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EXPERIMENTAL PAPER

Phytochemical characterisation and bioactive properties of *Solanum sodomaeum* L. fruits at two stages of maturation

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Summary

Introduction: *Solanum sodomaeum* L. has been observed to have several medicinal properties, in particular, in the treatment of several types of human skin cancer.

Objective: The influence of the maturation stage of S. *sodomaeum* fruits on the total lipid contents, fatty acid profiles, essential oil yields and compositions, as well as the antibacterial and antioxidant activities of the essential oils, was investigated.

Methods: The fatty acid and essential oil constituents were identified using gas chromatography (GC) and GC–mass spectrometry (GC–MS). The antioxidant properties of essential oil and vegetal oil were assessed using 1,1-diphenyl-2-picryl-hydrazyl (DPPH) scavenging and reducing power assays. The antibacterial ac-

tivity of essential oil was tested using the disc diffusion assay for resistance in human pathogenic bacteria.

Results: Mature fruits showed higher total lipid content (17%) and were characterised by polyunsaturated fatty acids (53.87%), represented mainly by linoleic acid (53.11%). Similar yields of essential oils were detected for immature (0.43%) and mature (0.45%) fruits. Tetrahydronaphthalene (41.79%) was detected as the major essential oil component at the immature stage versus dihydrocoumarin pentane (18.27%), hexadecanoic acid (17.43%) and 2-undecanone (13.20%) in mature fruits. The DPPH test showed that essential oils had better antioxidant properties; however, the vegetal oils showed better performance in the reducing power assay. Moreover, the essential oil of S. *sodomaeum* mature fruits was active against bacterial strains.

Conclusions: *S. sodomaeum* fruits could be a valuable source of natural antioxidants and antibacterial agents.

Key words: ***antibacterial activity, antioxidant activity, essential oils, fatty acids, fruit maturation, Solanum sodomaeum***

Słowa kluczowe: ***aktywność antybakteryjna, aktywność antyoksydacyjna, olejki eteryczne, kwasy tłuszczowe, dojrzewanie owoców, Solanum sodomaeum***

INTRODUCTION

The genus *Solanum* is widespread in temperate and tropical areas and includes about 1700 species. Species of the genus *Solanum* produce a class of useful biologically active secondary metabolites, the glycoalkaloids [1]. These nitrogen-containing steroidal glycosides have revealed antibiotic, antifungal, antimicrobial and antiviral properties [2] and show significant cytotoxicity against several human cancer cell lines and skin tumours [3]. Glycoalkaloids are toxic compounds at certain levels considering their role as plants' defensive allelochemicals against a number of pathogens and predators [4].

Among the numerous species of the genus, *Solanum sodomaeum* L. is common in Tunisia [5]. The fruits of *S. sodomaeum* are used in the treatment of external warts and eczema. The species is a source of solasodine, a raw material for the hemisynthesis of steroid hormones [5]. *S. sodomaeum* glycoalkaloids have been shown to be efficient in several types of human skin cancer therapies [6]. Steroidal glycosides extracted from the roots of the species exhibit antiproliferative activity in resistance to human promyelocytic leukaemia (HL-60) cells [7].

Previous investigations on *S. sodomaeum* have focussed on its alkaloids [7, 8]; therefore, the present paper attempts to valorise *S. sodomaeum* in relation to its contents of fatty acids and essential oil. According to our bibliographic investigation, the current study could be the first report on the variation of the fatty acid and essential oil compositions of *S. sodomaeum* fruits according to the maturation stage, as well as evaluation of the antibacterial properties of the essential oil and the antioxidant properties of both essential and vegetal oils.

MATERIAL AND METHODS

Plant material

S. sodomaeum fruits were arbitrarily harvested from several individual plants in Borj-Cédria (Hammam-Lif, northeast of Tunisia, 36°3′48″N, 0°21′0″E) in the months of January and February 2012. Samples were collected at two phases of maturation on the basis of their colour. Full green fruits represented the immature stage and yellow ones, the mature stage. The harvested *S. sodomaeum* fruits were freeze-dried, powdered by using an electric mill and were preserved in a desiccator at ambient temperature (25°C) in darkness. A voucher specimen was stored at the Herbarium of the Laboratory of Aromatic and Medicinal Plants at the Centre of Biotechnology of Borj-Cédria (Hammam-Lif, Tunisia) under the number SS-2012-07.

