Aromatherapeutic Textiles

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Additional information is available at the end of the chapter

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Abstract

Only innovative products will be sustainable to open up new markets and new horizons for textile industry. As a response to consumer demand, in recent years textile manufacturers are demonstrating increasing interest in added value products by getting the insect repellents, cosmetics, antimicrobials, phase-change materials, fire retardants, counterfeiting, polychromic and thermochromic effects. Aromatherapy application in textile industry led to a series of value-added products that give besides comfort a number of other properties (anti-acne, antimicrobial, fragrance, anti-inflammatory sedation, or soothing properties). In recent years, aromatherapeutic textiles were applied in many fields such as food, cosmetics, medicine, tobacco, textiles, leather, papermaking and pharmaceutical industries. The purpose of this chapter was to present the essential oils used in textile finishing, textile supports used for aroma finishing, embedding methods and the controlled release of essential oils.

Keywords: aromatherapy, essential oils, textile materials

1. Introduction

Although medicinal plants have been used for centuries as remedies for human diseases, in recent years, they have reached a great interest due to their low toxicity, pharmacological activities and economic viability. It shows a more pronounced shift from chemical and nonsustainable products to natural products that are not harmful, biodegradable and with health and wellness benefits [1]. After Mahboob et al., a good part of the population prefer traditional medicine because of the scarcity and cost-effectiveness of this sector.

Natural additives from plants can be compounds, groups of compounds, or essential oils [2]. Among natural additives, essential oils present a particular interest due to multiple benefits it shows such as antiviral, antifungal, antibacterial, antioxidant, antiparasitic, insecticidal, radical-scavenging properties, anti-inflammatory, antiseptic, germicide, healing and emollient effects.

Essential oils are made up of complex mixtures of several hydrocarbons (alcohols, terpenes, aldehydes, esters, phenols, oxides and ketones) and are obtained by conventional or advanced methods (**Figure 1**) [3, 4].

Figure 1. Extraction methods of essential oils.

Essential oils are fat soluble and thus they have the ability to permeate the skin membranes and drained into the systemic circulation, which reaches all targets organs as described by Radulovic et al. [5] and Kandori [6]. Essential oils are considered “vital force” of the plants. The role of these oils in plants is similar to that of the blood in the body. Fat-soluble structure of essential oils is similar to that of cells and tissues in the human body. This makes them compatible with human proteins and allows them to be easily identified and accepted by the body. Due to the fat-soluble structure and very small-size molecules, essential oils serve as transport agents that easily penetrates the cell membrane. Only one application of essential oils is sufficient to stimulate and revitalize the entire body. Recent research has shown that essential oils are able to penetrate the barrier blood/brain due to their small size (≤ 500 amu) [7].

2. Chemical composition of essential oils

Essential oils represent less than 5% from vegetal dry matter and are complex mixtures of volatile compounds extracted from plants [8].

Chemical composition of the main essential oils used in textile industry, identified by gas chromatography (GC) and GC-mass spectrometry (GC-MS), is presented in **Table 1**:

Essential oil	Chemical type	Main compounds	Composition (%)	References
Peppermint	Oxygenated compounds	Menthol	36	[11]
		Menthone	21.24	
		Menthyl acetate	6.92	
		Eucalyptol	6.58	
		Isomenthone	4.71	
		Neomenthol	4.06	
	Bicyclic sesquiterpene	β -Caryophyllene	2.07	
	Monoterpenes	Pulegone	1.72	
		D-Limonene	2.09	
		β -Pinene	1.02	
		Menthofuran	3.00	
Citronella	Oxygenated compounds	Citronellal	55.24	[12]
		Citronellol	13.41	
		Geraniol	26.29	
Thyme	Oxygenated compounds	Carvacrol	14.1–77.6	[13]
		Thymol	0.5–27.8	
		Borneol	0.2–16.3	
	Monoterpenes	γ -Terpinene	3.8–6.6	
		p-Cymene	3.5–7.9	
		α -pinene	1.2–7.8	
<i>Ocimum sanctum</i> L.	Oxygenated compounds	Carvacrol	2.04	[14]
		Eugenol	61.30%	
	Bicyclic sesquiterpene	β -Caryophyllene	11.89%	
	Monocyclic sesquiterpenes	Germacrene-D	9.14%	
	Tricyclic sesquiterpene	α -Cubebene	2.54%	
	Byclic sesquiterpenes	β -Selinene	1.34%	
Lavender	Monoterpenes	α -Pinene	3.4%	[15]
	Oxygenated monoterpenes	1,8-cineole	33.0%	
		Camphor	23.1%	
		α -Bisabolool	14.1%	
	Monoterpene	β -Pinene	4.1%	
Sage	Oxygenated monoterpenes	1,8-cineole	13.7%	
		Camphor	23.8%	
	Bicyclic monoterpene	cis-thujone	5.9%	
		Camphene	5.2%	
Rosemary	Bicyclic Monoterpenes	α -Pinene	28.2%	

