents of increasing polarity, for which equations are metrologically developed for their quantitative determination (Lichtenthaler & Wellburn, 1983). Strong hydrogen bonding interactions (Dai *et al*., 2014) account for the improved stability of natural deep eutectic solvents (NADES) for safflower pigments when compared to water or ethanol. Extraction yields and selectivity for natural pigments using alternative solvents such as ionic liquids, eutectic solvents and surfactant solutions are aligned with sustainability goals (de Souza Mesquita *et al*., 2020). Important ecological roles have been played by the three major groups of floral pigments, betalains, carotenoids, and anthocyanins, and they have been targets for biotechnological modification (Grotewold, 2006). However, solvent compatibility, and implementation of novel extraction methods, can help improve recovery and stability of these valuable natural colorants.

However, scaling green solvents for industrial use faces economic challenges, including high costs, complicated product recovery, and recyclability issues (Usman *et al*., 2023; New *et al*., 2022). Additional challenges include biomass feedstock sourcing, cost fluctuations, and limited compatibility with existing processes (Usman *et al*., 2023). To address these challenges, future research should focus on developing alternative feedstock sources, improving solubility and separation techniques, optimizing process parameters, and designing cost-effective equipment (Usman *et al*., 2023). Despite these obstacles, green solvents have the potential to significantly impact industrial chemical processes, offering environmental and health benefits over traditional solvents (Sowbhagyam, 2024).

**EMERGING TRENDS AND FUTURE DIRECTIONS**

Eco friendly alternatives to traditional organic solvents has become a recent focus of novel solvent systems. Cyclopentyl methyl ether (CPME) has surfaced as a versatile, sustainable solvent for biotechnology and biorefineries (de Gonzalo *et al*., 2019). As low cost, easy preparation and renewable raw materials, DESs are a highly desirable class of solvents for a variety of biocatalytic processes (Xu *et al*., 2017). DESs and ionic liquids have been promising to participate in biomedical applications; drug solubilization, pharmaceutical delivery and protein stabilization (Curreri *et al*., 2021). Natural DESs have proven effective in lignocellulosic biomass processing in hydrolyzing of lignin carbohydrate complexes and improving enzymatic digestibility (Satlewal*et al*., 2018). All these novel solvent systems, which are low toxic, biodegradable and recyclable, adhere to sustainable chemistry principles. Research aimed at optimizing their properties and expanding their use in these and other fields such as biotechnology, biorefineries and biomedicine, is ongoing.

By using green solvents, natural plant pigments can be extracted from agri-food waste, which are sustainable alternative to synthetic colorants, which contributes to circular economy (Sharma *et al*., 2022). A practical example is to extract natural dyes from temple floral waste and vegetable peels by ultrasonication and spray drying. The extracted pigments can be used to dye fabrics, residual waste can be further utilized respectively for vermicomposting and biochar production in a closed loop system (Singh *et al*., 2017). In addition to waste management issues, this approach will lead to value added products as well as economies of scale, each generating environmental and economic benefits in the floriculture industry.

**CONCLUSION**

Green solvents offer a promising approach to sustainable pigment extraction in floriculture because not only might they simultaneously increase the extractability of polar and nonpolar compounds, they may also improve recovery rates of valuable bioactive compounds. Natural deep eutectic solvents (NADES) and vegetable oils are used as effective, non-toxic alternatives to conventional solvents retaining natural pigments and functional properties. In addition, ecofriendly extraction techniques, such as ultrasound assisted, microwave assisted, and enzyme assisted methods serve as viable replacements with traditional organic solvent based extraction methods. Although the laboratory studies have been successful, there are still challenges to scaling these methods for industrial applications. An integral part of assessing their overall sustainability will involve the integration of life cycle assessments. With the use of these, green solvents and advances in extraction techniques can open the door to more environmentally friendly, efficient strategies for pigment extraction conforming with the principals of a circular economy in the flower industry.

**REFERENCES**

* Aberoumand, A. (2011). A review article on edible pigments properties and sources as natural biocolorants in foodstuff and food industry. *World Journal of Dairy & Food Sciences, 6*, 71-78.
