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Lavanta İçin Yeni Bir Teknolojik Uygulama Alanı ve Tarımsal Üreticiler İçin Ekonomik Kar Analizi

Ayca Nur SAHIN DEMIREL[1*], Fatmagul BAGI[2], Bunyamin YILDIRIM[2], and Serkan DEMIREL[3]

Öne Çıkanlar:

- Lavanta esansiyel yağları (LEO'lar) kondansatör elektroliti olarak kullanılabilir
- LEO'lar 4 Volt' a kadar çalışabilir
- LEO elektrolit yıllık karı ~23697 USD olarak hesaplanmıştır
- LEO elektrolitleri enerji depolama sistemlerine uygulanabilir

Anahtar Kelimeler:

- Tarım Ekonomisi
- Kapasitör
- Elektrolit
- Enerji Depolama
- Lavanta

ÖZET:

Enerji ve tarım sektörlerinin finansal verimlilik için birleştiği günümüzde, "tarımda kullanılan elektrik enerjisi bir tarım ürünü ile depolanabilir mi?" sorusunu akıllara getirmiştir. Bu çalışmada, enerji depolama sisteminin bir parçası olarak *Lavandula angustifolia*'dan elde edilen lavanta esansiyel yağı kullanılmıştır. Uçucu yağ damıtma yöntemiyle üretilmiştir. Enerji depolama performans analizi için platin folyolar ve lavanta esansiyel yağı ile basit elektrokimyasal kondansatör oluşturulmuştur. Kondansatör uygulama performansları, lavanta esansiyel yağının 4 Volt'a (V) kadar enerji depolayabildiğini göstermiştir. Lavanta esansiyel yağı ile 0-4 V aralığında 92 mili-Farad/cm^2 (mF/cm^2) kapasite elde edilmiş ve bu değer lavanta esansiyel yağının kapasitörlerde elektrolit malzemesi olarak kullanılabileceğini göstermiştir. Sonuçlar tarım ekonomisi açısından değerlendirildiğinde dekara 1 ton lavanta bitkisi üretimi ile 1 cm^2 büyüklüğünde 1 milyon kapasitör üretilebilmektedir. Ayrıca lavanta kondansatörler ile 1000 hektarlık bir çiftlik için gereken enerji miktarı 10 cm^2'lik 1000 kondansatör ile depolanabilmektedir. Ayrıca, depolanan enerji, çiftliğin yıllık enerji tüketiminden daha fazladır ve çiftliğin enerji maliyetlerinde yılda ~534 USD tasarruf sağlar. Çiftlik enerjisinin tamamının yenilenebilir enerji kaynakları ile üretilmesi durumunda yıllık kar ~23697 USD olarak hesaplanmıştır. Ayrıca, lavanta esansiyel yağının elektrokimyasal kapasitör elektrolit özelliğinin araştırılması, tarım üreticileri için alternatif bir satış sahası oluşturabilir.

A New Technological Application Field for Lavender and Economic Profit Analysis for Agricultural Producers

Highlights:

- Lavender essential oils (LEOs) can be used as capacitor electrolyte
- LEOs can be work up to 4 Voltages
- LEOs electrolyte annual profit is calculated as ~23697 USD
- LEO electrolytes can be applied energy storage systems

Keywords:

- Agriculture economy
- Capacitor
- Electrolyte
- Energy storage
- Lavender

ABSTRACT:

Nowadays, the energy and agriculture sectors are united for financial efficiency, and it brought the question to minds "can be stored the electrical energy that used in agriculture with an agricultural product?". In this study, lavender essential oil, it obtained from *Lavandula angustifolia*, was used as a part of energy storage system. The essential oil was produced by distillation method. To energy storage performance analysis, the simple electrochemical capacitor was formed with platin foils and lavender essential oil. The capacitor application performances showed that the lavender essential oil can energy storage up to 4 Voltages (V). A capacity of 92 milli-Farad per cm2 (mF/cm^2) was obtained with Lavender essential oil in the range of 0-4 V, and this value showed that lavender essential oil can be used in capacitors, as an electrolyte material. The results when evaluated in terms of agricultural economics, 1 million capacitors with a size of 1 cm^2 can be produced with 1 ton lavender crops production per decare. Moreover, with lavender capacitors, the amount of energy required for a farm of 1000 hectares can be stored with 1000 capacitors of 10 cm^2. Also, the stored energy is more than the farm's annual energy consumption, saving the farm ~534 USD annually on energy costs. In the case that all farm energy is produced with renewable energy sources, the annual profit is calculated as ~23697 USD. Also, the exploring of electrochemical capacitor electrolyte property of lavender essential oil could create an alternative sales pitch for agricultural producers.

