Solar Drying of Lemongrass (*Cymbopogon citratus*) in Nepal

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Abstract

Lemongrass (*Cymbopogon citratus*) is an aromatic herb with widespread use in food, medicine and herbal tea production. In Nepal, post-harvest losses of agricultural products remain a significant challenge, and solar drying has been identified as a practical and economical preservation method for small-scale farmers. This thesis investigates how indirect solar drying affects selected quality parameters of lemongrass, including drying uniformity, antioxidant capacity, essential oil yield, microbiological safety, and sensory acceptability. Shade drying was included as a comparative reference method to evaluate the influence of different drying conditions, particularly temperature, on product quality.

The lemongrass was dried in an indirect solar dryer in Dhulikhel, Nepal, reaching temperatures of 40-45 °C and reducing moisture content from approximately 73% to 10% within 8-10 hours. Shade drying achieved a comparable moisture content over more than one week. Some variation in drying uniformity was observed, with the bottom tray of the right column consistently showing higher final moisture content, possibly due to differences in fan performance between the two columns of the dryer.

Antioxidant capacity, measured by DPPH assay, decreased slightly upon drying regardless of method, with solar and shade drying producing comparable results. Essential oil yield was approximately 70% lower in solar-dried leaves compared to fresh leaves, though considerable biological variation between batches limits the reliability of this finding. Both drying methods met WHO microbiological limits for herbal products, and no bacterial growth was detected in brewed tea under aerobic or anaerobic conditions. SEM analysis suggested that solar-dried samples potentially retained more intact glandular trichomes (the microscopic oil-storing structure on the leaf surface) than shade-dried samples. In the focus group, solar- and shade-dried teas were generally rated higher than commercially dried and fresh lemongrass teas for aroma and flavor by Nepalese participants, whereas no significant differences were observed among Swedish participants.

Overall, solar drying appears to be a promising method for processing lemongrass, preserving quality parameters at a level comparable to shade drying while offering a dramatically shorter drying time.

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Table of Contents

1. Introduction **1**

2. Aim and Objectives *2*

3. Background **3**

3.1. Nepal *3*
3.1.1. Nutrition in Nepal 3
3.1.2. Agriculture sector 4
3.1.3. Importance of Lemongrass in Nepal 4

3.2. Solar drying *4*
3.2.1. Heat Transfer & Moisture 5
3.2.2. Types of Solar Dryers 6

3.3. Lemongrass *7*
3.3.1. Traditional and Current Uses 8
3.3.2. Nutrition of Lemongrass 9
3.3.3. Essential Oil 9
3.3.4. Effect of Drying on Lemongrass 10
3.3.5. Quality and Safety 10

3.4. Antioxidants *11*
3.4.1. Antioxidant Capacity 11

4. Materials and Method **13**

4.1. Raw material *13*
4.1.1. Collection and Physical Characterization 13
4.1.2. Sanitation of the Lemongrass Leaves 14

4.2. Processing *14*
4.2.1 Solar Dryer 14
4.2.2. Shade Drying 17
4.2.3. Storage and Transportation 17

4.3. Analysis *17*
4.3.1. Moisture Content and Water Activity 17
4.3.2. Antioxidant Capacity 18
4.3.3. Oil extraction 19
4.3.4. Scanning Electron Microscopy 19
4.3.5. Sensory Evaluation 20
4.3.6 Microbial Evaluation 20

5. Results **22**

5.1. Solar Drying *22*
5.1.1. Initial Drying Experiment 22
5.1.2. Uniformity of the Solar Dryer 24

5.2. Shade Drying *29*

5.3. Moisture Content & Water Activity *30*
5.3.1. Moisture Content 30
5.3.2. Water Activity 30

5.4. Antioxidant Capacity *31*
5.5. Essential Oil Extraction *31*
5.6. SEM *32*
5.7. Sensory Evaluation *33*
5.7.1. Focus Group in Nepal 34
5.7.2. Focus Group in Sweden 35
5.8. Microbial Evaluation *36*
6. Discussion **37**
6.1. Solar Drying *37*
6.1.1. Uniformity of the Solar Dryer 37
6.1.2. Solar Drying vs Shade Drying 38
6.2. Antioxidant Capacity *38*
6.3. Oil Extraction *39*
6.4. SEM *39*
6.5. Sensory Evaluation *40*
6.5.1. Comparison between teas 40
6.5.2. Overall and Cultural differences 41
6.6. Microbial Evaluation *41*
7. Conclusion **43**
References **44**
Appendix **48**
A.1. Focus Group – Questions *48*
A.2. Solar Drying *48*
A.1.1. Drying rate 50
A.3. Antioxidant Analysis *50*
A.4. SEM *52*
A.5. Microbial Evaluation *53*

1. Introduction

Global food security is increasingly threatened by climate change and the growing frequency of natural disasters (NACCFL, 2025). Farmers worldwide are becoming more exposed to unpredictable weather patterns, which negatively affect crop yields and contribute to increasing post-harvest losses of agricultural products (Belessiotis & Delyannis, 2011).