Extraction and analysis of fatty acids

By using the slightly modified procedure of Bligh and Dyer [8], lipids of triplicate sub-samples (1 g) of *S. sodomaeum* fruits were extracted. Briefly, samples were kept in boiling water for 5 min, then ground with a mixture of chloroform-methanol-hexane

(2:1:1, v/v/v) and washed using the fixing water. The organic layer including lipids was recovered and dried using a nitrogen stream. Total fatty acids (TFAs) were trans-methylated by using sodium methylate solution (3%) according to the procedure of Cecchi *et al.* [9]. Methyl heptadecanoate (C17:0) was used as an internal standard.

The resulting fatty acid methyl esters (FAMEs) were analysed using a Hewlett-Packard (HP) 6890 gas chromatograph series II (Agilent Technologies, Palo Alto, CA, USA) supplied with a flame ionisation detector (FID) and an electronic pressure control (EPC) injector. Separation of individual constituents was made by using a polar HP INNOWax capillary column (30 m × 0.25 mm, coated with polyethylene glycol film of 0.25 μm thickness; Hewlett-Packard, Palo Alto, CA, USA). The temperature of the oven was set at 150°C for 1 min, elevated to 200°C at the rate of 15°C/min, maintained for 3 min and finally increased to 242°C at a rate of 2°C/min. The carrier gas was nitrogen with a flow rate of 1.5 ml/min, and the split ratio was 60:1. Temperatures were set at 250°C and 275°C for the injector and detector, respectively. Identification of FAMEs was performed by comparing their retention times with those of the co-injected authentic standards.

Isolation and analysis of essential oil

Hydro-distillation of *S. sodomaeum* fruits (100 g) at each stage of maturation was made by using a Clevenger-type apparatus for 3 h. Essential oils were dried over anhydrous sodium sulphate and stored at 4°C until analysis.

An aliquot (0.5 μl) of each essential oil sample was analysed using gas chromatography–mass spectrometry (GC–MS). The GC analysis was performed by using a HP-5890 Series II instrument equipped with HP-INNOWax and HP-5 capillary columns (30 m × 0.25 mm, 0.25 μm film thickness for both). The temperature programme was as follows: the initial oven temperature was set at 60°C for 10 min, then raised to 220°C at the rate of 5°C/min. The temperatures of the injector and the detector were set at 250°C. Nitrogen was the carrier gas, with a flow rate of 2 ml/min, the detector was dual FID and the split ratio was 1:30. The FID peak area normalisation yielded the percentages of the essential oil constituents. GC–MS analyses were conducted using a Varian CP3800 gas chromatograph equipped with a HP-5 capillary column (30 m × 0.25 mm; coating thickness: 0.25 μm) and a Varian Saturn 2000 ion-trap mass spectrometer. The injector and transfer line temperatures were 220°C and 240°C, respectively. The temperature of the oven was raised from 60°C to 240°C at 3°C/min. Helium was the carrier gas, with a flow rate of 1 ml/min. The split ratio was 1:30. The essential oil constituents were identified by comparison of their retention times with those of authentic samples, by comparing their linear indices relative to a series of n-hydrocarbons and by computer conformity with commercial standards (National Institute of Standards and Technology, 1999). In addition, identification was achieved using a homemade library of mass spectra built up from pure substances and components of known oils and mass spectra literature data [10-11]. Furthermore, GC–chemical ionisation MS (CIMS) permitted the confirmation of molecular weights of all identified substances, using methanol as CI ionizing gas.

Screening of antibacterial activity

The disc diffusion method was adopted to evaluate the antibacterial activity [13] against several human pathogenic bacteria, namely, *Bacillus cereus* ATCC 10876, methicillin-resistant *Staphylococcus aureus* ATCC 25922, *Listeria monocytogenes* ATCC 15313, *Salmonella* DMS 560 and *Pseudomonas aeruginos*a ATCC 27853. All bacteria were grown on Mueller–Hinton plate at 30°C for 18–24 h before inoculation into the nutrient agar. A loop of bacteria from the agar slant stock was cultivated in nutrient broth overnight; a sample of this culture was streaked with a sterile cotton swab onto Petri dishes containing 10 ml of API suspension medium and adjusted to the 0.5 McFarland turbidity standards with a Densimat (BioMerieux). Sterile filter paper discs (6 mm diameter) soaked in essential oils of *S. sodomaeum* fruits were put on the culture plates. After 1–2 h at 4°C, the treated Petri dishes were incubated at 25°C or 37°C for 18–24 h. Tetracycline was used as the positive control. The antimicrobial activity was assessed by measuring the diameter of the growth inhibition zone surrounding the discs. Triplicates of each experiment were performed.