Essential oil	Chemical type	Main compounds	Composition (%)	References
Chamomile	Oxygenated monoterpenes	1,8-cineole	7.4%	[16]
		Camphor	7.9%	
	Oxygenated compounds	Borneol	6.5%	
	Monoterpenes	Sabinene	27.9%	
		β -Pinene	16.0%	
		Limonene	2.0%	
Lemongrass	Oxygenated compounds	4-terpineol	1.4%	[17]
	Monoterpenes	α -Pinene	43.9%	
	Oxygenated compounds	α -Citral (geranial)	43.356	
		β -Citral (neral)	36.548	
		Geranyl N-butyrate	2.661	
	Sesquiterpenes	β -Caryophyllene	1.998	
Citrus	Monoterpene	cis-Verbenol	1.495	[18, 19]
		Camphene	1.005	
	Monoterpenes	Limonene	84.73–98	
		β -Pinene	1.37–3.36	
		Sabinene	0.28	
		α -Pinene	0.27–1.06	
Geranium		Myrcene	1.2–2.16	[20]
	Oxygenated compounds	Octanol	0.34–0.54%	
		L- α -Terpineol	2.80	
		Terpinen-4-ol	1.18	
	Oxygenated compounds	Citronellol	26.7	
		Geraniol	13.4	
Turmeric		Nerol	8.7	[21]
		Citronellyl formate	7.1	
		Geranyl formate	2.5	
	Sesquiterpenes	β -Caryophyllene	1.5	
		10-epi-g-Eudesmol	4.4	
	Oxygenated compounds	Geranyl propionate	1.00	
Turmeric		Geranyl tiglate	1.0	[21]
		Geranyl butyrate	1.4	
	Sesquiterpenes	α -Phellandrene	33.9	
	Oxygenated monoterpenes	Eucalyptol (1,8-cineole)	10.6	
	Monoterpenes	Terpinolene	21.1	

Essential oil	Chemical type	Main compounds	Composition (%)	References
Eucalyptus	Oxygenated compounds	α -Pinene	1.7	[22]
		Myrcene	3.3	
		p-Cymene	5.6	
		γ -Terpinene	2.9	
		Carvacrol	2.2	
		Curlone	1.3	
	Monoterpenes	α -Pinene	3.8	
	Sesquiterpenes	α -Phellandrene	1.9	
		Aromadendrene	19.7	
		Allo-aromadendrene	2.5	
		Ledene	3.1	
	Oxygenated monoterpenes	Eucalyptol (1,8-cineole)	19.8	
		Isovaleraldehyde	2.4	
	Oxygenated Sesquiterpenes	Epiglobulol	6.4	
		Globulol	23.6	
		Eudesmol	2.1	

Table 1. Chemical composition of essential oils.

2.1. Terpene hydrocarbons

Terpenes are found in a wide variety of essential oils and many of them are of industrial importance [4]:

- *Monoterpene hydrocarbons*: Monoterpene consists of two isoprene units and can be classified into three categories: acyclic, monocyclic and bicyclic. The chief sources of the monoterpenes and their derivatives are the essential oils obtained by distillation or extraction under pressure of various plant parts [9].
- *Sesquiterpenes*: Sesquiterpenes are made of isoprene units and have empirical formula of $C_{15}H_{24}$. Some plant-derived sesquiterpenoids have been identified as anti-inflammatory and anti-carcinogenic species [10].

2.2. Oxygenated compounds

- *Phenols* (thymol, eugenol, carvacrol and chavicol);
- *Alcohols* (linalol, menthol, borneol, santalol, nerol, citronellol and geraniol);
- *Aldehydes* (citral, myrtenal, cuminaldehyde, citronellal, cinnamaldehyde and benzaldehyde);

- *Ketones* (carvone, menthone, pulegone, fenchone, camphor, thujone and verbenone);
- *Esters* (linalyl acetate, geraniol acetate, eugenol acetate and bornyl acetate);
- *Lactones* (nepetalactone, bergaptene, costuslactone, dihydronepetalactone and alantrolactone);
- *Coumarins* (warfarin, acenocumarol and phenprocoumon);
- *Ethers* (linalyl acetate, geraniol acetate, eugenol acetate and bornyl acetate);
- *Oxides* (bisabolone oxide, linalool oxide, sclareol oxide and ascaridole).

3. Application of essential oils in textile field

Due to essential oils that can act both at local level and through odor, they have great important applications in many fields such as food, cosmetics, medicine, tobacco, textile, leather, papermaking, pharmaceutical and perfume industries [23].

Essential oils add much value to the textile materials. The most commonly used essential oil in aroma finishing is lavender essential oil due to its properties: anti-acne, antibacterial, calming, anti-inflammatory, treatment of eczema and dermatitis. The most used essential oils in the textile industry are presented in **Table 2**.

Introducing the concept of aromatherapy, textile materials came with increasing consumer demands in terms of quality, comfort and functionality of textiles. There was a shift in their

Essential oil	Final product destination/effect	References
Peppermint	Sedative, stimulatory, antiviral, and antibacterial properties	[24]
Citronella	Mosquito repellent	[25]
Thyme <i>Ocimum sanctum</i> L.	Antimicrobial natural textiles	[26, 27]
Lavender	Garment's packaging and storage system Health and well-being Medical applications in treatments at skin level Antibacterial textiles	[28–30]
Chamomile	Garment's packaging and storage system Health and well-being	[31]
<i>Moluccella spinosa</i> L.	Antibacterial activity for historical textiles	[32]
Lemongrass	Antibacterial and antifungal properties	[33]
Citrus species	Medical textiles Fragrant textiles Cosmetic textiles	[34–37]
Geranium	Health-care textiles	[38]
Turmeric	Food-packaging materials	[39]
Eucalyptus	Antibacterial wound dressing	[40]
Rosemary Sage Lavender	Health-care textiles Antimicrobial skin-care textiles Nonwoven textile shoe insoles	[41–43]

Table 2. Major essential oils used in textile finishing.

values. Instead of wanting the finest natural materials, people look at beauty through engineering, innovative design, smart appearance and added value of products [44].