* Abdussalam-Mohammed, W., Ali, A.Q. & Errayes, A.O. (2020). Green Chemistry: Principles, Applications, and Disadvantages. *Chemical Methodologies.*
* Adriana, V., López-Malo, D., Esteve, M.J., Frígola, A. &Blesa, J. (2023). Green Solvents: Emerging Alternatives for Carotenoid Extraction from Fruit and Vegetable By-Products. *Foods.*doi: 10.3390/foods12040863
* Ali Naziri Mehrabani, S., Vatanpour, V. & Koyuncu, I. (2022). Green solvents in polymeric membrane fabrication: A review. *Separation and Purification Technology.*
* Amir-Al Zumahi, S. M., Arobi, N., Taha, H., Hossain, M. K., Kabir, H., Matin, R., ... & Rahman, M. M. (2020). Extraction, optical properties, and aging studies of natural pigments of various flower plants. *Heliyon*, *6* (9).
* Amita, C., Dwivedi, A.,& Upadhyayula, S. (2021). Supercritical fluids as green solvents. doi: 10.1016/B978-0-12-821938-6.00028-1
* Ateeq, H., & Saeed, F. (2022). Phytochemical profile and food applications of edible flowers: a comprehensive treatise. *Journal of Food Processing and Preservation*.
* Dai, Y., Rozema, E., Verpoorte, R. & Choi, Y. H. (2016). Application of natural deep eutectic solvents to the extraction of anthocyanins from Catharanthus roseus with high extractability and stability replacing conventional organic solvents. *Journal of Chromatography A*, *1434*, 50-56.
* de Gonzalo, G., Alcántara, A. R. & Domínguez de María, P. (2019). Cyclopentyl methyl ether (CPME): a versatile eco‐friendly solvent for applications in biotechnology and biorefineries. *Chem Sus Chem*, *12*(10), 2083-2097.
* de Souza Mesquita, L. M., Martins, M., Pisani, L. P., Ventura, S. P., & de Rosso, V. V. (2021). Insights on the use of alternative solvents and technologies to recover bio‐based food pigments. *Comprehensive Reviews in Food Science and Food Safety*, *20*(1), 787-818.
* Ballentine, E. (2020). *Marigold.* Blooming Flowers.
* Bennurmath, P., S Bhatt, D., Gurung, A., Singh, A.A. & Bhatt, S. (2021). Novel green approaches towards utilization of flower waste: A review. *Environment Conservation Journal.*
* Benvenuti, J. & Santos, J.H. (2021). Green solvents for remediation technologies.
* Benvenuti, S. &Mazzoncini, M. (2021). The Biodiversity of Edible Flowers: Discovering New Tastes and New Health Benefits. *Frontiers in Plant Science, 11.*
* Bijttebier, S., Van der Auwera, A., Foubert, K., Voorspoels, S., Pieters, L. & Apers, S. (2016). Bridging the gap between comprehensive extraction protocols in plant metabolomics studies and method validation. *Analytica Chimica Acta, 935*, 136-150.
* Bohra, M., &Visen, A. (2022). Nutraceutical Properties in Flowers. *Research Anthology on Recent Advancements in Ethnopharmacology and Nutraceuticals.*
* Brera, G.N., Mukhtar, K., Ahmed, W., Manzoor, M.F., Kieliszek, M., Bhat, Z.F. & Aadil, R.M. (2023). Natural pigments: Anthocyanins, carotenoids, chlorophylls, and betalains as food colorants in food products. *Food Bioscience, 52*, 102403. doi: 10.1016/j.fbio.2023.102403
* Bubalo, M.C., Vidovic, S.S., Redovniković, I.R. & Jokić, S. (2015). Green solvents for green technologies. *Journal of Biotechnology.*
Capello, C., Fischer, U., &Hungerbühler, K. (2007). What is a green solvent? A comprehensive framework for the environmental assessment of solvents. *Green Chemistry, 9*, 927-934.
* Clarke, C.J., Tu, W., Levers, O., Bröhl, A.,& Hallett, J.P. (2018). Green and Sustainable Solvents in Chemical Processes. *Chemical Reviews, 118(2)*, 747-800.
* Curreri, A.M., Mitragotri, S.S. & Tanner, E.E. (2021). Recent Advances in Ionic Liquids in Biomedicine. *Advanced Science, 8.*
* C., R.V., Sousa. (2022). Anthocyanins, Carotenoids and Chlorophylls in Edible Plant Leaves Unveiled by Tandem Mass Spectrometry. *Foods, 11(13),* 1924. doi: 10.3390/foods11131924.