Nepal is particularly vulnerable to these challenges. Agriculture is a central component of the Nepalese economy, accounting for approximately 34.2% of the national gross domestic product (GDP), while small-scale farming employs around 78% of the workforce (FAO, n.d.). Despite this dependence on agriculture, Nepal faces significant challenges with both post-harvest losses and malnutrition. Malnutrition among children under the age of five in Nepal exceeds global averages, highlighting the importance of improving food availability, quality, and preservation (WHO, 2024).

Solar drying has been identified as a practical and economical solution to reduce post-harvest losses, particularly for small- and medium-scale farmers in developing countries. While small-scale farmers in Nepal already use traditional direct sun drying methods, these are often inefficient and expose products to contamination and adverse weather conditions. Indirect solar dryers offers a more controlled and hygienic alternative, capable of achieving faster drying while better preserving product quality (Belessiotis & Delyannis, 2011).

This thesis is conducted within the framework of the SolarFood project, led by Ruralis and funded by the Research Council of Norway, which aims to develop inclusive business models for solar food drying in Nepal and Bhutan (Remøy, 2025). The present thesis contributes the food science and engineering perspective by investigating how solar drying affects the nutritional quality of lemongrass (*Cymbopogon citratus*). Specifically, the study examines drying uniformity within the solar dryer, and investigates changes in antioxidant capacity, essential oil content, and microbiological safety of lemongrass before and after solar drying conducted in Dhulikhel, Nepal.

The following research questions are going to be answered:

- Does the lemongrass dry uniformly within the solar dryer?
- How does the antioxidant capacity change during solar drying?
- How does solar drying affect the essential oil content of the lemongrass?
- Do the dried lemongrass and lemongrass tea meet acceptable microbiological standards for food safety?
- How do elevated temperatures of solar drying affect quality compared to shade drying as a low-temperature reference method?

2. Aim and Objectives

The general objective of this thesis is to evaluate the impact of solar drying on the nutritional, chemical, and microbiological quality of lemongrass (*Cymbopogon citratus*).

The specific objectives are:

- To evaluate drying uniformity in a solar dryer
- To analyze change in antioxidant capacity during drying
- To determine the effect of solar drying on essential oil content
- To assess microbiological safety of dried lemongrass and brewed tea
- To compare solar drying with shade drying

3. Background

3.1. Nepal

Nepal is a country located in South Asia, situated along the southern slopes of the Himalayan mountain range. It borders China to the north and India to the east, west, and south. The country covers an area of 147 000 square kilometers and has a population of approximately 30 million people (Proud, 2026). Nepal remains a predominantly rural country, with approximately 78% of the population living in rural areas (World Bank, 2023), based on international urbanization definitions.

A large portion of the country is made up of mountains, with approximately three-quarters of land consisting of hills and high mountains. The climate varies significantly depending on altitude but is generally influenced by its subtropical geographic location. In the capital city, Kathmandu, temperatures typically range from around 10°C in January to about 26°C in July. The average annual rainfall is about 1 400 mm, most of which falls during the monsoon season from June to September (Proud, 2026).

Dhulikhel, where the solar drying was conducted, is located approximately 30 km east of Kathmandu. It is located at 1550 meters above sea level, in the south of the Himalayas, in a district called Kavrepalanchok (Dhulikhel Municipality, n.d.).

3.1.1. Nutrition in Nepal

Nepal is considered a low-income country within South Asia and is experiencing a significant burden of malnutrition. At an individual level, nutrition deficiency negatively affects health, learning ability, and overall productivity (Adhikari et al., 2023).

According to the 2022 Nepal Demographic and Health Survey, malnutrition among children under five years of age remains a major public health concern in Nepal. The survey reported that approximately 25% of the children were stunted (low height for age), 8% were wasted (low weight for height), and about 19% were underweight, while 1% were classified as overweight. In comparison, global estimates for 2022 show lower prevalences, with about 23% of children under five affected by stunting and 7% by wasting (WHO, 2024).

Undernutrition in early childhood has serious consequences for health and development. In Nepal, undernutrition problems such as stunting, wasting, and underweight have been estimated to contribute to approximately 52% of child mortality. Children who survive undernutrition may also experience limited intellectual development, and reduced cognitive performance, which can negatively affect their educational outcomes (Government of Nepal, 2017).

Malnutrition is also present among other vulnerable population groups. For example, a study conducted among elderly individuals living in old age homes in Kathmandu municipality found that 15.5% were malnourished, while an additional 61% were at risk of malnutrition (Singh & Shrestha, 2016). These findings highlight that nutritional challenges in Nepal affect multiple age groups and remain an important public health concern.

3.1.2. Agriculture sector

The economy in Nepal is largely dependent on agriculture, providing the main source of employment, particularly in rural areas (Yogi et al., 2025). According to Food and Agriculture Organization of the United Nations [FAO] (n.d.), the agricultural sector accounts for approximately 34.2% of the gross domestic product (GDP), with small-scale farming alone employing approximately 78% of the workforce.

Despite the significance of agriculture, it continues to experience ongoing challenges such as low productivity, dependence on traditional practices, limited access to modern technologies, and increasing exposure to climate change. These constraints prevent its ability to fully contribute to economic growth, poverty reduction, and national food security (Yogi et al., 2025).