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INTRODUCTION

In agriculture, using renewable energy instead of fossil sources, which is one of the essential input costs for producers, has gained importance in recent years (Usman and Makhdum, 2021; Tomasz et al., 2021). The produced energy by utilizing renewable energy sources such as biomass, solar, wind, hydroelectric and geothermal energy; it meets the energy needs of many systems such as drying and irrigation of agricultural products, heating, lighting, and ventilation of greenhouses (Aroonsrimorakot et al., 2021; Babu et al., 2021; Gorjian et al., 2021). It is essential to store the produced energy from such renewable energy sources to make it more efficient for energy usage.

Batteries and capacitors, which can be used in almost every technological field today, store the produced energy electrochemically, enabling it to be used at different times (David et al., 2021; Oliveria et al., 2021). The efficient use of energy by batteries and capacitors created the idea of bringing together the fields of agriculture and energy storage in a typical study. In particular, using an agricultural product as an energy storage system material may provide cost benefits for the agriculture and energy sectors. Of course, for such a multidisciplinary study, agricultural products must be usable material forms for energy storage cells. For example, products such as coconut, walnuts, and hazelnuts can be carbonized and used as electrodes in powder form (Javed et al.,2021; Kucuk et al., 2021; Wang et al., 2021). The other products are similarly carbonized and have the potential to be used in energy storage systems in powder form. Nevertheless, can the energy be stored with different contents of products (permanent oil, essential oil, pulp, etc.) without carbonization?

The essential oils can be produced by subjecting many products such as Teatree, Jasmine, Peppermint, Cormint, and Lemon to various processes. Among these products, the Lavender plant, whose essential oil can be extracted, is one of the most preferred products as a perfume in cosmetics, disease treatment, cleaning, and disinfection, especially with its high linalyl acetate and linalool content. The lavender (*Lavandula spp.*) is a perennial and semi-shrub plant belonging to the Lamiaceae family (Guenther, 1952). Although it is not selective regarding soil demand, it develops better in light soils rich in plant nutrients. It is a Mediterranean climate plant that loves light and heat. It is an evergreen medicinal and aromatic plant with purple flowers and a height of up to 1 meter. Lavender flowers have at least 1-4% essential oil content (Ceylan et al., 1988). This rate varies according to growing conditions and species. There are three lavender species of commercial importance in the world. These are *Lavandula Angustifolia*, *Lavandula x Intermedia* and *Lavandula Spica*. The highest quality lavender oil is obtained from *Lavandula Angustifolia*, known as "English Lavender" (Beetham and Entwistle, 1982).

The fact that the essential oils of lavender flowers can be quickly produced, that its cultivation in agricultural production does not require much effort and financial investment and that the most important factor is healthy and not harmful to the environment has revealed the idea of testing lavender essential oil in different technological fields (Guenther, 1952).

In order to make a difference, this study is aimed to use the essential oil, which can be obtained from herbal products, in energy storage systems. In this context, the lavender plant, which is used to produce the most popular essential oil, was chosen. The essential oil produced using lavender (*Lavandula Angustifolia*), the highest quality essential oil produced, was used as the electrolyte material of the energy storage system. The capacitors created with lavender essential oil were tested up to 4 Voltages (V) level, and their economic contribution to farms was examined. The results have shown that more electrical energy than the energy requirement may be provided with lavender energy storage systems for 1000-ha areas of crops farm.

MATERIALS AND METHODS

Energy Consumption and Energy Cost Determinations

In this study, the data from websites which are secondary sources were used to determine the tools and machines that may be operated by the capacitors produced with lavender essential oil. Also, to give a more realistic result, the electrical energy consumption data is used for an agricultural farm (Fuchs et al., 2021). The energy consumption detected for a 1000 ha agricultural farm is based on lighting, high-pressure cleaning equipment, fuel station, electric welding machines, computer, electric tractor and hydraulic machines, and drying fan energy usage amounts. The daily energy consumed for these types of equipment is calculated as 245.8 kWh (Fuchs et al., 2021). For calculating energy costs in the economic modeling part of the study, the UK 2021 March household electricity consumption price is taken as a basis (Anonymous, 2021). According to the data of March 2021, the cost of 1 kWh of electricity was determined as 0.265 USD.