Aroma finish is a process by which the textile materials are treated with bioactive systems (e.g., chitosan/essential oil, alginate/essential oil systems) and finally get the multifunctional properties such as therapeutic effects and a feeling of well-being and freshness in the wearer.

Aromatherapy textiles are used in medicine and alternative healing, home textiles, body-care textiles, household cleaning and cosmetic products.

Aromatherapeutic textiles first appeared on the market were scented women's tights. Hosiery and intimate apparel have been the more widely explored product categories to apply aroma finishing. In recent years, a number of companies around the world turned their attention to aromatherapy textiles. Woolmark™ is applying aroma technology to hosiery, lingerie, socks, outdoor clothing, underwear, carpeting and other interior textiles. The Invista Company, owner of fiber brands such as LYCRA®, TACTEL® and SUPPLEX®, launched the LYCRA® Body Care Collection that includes moisturizing and fragrance features in the yarns to enhance the wearer's sense of well-being in the intimate apparel category. The Nike clothing brand has also explored encapsulation methods to a limited extent [45, 46].

Cooperation of specialists from medical and textile fields leads to rapid development in various fields, such as medical, barrier, hygiene and controlled-release textiles. Textiles used for obtaining aroma products are presented in **Table 3**.

Textiles	Destination	References
Linen/cotton blended fabric 100% eco-friendly cotton knitted fabrics Cotton/ regenerated bamboo (50/50) knitted fabrics Flax knitted fabrics	Antimicrobial protection	[47–57]
knitted fabrics (plain stitch) of polyamide	Cosmeto-textiles	[48]
Pure cotton Polyester/cotton (40:60) blend fabrics Silk Synthetic fibres (polyamide or polyester)	Flavors and fragrances in textile applications	[49–52, 55, 56]
100% Viscose Hydroentangled nonwoven	Medical textiles	[53]
Nylon net fabrics Cotton fabrics	Mosquito repellent efficiency	[54]

Table 3. Textiles used in aromatherapy.

4. Embedding techniques of essential oils

Losses by evaporation and difficulties in their controlled release make essential oils commercial application limited. In this case, nanocarrier systems (lipid-based particles, nanoemulsions and biocompatible polymer-based particles) can provide an ideal solution for realizing a controlled and targeted delivery of the essential oil. In the last few years, the application of a biocompatible and biodegradable polymer-based formulations as a controlled-release form has generated immense interest [58]. Because polymers (e.g., chitosan, alginates, starch, poly (DL-lactide-co-glycolide), poly-ε-caprolactone, polyethylene glycol, gum Arabic, maltodextrin,

modified starches, mesquite gum) are friendly for the environment and safe for human health, they are commonly used in medicine, pharmacy, textiles, food and other fields [59]. As known, essential oils are adsorbed by the skin from the textile fabric through a mechanism of controlled release [60].

Bioactive systems are applied to the textile materials by a variety of techniques such as follows.

4.1. Microencapsulation techniques

Microcapsules are spherical or irregular shape (1–100 μm) containing one or more active ingredients (core) coated by synthetic or natural polymer (shell) material which gives controlled release of core materials. The core may contain a solid or liquid substances, solutions or suspensions and mixture of solids or liquids.

The shell material is generally formed of a polymer that must meet some conditions:

- Physicochemical compatibility with the core material
- Flexibility
- Impermeability
- Stability

Compatibility from core and wall material is an important criterion for efficacy microcapsules. Core size plays an important role in the diffusion, permeability, or controlled release of the active compound. The wall material protects temporarily or permanently the core from external factors and may be:

- Permeable
- Semipermeable (wall material is impermeable to the active compound and permeable to liquids with low molecular weight)
- Waterproof (membrane protects the active compound from external factors. Active compound is released by breakage or degradation of the wall) [61]

The main used methods of microencapsulation are shown in **Table 4** [62].

Microcapsules (core-shell system) in terms of morphology can be classified into mononuclear and polynuclear matrix (**Figure 2**).

Microencapsulation techniques			
Chemical methods	Simple coacervation Coacervation phase separation extraction Solvent evaporation In situ polymerization Interfacial polymerization Nanoencapsulation Matrix polymerization Liposome polymerization	Physical methods	Spray drying Spray chilling Pan coating Rotary disk atomization Air-suspension coating Stationary nozzle coextrusion Multiorifice-centrifugal process Centrifugal extrusion

Table 4. Encapsulation process.

Figure 2. Morphology of microcapsules.

The microcapsules have many advantages, among which the most important are:

- protection of biologically active compound against environment;
- extends the life of biologically active compound by avoiding degradation reactions (oxidation and dehydration);
- controlled release of biologically active compound;
- microorganisms and enzyme immobilization.

The main useful shell materials used for obtaining microcapsules are presented in Figure 3.

Figure 3. The main useful shell materials.