Both the country and its farming communities are becoming increasingly exposed to climate change-related risks, including unpredictable weather conditions, flooding, and drought, all of which negatively affect crop yields. This situation is further intensified by the dependence on rain-fed irrigation, making agricultural production highly uncertain and climate-dependent (NACCFL, 2025). Due to widespread poverty combined with a high dependency on natural resources, the capacity to adapt to future climate change remains limited in Nepal (FAO, n.d.).

In areas of high elevation, climate change is accelerating the melting of snow and glaciers, increasing the risk of glacial lake outburst floods. Consequently, effective adaptation strategies are needed to protect livelihoods, and limit further increases in food insecurity, which already affects 3.5 million Nepalese citizens (FAO, n.d.).

3.1.3. Importance of Lemongrass in Nepal

Lemongrass is cultivated in the mid-hills and Terai regions of Nepal, where the subtropical climate provides suitable growing conditions. It has become an important cash crop for rural smallholder farmers, particularly for women who have organized into cooperative farming groups. These groups cultivate lemongrass on community forest land, harvesting essential oils for both domestic and international markets. Lemongrass oil sells at approximately Rs 2200 (approximately 20 €), and Nepalese lemongrass oil is now exported to markets in Europe. Beyond its economic value, lemongrass cultivation has contributed to the restoration of degraded land and supported women's economic empowerment in rural communities (Nepali Times, 2020).

Given these economic benefits, improving post-harvest processing of lemongrass is particularly relevant for Nepalese farmers, as quality losses after harvest can directly affect income and market potential.

3.2. Solar drying

Solar drying is a preservation technique that works by removing moisture from a product. When the moisture content of a food product is reduced to a certain level, microbial activity is inhibited, which delays deterioration and extends the product's storage life (Belessiotis & Delyannis, 2011).

In developing countries, significant postharvest losses of agricultural products occur due to limited access to effective preservation technologies. The use of solar dryers has been identified as a practical solution to reduce these losses. Solar drying has been shown to be an economical option, especially for small- and medium-scale agricultural production (Belessiotis & Delyannis, 2011; Salvador et al., 2025).

3.2.1. Heat Transfer & Moisture

Solar radiation serves as the primary driving force in solar drying, providing the thermal energy that heats the product and the surrounding air, which in turn initiates and sustains the moisture removal process (Belessiotis & Delyannis, 2011).

During the drying process, two main mechanisms of moisture transfer occur: the migration of moisture from the mass to its surface, followed by the evaporation of moisture from the surface into the surrounding air as water vapor (Belessiotis & Delyannis, 2011).

3.2.1.1. Drying Rate

The drying rate refers to the rate at which moisture is removed from a product per unit time during the drying process. This is determined by the moisture content and temperature of the product, but also the surrounding drying air and its temperature, relative humidity and velocity (Belessiotis & Delyannis, 2011).

The drying rate is usually divided into two phases, the constant rate period and the falling rate period.

During the constant rate period, evaporation occurs at a constant rate because the surface of the material remains saturated with moisture. At this stage, sufficient water is present at the surface, allowing continuous evaporation similar to that from a free water surface (Belessiotis & Delyannis, 2011).

During the falling rate period, the drying rate begins to decrease as the surface is no longer saturated with moisture, reaching what is referred to as the critical point. Moisture movement is mainly controlled by diffusion of water from the interior of the material toward the surface, while the surface gradually becomes depleted of water (Belessiotis & Delyannis, 2011).

Some materials also exhibit a third falling phase, during which moisture content continues to decrease at a progressively slower rate until equilibrium moisture content is reached and drying effectively stops. This phase is typically observed in hygroscopic materials and is not considered applicable to lemongrass (Belessiotis & Delyannis, 2011).

3.2.1.2. Water Activity

Water activity (a_w) is a measure of the availability of free water in a food product for microbial growth and chemical reactions. It is defined as the ratio of the vapor pressure of water in the food to the vapor pressure of pure water under the same conditions, expressed on a scale from 0 to 1. For example, a water activity of 0.80 indicates that the food's vapor pressure is 80% that of pure water (FDA, 1984).

In the context of drying, reducing water activity is a primary goal, as it limits microbial growth and enzymatic activity, thereby extending shelf life. Different microorganisms have varying water activity thresholds for growth. Most bacteria require a water activity above 0.85, while fungi generally do not grow below 0.70, and most molds and yeasts are inhibited below 0.61 (Belessiotis & Delyannis, 2011). For dried herbs such as lemongrass, a water activity below 0.60 is therefore considered necessary to ensure microbiological safety during storage.

3.2.2. Types of Solar Dryers

There are two main types of solar drying. The first type is the direct solar dryer, which is an open-air sun dryer with direct exposure to the sun. The other one is indirect solar drying, in which the product is not directly exposed to the sun but is instead heated by air that has passed through a separate solar collector (Belessiotis & Delyannis, 2011).

3.2.2.1. Direct Solar Dryer

Direct solar drying is one of the oldest food preservation methods and has evolved little over time. Although it is inexpensive and widely used, especially by small farmers in developing countries, it has several major limitations. The process is slow, depends heavily on weather conditions, and offers little control over drying parameters or final product quality. In addition, products are directly exposed to contamination from dust, insects, animals, and microbial growth, which can lead to significant quality and quantity losses (Belessiotis & Delyannis, 2011). Traditional open-sun drying is furthermore associated with uncontrolled drying conditions and nutrient degradation (Salvador & Gómez Galindo, 2025).

