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Review

Sustainable Natural Dyes for Textile Use from Food Industry By-Products: A Review

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Abstract: The valorization of food industry by-products has become very trendy in recent years, several researchers valorized these wastes as sustainable natural colorants for various applications. In this review, the valorization of these by-products in literature as natural dyes in textile application is investigated. Indeed, the history of natural dyes is presented, followed by a study of the advantages and disadvantages of these dyes. Finally, the most significant food industry by-products used as sources of natural dyes for textile applications are listed, along with detailed explanations of their dyeing applications on textile fibers. A special interest is given to natural dyes extracted from food industries wastes of winemaking, olive oil, tomato processing, red pepper by-products and dates paste processing. The majority of studies have demonstrated the strength and superior dyeability of textiles dyed with these waste materials. There have also been assertions that certain fragments have light- and antibacterial-blocking properties.

***Keywords*:** food industry, by-product, natural dyes, wastes valorization, textile application

1. Introduction

The agri-food industry aims to manufacture food for humans, but it has always generated raw materials that could not be consumed directly by humans but which may be of interest to several other sectors. According to the Agromedia newsletter,[1] food industry waste is a major problem today, both for consumers, producers and manufacturers. Since the years 1970-80, environmental regulations have become more and more demanding in order to reduce the pollutant load of food industries, resulting in increasing taxation of the discharge of organic materials resulting from technological and non-valued processes.[2] Despite the efforts made by food industries to optimize their manufacturing processes and add value to their by-products, allowing them to greatly reduce their amount of waste, they still produce tons of waste every year and must therefore contribute to the reduction effort.

In France, according to the Bureau of Structural, Environmental and Forestry Statistics,[3] the food industry activity, in 2016, generated 3.8 million tons of non-hazardous waste, 70% of which came from animals or plants. The recovery of food by-products and residues represents an attractive economic option for companies, since it makes it possible to reduce or eliminate their waste disposal costs, while generating a second income.[4-5] Thus, the majority of waste is

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generally reused, as raw material or for energy production. However, several other valorization routes are also possible.[6] Among the sectors targeted, there may be mentioned in particular the market of natural dyes for textile use. Indeed, the majority of food industries by-products present a potential source of colored phenolic compounds such as flavonoids, anthocyanins and tannins which could be applied for textile dyeing. Natural dyes sources are available and accessible through nature.[7] They could be obtained from plants, minerals and insects. Several extraction processes of natural dyes have been studied in literature.[8-11] Basing on the literature, a special interest will be given in this review, to the extraction of natural dyes exclusively from food industries by-products, namely: olive mill waste water, olive pomace, olive leaves, red pepper, tomato pomace and date palm pits.

The grape, fruit of the vine (*Vitis vinifera*), is one of the best-known and most widely cultivated fruits in the world. Grape by-products can be divided into three categories: pomace and its by-products (pulp and seeds), concentrated grape juice and leaves and branches.

The main by-products of the olive tree are: (i) pruning products; (ii) pomace, which consists of the stone, pulp, skin and, in some cases, the vegetation water of the olives; (iii) olive mill waste water, which comes from the liquid fraction of the olives and any water added during the crushing process.

Produced in 144 countries each year, 100 million tons of fresh tomatoes are produced, making them the second most important vegetable crop. Large volumes of leftovers, such as tomato seeds and peels, are produced during industrial tomato processing and account for 10-40% of all processed tomatoes.

1.1 *History of the use of natural dyes*

The use of natural dyes goes back much further than the appearance of the first traces of writing. Indeed, man has appropriated very early the coloring properties of plant, animal and mineral origin, used for the realization of paints, lacquers and essentially dyes. Until the end of the 19th century, the dyeing of fabrics was carried out with the help of vegetable dyes such as indigo blue extracted from the woad, the red extracted from the roots of the madder and the yellow coming from the gaude.[12] In 1856, the synthesis of the mauveine (the first synthetic industrial dye), by William Henry Perkin, gave birth to the industry that revolutionized the sewing and fashion industry by creating a great interest in the commercial applications of dye chemistry.[13] Then, in 1862, J. Griess an English chemist proceeded to the synthesis of the first nitrogenous dyes. Then, after four years, these experiments were crowned by obtaining the first patent for the synthesis of a dye (methylene blue) by the chemist H. Caro. Thus, the transition to synthetic dyes was rapid since these dyes were safe and especially less expensive at the industrial level. Nevertheless, several studies have shown that textile dyes of synthetic origin not only cause allergies in humans,[14-15] but they also confirmed that their releases are often polluted and non-biodegradable.[16] This has led to a renewed interest among dyers in the application of natural dyers to apply natural dyes.[17]

1.2 *Advantages and limitations of natural dyes*

Nowadays, there is a growing awareness among consumers, worldwide, of the harmful effects of synthetic dyes, whether on human health or on the environment. This is accompanied by a renewed interest in the potentially renewable resources that constitute natural dyes, perceived a priori as harmless and even beneficial to health. Indeed, several research works have been developed to demonstrate the advantages of using natural dyes in the dyeing of textile fibers:

- First of all, this type of dyes allows for bright and diverse colors.[18]

- In addition, these dyes are all based on a very large number of renewable sources and which are offered by nature (vegetable and animal).[19-21]

These dye sources are not only renewable but also biodegradable.[22] In addition, the production and use of natural dyes are much less polluting than most synthetic dyes. In fact, synthetic dyes generate harmful wastes especially when these by-products are deposited directly into the environment without any specific treatment of harmful constituents. Therefore, the use of natural dyes reduces the environmental impact of the products obtained.

Several natural dye extracts also exhibit a broad spectrum of antibacterial activity.[23] For example, the study of curcumin,[24] gallnut and pomegranate extracts[25] shows that they have antibacterial activity against several known bacteria. Other research has also shown that extracts of several plants can be used as deodorizers[26] as well as UV-absorbers to protect textiles from ultraviolet radiation and to improve the light fastness of some textile fibers.[27]

Sandalwood red oil extract has also been shown to prevent the development of skin tumors and has antiviral activity against herpes simplex.[28-29] It has also been reported by some research studies that several textile fibers dyed with natural dyes have antifungal activities. One example is wool dyed with *Rheum emodi* L. which has antifungal activity against Candida Albicans and Candida Tropicalis.[30] Carpets, upholstered clothing and blankets encounter great problems during their storage. These products could be attacked by several insects. Kato et al.[31] demonstrated that some natural dyes (such as gall nuts, red cabbage, etc.) serve as insect repellents that protect textile fibers from damage by certain insects. In addition to the applications mentioned above, there is currently great attention to the use of natural dyes to impart color to wood,[32] to various plastics,[33] to cosmetics,[34-35] to color selected pharmaceutical preparations,[36] to dye hair,[37-38] and to dye leather as well.[39-40]

Despite its advantages, natural dyeing suffers from several inherent limitations that were the reason for its abundance.