* Dai, Y., Verpoorte, R., & Choi, Y. H. (2014). Natural deep eutectic solvents providing enhanced stability of natural colorants from safflower (Carthamus tinctorius). *Food chemistry*, *159*, 116-121.
* Dharani, S., Ramalingam, P., Priya, Basavraju, S., Saraswathy. (2022). Extraction of lutein from *targetes erecta* using deep eutectic solvents. AIP Conf. Proc. 2446, 02001
* *Faisal, Z., Saeed, F., Afzaal, M., Akram, N., Shah, Y.A., Islam, F., & Ateeq, H.* (2022). Phytochemical profile and food applications of edible flowers: a comprehensive treatise. *Journal of Food Processing and Preservation.*
* Gao, F., Bai, R., Ferlin, F., Vaccaro, L., Li, M. & Gu, Y. (2020). Replacement strategies for non-green dipolar aprotic solvents. *Green Chemistry, 22*, 6240-6257.
* Ghorbani, E., Hasani Keleshteri, R., Shahbazi, M., Moradi, F.& Sadri, M. (2015). Optimization of extraction yield of carthamine and safflower yellow pigments from *Carthamus tinctorius* L. under different treatments and solvent systems. *Research Journal of Pharmacognosy, 2(1)*, 17–23.
* Ghosh, S., Sarkar, T. & Chakraborty, R. (2023). Underutilized plant sources: A hidden treasure of natural colors. *Food Bioscience.*
* Grotewold, E. (2006). The genetics and biochemistry of floral pigments. *Annual Review of Plant Biology, 57*, 761-780.
* Gupta, V. (2019). Fundamentals of Natural Dyes and Its Application on Textile Substrates. *Chemistry and Technology of Natural and Synthetic Dyes and Pigments*.
* Hashemi, B., Shiri, F., Švec, F. & Nováková, L. (2022). Green solvents and approaches recently applied for extraction of natural bioactive compounds. *TrAC Trends in Analytical Chemistry.*
* Hassan, A.I. & Saleh, H.M. (2021). Principles of Green Chemistry. *Green Organic Reactions.*
* Henderson, R.K., Jiménez-González, C., Constable, D.J., Alston, S.R., Inglis, G.G., Fisher, G., Sherwood, J., Binks, S.P.&Curzons, A.D. (2011). Expanding GSK's solvent selection guide ― embedding sustainability into solvent selection starting at medicinal chemistry. *Green Chemistry, 13*, 854-862.
* Hirabayashi, Y., Yamamoto, K., & Odaka, F. (1980). Extraction of pigments from microalgae.
* Hoang, H.T., Moon, J., & Lee, Y. (2021). Natural Antioxidants from Plant Extracts in Skincare Cosmetics: Recent Applications, Challenges and Perspectives. *Cosmetics.*
* Hossain, A.S., Boyce, A.B., & Majid, H.M. (2008). Vase life extension and chlorophyll fluorescence yield of bougainvillea flower as influenced by ethanol to attain maximum environmental beautification as ornamental components. *American Journal of Environmental Sciences, 4*, 625-630.
* Howard, J.E., Villamil, M.B., & Riggins, C.W. (2022). Amaranth as a natural food colorant source: Survey of germplasm and optimization of extraction methods for betalain pigments. *Front. Plant Sci., 13*, 932440.
* Ibrahim, M.K. & Khalid, M. (2019). Optimization extraction of *Bougainvillea glabra* violet bracts pigment. *Journal of University of Duhok, 22(2)*, 206-217.
* Ito, H., Hayashi, T., Hashimoto, M., Miyagawa, K., Nakamura, S., Mizuta, Y. & Yazawa, S. (2010). A Protocol for Preparing Preserved Flowers with Natural Color and Texture. *HortTechnology, 20*, 445-448.
* Ivanković, A., Dronjić, A., Bevanda, A.M.&Talić, S. (2017). Review of 12 Principles of Green Chemistry in Practice. *International Journal of Literature and Arts, 6*, 39.
* *Janarny, G., Gunathilake, K.D., & Ranaweera, K.* (2021). Nutraceutical potential of dietary phytochemicals in edible flowers-A review. *Journal of Food Biochemistry*, e13642.
* Jordeva, S., Kertakova, M., Zhezhova, S., Golomeova-Longurova, S. &Mojsov, K. (2020). Dyeing of textiles with natural dyes. Tekstilnaindustrija.