3.2.2.2. Indirect Solar Dryer

Indirect solar drying is a relatively new technique, which has not yet been standardized or widely commercialized. It typically consists of a solar collector to capture thermal energy and a drying chamber where the product is placed. The dryers exist in several sizes and designs, and they often operate based on experience rather than according to defined criteria to meet the specific drying requirements of food products (Belessiotis & Delyannis, 2011).

Indirect solar dryers offer several advantages over direct methods. They enable faster drying and allow precise control of moisture content to ensure long-term storage. Improved solar dryers have been shown to reduce drying time considerably compared with open-sun drying, while achieving safe moisture content levels (Salvador & Gómez Galindo, 2025). They enable faster drying, typically completing in 15-30 hours, and allow precise control of moisture content to ensure long-term storage. Products are protected from weather and contamination, reducing losses, and the stacked tray design requires less space while increasing productivity through quick reloading. In addition, indirect solar dryers are flexible, capable of handling different seasonal crops throughout the year (Belessiotis & Delyannis, 2011; Salvador et al., 2025). Moreover, indirect solar drying is particularly suitable for aromatic and medicinal herbs, which are sensitive to high temperatures that may reduce their medicinal and aromatic properties (Al-Hamdani et al., 2022).

However, the main limitations are the high initial cost for the dryer and equipment needed, and the need for personnel with skills to operate the drying process. Although the initial cost is

higher than traditional methods, the resulting improvements in efficiency and product quality make it worthwhile investment (Belessiotis & Delyannis, 2011; Salvador & Gómez Galindo, 2025).

3.2.2.3. Shade Drying

Shade drying is one traditional methods of drying medicinal and aromatic plants, particularly in Asian and African countries where it has long been used as a low-cost post-harvest preservation technique (Sivakumar et al., 2020). The method operates at ambient temperatures without direct sunlight exposure, which may help retain heat-sensitive compounds. However, the slow drying rate associated with shade drying can allow metabolic activity to continue post-harvest, potentially leading to degradation of chemical constituents, and the method is most suitable for small quantities or situations where economic constraints limit access to more advanced drying technologies (Nakra & Tripathy, 2025).

3.3. Lemongrass

Lemongrass, also known as citronella grass, is an aromatic medicinal grass. It is a member of the Poaceae family and the genus *Cymbopogon*. This genus consists of approximately 140 species, with a widespread distribution across Asian, American and African continents (Ranade & Thiagarajan, 2015). Throughout the world, lemongrass is cultivated over an area of 16,000 ha, and annually, around 1000 ton of essential oil is generated (Haque et al, 2018).

Two of the most common species of lemongrass are *Cymbopogon citratus* and *Cymbopogon flexuosus* (Ranade & Thiagarajan, 2015).

Lemongrass consists of long, thin, bright green leaves with a pale, bulbous pseudostem base. The leaves typically grow to around 1.3-2.5 cm in width and can reach lengths of around 90 cm (Ranade & Thiagarajan, 2015). In *Figure 1,* a picture of *Cymbopogon citratus* is shown.

Figure 1: *Cymbopogon citratus, photographed in Chitwan, Nepal.*

The essential oil of Cym*bopogon citratus* is stored in glandular trichomes, which are specialized secretory structures found predominantly on the abaxial (lower) surface of the leaf. These trichomes provide an optimal environment for essential oil storage due to reduced direct sunlight exposure and higher humidity compared to the upper leaf surface (Adhawati et al., 2025). *Figure 2* Shows glandular trichomes on the abaxial surface of fresh lemongrass leaves.

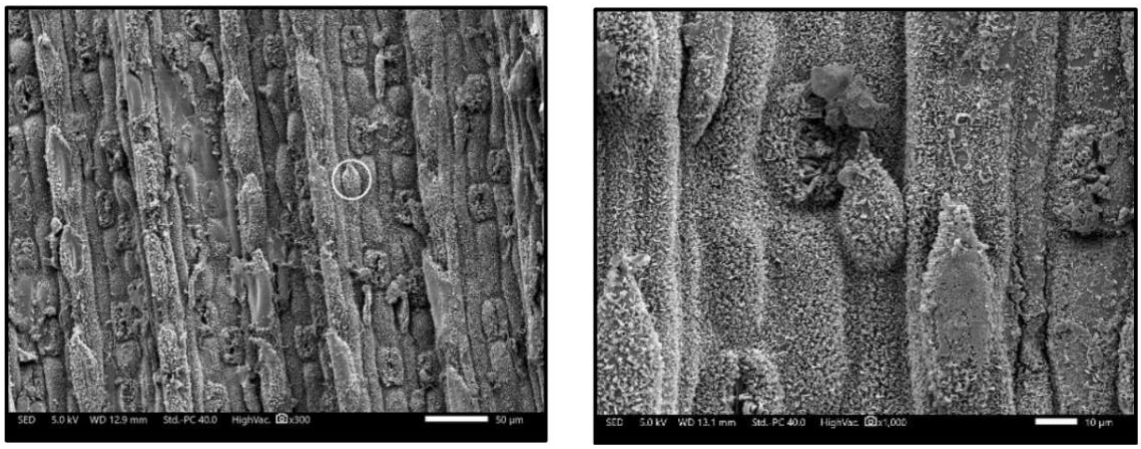

Figure 2: *Abaxial microstructure of fresh Cymbopogon citratus leaf (left) and glandular trichomes of lemongrass leaf (right) (Adhawati et al., 2025).*

One of the most prominent feature of the lemongrass is its strong lemon fragrance, which is due to the high citral content in its essential oil (Ranade & Thiagarajan, 2015).