Obtaining Lavender Essential Oil

Lavenders (*Lavandula angustifolia*) used in experimental studies were obtained from the scientific landscape area of Igdir University. The distillation method was used to obtain essential oil from the dried lavender. Distillation separates two or more liquid components from a mixture based on the boiling point difference (Figure 1-a) (Kiss, 2014). For the distillation process, 100 g of dried and stemmed lavender was placed in a glass balloon. The lavenders were placed in the Clevenger system by adding 1 lt of distilled water. Afterward, the boiling process was carried out during 30-45 minutes. At the end of this process, the water and oil collected in the capillary tube are separated by the density difference. In the last section, the lavender essential oil is transferred to the Eppendorf tube by flowing through a valve.

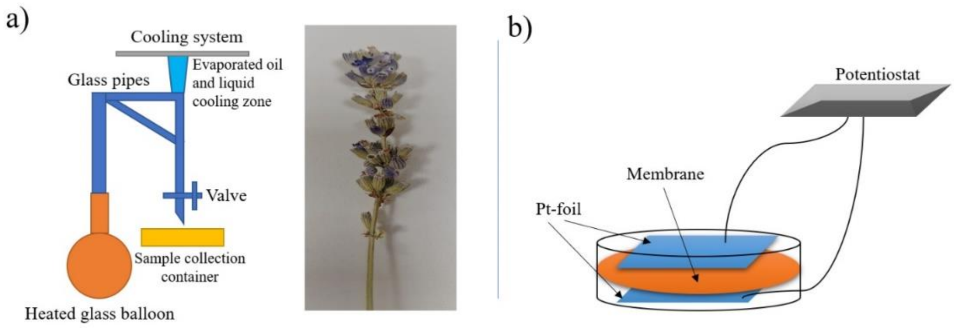

Figure 1. a) Distillation method schematics and dried lavender, b) Simple capacitor cell schematics

Energy Storage Feature Investigation

The lavender essential oil has been studied as an electrolyte material in capacitor applications. Two same 2x2 cm2 sized Platinum (Pt) foils were used as electrodes forming the positive (+) and negative (–) poles in the capacitor cell construction (Figure 1-b). A cellulosic paper membrane was placed between the platinum foils to prevent possible short-circuiting caused by the lavender essential oil. In the creation of this cell, the first platinum foil was placed inside the cell, and 0.5g of lavender essential oil was dropped on the platinum foil. The paper membrane was then placed on the first Pt-foil. After, 0.5g of Lavender essential oil was dropped on the paper membrane, and the second Pt-foil was placed on the paper membrane. Gamry 1010-E model potentiostat/galvanostat was used for energy storage measurements. In order to determine the energy storage feature, cyclic voltammetry (CV) measurements were made. The CV measurements were made at constant scanning rates of 200, 400, and 800 mV/s. The charge-discharge measurements were made 100 times with a constant scanning speed of 400 mV/s in the ranges of 0-0.5 V, 0-1 V, 0-2 V, and 0-4 V. After the obtained current values in these voltage ranges, the energy storage capacity was revealed of the simple capacitor formed with lavender essential oil by calculation as in literature (Cicek and Demirel, 2021; Demirel et al., 2023).

RESULTS AND DISCUSSION

The Energy Storage Performance Analysis

Figure 2 shows the first charge-discharge performances of capacitors. The initial charge-discharge capacitance values and capacitance patterns show similar behaviors for the 0-0.5V, 0-1V, 0-2V, and 0-4V ranges. Under normal conditions, the capacitors are called "Supercapacitors" when they have a capacitance above the Farad level. In addition, it is known that supercapacitors are used in power systems of high-performance electric vehicles in today's technology. In this context, when the first charge-discharge capacity values are analyzed, 25 mF/cm2 charge and 16 mF/cm2 discharge capacitance for the 0-0.5V range; 28 mF/cm2 charge, 23 mF/cm2 discharge capacitance for 0-1V range; 47 mF/cm2 charge, 40 mF/cm2 discharge capacitance for 0-2V range; for the 0-4V range, 92 mF/cm2 charge and 79 mF/cm2 discharge capacitance was obtained.