4.2. Application of biologically active compounds in the form of hydrogels

Hydrogel is a water-swollen and cross-linked polymeric network produced by the reaction of one or more monomers. The hydrogels can be classified on different bases as detailed below [63]:

Hydrogel source:

- Natural
- Synthetic hydrogels

Polymeric composition:

- Homopolymeric hydrogels
- Copolymeric hydrogels
- Multipolymer interpenetrating polymeric hydrogel

Hydrogels configuration:

- Amorphous hydrogels
- Semicrystalline
- Crystalline

Type of cross-linking:

- Chemically cross-linked networks
- Physical cross-linked networks

Physical appearance of hydrogels:

- Matrix
- Film
- Microsphere

Network electrical charge:

- Nonionic
- Ionic
- Amphoteric
- Zwitterionic

4.3. Application of biologically active compounds in the form of polymer matrices

There are various materials that can be used to attach the biologically active compounds, such as synthetic polyelectrolytes, natural polyelectrolytes, inorganic nanoparticles, fats, dyes, or polyvalent ions.

Generally, for polymer matrices, two classes of materials were used:

Natural materials [64] include

- Carbohydrates: agarose, carrageenan, alginate, chitosan, gellan gum and hyaluronic acid

- Proteins: collagen, gelatin, fibrin, elastin, silk fibroin

Synthetic polymers [65]: aliphatic polyesters, polyacrylates, polyamides, polyepoxides, polyphosphazenes and poly(ethylene glycol).

4.4. Functional coatings

Functional coatings are applied to textile surfaces for decorative, protective, or functional purposes. The term “functional coatings” describes systems that presents besides basic functions (protective and decorative) and additional functions [66].

Functional coatings can be classified according to their characteristics [67] as follows:

- Functional coatings with optical properties (fluorescent, phosphorescent, or photochromic coatings)
- Functional coatings with physicochemical properties (hydrophilic or hydrophobic coatings)
- Functional coatings with thermal properties (heat-resistant coatings)
- Functional coatings with mechanical properties (anti-abrasive coatings)
- Functional coatings with electric/magnetic properties (antistatic, conductive, dielectric, or piezoelectric coatings)
- Functional coatings with hygienic properties (antimicrobial coatings)

4.5. Application of biologically active compounds by activating the textile support

Plasma treatment of textile materials is an alternative to chemical treatments in order to obtain new characteristics of the final product.

Usually, it is used in low-pressure plasma treatments and atmospheric pressure plasma treatments of textiles (ex. for hydro- and oleo-repellence). For the enhancement of the wettability of different fabrics, the plasma treatment with a dielectric barrier discharge [68] is most often used.

The main plasma treatment effects are increasing the hydrophilic character, enhancing adhesion (composite materials, coated and laminated textiles), improving dyeing and printing properties, hydrophobicity and oleophobicity, deposition of fiber coatings (metallic coatings and polymer coatings), surface cleaning, inactivation of microorganisms, influencing physical properties of fibers (optical, mechanical and electrical properties), shrink-proofing of wool, improving the efficiency of wet-finishing processes and formation of radicals [69].

4.6. Controlled release of essential oil

Micro-encapsulation ensures the storage life of essential oils and can effectively control the release rate of the biologically active compounds.

Controlled release of biologically active compounds from shell material can be classified as [70] follows:

The methods for investigating the kinetics of biologically active compound release from controlled-release formulation can be classified into three categories [71]:

- Statistical methods
- Model-dependent methods: zero-order, first-order, Higuchi, Korsmeyer-Peppas model, Baker-Lonsdale model, Weibull model and so on
- Model-independent methods: difference factor (f_1), similarity factor (f_2)

The most used methods to investigate the release profile of essential oils are model-dependent methods. For empirical/semi-empirical mathematical modeling of biologically active compounds from polymeric layer, the Korsmeyer-Peppas model is generally favorable and is based on the Fickian diffusive release from a thin polymeric film [72]:

$$M_t/M_\infty = k \cdot t^n \quad (1)$$

where

K —Peppas release rate constant;

t —time (s);

M_t/M_∞ —fraction of active compound released at time t ;

n —the release exponent.

Transport mechanisms of active principle function are shown in **Table 5**.

The release mechanism for the biologically active compound from the textile supports is primarily based on the diffusion process of the oil molecules. The main mechanism of essential oils release from shell materials is presented in **Table 6**.

Release exponent (<i>n</i>)	Active compound transport mechanism	<i>dM_t/dt</i> as a function of time
<i>n</i> = 0.5	Fickian diffusion	<i>t</i> ^{-0.5}
0.5 < <i>n</i> < 1	Non-Fickian transport	<i>t</i> ^{<i>n</i>-2}
<i>n</i> = 1	Case II transport	Zero-order release
<i>n</i> > 1	Super case II transport	<i>t</i> ^{<i>n</i>-1}

Table 5. Transport mechanism of biologically active compound.