3.3.1. Traditional and Current Uses

Lemongrass (*Cymbopogon citratus*) has traditionally been used to improve various health conditions. The therapeutic properties of the plant are largely attributed to its production of bioactive secondary metabolites. In many traditional practices, lemongrass has been used to treat conditions such as fever, cough, flu, malaria, elephantiasis (a parasitic disease causing swelling), and digestive disorders (Ranade & Thiagarajan, 2015).

In addition, lemongrass is commonly used in culinary practices, particularly in Asian cuisine, where both the leaves and essential oil are valued for their characteristic lemon-like flavor. The dried leaves of lemongrass are also commonly used in herbal teas, where the leaves are prepared by either infusion or decoction in hot water. Lemongrass leaves may also be blended with other teas, such as green or black tea, to enhance flavor and aroma (Joy et al., 2006).

In recent years, there has been a significant increase of scientific interest in lemongrass, leading to a growing number of studies investigating its potential applications. Many of these studies focus on its biological activities and explore its use in fields such as medicine, food science, cosmetics, and agriculture. Beyond these applications, lemongrass has also been explored in material science, including uses in pulp and paper production and as a raw material for energy generation, though these remain secondary to its primary food and medicinal applications (Haque et al., 2018).

3.3.2. Nutrition of Lemongrass

Antioxidants have been shown to be abundant in lemongrass. *Cymbopogon citratus* contains a considerable range of bioactive compounds, including flavonoids, phenolic compounds, and essential oils, which collectively contribute to its antioxidant activity (Oladeji et al., 2019).

IC50 is defined as the concentration of a sample required to inhibit a specific biological or chemical process by 50%. In the context of antioxidant assays, it represents the concentration needed to scavenge 50% of the free radicals present. A lower IC50 value indicates higher antioxidant capacity. The IC50 can be calculated from a plot of inhibition percentages against sample concentration (Gulcin, 2020).

IC50 values from literature for *Cymbopogon citratus* leaf extracts, evaluated by 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, are presented in *Table 1.* It shows that the values range from 61.5 µg/ml (Dwivedi, 2024) to 258.9 µg/ml (Vieria et al., 2014), indicating considerable variation across studies.

Table 1: *IC50 values for Cymbopogon citratus leaf extracts reported in the literature, determined by DPPH assay.*

Study	Condition	Solvent	IC50 (µg/ml)
Singh et al., 2021	Leaf powder	Methanol	67.69
Sah et al., 2012	Oven-dried	Ethanol (40%)	212
Dwivedi, M, 2024	Shade-dried	Methanol	61.5 +- 2.3
Vieria et al, 2014	Fresh	Ethanol (50%)	258.9

The variation in reported values across studies is likely attributed to differences in geographical origin, plant maturity, extraction method, and season of harvest (Oladeji et al., 2019). Additionally, the samples across studies represent different processing conditions, ranging from fresh to oven dried and shade-dried, which may further contribute to the observation.

3.3.3. Essential Oil

The essential oil of *Cymbopogon citratus* contains numerous bioactive volatile compounds, among which citral is the most prominent. Citral exists as two isomers, geranial and neral, which collectively contribute to the characteristic citrusy and lemony aroma of lemongrass essential oil. Other notable compounds include geraniol, which is responsible for the pleasant fragrance and exhibits antioxidant and antimicrobial properties, limonene, which contributes to the citrus scent and is recognized for its antioxidant properties (Ashaq et al, 2024).

Oil yields (%), defined by the percentage of the whole leaf, have been estimated in different studies and are shown in *Table 2.* The values of the oil yield vary between the studies, likely due to differences in geographical origin, plant cultivar, batch conditions and degree of processing, as the samples across studies represent a range of conditions from fresh to oven-dried and shade-dried.

Within each study, oven drying consistently produces the highest oil yield among the dried conditions, while the lowest yield is found in either sun or shade drying depending on the study.

Table 2: *Oil yield (%) for Cymbopogon citratus under different drying conditions, as reported in literature.*

Study	Condition	Oil yield (%)
Hanaa et al., 2012	Fresh	2.86
Hanaa et al., 2012	Sun-dried (36 h)	2.10
Hanaa et al., 2012	Shade-dried (48 h)	2.12
Hanaa et al., 2012	Oven-dried (45 C, 7 h)	2.34
Salimi, et al. 2024	Shade-dried (5 days)	0.93
Salimi, et al. 2024	Sun-dried (3 days)	1.08
Salimi, et al. 2024	Oven-dried (35 C, 4 days)	1.08
Salimi, et al. 2024	Oven-dried (45 C, 2 days)	1.15

3.3.4. Effect of Drying on Lemongrass

Drying is a widely used post-harvest processing method for lemongrass, aimed at reducing moisture content and extending shelf life. However, the drying process can significantly affect the nutritional quality of the plant material.