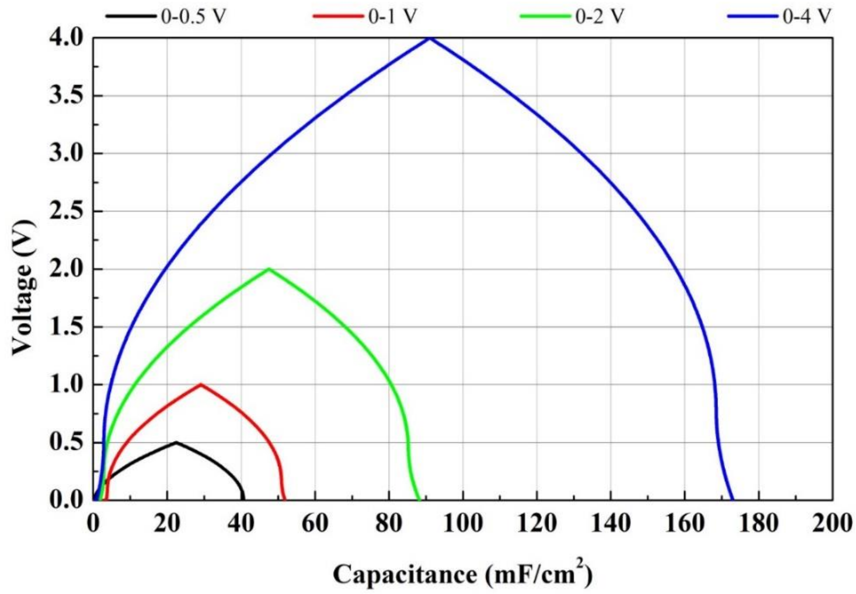

Figure 2. First charge-discharge performances of the lavender essential oil

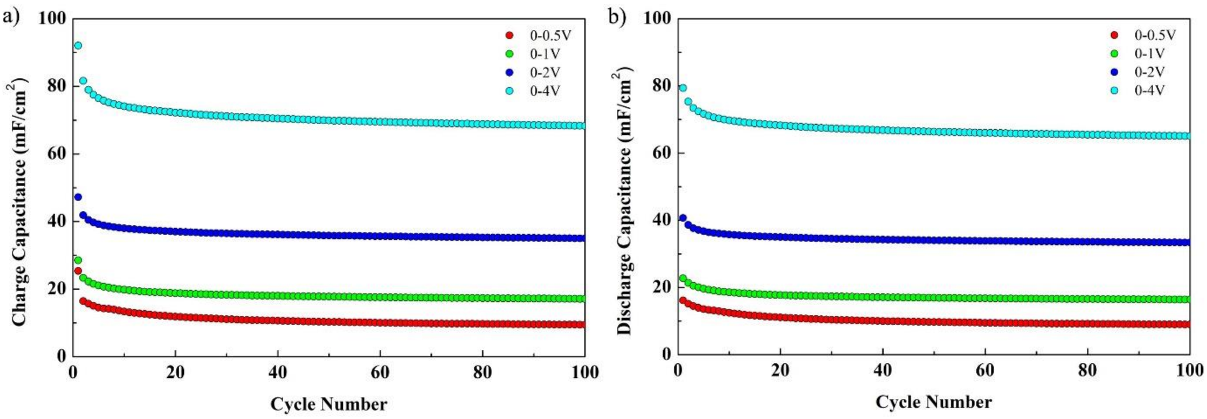

Figure 3. Cycle-life performances of Lavender electrolyte a) charge capacitance b) discharge capacitance

Figures 3-a and b show the charge and discharge capacitance characteristics during 100 charge-discharge cycles. It was determined that while there was a slight decrease in capacitance values in the first 3 cycles for all voltages, the lavender essential oil exhibited a stable energy storage behavior in the ongoing cycles. This stable behavior indicates that lavender oil has a characteristic capacitor feature.

This shows that the capacitors produced with lavender essential oil can be operated stably over long cycles. It is an electrolyte material used for industrial and technological applications.