- Most natural dyes exhibit low bath depletions as well as low fastnesses. To remedy these problems, the application of these stains has often been accompanied by the use of metallic mordants according to various application techniques (preliminary, simultaneous or subsequent mordanting). Several studies have shown that the staining strength improves following this treatment.[41-42] However, this is also accompanied by shade shifts which is sometimes an undesired result.[43]

- The metallic mordants used are generally discouraged due to their adverse effects on consumer health. Some standards require that the bleeding of dyed and mordanted fabrics does not exceed certain concentration limits.

Moreover, the application on an industrial scale of these natural dyes was often limited by the problems of reproducibility of the different shades obtained (e.g. due to the non-stability of the different components of the plants according to their maturity, the region of harvest, etc.). Also, this is accompanied by the absence of a regular and economically studied protocol of the extraction and dyeing process of these dyes.

- The procurement of “organic” products generally reaches a niche population with rather high revenues. Indeed, the costs of these products are high even though they are intended for daily use.

- It is important to remember the risk that could accompany this phenomenon of fashion and the craze for natural dyes and colorants. Indeed, this wave of massive industrial production for large-scale use can lead to the catastrophic plundering of the natural stations of many wild dye species. In order to avoid this, and to meet the challenge of scaling up, complementary approaches need to be designed for sustainable development of natural dye production.

2. Methodology

Most food industries produce significant amounts of solid and liquid wastes. These wastes represent potential pollutants with associated disposal problems. These wastes are either used as animal feed or are composted or disposed. However, wastes from pressed berries, distillation residues, peels and wastes from vegetable manufacturing which contain dyes are available at about zero cost. Some investigations into the use of plant residues from the food and beverage industry as a possible source for natural dyeing of wool fibers have been studied. There is a necessity to identify new sources of natural dyes. Even though the use of forestry, agricultural and industrial wastes in textile dyeing has been investigated in the literature, research in this field is limited and few in number.

In addition, there is no available common database of residues used as natural dyes in textile dyeing. Thus, this review discusses a few wastes that can be used as potential sources of textile dyes, many of which are associated with multifunctional properties.

In this paper, studies already undertaken by scientists have been discussed to provide a clear understanding of the source of wastes, as well as their effectiveness in imparting color to textiles (see Table 1).

Table 1. List of by-products used as source of natural textile dyeing

Industry	By-products	Picture	Supporting References
Olive oil extraction process	Olive mill waste water		44-47
	Olive pomace		48-50
	Olive leaves		51
Winemaking industry	Grape pomace		8,52-53
Red pepper industry	Red pepper		54
Tomato processing industry	Tomato pomace		55
Dates paste processing industry	Date palm pits		56-57

3. Food industry wastes used as natural dyes

3.1 *Winemaking industry*

Grape, the fruit of the vine (*Vitis vinifera*), is one of the best known and most widely cultivated fruits in the world.[58-59] Wine growing is one of the most important agricultural activities in the world. As most fermentation systems, the vinification cycle does not just give rise to wine, but by-products as well (Figure 1).

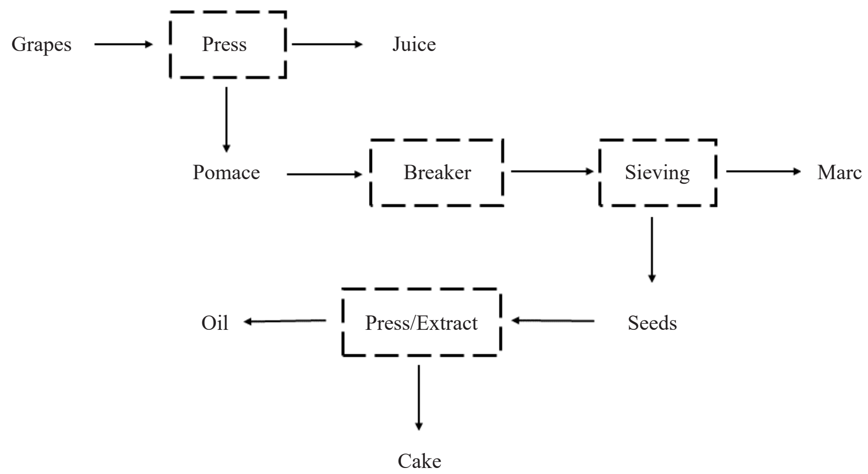

Figure 1. Flow diagram showing the processing of grapes and their wastes

Grapevine by-products could be classified into three categories: pomace and its derivatives (pulp and seeds), concentrated grape juice, and leaves and branches.

Grape marc is therefore the main by-product of winemaking, which may be rich in compounds of interest. It consists of the solid residue (pips, skins, stalks) remaining after the pressing stage of white or red wine.[60] Grape marc constitutes about 20% of the weight of grapes used for wine making, generating almost nine million tons per year.[61]

Procyanidin, prodelphinidin, glucosylated procyanidin, and gallated procyanidin are the tannins that give grape pomace its color. Polyphenols such as phenolic acids, flavonols, and anthocyanins may be found in large and reasonably priced quantities in grape pomace.