Essential oil	Shell material	Release mechanism	References
Rosemary	Chitosan film	Non-Fickian mechanismZero-order mechanism	[73]
Geranium	Chitosan matrix	Fickian mechanism	[74]
Citronella	GelatinGum Arabic	Fickian mechanismNon-Fickian mechanism	[75]
CloveThyme	Orabase	Mixed mechanism	[76]
Tea tree	Sodium alginate/quaternary ammonium salt of chitosan	Ritger-Peppas mode	[77]
<i>Calendula officinalis</i> L.	Chitosan grafted with sodium acrylate-co-acrylamide	Non-Fickian (coupling of Fickian diffusion and relaxation of entangled chains of the encapsulating polymer)	[78]
<i>Coriandrum sativum</i> L.	Chitosan/alginate/inulin microcapsules	Non-Fickian transport mechanism (diffusion or diffusion-swelling-controlled process)	[79]
Peppermint Eucalyptus	Polyvinyl pyrrolidone (PVP)Ethyl cellulose (EC)	Zero-order release kinetic	[80]
Cardamom	Alginate-whey protein	Fickian diffusion	[81]

Table 6. Controlled release kinetics.

5. Conclusions

Aromatherapeutic textiles are a good choice for people who want to maintain harmony between their physical and psychological comfort. Applying of essential oils on textile materials shows great potential for the value-added textiles. Aromatherapy textiles application in various fields (cosmeto-textiles, home textiles, sport wears, medical textiles, etc.) made them indispensable in day-to-day life.

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References

- [1] West AJ, Annett-Hitchcock KE. A critical review of aroma therapeutic application for textiles. *Journal of Textile and Apparel, Technology and Management*. 2014;**9**(1):1–13.
- [2] Boulekbache-Makhlouf L, Rigoub P, Remini H, Adjaouda A, Khoudjaa NK, Madani K. Essential oils composition, antibacterial and antioxidant activities of hydrodistilled extract of *Eucalyptus globulus* fruits Z. Bey - Ould Si Saida, H. Haddadi - Guemghar, L. Boulekbache - Makhlouf, P. Rigoub, H. Remini, A. Adjaouda, N.K. Khoudjaa, K. Madani. *Industrial Crops and Products*. 2016;**89**:167–175.
- [3] Ghosha S, Chipot N. Embedding aromatherapy essential oils into textile fabric using β -cyclodextrin inclusion compound. *Indian Journal of Fibre & Textile Research*. 2015; **40**:140–143.
- [4] El Asbahani A, Miladi K, Badri W, Sala M, Aït Addi EH, Casabianca H, El Mousadik A, Hartmann D, Jilale A, Renaud FNR, Elaissari A. Essential oils: from extraction to encapsulation. *International Journal of Pharmaceutics*. 2015;**483**:220–243.
- [5] Radulovic N, Dekic M, Radi ZS, Palic R. Chemical composition and antimicrobial activity of the essential oils of *Geranium columbinum* L. and *G. lucidum* L. (Geraniaceae). *Turkish Journal of Chemistry*. 2011;**35**:499–512.
- [6] Kandori I. Diverse visitors with various pollinator importance and temporal change in important pollinators of *Geranium thunbergii* (Geraniaceae). *Ecological Research*. 2002; **17**:283–294.
- [7] Balabai, I.V. *Rastenia, coterie nas leceat/ I.V. Balabai, A.C. Nistrean, Chisinau, 1988, 351 pages.*
- [8] Abraham MH, Gola JRM, Gil-Lostes J, Acree Jr. WE, Cometto-Muñizc JE. Determination of solvation descriptors for terpene hydrocarbons from chromatographic measurements. *Journal of Chromatography A*. 2013;**1293**:133–141.
- [9] Rachwalik R, Hunger M, Sulikowskic B. Transformations of monoterpene hydrocarbons on ferrierite type zeolites. *Applied Catalysis A: General*. 2012;**427–428**:98–105.
- [10] Duhamela N, Martin D, Larcher R, Fedrizzia B, Barker D. Convenient synthesis of deuterium labelled sesquiterpenes. *Tetrahedron Letters*. 2016;**57**(40):4496–4499.