During drying, volatile compounds such as citral and limonene are difficult to retain due to their high volatility and the adverse effects caused by thermal treatment. These compounds contribute significantly to the characteristic aroma of lemongrass but can easily evaporate or degrade when exposed to elevated temperatures or prolonged heating (Hashim et al., 2019). Therefore, preserving aroma during the drying process can be challenging, and drying conditions such as temperature and duration must be controlled to maintain product quality.

A study conducted by Mabai et al. (2018) investigated the effect of drying on the quality and sensory attributes of lemongrass tea found that drying temperatures and time were main factors affecting color and aroma retention. Oven drying at 40°C produced the highest scores for color, aroma, taste, and overall acceptability, suggesting that lower drying temperatures are preferable for preserving the sensory quality of lemongrass tea. Another study, by Sucipto et al. (2022), showed that the temperature and drying time directly influence the antioxidant capacity of dried lemongrass products, further highlighting the importance of temperature control during the drying process.

Indirect solar drying has been investigated as a viable method for drying lemongrass. A study by Bareen et al. (2023) using an indirect solar dryer achieved drying temperatures between 42-59°C while reporting improved quality and reduced mass losses. These temperatures align with the recommended range for preserving volatile compounds and antioxidant content in aromatic herbs, suggesting that indirect solar drying is a promising approach for maintaining the nutritional quality of dried lemongrass.

3.3.5. Quality and Safety

The quality and safety of dried lemongrass as a final product requires considering several parameters. While nutritional quality such as essential oil yield and antioxidant capacity are discussed in *Section 3.3.3.* and *3.4.,* two additional important quality factors are microbial safety and color. Microbial count must be within acceptable limits to ensure consumer safety, while

color serves as a primary visual indicator of product quality that directly influences consumer perception.

3.3.5.1. Microbial Count

To ensure that the final product is safe to consume, the microbial count has to be within specific limits.

According to WHO, the total aerobic microbial count (TAMC) must not exceed 10^7 CFU/g, and the total yeast and mold count (TYMC) must not exceed 10^5 CFU/g for herbal products, and the products must be free from Clostridium difficile, Salmonella, and Shigella (Abualhasan, 2020).

3.3.5.2. Color

The color of the final product is a primary indicator of quality, which influences consumers perception to both taste, freshness and safety (Giusti et al., 2024). In dried herbs, color changes during processing can signal degradation of bioactive compounds such as chlorophyll (Thamkaew et al., 2020).

3.4. Antioxidants

Antioxidants are molecules that can inhibit or delay the oxidation of other molecules by neutralizing free radicals and reactive oxygen species (ROS). In food systems, they help maintain quality during storage by delaying lipid peroxidation, which causes undesirable changes in flavor, color, and texture. In addition to their role in food preservation, antioxidants are also important for human health, as they help protect the body from oxidative damage that has been linked to chronic diseases such as cardiovascular disease and cancer (Gulcin, 2020).

Among the compounds responsible for the antioxidant capacity of plant-based foods, phenolic compounds are considered the most significant. Phenolics act as antioxidants by donating hydrogen atoms to free radicals, thereby interrupting the chain reactions of oxidation. A particularly important subclass of phenolics are flavonoids, which along with other phenolic compounds are considered the major bioactive contributors to the antioxidant capacity of plant foods (Gulcin, 2020).

3.4.1. Antioxidant Capacity

Antioxidant capacity can be defined as the efficiency of antioxidants to inhibit the oxidative degradation of biological compounds, expressed as the number of free radicals scavenged by a sample (Flieger et al., 2021).

There are different types of methods that can be used to measure the antioxidant capacity, for example 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay and 2,2’-azino-bis(3-ethylbenzo-thiazoline-6-sulfonic acid (ABTS) assay. In this thesis DPPH assay is used, which is described in the following section.

2.4.1.1. DPPH Assay

2,2-diphenyl-1-picrylhydrazyl (DPPH) assay measures a sample’s ability to scavenge the DPPH radical and thereby estimate the antioxidant capacity of the sample (Gulcin & Alwasel, 2023).

DPPH is a synthetic stable organic nitrogen radical, with a deep purple color, and when it gets in contact with a hydrogen donor, the molecule will get reduced into a non-radical DPPH-H, that has a yellow color (Gulcin & Alwasel, 2023). This reaction is visualized in *Figure 3*.

$$DPPH^{\cdot} + AH \rightarrow DPPH_2 + A^{\cdot}$$

Figure 3: *The DPPH radical reaction, in which an antioxidant (AH) donates a hydrogen atom to the DPPH radical, reducing it to the non-radical DPPH-H form (Gulcin & Alwasel, 2023).*

A sample with antioxidant is usually mixed with the DPPH solution and are incubated in the dark to let the reaction take place. The more antioxidants present in the sample, the greater the color change from purple to yellow. The color intensity of the reaction can then be recorded with a spectrophotometer at 517 nm, where deep purple has its absorption maximum (Gulcin, 2020).

4. Materials and Method

The lemongrass was collected in Kathmandu and Chitwan, Nepal. All experiments were carried out in either Dhulikhel, Nepal, or at Lund University, Sweden.

4.1. Raw material

4.1.1. Collection and Physical Characterization

The lemongrass used for the solar drying experiments were harvested from Chitwan and transported to Dhulikhel, in a plastic bag, by car and flight. The drying of the leaves was conducted within 24-48 hours of harvesting. *Figure 4* shows the collected fresh leaves.