Baaka et al.[51-53] have investigated the utilization of grape marc for dyeing both natural fibers such as cotton, silk and wool and synthetic fibers such as acrylic and polyamide. The authors were interested in the development of an extraction process in an aqueous alkaline medium. The effects of several physicochemical parameters on the quality of extraction were studied. A Composite Centered Design (CCD) was set up to study the performance of aqueous extraction of coloring matters from grape marc and to identify the interactions between the different parameters. The optimal values of the parameters affecting the extraction were calculated and are: (i) a quantity of grape marc of 70 g/L, (ii) a concentration of sodium hydroxide of 0.13 M, (iii) an extraction time of 70 minutes, (iv) an extraction temperature of 80 °C.[52]

The authors carried out a comparative study between the two dyeing processes (conventional and ultrasonic) of wool with the aqueous extract of grape marc. The study of the main operating dyeing process parameters like the dyeing bath pH, the duration, the concentration of salt added in the dyeing bath and the temperature were studied. In this study, ultrasonic assisted dyeing showed its effectiveness and significantly improved the dyeing resistance values (K/S) of the studied samples. In addition, the authors were interested in the study and development of a dyeing process for cotton modified with an aqueous extract of grape marc using two modification techniques (cationization and plasma treatment). In this part, a comparative study between different cationization agents was carried out in order to select the one leading to the best dyeing yields. It was finally found that cationization of cotton improves the dyeing quality, and that Croscolor

DRT is the best product to use for the cationization step of cotton. Plasma treatment also significantly increased the dyeing strength of cotton fabrics dyed with aqueous grape pomace extract.

This work also allowed us to evaluate the physico-chemical parameters of the dye waste bath (COD and BOD_5). The analysis of these parameters allowed us to conclude that the dyeing with the aqueous extract of grape marc decreases the polluting organic load of the dyeing bath.

Preliminary tests of acrylic dyeing with the aqueous extract of grape marc showed that the extracted dyeing matter does not have a great affinity with the acrylic fiber. This affinity was significantly improved by using two acrylic modification techniques, namely: cationization by a cationizing agent (Croscolor DRT) and chemical modification.

The study of antimicrobial activities (antibacterial and antifungal) showed that grape marc extracts had inhibitory effects on bacterial growth against all tested strains. The results also showed that fabrics dyed with aqueous grape marc extract have good to very good washing and rubbing fastnesses and average light fastnesses. The addition of a mordanting step improved the obtained fastnesses.

Samples (wool, cotton and acrylic) dyed with aqueous grape marc extract without and with the addition of mordants showed higher protection factor (PF) values than undyed samples. In fact, the protection factor values increased after dyeing, providing greater Ultraviolet (UV) protection than the undyed reference samples (Table 2).

Table 2. UPF values of different fibers before and after dyeing with grape pomace extract with and without metallic mordants[53]

Processes/Fibers	Protection factor (PF)				
	Wool	Silk	Cotton	Acrylic	Polyamide
Control (without dyeing and mordanting)	5	2	5	25	20
Fabric dyed with grape pomace extract without the use of any mordants	30	18	25	30	26
Fabric simultaneously dyed with grape pomace extract and mordanted with aluminium sulphate	50+	24	40	30	40
Fabric simultaneously dyed with grape pomace extract and mordanted with ferrous sulphate	50+	40	35	50+	35

3.2 *Olive oil industry*

The cultivation of the olive tree is part of the tradition of the Mediterranean basin and represents a symbol of civilization for the Mediterranean people, as well as being an indispensable food on their table. There are about 840 million olive trees in the Mediterranean basin and 90 million in the rest of the world. Olive growing occupies an important place in the national economy of these countries, including Spain, Italy, Greece, Turkey, Tunisia and Morocco. Indeed, Tunisia presents the southern Mediterranean country as the first producer of olive oil and the first exporter after the European Union.[62-63]

The process of extracting oil from olives produces mainly olive oil and also generates two types of residues: the first is a liquid residue called the olive mill wastewater and the second residue is in solid form called the pomace. The olives generally contain about 20% oil, 30% pomace and 50% vegetation water. Thus, the olive mill wastewater is composed of about 50% of the vegetation water that comes from the olive fruit and the rest of the water is added during the oil making process (Figure 2).[62]

It was reported that the major coloring components in olive mill waste water are tannins and phenolic compounds. Examples of phenolic compounds present in olive mill waste water are: cinnamic acid derivatives such as caffeic acid, and benzoic acid derivatives such as protocatechuic acid. olive mill waste water also contains flavonoid compounds like apigenin, luteolin and quercetin.

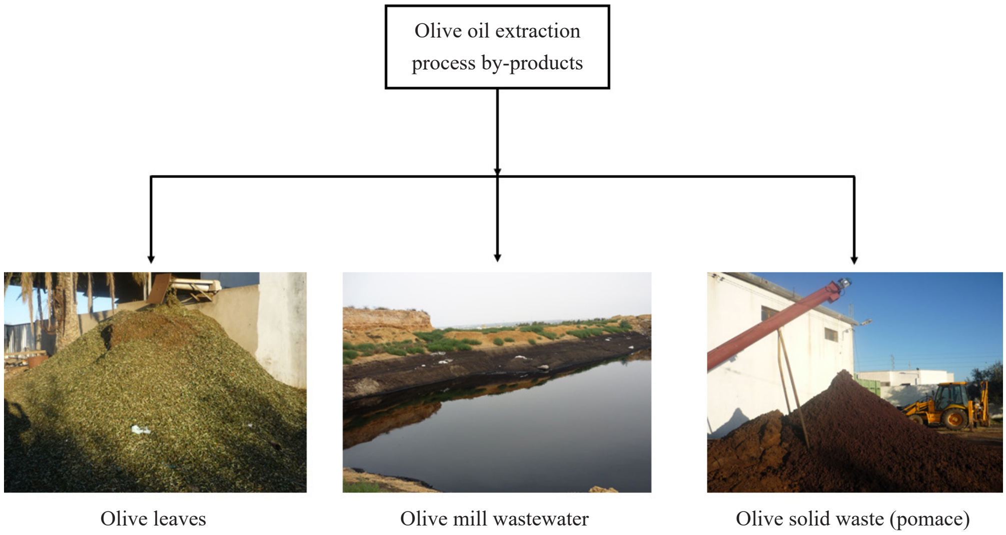

Figure 2. Olive oil extraction process by-products

Studies[44] show that the presented method of dyeing wool with oil mill wastewater is both attractive and interesting because it helps, in the first place, to solve the environmental issues of the oil mill wastewater. Besides, this natural dye is not only renewable, but also available in big volumes in all olive oil manufacturing countries without any cost.