Table-1 compares the lavender essential oil with an aqueous NaCl electrolyte used as an electrolyte under conditions like our study. Because the NaCl electrolyte is aqueous (water-based), which works in similar operating voltage ranges with Lavender, the maximum voltage it can operate at is ~1.7 V. At the same time, it has been determined that Lavender has a very superior performance in 0-1 V range comparisons. Moreover, with Lavender essential oil capacitors, operation in the 0-4 V range can be successfully achieved during long cycles.

Table 1. Comparison of aqueous NaCl electrolyte with the similar experimental environment with our study

Electrolyte	Capacitance (mF/cm^2)	Working Potential (V)	Reference
NaCl	0.11	0-0.3	(Fujii et al., 2010)
	0.14	0-0.5	
	0.35	0-1	
Lavender Essential Oil	25	0-0.5	This Study
	28	0-1	
	47	0-2	
	92	0-4	

As a result of the comparison made in Table-1, it has been determined that the capacitive performance of the lavender essential oil electrolyte is at reasonable levels, and it can operate in a higher operating potential range as many toxic and environmentally harmful electrolytes. In addition, the literature studies have shown that capacitive performance can be increased by changing the electrode materials used in capacitors. This indicates that primarily if the lavender essential oil is used with different types of electrodes (activated carbon, MnO2, NiO, etc.), it may also show supercapacitor electrolyte propert (Shi and Zhitomirsky, 2005; Chu et al., 2016; Liu et al., 2017).

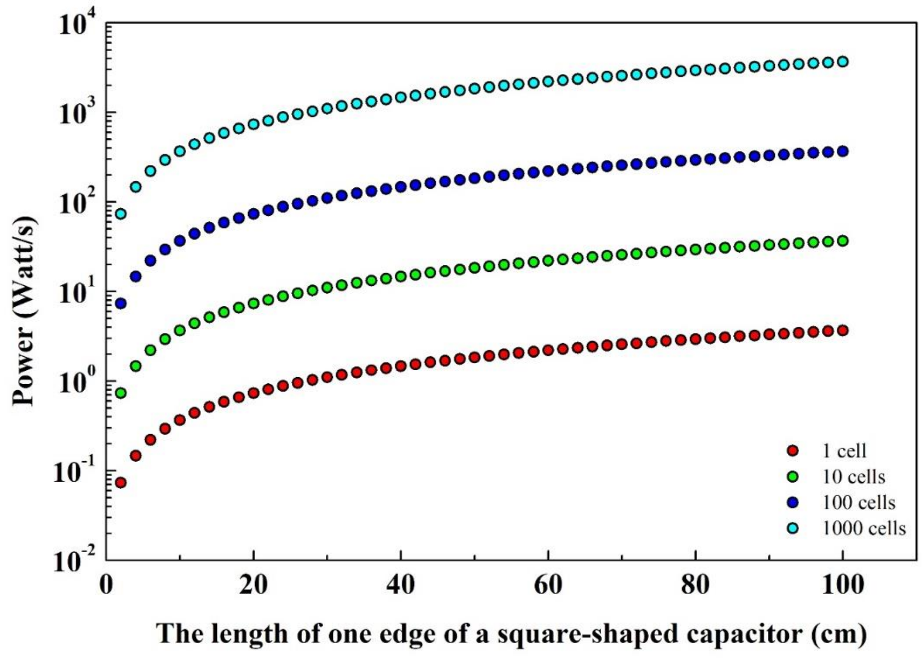

Figure 4. Possible amounts of power that can be obtained based on capacitor sizes and numbers.

As a result of the potential power amount calculations that the capacitors produced with lavender essential oil can have, a power of 0.736 W/s is obtained with a single 2 cm2 capacitor in the 0-4 V range (Figure 4). In this case, it has been determined that a possible power amount of up to 36.8 kW/s can be obtained by increasing the capacitor sizes and the number of capacitors connected in parallel. Also, the lavender capacitors can benefit from electric tools in agriculture, which are explained in detail in the "Agricultural Economics Benefits" section with examples.

Agricultural Economics Benefit and An Economic Model Developments

Economic benefits of lavender energy storage system usage

Lavender essential oil is among the fifteen most produced essential oils in the world, and it is a source of annual essential oil exports and imports of approximately 2 billion dollars worldwide (Yilmaz, 2018; Malloggi et al., 2022). Proving the use of lavender essential oil in energy storage systems creates a new export area for lavender producers outside of the ordinary. However, the question that comes to mind is how much lavender essential oil can be produced from the flower. Although the oil extraction processes are carried out with different methods, the amount of oil that can be obtained from a lavender plant is within certain limits. An average of 2.5 to 3 grams of essential oil can be produced from 100 grams of lavender flowers, both in our study and the literature (Kara and Baydar, 2013; Sönmez and Okkaoğlu, 2019). Especially in our study, this level was measured as 2.78 g. So, "will this amount of essential oil be suitable for energy storage systems?"