Figure 4: *Cymbopogon citratus, collected in Chitwan, Nepal.*

Only green, healthy lemongrass leaves were used for the experiment, and discolored or damaged parts were removed.

The length and width of 26 lemongrass leaves were measured prior to drying to characterize the physical properties of the raw material. Leaf surface area was estimated by assuming a rectangular shape, calculated as length x width x 2 (as an approximation suitable for thin, elongated leaves), and is used for drying rate calculations. An assumption is made that the drying occurs from both the top and bottom of the leaves. The average and standard deviation of each parameter are presented in *Table 3*.

Table 3: *Calculated average length, width, and area of 26 lemongrass leaves, with calculated standard deviation.*

Length (cm)	21.3 ± 5.0
Width (cm)	0.9 ± 0.1
Area (cm^2)	39.4 ± 9.5

4.1.2. Sanitation of the Lemongrass Leaves

To reduce surface microbial contamination and minimize the risk of spoilage or cross-contamination during subsequent handling and analysis, the fresh lemongrass leaves were sanitized using chlorinated water. Chlorine washing is a commonly applied method for fresh produce sanitation due to its effectiveness in controlling bacteria, yeast, and molds.

According to Kitinoja & Kader (2003), fruits and vegetables may either be washed with 25 ppm available chlorine for 2 minutes or be dipped in 50-70 ppm available chlorine to control bacterial decay.

During this study, the fresh lemongrass leaves were dipped in 50 ppm available chlorine water for approximately 10 seconds. The leaves were then washed with distilled water to remove residual chlorine. After, they were air-dried on aluminum foil until the surface moisture was removed. Excess surface moisture was gently patted dry using paper towels.

4.2. Processing

4.2.1 Solar Dryer

The solar dryer used is a 5th generation hybrid solar dryer built by the Energy Department at Lund University, shown in *Figure 5.* It consists of 2 columns of drying trays, with space for up to 10 trays stacked vertically in each column, and three fans installed on the top of each column (See *Figure 5*). During the experiments, the solar dryer was operated with a target drying temperature of approximately 40°C. The fans were operated at 0.52 V, via a voltage regulator dial.

Figure 5: *5th Generation hybrid solar dryer located in Dhulikhel, Nepal.*

The temperature and humidity were measured every five minutes, with five different SD800 CO2/humidity/temperature dataloggers (EXTECH instruments). *Figure 6* shows where four of the dataloggers were placed in the solar dryer.

Figure 6: *Inside of solar dryer, the red numbers (1-4) indicates where the dataloggers were placed in the dryer. The white arrows show the placement of the fans in the dryer.*

One of the dataloggers were placed outside of the solar dryer in the shade, on the north side, to measure the ambient temperature and ambient relative humidity.

All experiments were conducted on sunny days, approximately from 11 am, and each drying experiment was carried out over two consecutive days.

The drying experiments were divided into two parts: initial drying experiment to evaluate the performance of the solar dryer, and uniformity experiments to assess drying consistency across tray positions.

4.2.1.1. Initial Drying Experiments

The initial drying experiments were conducted to evaluate the temperature conditions and approximate drying duration within the solar dryer. Approximately 30 grams of lemongrass leaves were distributed across two trays per replicate. For the first replicate, lemongrass purchased in Latipur, Kathmandu was used. For the second replicate, lemongrass from plants purchased in Manharajganj, Kathmandu was used.

4.2.1.2. Uniformity of the solar dryer

To assess drying uniformity across tray positions, a fuller tray capacity was used. Approximately 30 grams of lemongrass leaves were placed on each tray, distributed across 5-6 trays during two replicates. For both replicates, the leaves were received from a farm in Chitwan. The tray positions used are shown in *Figure 6*.

Figure 7: *Tray positions within the solar dryer, numbered 1-6, used for uniformity assessment.*

Trays 1-3 are located in the left column (top to bottom) and trays 4-6 in the right column (top to bottom).

4.2.1.4. Drying Curves and Drying Rate

The weight of each tray, together with the lemongrass on it, was measured every one to four hours. The change in weight over time was used to set up a drying curve for each tray, in relation to the initial weight of the samples.

Moisture content during drying was estimated from the recorded sample weights and the final moisture content determined at the end of drying. The dry matter content was assumed to remain constant throughout the drying process, allowing moisture content at each sampling point to be calculated from the corresponding sample weight. It was calculated with *Equation 1*,

$$MC_t = \frac{W_t - DM}{W_t} \cdot 100 \quad (1)$$

where MC_t is the moisture content (%) at time t, W_t is the sample weight at time t, and DM is the dry matter weight determined from the final moisture content.

The drying rate for each tray was calculated with *Equation 2*,

$$Drying\ rate = \frac{\Delta m}{A \Delta t} \quad (2)$$

where Δm is the change in mass [g] in the time interval Δt [h] between consecutive measurements, and A is the area [cm^2].

The drying rate was then plotted against time for each tray.

One drying curve and drying rate curve were made for each tray to assess drying uniformity across different tray positions within the dryer.