Furthermore, the investigation of the influence of several factors on the dyeability of wool by oil mill wastewater showed that the temperature and pH of the dye bath as well as the dyeing time strongly impacted the color strength. The best results were achieved at pH 2, 100 °C and 90 min, respectively. The addition of salts to the dye bath caused some decrease in the color strength.

The study of Nizar Meksi et al.[47] investigated the valorization of olive mill wastewater on the dyeing of modified cotton fabrics. It was found that cotton cationised with Croscolor DRT gave usually a higher color yield than cotton modified with Tannic acid. The authors also studied the environmental impact of the residual dye bath. The results obtained confirmed on the one hand that the compounds responsible for the dyeing are polyphenols since the rate of total phenols decreased after the dyeing and on the other hand these results also showed that the dyeing with this aqueous discharge allowed to decrease considerably its organic pollution (The percentages of decrease of COD and BOD5 were respectively 17.5 % and 42.66 %).

The studies of Wafa Haddar et al.[45-46] demonstrated that the olive mill wastewater could be successfully exploited as a natural dye for dyeing synthetic fibers (polyamide and acrylic).

They studied the effect of ultrasonic energy on the dyeing quality of polyamide fiber with the olive mill wastewater. The effects induced by varying the various dyeing parameters showed that the conventional dyeing process was interesting. However, the ultrasound assisted dyeing resulted in a marked improvement in the dyeing strength (K/S) of the samples studied, an improvement in the fastness values.

The research of Ekrami et al.[50] aimed to study the applicability of olive waste that is usually removed during the olive oil extraction process as an inexpensive raw material for the natural dyeing of wool fabrics. Brownish and beige shades were obtained by applying the extracted natural dye on wool samples. A variety of shades ranging from beige to dull-brown were obtained by using three mordants (alum, copper sulphate, potassium dichromate). The fastness properties of the studied natural dye were acceptable for textile applications.

In the study of İsmal,[49] the crude prina (olive pomace/cake), a cheap olive byproduct was examined in natural dyeing. Different concentrations of waste material (7, 13, 20, 27, 33, 40, 53, 67, 80, and 100 $g \cdot L^{-1}$) were boiled for 1 h in water (Table 3).

Table 3. CIELab coordinates for different waste concentrations[49]

Waste concentration ($g \cdot L^{-1}$)	L*	a*	b*	C*	h*
7	78.15	1.34	16.07	16.12	85.23
13	77.22	1.57	15.72	15.8	84.27
20	75.77	1.97	16.23	16.36	83.09
27	75.32	2.24	16.91	17.06	82.44
33	73.06	2.9	17.54	17.78	80.63
40	73.1	3.05	17.47	17.74	80.11
53	70.84	3.46	18.58	18.9	79.46
67	69.21	3.45	19.2	19.51	79.81
80	68.77	4.35	19.83	20.3	77.65
100	70.22	3.9	19.31	19.7	78.58

Five known conventional mordants most commonly used in current natural dye research (alum, copper (II) sulphate, iron (II) sulphate, stannous chloride, potassium dichromate) were used in the present study. Many color shades such as cream, apricot, beige, straw, cumin, khaki and olive were obtained. All of the mordants resulted in an increase in color strength.

Elksibi et al.[48] optimized the natural dye extraction method from solid olive waste. The efficiency of the extraction process was evaluated by measuring the total phenolic content of the extract and the color yield (K/S) of dyed wool fabrics. Through the use of a Box-Behnken model of experimental design in the response surface methodology (RSM), the writers have concluded that the optimal extraction conditions can be achieved at 71.23 °C, 62.11 min, 0.14 mol/L, and 4.5 g for temperature, extraction duration, sodium hydroxide concentration, and waste mass, respectively.

3.3 *Tomato processing wastes*

After the potato, the tomato (grown on more than 4.8 million hectares worldwide) is the second most consumed vegetable in the world. The tomato is one of the most widespread horticultural species in the world. It is difficult to imagine a kitchen without tomatoes. With various traditions and national foods based on this culinary vegetable, it is said to be one of the most famous symbols of the Mediterranean kitchen. In fact, this vegetable can be used in many different forms, from its consumption in its fresh state to its use as a manufactured derivative (sauce, peel, juice, ketchup, etc.).[64]

The industrial processing chain of tomatoes produces considerable quantities of residues, generally called tomato pomace or by-products (Figure 3), which can represent up to 10% of the weight of fresh tomatoes. Tomato by-products include a rich variety of biologically active substances, mainly lycopene, whose antioxidant, hypolipidemic and anticarcinogenic activities have been demonstrated by in vitro and in vivo studies.

Baaka et al.[55] studied the process of pigments extraction from tomato industry waste. The authors have developed a five-level, five-factor central composite design to study the effect of selected parameters on the extraction of pigments from tomato industry waste.

The yield of carotenoids was 80.7 μg/g, under the optimal conditions:

(i) solvent solid ratio: 90:1 (v/w),

(ii) hexane percentage in the solvent mixture: 60%,

(iii) extraction time: 50 min,
(iv) number of extractions: 4,
(v) extraction temperature: 35 °C.

The extracted natural pigments from tomato by-products could be used to dye both natural and man-made textile fabrics (wool, silk, and polyamide) with:
(i) reddish-yellowish shades
(ii) good fastness properties.