* Kerton, F.M. (2016). *Solvent systems for sustainable chemistry.*
* Kumar, M. Barbhai, M.D. Puranik, S. Radha, Natta, S. Senapathy, M. DHUMAL, S.S. Singh, S. Kumar, S. Deshmukh, V.P. Anitha, T. Dey, A. Pandiselvam, R. & Lorenzo, J.M. (2023). Combination of green extraction techniques and smart solvents for bioactives recovery. *TrAC Trends in Analytical Chemistry.*
* Kumar Kashyap, P. Singh, S. Kumar Singh, M. Gupta, A. Tandon, S. Shanker, K. Kumar Verma, R. & Swaroop Verma, R. (2022). An efficient process for the extraction of lutein and chemical characterization of other organic volatiles from marigold (*Tagetes erecta* L.) flower. *Food Chemistry, 396*, 133647.
* Kumar, S. & Brooks, M.S. (2021). Natural deep eutectic solvents for sustainable extraction of pigments and antioxidants from agri-processing waste. *Valorization of Agri-Food Wastes and By-Products.*
* Kurtulbas, E. Pekel, A.G. Bilgin, M. Makris, D.P. & Sahin, S. (2020). Citric acid-based deep eutectic solvent for the anthocyanin recovery from *Hibiscus sabdariffa* through microwave-assisted extraction. *Biomass Conversion and Biorefinery, 12*, 351–3.
* Lopez, M. A. H., Luna-Suárez, S., Macuil, R. J. D., & Cárdenas, F. F. R. (2023). Simple and efficient protocol for amaranth betalains extraction and stability analysis by ATR-FTIR spectroscopy. *Journal of Cereal Science, 113*, 103745.
* Lichtenthaler, H. K. & Wellburn, A. R. (1983). Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. *Biochemical Society Transactions, 11*, 591-592.
* Li, M., Gao, F. & Gu, Y. (2020). Several alternative strategies for non-green polar aprotic solvents. *SCIENTIA SINICA Chimica.*
* Mammino, L. (2022). *Green chemistry: Chemistry working for sustainability.Green Chemistry and Computational Chemistry.*
* Marzena, B., Paulina, M. & Katarzyna, B. (2020). Characteristics of carotenoids and their use in the cosmetics industry. *Journal of Education, Health and Sport, 10*(7), 192-196. https://doi.org/10.12775/JEHS.2020.10.07.020.
* Mehrabani, S. A. N., Vatanpour, V. & Koyuncu, I. (2022). Green solvents in polymeric membrane fabrication: A review. *Separation and Purification Technology*, *298*, 121691.
* Moity, L., Durand, M. R., Benazzouz, A., Pierlot, C., Molinier, V. & Aubry, J. (2012). Panorama of sustainable solvents using the COSMO-RS approach. *Green Chemistry, 14*, 1132-1145.
* Morón-Ortiz, Á., Mapelli-Brahm, P. & Meléndez-Martínez, A. J. (2024). Sustainable green extraction of carotenoid pigments: Innovative technologies and bio-based solvents. *Antioxidants, 13.*
* Mustafa, Z. O. &Göğüş, F. (2014). Subcritical water as a green solvent for plant extraction. https://doi.org/10.1007/978-3-662-43628-8\_4
* Nabi, B. G., Mukhtar, K., Ahmed, W., Manzoor, M. F., Ranjha, M. M. A. N., Kieliszek, M., ... & Aadil, R. M. (2023). Natural pigments: Anthocyanins, carotenoids, chlorophylls, and betalains as colorants in food products. *Food Bioscience*, *52*, 102403.
* Netravati, S., Gomez, S., Pathrose, B., Raj, M. N., Joseph, M. P. & Kuruvila, B. (2022). Comparative evaluation of anthocyanin pigment yield and its attributes from *Butterfly pea (Clitoria ternatea L.)* flowers as a prospective food colorant using different extraction methods. *Future Foods, 6*, 100199.
* Nelson, W. M. (2003). *Green solvents for chemistry: Perspectives and practice.*
* Naqvi, S. A., Akbar, N., Shah, S. M., Ali, S. J. & Abbas, A. K. (2021). Green approaches for the extraction of bioactive compounds from natural sources for pharmaceutical applications.