1,1-Diphenyl-2-picryl-hydrazyl radical (DPPH•)-scavenging activity

The activity of *S. sodomaeum* samples against free radicals was evaluated according to the procedure of Hanato *et al.* [14]. Accordingly, 0.5 ml of a methanolic solution of DPPH (0.2 mM) was added to the essential oil and vegetal oil of *S. sodomaeum* fruits.

The mixture was incubated for 30 min at room temperature, and the absorbance was read against a blank at 517 nm; the positive control was butylated hydroxytoluene (BHT).

The equation adopted to assess the inhibition percentage (I%) of DPPH free radical was as follows:
$I\% = [(A_0 - A_1)/A_0] \times 100$,
where A_0 is the absorbance of the control and A_1 is the absorbance of the samples in the mixture.

Reducing power assay

The procedure proposed by Oyaizu [15] was used to evaluate the reducing power of *S. sodomaeum* samples. Thus, 1 ml of essential oil or vegetal oil was added to 2.5 ml of a solution of sodium phosphate buffer (0.2 M, pH 6.6) and a solution of potassium ferricyanide (2.5 ml of 1% solution). The mixture was incubated in a water bath at 50°C for 20 min. Subsequently, 2.5 ml of 10% trichloroacetic acid was added, and the mixture was submitted to centrifugation at 650 g for 10 min. Thereafter, 2.5 ml of distilled water and 0.5 ml of a solution of iron (III) chloride (0.1%) were mixed with 2.5 ml of supernatant. The absorbance was read at 700 nm, and vitamin C was adopted as the positive control.

Statistical analysis

Results were expressed as mean values ± standard deviation of triplicates. Differences between groups were analysed by analysis of variance (ANOVA) procedure, and significant ($p<0.05$) differences were evaluated according to Duncan's multiple-range test.

Ethical approval: The conducted research is not related to either human or animal use.

RESULTS AND DISCUSSION

Total lipids and fatty acid constituents

Total lipids and percentages of the identified fatty acids of *S. sodomaeum* fruits at the two phases of maturation are shown in Table 1. The level of total

Table 1.

Variations in total lipid contents and fatty acid compositions during the maturation process of *Solanum sodomaeum* fruits

Parameters	Maturation stage	
	Immature fruits	Mature fruits
Total lipid content [%, w/w]	12%	17%
C 12:0	0.48±0.31 a	0.46±0.12 a
C 14:0	1.32±0.56 a	0.86±0.35 a
C 16:0	21.96±1.60 a	15.63±1.17 b
C 16:1	0.34±0.01 a	0.42±0.02 a
C 18:0	33.32±11.19 a	14.45±4.84 b
C 18:1	5.06±2.07 b	11.69±1.75 a
C 18:2	34.017± 4.11 b	53.11±7.89 a
C 18:3	1.75±0.58 a	0.76±0.11 b
C 18:4	0.38±0.05	ND
C 20:0	1.01±0.24 a	0.54±0.18 b
C 20:1	0.26±0.07 a	0.64±0.60 a
C 22:0	0.44±0.03 b	1.09±0.26 a
C 22:1	0.33±0.13 b	0.53±0.13 a
Saturated fatty acids	58.52	33.03
Monounsaturated fatty acids	6.01	13.28
Polyunsaturated fatty acids	36.30	53.87

Compounds are listed in order of their elution in the HP-INNOWax column; values are represented as mean values ± standard deviation of three independent replicates (n=3); values followed by the same letter did not share significant differences at 5% (Duncan test); ND: not detected

oil reached 12% in the immature stage (green fruits) and then sharply increased to ~17% at the mature stage (yellow fruits). There are no investigations on the total lipid accumulation during the course of the maturation process of *S. sodomaeum*. Nevertheless, several researchers have focussed on the effect of the stage of maturation on the accumulation of lipids in diverse species. In accordance with our results, Glew et al. [16] demonstrated low accumulation of total lipids at an earlier stage of the development of date plum persimmon, while the level was enhanced quickly in the course of the last stage. The same behaviour was also observed in juçara (*Euterpe edulis* Martius) fruits [17] and *Rhus tripartitum* fruits [18].