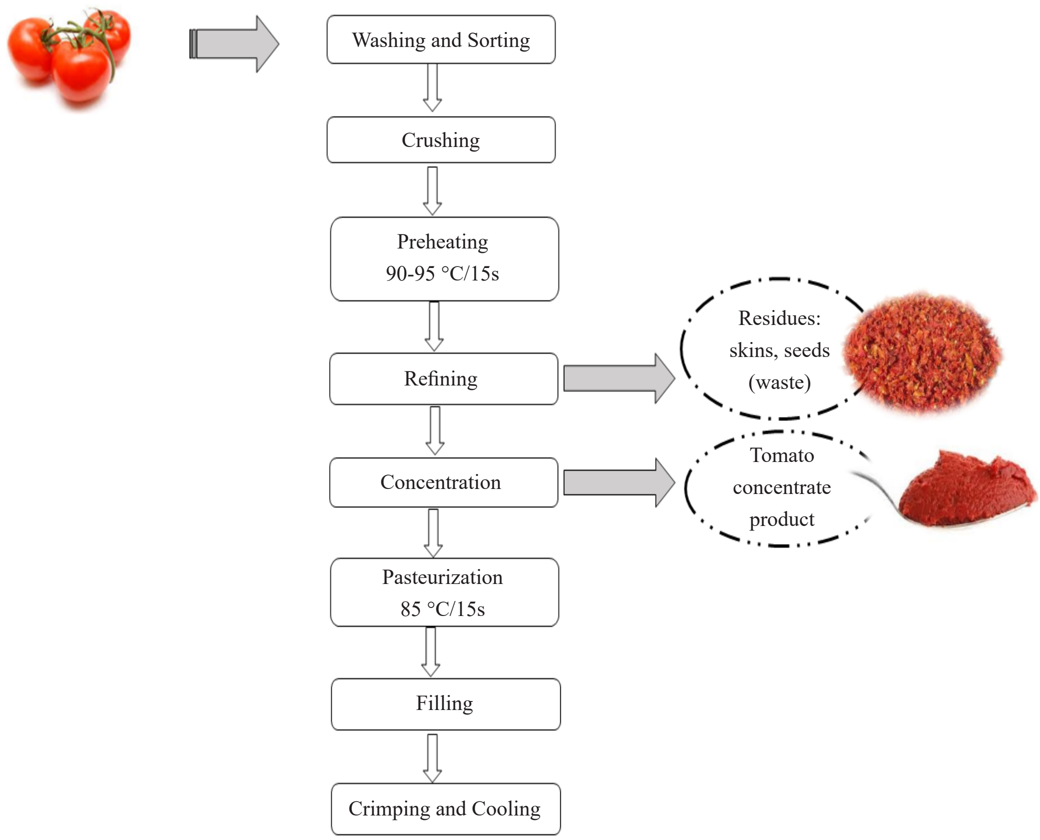

Figure 3. Flow chart of tomato concentrate production

3.4 *Red pepper industry by-products*

Chillies are native to Latin America. Remains of chili peppers dating back to more than 7000 BC have been found in archaeological sites in southeastern Mexico. Columbus and other explorers, after the discovery of America, brought them to Europe, from where they were later exported to Asia and less than a century after its introduction to the old world.[65]

The fruits of Capsicum were probably one of the first food additives used and are the first cultures in Mexico and northern South America that realized its contribution to the color and taste of food. Ancient civilizations knew the great potential and stimulating action of chilies that increase the flavor of food, increasing salivation and the sensation of heat in the mouth.[66]

Peppers belong to the genus Capsicum, of the family Solanaceae, which includes tomatoes, potatoes and eggplants. The Capsicum genus contains a total of twenty-three species. Five species are cultivated: *C. annuum*, *C. frutescens*, *C. chinense*, *C. baccatum and C. pubescens*.

The pepper is an annual plant with large, soft leaves and small white flowers giving berries, fleshy fruits with pips (containing multiple seeds in its interior cavity). Its size can vary from 5 to 15 cm and its diameter from 1 to 5 cm, and it has a particular structure.[67]

The harvest of peppers takes place from October to December. The industrial production of harissa is made from fresh red pepper with a recipe of condiments (garlic, coriander, caraway and salt) standardized. The steps of the industrial process are presented in Figure 4.

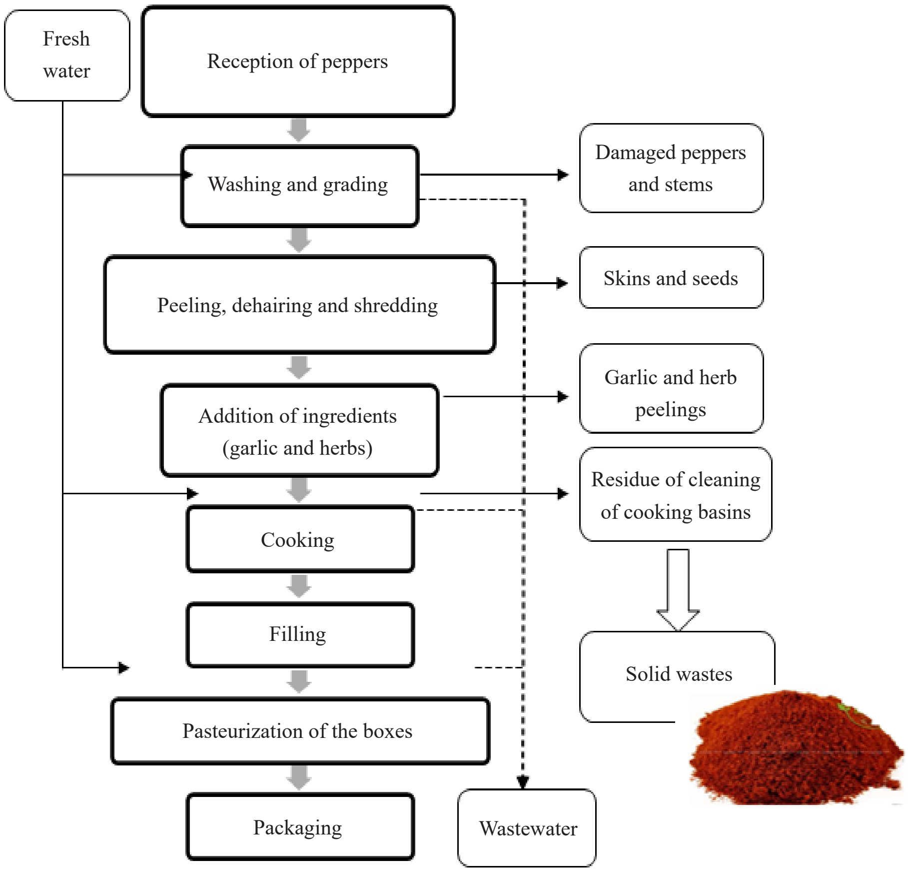

Figure 4. Diagram of Harissa's production wastes and treatments

At the reception of the production unit, the peppers are sorted manually by workers, then they are washed and rinsed. After rinsing, they are put in a cooker where they are crushed and heat treated to obtain a mixture of juice, seeds and skin. This mixture passes through a strainer by which we recover the juice of peppers. The juice passes through concentrating balls to obtain a concentrate of about 14% minimum. The concentration of harissa passes in a pasteurizer where it undergoes a heat treatment of 92 °C, to be finally packaged and stored.