- [11] Skalicka-Wozniak K, Walasek M. Preparative separation of menthol and pulegone from peppermint oil (*Mentha piperita* L.) by high-performance counter-current chromatography. *Phytochemistry Letters*. 2014;**10**:xciv–xcviii.
- [12] Timung R, Barik CR, Purohit S, Goud VV. Composition and anti-bacterial activity analysis of citronella oil obtained by hydrodistillation: process optimization study. *Industrial Crops and Products*. 2016;**94**:178–188.
- [13] Jamali CA, Kasrati A, Bekkouche K, Hassani L, Wohlmuth H, Leach D, Abbad A. Phenological changes to the chemical composition and biological activity of the essential oil from Moroccan endemic thyme (*Thymus maroccanus* Ball). *Industrial Crops and Products*. 2013;**49**:366–372.
- [14] Kumar A, Shukla R, Singh P, Dubey NK. Chemical composition, antifungal and antiaflatoxic activities of *Ocimum sanctum* L. essential oil and its safety assessment as plant based antimicrobial. *Food and Chemical Toxicology*. 2010;**48**(2):539–543.
- [15] J. González-Rivera, C. Duce, D. Falconieri, C. Ferrari, L. Ghezzi, A. Piras, M.R. Tine. Coaxial microwave assisted hydrodistillation of essential oils from five different herbs (lavender, rosemary, sage, fennel seeds and clove buds): chemical composition and thermal analysis. *Innovative Food Science & Emerging Technologies*. 2016;**33**:308–318.
- [16] Bouhekrit M, Laouer H, Hajji M, Nasri M, Haroutounian SA, Akkal S. Essential oils from *Elaeagnus oleae*: chemical composition, antimicrobial and antioxidant properties. *Asian Pacific Journal of Tropical Biomedicine*. 2016; <http://dx.doi.org/10.1016/j.apjtb.2016.07.014>
- [17] Leimann FV, Gonçalves OH, Machado RAF, Bolzan A. Antimicrobial activity of microencapsulated lemongrass essential oil and the effect of experimental parameters on microcapsules size and morphology. *Materials Science and Engineering: C*. 2009;**29**(2):430–436.
- [18] Zarrad K, Hamouda AB, Chaieb I, Laarif A, Mediouni-Ben Jemâa J. Chemical composition, fumigant and anti-acetylcholinesterase activity of the Tunisian *Citrus aurantium* L. essential oils. *Industrial Crops and Products*. 2015;**76**:121–127.
- [19] AL-Jabri NN, Hossain MA. Chemical composition and antimicrobial potency of locally grown lemon essential oil against selected bacterial strains. *Journal of King Saud University – Science*. 2016; <http://dx.doi.org/10.1016/j.jksus.2016.08.008>
- [20] Sienkiewicz M, Poznańska-Kurowska K, Kaszuba A, Kowalczyk E. The antibacterial activity of geranium oil against Gram-negative bacteria isolated from difficult-to-heal wounds. *Burns*. 2014;**40**(5):1046–1051.
- [21] Zaibunnisa AH, Norashikin S, Mamot S, Osman H. An experimental design approach for the extraction of volatile compounds from turmeric leaves (*Curcuma domestica*) using pressurised liquid extraction (PLE). *LWT—Food Science and Technology*. 2009;**42**(1):233–238.
- [22] Bey-Ould Si Saida Z, Haddadi-Guemghara H, Boulekbache-Makhloufa L, Rigoub P, Reminia H, Adjaouda A, Khaled Khoudjaa N, Madania K. Essential oils composition,

- antibacterial and antioxidant activities of hydrodistilled extract of *Eucalyptus globulus* fruits. *Industrial Crops and Products*. 2016;**89**:167–175.
- [23] Hu J, Xiao Z, Zhou R, Ma S, Wang M and Li Z. Properties of aroma sustained-release cotton fabric with rose fragrance nanocapsule. *Chinese Journal of Chemical Engineering*. 2001;**19**(3):523–528.
- [24] Ciobanu A, Mallard AI, Landy D, Brabie D, Nistor D, Fourmentin S. Retention of aroma compounds from *Mentha piperita* essential oil by cyclodextrins and crosslinked cyclodextrin polymers. *Food Chemistry*. 2013;**138**:291–297.
- [25] Specos MM, García JJ, Tornesello J, Marino P, Vecchia MD, Tesoriero MV, Hermida LG. Microencapsulated citronella oil for mosquito repellent finishing of cotton textiles. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 2010;**104**(10):653–658.
- [26] Walentowska J, Foksowicz-Flaczyk J. Thyme essential oil for antimicrobial protection of natural textiles. *International Biodeterioration & Biodegradation*. 2013;**84**:407–411.
- [27] Ravindra KB, Murugesh Babu K. Study of antimicrobial properties of fabrics treated with *Ocimum sanctum* L. (tulsi) extract as a natural active agent. *Journal of Natural Fibers*. 2016;**13**(5):619–627.
- [28] West A, Annett-Hitchcock K. The development of an herb-infused bag that regenerates aromatherapy textiles. *International Journal of Designed Objects*. 2016;**10**(2):17–30.
- [29] Cerempei A, Ciobanu L, Muresan E, Măluțan C, Butnaru R. Textile materials functionalised with natural biologically active compounds. *Romanian Biotechnological Letters*. 2010;**15**(5):5537–5544.
- [30] Balasubramanian K, Kodam KM. Encapsulation of therapeutic lavender oil in an electrolyte assisted polyacrylonitrile nanofibres for antibacterial applications. *RSC Advances*. 2014;**4**(97):54892–54901.
- [31] West A, Annett-Hitchcock K. The development of an herb-infused bag that regenerates aromatherapy textiles. *International Journal of Designed Objects*. 2016;**10**(2):7–30.
- [32] Casiglia S, Ben Jemia M, Riccobono L, Bruno M, Scandolera E, Senatore F. Chemical composition of the essential oil of *Moluccella spinosa* L. (Lamiaceae) collected wild in Sicily and its activity on microorganisms affecting historical textiles. *Natural Product Research*. 2015;**29**(13):1201–1206.
- [33] Dutra JAP, Carvalho SG, Villanova JCO, Ayres E. Preparation of β -cyclodextrin/latex dispersion for coating of cellulose fabric. M. Cotrim. *Journal of Renewable Materials*. 2016;**4**(1):9–17.
- [34] Wolffenbüttel AN, Zamboni A, dos Santos MK, Borille BT, Augustin OA, Mariotti KC, Leal MB, Limberger RP. Chemical components of Citrus essential oils from Brazil. *Natural Products Journal*. 2015;**5**(1):14–27.
- [35] Kumari P, Rose NM, Jeet Singh SS. Microencapsulation of lime essential oil for fragrant textiles. *Annals of Agri Bio Research*. 2015;**20**(1):152–157.