To our knowledge, the current study is the first investigation on fatty acid accumulation in *S. sodomaeum* fruits. Totally, 13 fatty acids were determined in the vegetal oils. The fatty acid profiles were qualitatively similar, but they displayed significant (p<0.05) quantitative differences, in particular for the most abundant constituents, according to the maturation phase (tab. 1). In the immature phase, the vegetal oils of the *S. sodomaeum* fruit were defined by the preponderance of saturated fatty acids (SFA), with a level of 58.52% of TFAs. The latter fraction is mainly represented by stearic acid (C18:0; 33.32%) and palmitic acid (C16:0; 21.96%). In addition, linoleic acid (C18:2; 34.17%) was detected as one of the most abundant fatty acids in immature fruits, and it increased considerably to reach the level of 53.11% at the mature stage. Linoleic acid accumulation could be explained by the activity of the Δ12-desaturase, a membrane-bound enzyme, which ensures the desaturation of oleic to linoleic acid [19]. It is an essential fatty acid for humans, and it is preferentially used in industries for hydrogenation of oils [20]. In addition, *S. sodomaeum* fruits showed a more-than-twofold increase in the level of oleic acid (C18:1; 11.69%) and a significant (p<0.05) reduction in the contents of stearic (C18:0; 14.45%) and palmitic (C16:0; 15.63%) acids at the mature phase. The unsaturated fatty acid fraction was the most abundant fraction (67.15%) of the fruits' vegetal oil, in particular, polyunsaturated fatty acids (PUFAs) were highly represented (53.87%). It is worth noting that increased attention to PUFA as healthy components in the diet is due to their multiple benefits such as their role in relieving cardiovascular, inflammatory and heart disorders, atherosclerosis, autoimmune disease, diabetes and other health issues [21]. Furthermore, palmitic acid could cause several damages, such as oxidative DNA damage, human cell necrosis and apoptosis. These damages could be repressed by consuming – in parallel – other fatty acids, in particular PUFAs [22]. In regard to the context of the fatty acid contents, mature fruits seemed to be healthier since they contained higher percentages of PUFA and lower content of palmitic acid.

Essential oil composition

The essential oil yields of *S. sodomaeum* fruits ranged from 0.43% for immature fruits to 0.45% for mature fruits (v/w), and the differences in yield between the stages of maturation were not significant (p>0.05).

The composition of the essential oils of the *S. sodomaeum* fruits at two different maturation stages is illustrated in table 2. Thirty components were identified, with percentages of 99.61% and 95.10% of the total oil, respectively, for immature and mature fruits. The stage of immature fruits showed tetrahydronaphthalene (41.79%) as the major constituent of the essential oils. Considerable percentages of hexadecanoic acid (24.15%), dihydrocoumarin pentane (8.23%), tridecanone (3.61%) and 2-undecanone (2.69%) were also detected. Dihydrocoumarin pentane, hexadecanoic acid and 2-undecanone were found to be the most abundant components of essential oils of *S. sodomaeum* mature fruits, with the percentages of 18.27%, 17.43% and 13.20%, respectively.

On the whole, acenes were the most abundant chemical group at the immature stage (43.47%), and their percentages showed a substantial decrease at the mature stage (7.93%). Conversely, ketones (20.65%), aldehydes (9.32%), sesquiterpenes (5.12%), alcohols (10.28%) and esters (1.76%) were characterised by a significant (p<0.05) augmentation of their values at the mature phase.