For each capacitor produced, an average of 0.5g of Lavender essential oil was used as an electrolyte. 0.25g Lavender oil will be used for a 1 cm2-sized capacitor when evaluating the size of capacitors and electrolyte amounts. In this case, if 2.5g of high-purity essential oil is assumed to be extracted from 100g of lavender flowers, 10 pieces of 1 cm2 capacitors can be quickly produced. It will be possible to produce 100 pieces of 1 cm2 capacitors using 1kg of lavender flowers. When this situation is analyzed in terms of the agricultural economy, 1 ton of lavender per decare means an average of 250 kg of lavender essential oil production. This means 1 million capacitors can be produced per decare.

According to our study, the stored electrical power with lavender essential oil will be able to operate electric agricultural tools such as electric saws, agricultural spraying drones, wood cutting, hoes, etc. However, depending on the parameters used in the Figure 4 calculation, it may need to be corrected to comment on how long these instruments can be operated in practice because these tools' energy consumption may differ in actual agricultural field application conditions. This situation shows that many electrical tools used in agriculture can be operated with lavender, an agricultural product in general.

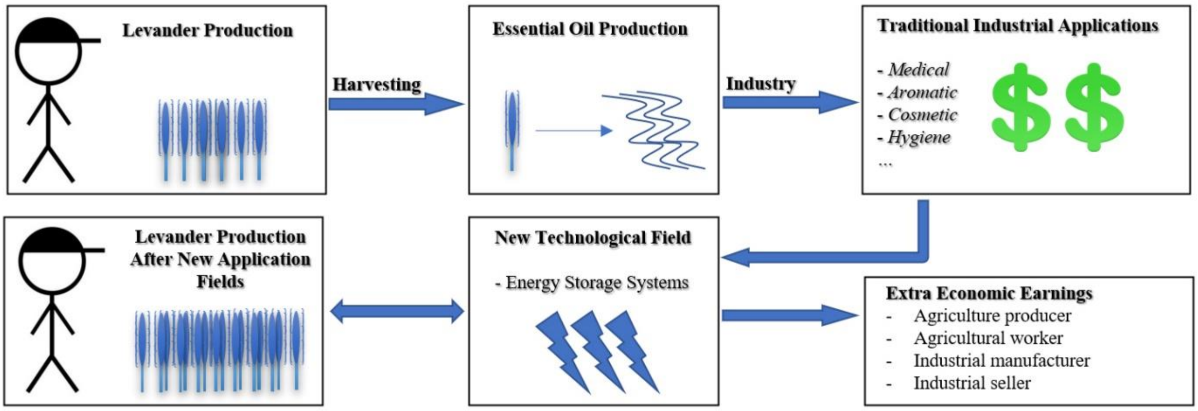

Figure 5. Potential benefit schematics of lavender essential oil using in energy storage systems

Figure 5 shows a simple economic benefit schematic of lavender essential oil depending on the industrial application fields in today's conditions. Lavender essential oil, which is used in such as medical, aromatic, cosmetic, etc., if it is an alternative product for energy storage systems, it will increase the production of lavender in agriculture, and it will provide extra income to agricultural producers, agricultural workers, industrial producers, and sellers. If we make a general analysis of agricultural economics, the emergence of alternative use of lavender essential oil for the producer in terms of lavender cultivation shows that material profit may increase in an area with a future and high financial gain such as energy.