* New, E. K., Tnah, S. K., Voon, K. S., Yong, K. J., Procentese, A., Yee Shak, K. P., Subramonian, W., Cheng, C. K. & Wu, T. Y. (2022). The application of green solvent in a biorefinery using lignocellulosic biomass as a feedstock. *Journal of Environmental Management, 307*, 114385.
* *Oktaviyanti, N.D., Kartini, &Mun'im, A.* (2019). Application and optimization of ultrasound-assisted deep eutectic solvent for the extraction of new skin-lightening cosmetic materials from *Ixora javanica* flower. *Research article, 5(11)*, e02950.
* Ozel, M. Z., Yanık, D. K., Gogus, F., Hamilton, J. F. & Lewis, A. C. (2014). Effect of roasting method and oil reduction on volatiles of roasted Pistacia terebinthus using direct thermal desorption-GCxGC-TOF/MS. *LWT-Food Science and Technology*, *59*(1), 283-288.
* Parra-Pacheco, B., Cruz-Moreno, B. A., Aguirre-Becerra, H., García-Trejo, J. F. & Feregrino-Pérez, A. A. (2024). Bioactive compounds from organic waste. *Molecules, 29.*
* Pinela, J., Prieto, M. A., Pereira, E., Jabeur, I., Barreiro, M. F., Barros, L. & Ferreira, I. C. F. R. (2019). Optimization of heat- and ultrasound-assisted extraction of anthocyanins from *Hibiscus sabdariffa* calyces for natural food colorants. *Food Chemistry, 275*, 309–321.
* Prakash, S., Goswami, A., Patil, R., Mitra, A. & Kutty, N. N. (2024). An eco-friendly approach to extract anthocyanins from rose flowers using natural deep eutectic solvents. *Industrial Crops and Products, 210*, 118059.
* Prat, D., Wells, A., Hayler, J. D., Sneddon, H. F., McElroy, C. R., Abou-Shehada, S. & Dunn, P. J. (2016). CHEM21 selection guide of classical and less classical solvents. *Green Chemistry, 18*, 288-296.
* Paulino, M. T., Grieser, D. D., Gasparino, E., Maia, K. M., Toledo, J. B., Ton, A. P., Budel, E. C. & Marcato, S. M. (2022). Influence of pigments on the shelf life of eggs from layer hens in the final phase of production. *Research, Society and Development.*
* Qaisar, U., Afzal, M., & Tayyeb, A. (2019). Commercial application of plant pigments. *International Journal of Biotech Trends and Technology*, *9*(3), 18.
* Rajadurai, K. R. & Selvi, S. (2022). Evaluation and selection of *Hibiscus (Hibiscus rosa-sinensis L.)* genotypes for enhanced pigment content. *International Journal of Plant Sciences.*
* Roriz, C. L., Heleno, S. A., Carocho, M., Rodrigues, P., Pinela, J., Dias, M. I., Fernandes, I. P., Barreiro, M. F., Morales, P. & Barros, L. (2020). Betacyanins from *Gomphrena globosa L.* flowers: Incorporation in cookies as natural coloring agents. *Food Chemistry, 329*, 127178.
* Rajendran, P., Somasundaram, P. &Dufossé, L. (2023). Microbial pigments: Eco-friendly extraction techniques and some industrial applications. *Journal of Molecular Structure.*
* Reichardt, C. (1988). *Solvents and solvent effects in organic chemistry.*
Satlewal, A., Agrawal, R., Bhagia, S., Sangoro, J. R. & Ragauskas, A. J. (2018). Natural deep eutectic solvents for lignocellulosic biomass pretreatment: Recent developments, challenges, and novel opportunities. *Biotechnology Advances, 36(8)*, 2032-2050.
* Sanjeeda, I., & Taiyaba, A. (2014). NATURAL DYES : THEIR SOURCES AND ECOFRIENDLY USE AS TEXTILE MATERIALS.
* Sethi, S., Bk, P., Nayak, S. L. & M, M. (2023). Ornamental plant extracts: Application in food colorization and packaging, antioxidant, antimicrobial, and pharmacological potential–A concise review. *Food Chemistry Advances.*
* Segura‐Carretero, A., Puertas-Mejía, M. A., Cortacero-Ramírez, S., Beltrán, R., Alonso-Villaverde, C., Joven, J., Dinelli, G. & Fernandez-Gutiérrez, A. (2008). Selective extraction, separation, and identification of anthocyanins from *Hibiscus sabdariffa L.* using solid-phase extraction‐capillary electrophoresis‐mass spectrometry.