Red pepper (*Capsicum annum* L.) by-products were used to extract natural dyes.[67] The by-products, including seeds (15.9%), skin remnants (34.7%) and stems (49.4%) (weight percentage), were provided by a canned food producer based in Nabeul (Tunisia). In an attempt to choose the most appropriate solvent for the extraction of phenolic compounds from pepper by-products, the authors compared various solvent mixtures. The three solvents ethanol, acetone and water were used. Obtained results showed that the most suitable solvents for extracting flavonoids and phenols from red pepper by-products, were around (35-65-0%) for water- acetone-ethanol, respectively.

The colored extract of pepper by-products has been used to dye woolen fabrics with acceptable antimicrobial properties.

3.5 *Dates paste processing industry*

The dates paste processing is considered one of the most important commercial and industrial food processing (Figure 5).[68-70]

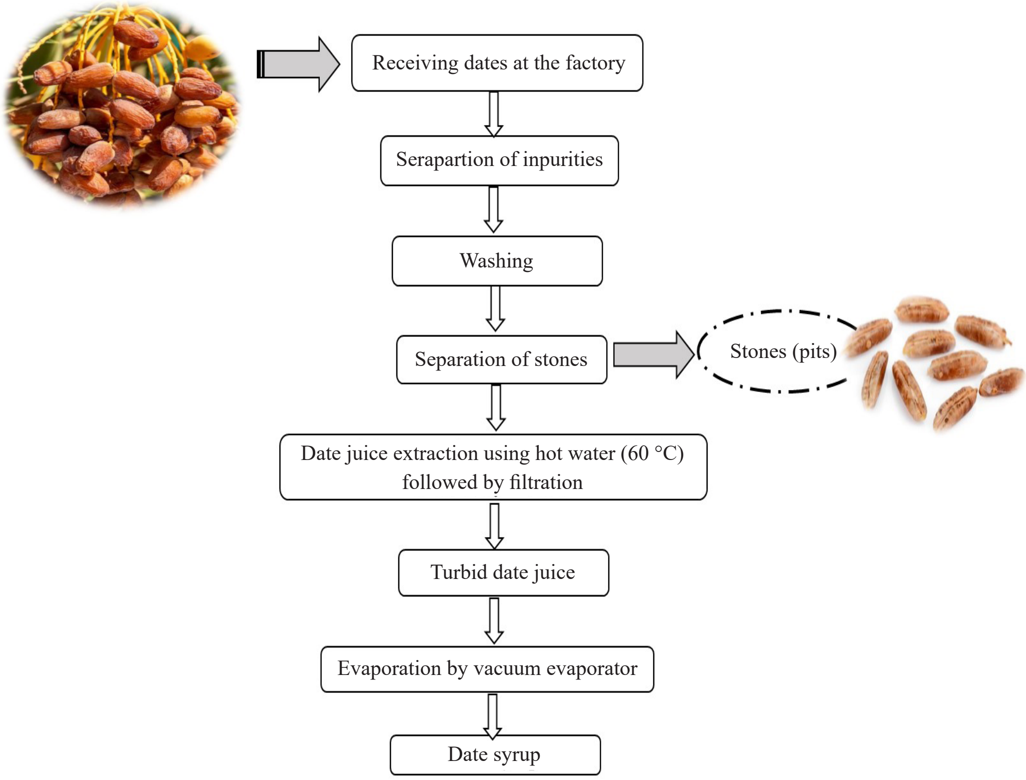

Figure 5. Large scale process chart of production of date syrup.[70]

The date palm pits resulting from this process could be valorized by several methods. In this context, Souissi et al.[56-57] investigated the coloring potential of date palm pits to dye cotton fabrics. At first, the colored solution extracted from date palm pits was stored at 3 °C and protected from light for less than two weeks. The chemical composition of this extract was analyzed and found to be rich of phenolic compounds. Then, Souissi et al.[56] optimized the extraction process using a Taguchi experimental design. The optimal extraction conditions were found to be:

-An extraction solvent composed of 10% acetone and 90% water.

-An extraction temperature of 80 °C.

-An extraction duration of 90 min

Second, Souissi et al.[57] studied the dyeability of cotton fabrics with the optimal colored extract from date palm pits. A dyeing process optimization was investigated using a Box-Behnken experimental design. Then, to improve fastness properties, several metallic and natural mordants were applied. Good dyeing fastness was achieved when applying the natural mordants.

4. Future perspective

Transitioning industries to meet present human demands while protecting the environment is necessary to achieve sustainable development. This all-encompassing method takes into account factors like human welfare, politics, social dynamics, economics, ecology, and cultural issues. Textile dyeing faces substantial sustainability issues due to the availability and use of natural dyes in their current state. However, because natural dyes are non-toxic, eco-friendly, biodegradable, and health-conscious, people are favoring them more and more. Incorporating natural dyes into textile substrates indicates significant market potential and bright futures for new business endeavors in a range of industries, including leather, textiles, apparel, cosmetics, culinary arts, medicines, paints, and more.

In addition, several of the plant sources mentioned here have additional therapeutic qualities that can be advantageously absorbed by skin contact, such as antimicrobial, antibacterial, antioxidant, and anti-inflammatory actions.

5. Conclusions

In conclusion, the exploration of sustainable natural dyes derived from food industry by-products presents a promising avenue for the textile industry. Through this review, it is evident that these by-products offer a rich source of pigments that can be harnessed to create vibrant and eco-friendly dyes, thereby reducing reliance on synthetic alternatives and minimizing environmental impact. The utilization of food industry by-products not only mitigates waste but also fosters a circular economy model. However, further research and development are essential to optimize extraction methods, enhance colorfastness, and scale up production for commercial use. By embracing these sustainable practices, the textile industry can move towards a more environmentally conscious future, where innovation and resource efficiency go hand in hand to create beautiful, durable textiles while preserving the planet for generations to come.

Author contributions

Conceptualization, M.B.T. and N.B.; methodology, N.B; software, M.B.T.; validation, M.B.T., N.B. and W.H.; formal analysis, B.N.; investigation, N.M.; resources, H.D.; data curation, N.B.; writing-original draft preparation, M.B.T. and N.B.; writing-review and editing, M.B.T. and N.B; visualization, W.H.; supervision, N.M. and H.D.; project administration, H.D. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no competing financial interest.