- [36] Chelaru C, Ignat M, Albu M, Meghea A. Polymeric microcapsules for cosmetic applications, based on Lemon essential oil (*Citrus limon*). UPB Scientific Bulletin, Series B: Chemistry and Materials Science. 2015;**77**(4):101–112.
- [37] Lee AR, Han CH, Yi E. Preparation and characterization of melamine-formaldehyde microcapsules containing Citrus unshiu essential oil. *Fibers and Polymers*. 2014;**15**(1):35–40.
- [38] Cerempei A, Muresan EI, Cimpoesu N. Biomaterials with controlled release of geranium essential oil. *Journal of Essential Oil Research*. 2014;**26**(4):267–273.
- [39] Navarro S, Finkelman S. Protecting food packaging materials by natural nontoxic insect repellents. *Acta Horticulturae*. 2014;**1015**:137–144.
- [40] Khajavi R, Abbasipour M, Barzi MG, Rashidi A, Rahimi MK, Mirzababa HH. Eucalyptus essential oil-doped alginate fibers as a potent antibacterial wound dressing. *Advances in Polymer Technology*. 2014;**33**(2):n/a.
- [41] Cerempei A, Muresan EI, Sandu I, Chirila L, Sandu IG. Textile materials with controlled release of rosemary essential oil. *Revista de Chimie*. 2014;**65**(10):1154–1157.
- [42] Cerempei A, Abramiuc D, Popescu C, Muresan R, Muresan A. Textile materials treated with antimicrobial skin care emulsion optimized by mathematical modelling. *Industria Textila*. 2014;**65**(4):213–218.
- [43] Boh B, Knez E. Microencapsulation of essential oils and phase change materials for applications in textile products. *Indian Journal of Fibre and Textile Research*. 2006;**31**(1):72–82.
- [44] Monllor P, Angeles Bonet M, Cases F. Characterization of the behaviour of flavour microcapsules in cotton fabrics. *European Polymer Journal*. 2007;**43**:2481–2490.
- [45] Wang CX, Chen ShL. Aromachology and its applications in the textile field. *Fibres & Textiles in Eastern Europe*. 2005;**13**(6):41–44.
- [46] “Hand-book of Technical Textiles” Edited by A.R. Horrocks and S.C. Anand. Published by Woodhead Publishing Limited in association with The Textile Institute. 2010.
- [47] Walentowska J, Foksowicz-Flaczyk J. Thyme essential oil for antimicrobial protection of natural textiles. *International Biodeterioration & Biodegradation*. 2013;**84**:407–411.
- [48] Alonso C, Martí M, Barba C, Lis M, Rubio L, Coderch L. Skin penetration and antioxidant effect of cosmeo-textiles with gallic acid. *Journal of Photochemistry & Photobiology, B: Biology*. 2016;**156**:50–55.
- [49] Sharaf S, Higazy A, Hebeish A. Propolis induced antibacterial activity and other technical properties of cotton textiles. *International Journal of Biological Macromolecules*. 2013;**59**:408–416.
- [50] Hu J, Xiao Z, Zhou R, Ma S, Wang M, Li Z. Properties of aroma sustained-release cotton fabric with rose fragrance nanocapsule. *Chinese Journal of Chemical Engineering*. 2011;**19**(3):523–528.

- [51] Badulescu R, Vivod V, Jausoved D, Voncina B. Grafting of ethylcellulose microcapsules onto cotton fibers. *Carbohydrate Polymers*. 2008;**71**(1):85–91.
- [52] Ghosh S, Chipot N. Embedding aromatherapy essential oil into textile fabric using β -cyclodextrin inclusion compound. *Indian Journal of Fibre and Textile Research*. 2015; **40**:140–143.
- [53] Chinta SK, Landage Abhishek SM, Sonawane KD and Jalkate CB. Medical textiles – application of essential oil as antimicrobial agent on nonwoven. *G.J.B.B.* 2012;**1**(1):75–80.
- [54] Raja ASM, Kawlekar S, Saxena S, Arputharaj A, Patil PG. Mosquito protective textiles—a review. *International Journal of Mosquito Research*. 2015;**2**(4):49–53.
- [55] Alonso D, Gimeno M, Sepúlveda-Sánchez JD, Shirai K. Chitosan-based microcapsules containing grapefruit seed extract grafted onto cellulose fibers by a non-toxic procedure. *Carbohydrate Research*. 2010;**345**(6):854–859.
- [56] Rodrigues SN, Martins IN, Fernandes IP, Gomes PB, Mata VG, Barreiro MF, Rodrigues AE. Scentfashion®: Microencapsulated perfumes for textile application. *Chemical Engineering Journal*. 2009;**149**(1–3):463–472.
- [57] Rîmbu C, Cerempei A, Muresan R, Guguianu E, Ursache M, Borhan O, Muresan A. Eco-friendly antibacterial finish for natural knitted fabrics. *TEKSTİL ve KONFEKSİYON*. 2015;**25**(4):359–364.
- [58] Cerempei A, Muresan EI, Cimpoesu N. Biomaterials with controlled release of geranium essential oil. *Journal of Essential Oil Research*. 2014;**26**(4):267–273.
- [59] González JW, Yeguerman C, Marcovecchio D, Delrieux C, Ferrero A, Fernández Band B. Evaluation of sublethal effects of polymer-based essential oils nanoformulation on the german cockroach. *Ecotoxicology and Environmental Safety*. 2016;**130**:11–18.
- [60] Mureşan A, Cerempei A, Dunca S, Muresan R, Butnaru R. Aromatherapeutic characteristics of cotton fabrics treated with rosemary essential oil. *Cellulose Chemistry and Technology*. 2009;**43**(9–10):435–442.
- [61] Patil DK, Agrawal DS, Mahire RR, More DH. Synthesis, characterization and controlled release studies of ethyl cellulose microcapsules incorporating essential oil using an emulsion solvent evaporation method. *American Journal of Essential Oils and Natural Products*. 2016;**4**(1):23–31.
- [62] Dubey R, Shami TC, Bhasker Rao KU. Microencapsulation technology and applications. *Defence Science Journal*. 2009;**59**(1):82–95.
- [63] Ahmed EM. Hydrogel: Preparation, characterization and applications: a review. *Journal of Advanced Research*. 2015;**6**:105–121.
- [64] Gasperini L, Mano JF and Reis RL. Natural polymers for the microencapsulation of cells. *Journal of the Royal Society Interface*. 2014;**11**(100):20140817. <http://dx.doi.org/10.1098/rsif.2014.0817>