It is worth noting that the ketone fraction, in particular, 2-undecanone and tridecanone, have been widely reported to be toxic for several arthropod pests [23]. Also, hexadecanoic acid, a monocarboxylic acid, contributes to the aromatic character of several plants. This acid has been evaluated for inducing resistance in crop plants, such as tomato, against *Botrytis cinerea* [24], and citrus, against the fungus *Alternaria alternata* [25]. Aldehydes are reported to be responsible of the floral and fruity aroma of citrus [26]. It must be taken into consideration that the components in lower amounts, such as α-pinene, β-pinene, D-limonene, camphene, p-cymene and β-thujone, contribute to the antifungal property of the essential oils, as previously demonstrated by Sacchetti *et al.* [27]. Additionally, the

Table 2

Variations in the essential oil composition [% total peak area] at the two stages of maturation of *Solanum sodomaeum* fruits

Components	IR	Immature fruits	Mature fruits
α-Pinene	935	0.54±0.13	ND
Camphene	951	0.40±0.08	ND
β-Pinene	980	ND	0.54±0.06
p-Cymene	1023	0.29±0.06	ND
D-Limonene	1027	1.11±0.13 b	1.39±0.16 a
2, 6-Dimethyl-5-heptenal	1053	1.39±0.52 b	3.83±1.03 a
2-Nonanone	1094	0.26±0.03	ND
β-Thujone	1107	0.73±0.14 a	0.57±0.29 a
Camphor	1142	0.66±0.12	ND
Decanal	1206	0.51±0.18 b	1.24±0.14 a
1-Decanol	1269	1.50±0.55 b	3.93±0.91 a
Undecanal	1290	0.73±0.24 b	1.88±0.31 a
2-Undecanone	1295	2.69±0.39 b	13.20±1.32 a
Carvacrol	1303	2.01±0.15 a	2.41±0.39 a
Dodecanal	1410	1.51±0.23	ND
Caryophyllene	1428	0.92±0.19 b	1.46±0.17 a
Pentadecanone	1454	0.83±0.20 b	2.55±0.15 a
Dihydrocoumarin pentane	1486	8.23±1.88 b	18.27±1.90 a
Tridecanone	1497	3.61±0.49 a	4.33±0.38 a
1-Tridecanol	1553	0.38±0.09 b	1.00±0.17 a
Z-3-Hexenyl benzoate	1564	0.50±0.13 b	1.76±0.18 a
Caryophyllene alcohol	1572	0.48±0.10 b	1.19±0.34 a
Humulene oxide	1607	1.00±0.11 b	2.19±0.47 a
Tetradecanal	1621	0.56±0.12 b	1.22±0.30 a
Pentadecanal	1719	ND	1.15±0.03
Trimethyl hexanol	1820	0.51±0.12 b	4.17±0.66 a
7,11,15-Trimethyl neophytadiene	1837	1.68±0.42 a	1.58±0.33 a
Cyclopropanaphthalene	1919	0.67±0.12 b	1.59±0.12 a
Tetrahydronaphthalene	1920	41.79±5.58 a	6.36±0.96 b
Hexadecanoic acid	1965	24.15±9.11 a	17.43±1.63 a
Total	99.61±1.46 a	95.10±5.33 a	
		Chemical classes [%]	
Acenes	–	43.47±5.84 a	7.93±0.78 b
Acids	–	24.15±9.11 a	17.43±1.63 a
Phenols	–	2.01±0.15 a	2.41±0.39 a
Ketones	–	8.78±0.79 b	20.65±2.06 a
Aldehydes	–	4.70±1.04 b	9.32±1.56 a
Monoterpenes	–	2.34±0.40 a	1.93±0.17 a
Sesquiterpenes	–	2.59±0.41 b	5.12±0.50 a
Alcohols	–	2.86±0.58 b	10.28±0.91 a
Esters	–	0.50±0.13 b	1.76±0.18 a
Others	–	8.23±1.88 b	18.27±1.90 a

Compounds are listed in the order of their elution on a HP-INNOWax column; values followed by the same letter did not share significant differences at 5% (Duncan test); ND: not detected; values are represented as mean values ± standard deviation of three independent replicates.

minor components might contribute to some type of synergism with other different bioactive components [28].

According to our bibliographic investigation, there is no previous survey on the variation of the chemical composition of essential oils of *S. sodomaeum* during fruit maturation. Nevertheless, such studies have been undertaken for several medicinal and aromatic plants, which showed significant changes in the composition of the oils according to the maturation phase. These changes could be due to variations in climatic conditions, such as temperature, relative humidity, sunshine hours and precipitations [29], and may be associated with metabolic changes that precede the process of and prepare the fruit for maturation.