References

[1] La newsletter Agromedia: Déchets de l'agroalimentaire: comment les valoriser (The Agromedia newsletter: Food industry waste: how to recycle it). 2016. https://www.agro-media.fr/analyse/dechets-de-lagroalimentaire-valoriser-21246.html (accessed December 1, 2021).
[2] Chapoutot, P.; Rouille, B.; Sauvant, D.; Renaud, B. *INRA Prod. Anim.* **2019,** *31*, 201-220.
[3] Bureau des statistiques structurelles, environnementales et forestières (Bureau of Structural, Environmental and Forestry Statistics). La production de déchets non dangereux dans les industries agroalimentaires Des déchets organiques largement réutilisés (Non-hazardous waste production in the agri-food industries Organic waste largely reused). 2020. https://agreste.agricu ture.gouv.fr/agreste-web/disaron/Pri2002/detail/ (accessed December 1, 2021).

[4] Socas-Rodríguez, B.; Álvarez-Rivera, G.; Valdés, A.; Ibáñez, E.; Cifuentes, A. *Trends Food Sci*. **2021,** *114*, 133-147.
[5] Roy, P.; Mohanty, A. K.; Dick, P.; Misra, M. A. *ACS Environ. Au.* **2023,** *3*, 58-75.
[6] Jacobs, C.; Soulliere, K.; Sawyer-Beaulieu, S.; Sabzwari, A.; Tam, E. *Sustainability* **2022,** *14*, 2576.
[7] Younis, M.; Adeel, S.; Haider, M. Z.; Mia, R.; Imran, M. *Sustain. Chem. Pharm.* **2024,** *37*, 101410.
[8] Bouzidi, A.; Ammi, Y.; Baaka, N.; Hentabli, M.; Maouz, H.; Maamar Laidi, M.; Hanini, S. *Chem. Afr.* **2024,** *7*, 99-109.
[9] Aftab, M.; Ahmad, T.; Adeel, S.; Javed, M. *Sustain. Chem. Pharm.* **2024,** *37*, 101401.
[10] Ben Ticha, M.; Meksi, N.; Attia, H. E.; Haddar, W.; Guesmi. A.; Ben Jannet, H.; Mhenni, M. F. *Dyes Pigm.* **2017,** *141*, 103-111.
[11] Ben Ticha, M.; Slama, N.; Dhouibi, N.; Boudokhane, C.; Dhaouadi, H. *J. Nat. Fibers* **2022,** *19*, 5282-5296.
[12] Perrin, R.; Scharff, J. P. *Chimie Industrielle*; Publishing Masson: Paris, 1995.
[13] Holme, I. *Color. Technol*. **2006,** *122*, 235-251.
[14] Hatch, K. L. *Curr. Probl. Dermatol.* **2003,** *31*, 139-147.
[15] Smith, J.; Gawkrodger, D. J. *Contact Dermatitis.* **2002,** 47, 112-113.
[16] Lellis, B.; Fávaro-Polonio, C. Z.; Pamphile, J. A.; Polonio, J. C. *Biotechnol. Res. Innov*. **2019,** *3*, 275-290.
[17] Glover, B.; Pierce, J. H. *J. Soc. Dyers Color* **1993,** *109*, 5-14.
[18] Dawson, T. L. *Color. Technol.* **2009,** *125*, 61-73.
[19] Mia, R.; Mofasser, A. Z. M.; Bhat, M. A.; Howlader, M. I.; Ibn Sayed, N.; Abu Bakar, M.; *Sustain. Chem. Pharm.* **2024,** *38*, 101489.
[20] Mirki, L. K.; Barani, H.; Khaleghi, S. *Sustain. Chem. Pharm.* **2024,** *37*, 101382.
[21] Barani, H.; Rahmani, F. *Fibers Polym.* **2023,** *24*, 2785-2797.
[22] Bechtold, T.; Mahmud-Ali, A.; Komboonchoo, S. Sustainable dyes from agrifood chain co-products. In *Total Food*; Walden, K. W., Moates, G. K., Faulds, C. B., Eds.; RSC Publishing: Cambridge, 2009.
[23] Rani, K.; Aliya, R.; Solangi, B. A.; Pervez, M. K.; Akhtar, N.; Ahmed, F. *Pakistan J. Weed Sci. Res.* **2020,** *26*, 403-414.
[24] Han, S.;Yang, Y. *Dyes Pigm.* **2005,** *64*, 157-161.
[25] Ennaceur, S.; Bouaziz, A.; Gargoubi, S.; Mnif, W.; Dridi, D. *Processes.* **2022,** *10*, 2263.
[26] Lee, Y. H.; Hwang, E. K.; Jung, Y. J.; Do, S. K.; Kim, H. D. *J. Appl. Polym. Sci.* **2008,** *115*, 2246-2253.
[27] Sharma, N.; Srivastava, S.; Singh, A.; Sheikh, J. *Prog. Color Color. Coat*. **2024,** *17*, 289-296.
[28] Dwivedi, C.; Zhang, Y. *Eur. J. Cancer Prev.* **1999,** *8*, 449-455.
[29] Benencia, F.; Courreges, M. C. *Phytotheray Res.* **1999,** 9, 119-128.
[30] Shafat, A.; Khan, A.; Aijaz, I.; Mohd, K.; Mohd, Y.; Mohamed, S.; Nikhat, M.; Faqeer, M. *Dyes Pigm*. **2012,** *95*, 206-211.
[31] Kato, H.; Hata, T. Tsukada, M. *Jpn. Agr. Res. Q.* **2004,** *38*, 241-251.
[32] Goktas, O.; Duru, M. E.; Yeniocak, M.; Ozen, E. *For. Prod. J.* **2008,** *58*, 77-80.
[33] Van den Oever, M. J. A.; Boeriu, C. G.; Blaauw, R.; Van Haveren, J. *J. Appl. Polym. Sci.* **2004,** *92*, 2961-2969.
[34] Kapoor, V. P. *Nat. Prod. Rad.* **2005,** *4*, 306-314.
[35] Kapoor, V. P.; Katiyar, K.; Pushpangadan, P.; Singh, N. *Nat. Prod. Rad.* **2008,** *7*, 22-29.
[36] Chigurupati, N.; Saiki, L.; Gayser Jr., C.; Dash, A. K. *Int. J. Pharm.* **2002,** *241*, 293-299.
[37] Boonsong, P.; Laohakunjit, N.; Kerdchoechuen, O. *J. Clean. Prod.* **2012,** *37*, 93-106.
[38] Rao, Y. M.; Shayeda, S. P. *Nat. Prod. Rad.* **2008,** *7*, 45-48.
[39] Chowdhury, M. J.; Uddin, M. T.; Biswas, M. I.; Lyzu, C.; Parveen, S.; Eti, S. A.; Razzaq, M. A. *Ind. Crops Prod.* **2024,** *210*, 118159.
[40] Bashir, M.; Adeel, S.; Aftab, M.; Mia, R.; Imran, M. *Sustain. Chem. Pharm*. **2024,** *37*, 101336.
[41] Jiang, Z.; Zheng, G.; Cui, Y.; Wang, W.; Shang, X.; Wei, Y.; Wang, Q. *Chem. Eng. J*. **2024,** *481*, 148319.
[42] Nitayaphat, W.; Jintakosol, T. *J. Nat. Fibers* **2024,** *21*, 2313867.
[43] Rezic, I.; Steffan, I. *Microchemestry J.* **2007,** *85*, 46-51.
[44] Meksi, N.; Haddar, W.; Hammami, S.; Mhenni. M. F. *Ind. Crops Prod.* **2012,** *40*, 103-109.
[45] Haddar, W.; Baaka, N.; Meksi, N.; El Ksibi, I.; Mhenni. M. F. *J. Clean. Prod.* **2014,** *66*, 546-554.
[46] Haddar, W.; Baaka, N.; Meksi, N.; Ben Ticha, M.; Guesmi, A.; Mhenni. M. F. *Fibers Polym*. **2015,** *16*, 1506-1511.
[47] Meksi, N.; Haddar, W.; Baaka, N.; Mejri, M.; Mhenni, M. F. *IJARTex.* **2018,** *6*, 46-64.
[48] Elksibi, I.; Haddar, W.; Ben Ticha, M.; Gharbi, R.; Mhenni, M. F. *Food Chem.* **2014,** *161*, 345-352.
[49] İsmal, Ö. E. *Color. Technol.* **2014,** *130*, 147-153.
[50] Ekrami, E.; Mafi, M.; Motlagh. M. S. *World Applied Scien. J.* **2011,** *13*, 996-999.