Economic model development

The 1000 capacitor cells of 10 cm2 sized can be stored at 368 W/s power. This means 13.24 kWh of energy storage when calculated in kWh type. This shows that 317.76 kWh of energy can be stored and used daily. In the study of Fuchs *et al*. (2021), the maximum system power needed for a farm with an area of 1000 ha (only planting and harvesting plants) was determined as ~245 kWh. This situation shows that supercapacitors with lavender essential oil can meet all the energy needs for a 1000-ha area. Depending on the energy expenditures, daily and annual profit calculations are calculated with the formulas given below.

$$E_{efd} = \frac{EC_d}{ES_d} \tag{3}$$

$$E_{yefd} = 365\ x\ \frac{EC_d}{ES_d} \tag{4}$$

$$ES_y = \frac{E_{yefd}\ x\ 100}{365} \tag{5}$$

$$ESC_y = (365 - E_{yefd})\ x\ (24\ x\ EC_c) \tag{6}$$

Here, Eefd is the energy efficiency by day (kWh/d), Eyef is the annual energy efficiency (days), ESd is the daily stored energy (kWh), ECd is the daily energy consumption (kWh), ESy is the annual yield of stored energy (%), ESCy is the annual profit amount (USD), ECc is the energy consumption cost per kWh (USD). According to these calculations, the amount of energy for 365 days can be stored in 281 days. In other words, obtaining an 84-day profit from the annual energy is possible. 84-day profit when the kWh cost is taken as 0.265 dollars from the equation (4), provides a total profit of 534.24 USD (Anonymous, 2021). Of course, this profit can be increased by changing the size of the capacitors and the types of electrodes used (as higher capacitance can be obtained).

On the other hand, depending on the calculations above, how much of the lavender harvest and how much essential oil production will generate the income,

$$EOA_{sc} = CS\ x\ EOC_{po} \tag{7}$$

$$EOA_{hc} = EOA_{sc}\ x\ 100 \tag{8}$$

$$EOE_{pg} = \frac{ESC_y}{EOA_{hc}} \tag{9}$$

$$EOP_{ph} = \frac{EOA_{hc}\ x\ 100}{2.6} \tag{10}$$

$$EOP_{na} = 1_{(ha)} x \frac{EOP_{ph}}{2000} \tag{11}$$

calculated using these formulas. In these calculations, EOAsc is the amount of essential oil to be used for a single capacitor; CS; capacitor size, EOCpo is the essential oil used for 1 cm2 (0.025 g), EOAhc is the amount of essential oil to be used for 1000 ha area (per 1000 capacitors), EOEpg is the profit from essential oil use per gram (dollar), EOPph is the amount of lavender to be produced for the amount of essential oil to be used for 1000 ha area (kg), EOPna is the amount of agricultural land required for the amount of lavender to be produced (ha).

When the EOPna is calculated based on the 2000 kg lavender production yield per 1 ha as a result of the processes, the lavender essential oil will be produced at a level that will meet the total energy needs of the 1000 ha agricultural land of the 1.5 ha lavender production. This amount will also cause the agricultural producer to provide a profit of ~534 USD. Moreover, when the calculations are made, a profit of 0.83 USD per gram can be obtained with lavender essential oil. If the energy to be used in the farm is met with renewable energy sources (solar energy, biomass, wind energy, etc.), the annual profit will be ~23697 USD. Considering this situation per lavender essential oil, a profit of ~37 USD per gram can be obtained.

CONCLUSION

The lavender essential oil, used in many different areas, has been successfully produced by the distillation method. Produced lavender essential oil was used in energy storage cells for the first time in the literature. The simple capacitor form was formed with Pt-foils, and the lavender essential oil was added as a capacitor electrolyte. It has been determined that lavender essential oil allows energy storage up to 4V. This showed that Lavender essential oil was superior to aqueous electrolytes. In terms of the agricultural economy, it has been determined that 1 million capacitors of 1 cm2 size can be produced with 1-ton lavender production per decare. Lavender essential oil energy storage systems will also cause the agricultural producer to provide a profit of ~534 USD yearly. Also, in the case of the renewable energy sources (solar energy, biomass, wind energy, etc.) used in the farms as 100% energy storage, the annual profit will be ~23697 USD for agricultural producers. Moreover, the electrochemical capacitor electrolyte property discovery for lavender essential oil could create an alternative sales pitch for agricultural producers. The fact that lavender essential oil is an alternative electrolyte material for capacitors promises significant economic developments for the energy sector and agricultural producers.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them

Author's Contributions

The authors confirm contribution to the paper as follows: study conception and design: A.N.. Sahin Demirel and Serkan Demirel; data collection: F. Bagı and S. Demirel; analysis and interpretation of results: A.N. Sahin Demirel, S. Demirel and B. Yıldırım; draft manuscript preparation: All authors. All authors reviewed the results and approved the final version of the manuscript.

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