Antioxidant activity

The evaluation of the total antioxidant property of *S. sodomaeum* fruits cannot be estimated by using a single method, because of the variety of phytochemicals and the related chemical moieties [30]. So, in the present study, two methods – including DPPH test and reducing power assay – were used to assess the antioxidant activity of the essential oil and vegetal oil of immature and mature fruits.

Results of the DPPH radical scavenging and reducing power tests are given in Figure 1. As shown in Figure 1a, the oils of *S. sodomaeum* fruits at the two maturation phases revealed much lower capacity to reduce the DPPH radical to the yellow-coloured diphenylpicrylhydrazine, as compared with BHT (IC_{50} = 10.77 μg/ml). The best activities were observed for the essential oils with no significant differences (p>0.05) in levels between the immature (IC_{50} = 6.73 mg/ml) and mature (IC_{50} = 6.71 mg/ml) stages of the fruits. Lower DPPH-scavenging activities were detected for vegetal oils in the immature (IC_{50} = 28.50 mg/ml) and mature (IC_{50} = 28.47 mg/ml) phases of the fruits.

Reducing power is evaluated based on the measurement of the conversion of ferric iron (Fe3þ) to ferrous iron (Fe2þ) in the presence of antioxidants [31]. Contrary to results obtained for the DPPH assay (fig. 1b), the reducing power test showed higher antioxidant activity for vegetal oils with significant differences (p<0.05) in levels between the two stages of fruit maturation. The immature fruits (EC_{50}=3.75 mg/ml) revealed better reducing power compared with the mature ones (EC_{50}=16.93 mg/ml) and vitamin C (EC_{50}=8.33 mg/ml).

Previous investigations have suggested that there is an association between chemical composition and antioxidant activity. In accordance with the study by Hazzit *et al.* [33], the antioxidant capacity of essential oils could be ascribed to the phenolic components in plant oils, particularly thymol and/or carvacrol. In coherence with the current study, the

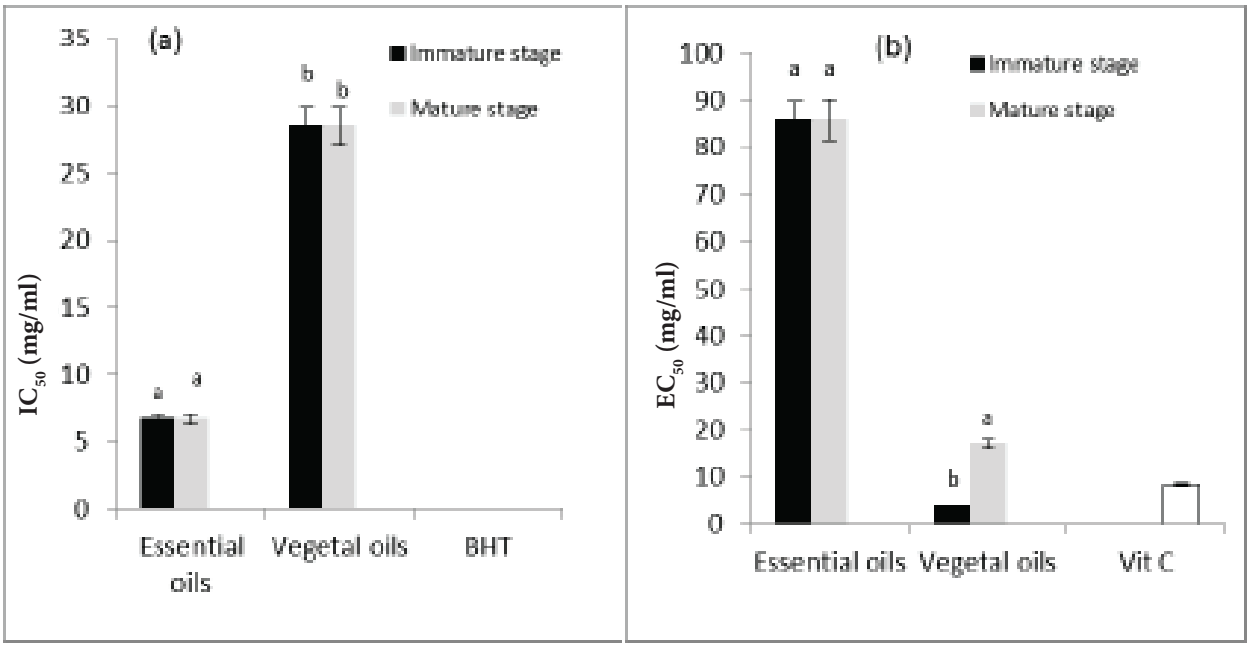

Figure 1.