[51] Baaka, N.; Ben Ticha, M.; Haddar, W.; Amorim, M. T. P.; Mhenni, M. F. *Nat. Prod. Res.* **2017,** *31*, 1655-1662.
[52] Baaka, N.; Ben Ticha, M.; Haddar, W.; Hammami, S.; Mhenni, M. F. *Fibers Polym.* **2015,** *16*, 38-45.
[53] Baaka, N.; Ben Ticha, M.; Haddar, W.; Mhenni, M. F. *Fibers Polym.* **2018,** *19*, 307-312.
[54] El Ksibi, I.; Ben Slama, R.; Faidi, K.; Ben Ticha, M.; Mhenni, M. F. *Ind. Crops Prod.* **2015,** *70*, 34-40.
[55] Baaka, N.; El Ksibi, I.; Mhenni. M. F. *Nat. Prod. Res.* **2017,** *31*, 196-203.
[56] Souissi, M.; Guesmi, A.; Moussa, A. *J. Clean Prod.* **2018,** *202*, 1045-1055.
[57] Souissi, M.; Guesmi, A.; Moussa, A. *J. Clean*. *Prod*. **2018,** *204*, 1143-1153.
[58] Chira, K.; Suh, J. H.; Saucier, C.; Teissèdre, P. L. *Phytotherapie* **2008,** *6*, 75-82.
[59] Xu, C.; Zhang, Y.; Cao, L.; Lu, J. *Food Chem.* **2010,** *119*, 1557-1565.
[60] Siller-Sánchez, A.; Luna-Sánchez, K. A.; Bautista-Hernández, I.; Chávez-González, M. L. *Current Food Sci. Technol. Rep.* **2024,** *2*, 7-16.
[61] Caponio, G. R.; Minervini, F.; Tamma, G.; Gambacorta, G.; De Angelis, M. *Sustainability* **2023,** *15*, 9075.
[62] Bottino, A.; Capannelli, G.; Comite, A.; Jezowska, A.; Pagliero, M.; Costa, C.; Firpo. R. *Membranes* **2020,** *10*, 1-16.
[63] Fernández-Lobato, L.; López-Sánchez, Y.; Baccar, R.; Fendri, M.; Vera, D. *Sustain. Prod. Consum*. **2022,** *32*, 908-923.
[64] Petropoulos, S. A.; Fernandes, A.; Xyrafis, E.; Polyzos, N.; Antoniadis, V.; Barros, L. et al. *Agronomy.* **2020,** *10*, 715.
[65] Swamy, K. R. M. *Int. J. Dev. Res*. **2023,** *13*, 61956-61977.
[66] Govindarajan, V. S.; Sathyanarayana, M. N. *Crit. Rev. Food Sci. Nutr.* **1991,** *29*, 435-473.
[67] Sim, K. H.; Sil, H. Y. *Int. J. Food Sci. Technol*. **2008,** *43*, 1813-1823.
[68] Chao, C. T.; Krueger. R. R. *HortScience* **2007,** *42*, 1077.
[69] Al-Harrasi, A.; Rehman, N. U.; Hussain, J.; Khan, A. L.; Al-Rawahi, A.; Gilani, S. A.; Al-Broumi, M.; Ali, L. *Asian Pac*. *J. Trop. Med.* **2014,** *7*, 591-598.
[70] Hazzouri, K. M.; Flowers, J. M.; Visser, H. J.; Khierallah, H. S. M.; Rosas, U.; Pham, G. M.; Meyer, R. S.; Johansen, C. K.; Fresquez, Z.A.; Masmoudi, K.; Haider, N.; El Kadri, N.; Idaghdour, Y.; Malek, J. A.; Thirkhill, D.; Markhand, G. S.; Krueger, R. R.; Zaid, A.; Purugganan, M. D. *Nat. Commun.* **2015,** *6*, 8824.