- [65] Olabisi RM. Cell microencapsulation with synthetic polymers. *Journal of Biomedical Materials Research A*. 2015;**103**(2):846–859.
- [66] Edge M, Allen NS, Turner D, Robinson J, Seal K. The enhanced performance of biocidal additives in paints and coatings. *Progress in Organic Coatings*. 2001;**43**:10–17.
- [67] *Functional Coatings*. Edited by Ghosh SK, 2006 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.
- [68] Zanini S, Freti S, Citterio A, Riccardi C. Characterization of hydro- and oleo-repellent pure cashmere and wool/nylon textiles obtained by atmospheric pressure plasma pre-treatment and coating with a fluorocarbon resin. *Surface & Coatings Technology*. 2016;**292**:155–160.
- [69] Morent R, De Geyter N, Verschuren J, De Clerck K, Kiekens P, Leys C. Non-thermal plasma treatment of textiles. *Surface & Coatings Technology*. 2008;**202**:3427–3449.
- [70] Tramón C. Modeling the controlled release of essential oils from a polymer matrix—a special case. *Industrial Crops and Products*. 2014;**61**:23–30.
- [71] Dash S, Narasimha Murthy P, Nath L, Chowdhury P. Kinetic modeling on drug release from controlled drug delivery systems. *Acta Poloniae Pharmaceutica—Drug Research*. 2010;**67**(3):217–223.
- [72] Maleki M, Amani-Tehrana M, Latifia M, Mathur S. Drug release profile in core-shell nanofibrous structures: a study on Peppas equation and artificial neural network modeling. *Computer Methods and Programs in Biomedicine*. 2014;**113**:92–100.
- [73] Muresan A, Cerempei A, Dunca S, Muresan R and Butnaru R. Aromatherapeutic characteristics of cotton fabrics treated with Rosemary essential oil. *Cellulose Chemistry and Technology*. 2009;**43**(9–10):435–442.
- [74] Cerempei A, Muresan EI and Cimpoesu N. Biomaterials with controlled release of geranium essential oil. *Journal of Essential Oil Research*. 2014;**26**(4):267–273.
- [75] Bezerra FM, Carmona OG, Carmona CG, Lis MJ, de Moraes FF. Cellulose. Controlled release of microencapsulated citronella essential oil on cotton and polyester matrices. 2016;**23**:1459–1470.
- [76] Labib GS, Aldawsari H. Innovation of natural essential oil-loaded Orabase for local treatment of oral candidiasis. *Drug Design, Development and Therapy*. 2015;**9**:3349–3359.
- [77] Chen M, Hu Y, Zhou J, Xie Y, Wu H, Yuana T, Yang Z. Facile fabrication of tea tree oil-loaded antibacterial microcapsules by complex coacervation of sodium alginate/quaternary ammonium salt of chitosan. *RSC Advances*. 2016;**6**:13032–13039.
- [78] Shruthi SB, Roy P, Sailaja RRN, Sengupta C. Encapsulation and release characteristics of Marigold oleoresin in chitosan grafted sodium acrylate-co-acrylamide. *Advanced Materials Letters*. 2016;**7**(10):795–801.

- [79] Dima C, Pătrașcu L, Cantaragiu A, Alexe P, Dima Ș. The kinetics of the swelling process and the release mechanisms of *Coriandrum sativum* L. essential oil from chitosan/alginate/inulin microcapsules. Food Chemistry. 2016;**195**:39–48.
- [80] Kumar A, Aggarwal G, Singh K, Harikumar SL. Comparison of vegetable and volatile oils as skin permeation enhancers for transdermal delivery of losartan potassium. Der Pharmacia Lettre. 2014;**6**(1):199–213.
- [81] Zandi M, Dardmeh N, Pirsā S, Almasi H. Identification of cardamom encapsulated alginate–whey protein concentrates microcapsule release kinetics and mechanism during storage, stew process and oral consumption. Journal of Food Process Engineering. DOI: 10.1111/jfpe.12314, 2015.