Antioxidant activity measured by the DPPH scavenging (a) and reducing power (b) assays at the immature and mature fruit stages. Data are represented as mean values ± standard deviation of three independent replicates. Bars sharing the same small letter did not share significant differences at p<0.05 (Duncan test)

moderate antioxidant capacity could be due to the low amounts of phenolic and terpenic compounds. However, it is worth noting that the antioxidant activity of the essential oils is not ascribed exclusively to the highly represented compounds and minor ones also could be implied in the total antioxidant activity; moreover, synergistic effects have also been described [33]. In addition, previous investigations have demonstrated that the antioxidant capacities of vegetal oils could be attributed in most part to PUFAs, tocopherols and phenolics [34, 35].

According to our bibliographic research, there is no previous investigation available regarding the antioxidant activities of *S. sodomaeum* essential oil and vegetal oil with respect to fruit maturation stages.

Antibacterial activity

Several essential oils and extracts from various plant species have been shown to be capable of inhibiting microorganisms in the contexts of skin infection, dental caries and food spoilage. The antimicrobial capacity of most essential oils or plant extracts is substantially less effective than that of synthetic antibiotics. However, they have diverse modes of action and, therefore, may be able to combat the resistant strains of microorganisms [36].

Results of the antibacterial activity analysis of the essential oils of *S. sodomaeum* fruits at two maturation phases against three Gram-positive bacteria (*B. cereus, L. monocytogenes* and *S. aureus*) and two Gram-negative bacteria (*P. aeruginosa* and *Salmonella* DMS 560) are illustrated in table 3.

The essential oil of immature fruits showed inhibitory activity against *Salmonella* (2.5 mm) which was lower by more than ten times than the activity of the control tetracycline (27.0 mm). The essential oil of mature fruits was more efficient than that of immature ones, since the growth inhibition of *P. aeruginosa, B. cereus, L. monocytogenes* and *S. aureus* was only observed for the oils extracted at the mature phase. Moreover, it is worth noting that the Gram-positive bacteria were more sensitive than Gram-negative ones to the essential oils (tab. 3). Previously, some investigations have demonstrated that Gram-negative bacteria were resistant to the effects of essential oil and its constituents [37]. The resistance has been ascribed to the existence of cell wall lipopolysaccharides that can screen out the essential oil [38].

Essential oils are a mixture of a variety of major and minor chemical components. Along with major components, previous investigations have reported that the less representative components and a potential interaction between the constituents could also influence the antimicrobial activities [37].

Results of the current study support the use of essential oils from the mature fruits of *S. sodomaeum* in the treatment of diseases caused by the tested bacteria, because of the natural origin of the remedy, the safety for the consumers and the low risk of development of resistance by pathogenic microorganisms [39].

CONCLUSION

The overall results permitted the valorisation of *S. sodomaeum* fruits for their antioxidant and antibacterial properties, which might lead to their potential use as nutraceuticals and agro-food supplements.

Conflict of interest: Authors declare no conflict of interest.

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Table 3

Antibacterial activity of essential oils of *Solanum sodomaeum* fruits against three Gram-positive and two Gram-negative bacteria

Bacteria species	Maturation stage		
	Immature	Mature	Tetracycline
Pseudomonas aeruginosa	-	8.5±1.0	23.0
Salmonella DMS 560	2.5±1.0	7.5±1.0	27.0
Bacillus cereus	-	16.0±2.0	22.0
Listeria monocytogenes	-	18.5±1.0	36.0
Staphyloccun aureus ATCC 25922	-	20.5±1.0	35.0

(–) absence of activity; the diameter of inhibition is measured in millimetres; experiments were done in triplicate.

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