* Shanab, K., Neudorfer, C., Schirmer, E. & Spreitzer, H. (2013). Green solvents in organic synthesis: An overview. *ChemInform, 44.*
* Sharma, M., Sridhar, K., Gupta, V. K. & Dikkala, P. K. (2022). Greener technologies in agri-food wastes valorization for plant pigments: Step towards circular economy. *Current Research in Green and Sustainable Chemistry*, *5*, 100340.
* Singh, P., Borthakur, A., Singh, R. P., Awasthi, S., Pal, D. B., Srivastava, P., Tiwary, D. & Mishra, P. K. (2017). Utilization of temple floral waste for extraction of valuable products: A close-loop approach towards environmental sustainability and waste management.
* Slater, C. &Savelski, M. J. (2007). A method to characterize the greenness of solvents used in pharmaceutical manufacture. *Journal of Environmental Science and Health, Part A, 42*, 1595-1605.
* Sowbhagyam, D. D. (2024). Ionic liquids as green solvents: A comprehensive review. *International Research Journal on Advanced Engineering Hub (IRJAEH).*
* Sowbhagya, H. B., Sampathu, S. R. & Krishnamurthy, N. (2004). Natural colorant from marigold-chemistry and technology. *Food Reviews International, 20*, 33-50.
* Sousa, C. (2022). Anthocyanins, carotenoids and chlorophylls in edible plant leaves unveiled by tandem mass spectrometry. *Foods*, *11*(13), 1924.
* Talele, G.S., &Shahare, H.V. (2020). Green Solvents for Pharmaceuticals.
* Tiwari, S., Yawale, P., & Upadhyay, N. (2022). Carotenoids extraction strategies and potential applications for valorization of under-utilized waste biomass. *Food Bioscience*.
* Tzanova, M.T., Yaneva, Z., Ivanova, D., Toneva, M., Grozeva, N., &Memdueva, N.Y. (2024). Green Solvents for Extraction of Natural Food Colorants from Plants: Selectivity and Stability Issues. *Foods, 13*.
* Tran, P. & Le, H.P. (2022). Plant Flavonoids as Potential Natural Antioxidants in Phytocosmetics. Journal of Technical Education Science.
* Usman, M., Cheng, S., Boonyubol, S. & Cross, J.S. (2023). Evaluating Green Solvents for Bio-Oil Extraction: Advancements, Challenges, and Future Perspectives. Energies.
* Usman, M., Nakagawa, M. & Cheng, S. (2023). Emerging Trends in Green Extraction Techniques for Bioactive Natural Products. Processes.
* Uzma, Q., Maira, A., & Asima, T. (2019). Commercial Applications of Plant Pigments. *9*(3), 18-22. doi: 10.14445/22490183/IJBTT-V9I3P604
* Verma, P.K. (2008). Preservation of botanical specimens retaining the natural colour pigments.
* Viñas-Ospino, A., López-Malo, D., Esteve, M. J., Frígola, A. & Blesa, J. (2023). Green solvents: emerging alternatives for carotenoid extraction from fruit and vegetable by-products. *Foods*, *12*(4), 863.
* Woodson, W. R. (1991). Biotechnology of floricultural crops. *Hort Science, 26*, 1029-1033.
* Welton, T. (2015). Solvents and sustainable chemistry. *Proceedings of the Mathematical, Physical, and Engineering Sciences / The Royal Society, 471.*
* *Xu, P., Zheng, G., Zong, M., Li, N., & Lou, W.* (2017). Recent progress on deep eutectic solvents in biocatalysis. *Bioresources and Bioprocessing, 4.*
* *Yuan, H., Zhang, J., Nageswaran, D.C., & Li, L.* (2015). Carotenoid metabolism and regulation in horticultural crops. *Horticulture Research, 2.*
* Yadav, I., Juneja, S.K. & Chauhan, S. (2015). Temple Waste Utilization and Management: A Review.
* Žlabur, J.Š., Žutić, I., Radman, S., Pleša, M., Brnčić, M., Barba, F.J., Rocchetti, G., Lucini, L., Lorenzo, J., Domínguez, R., Rimac Brnčić, S., Galić, A. &Voća, S. (2020). Effect of Different Green Extraction Methods and Solvents on Bioactive Components of Chamomile (*Matricaria chamomilla* L.) Flowers. Molecules, 25.