4.2.2. Shade Drying

After sanitation, a sample of the lemongrass leaves was shade-dried. The leaves were spread in a single layer on aluminum foil and placed at room temperature (approximately 20-25 °C) protected from direct sunlight. The leaves were dried until constant weight was achieved (approximately one week).

The weight of the shade-dried leaves was recorded every 24 hours to monitor moisture loss until constant weight was achieved. Moisture content (%) over time was calculated as drying curve according to *Equation 1*.

Shade drying was conducted as a low-temperature control, allowing for comparison with solar drying where the primary difference between the methods is the drying temperature.

4.2.3. Storage and Transportation

After drying, the leaves were wrapped in aluminum foil and put in plastic bags. These were then stored in room temperature away from direct sunlight.

Prior transportation to Sweden, the dried leaves were vacuum-packed in vacuum bags with a vacuum-sealer, to avoid moist entering the lemongrass and keep them dried.

4.3. Analysis

4.3.1. Moisture Content and Water Activity

The moisture content and water activity was measured for the fresh lemongrass leaves and the dried leaves.

4.3.1.1. Moisture Content

Prior to moisture content determination, the lemongrass leaves were cut into approximately 5-10 cm sections to increase surface area and ensure more uniform moisture removal during oven drying.

A known mass of lemongrass was weighed and placed in a drying oven [Baltra Microwave Oven], until constant weight was achieved, and reweighted again after. The moisture content was determined in triplicates for each sample condition.

The moisture content, on a wet basis, was then calculated with *Equation 3*,

$$W = \frac{m_{initial} - m_{final}}{m_{initial}} \quad (3)$$

where W is the moisture content, $m_{initial}$ is the total mass before drying in the oven and m_{final} is the total mass after drying in the oven.

4.3.1.2. Water Activity

Prior the water activity measurements, the leaves were cut into smaller pieces (approximately 5 mm). The leaves were then placed in a sample cup, were the leaves were covering the bottom of the cup. The sample cup was then placed into an AquaLab water activity meter (Decagon devices, Inc., Pullman, Washington, USA), and the water activity was measured.

4.3.2. Antioxidant Capacity

The antioxidant capacity was measured with 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay. Antioxidant capacity was measured on fresh lemongrass leaves, shade-dried leaves, and solar-dried leaves, across three independent biological batches representing different sources or harvesting times. Each batch is treated as a biological replicate.

The fresh leaves were extracted within 24-48 hours of harvesting. The shade-dried and solar-dried leaves were extracted within 1-3 days of drying.

4.3.2.1 Sample Preparation / Extraction

Firstly, the leaves were cut with scissors into smaller parts and ground, until all pieces were approximately 1 cm in length or smaller.

1 g of fresh sample was mixed with 20 mL 80:20 methanol:water (w/w), in a beaker. The beaker was then placed in a shaking incubator for 24 hours, at a set temperature of 29 °C and a speed of 120 rpm. After 24 hours, the mixture was filtered through a 0.45 μm syringe filter, to remove particulate matter.

For the dried samples, approximately 0.18 g was used instead of 1 g, as the reduced water content results in a more concentrated extract. The same extraction and dilution protocol was otherwise applied to all samples.

4.3.2.2. 1,1-Diphenyl-2-Picrylhydrazyl Assay

The extracted mixture was diluted to a 1:10 stock solution, by taking 1 mL of the extraction into 9 mL of methanol.

This stock solution was then diluted into 6 different concentrations, shown in *Table 4*. All concentrations were calculated in dry basis, calculated using the measured moisture content of each sample, to account for the differences in water content between fresh and dried samples.

Table 4: *Dilutions series prepared for the DPPH assay.*

Test tube	Stock solution (mL)	Methanol (mL)
1	0.10	0.90
2	0.20	0.80
3	0.40	0.60
4	0.60	0.40
5	0.80	0.20
6	1.0	0

1 mL of freshly made DPPH was then added to each test tube, covered in aluminum foil. The test tubes were gently inverted several times to ensure mixing. The test tubes were placed in a dark room for 30 minutes before the absorbance was measured. Two replicates were made for each dilution.

A control was made with 1 mL methanol and 1 mL DPPH at 0 min. Sample blanks (1 mL stock solution at each concentration and 1 mL methanol) was measured and assumed to be negligible (absorbance < 0.01).

The absorbance was measured with a spectrophotometer, at a wavelength of 517 nm.

The inhibition%, for each of the diluted concentration, was calculated with *Equation 4*,

$$Inhibition = \frac{A_{control} - A_{sample}}{A_{control}} * 100 \quad (4)$$

where, $A_{control}$ is the absorbance of the control (1 mL DPPH and 1 mL methanol) and A_{sample} is the absorbance of the samples, for the different concentrations.

A calibration curve was constructed by plotting inhibition percentage against sample concentration. The IC50 value (µg/mL) was determined from the linear regression of this curve. The IC50 value was used to compare the antioxidant capacity before and after drying.

4.3.3. Oil extraction

To compare how much of the essential oil in the oil glands was preserved during the solar drying, the essential oil was extracted from the fresh leaves and the solar-dried leaves, respectively. The extraction was performed on two independent biological batches, which are not related to the batches for antioxidant capacity measurements.

The essential oil extraction was done with a Clevenger apparatus. Leaves were weighed and placed in the glass bowl, and ten times as much water was added. The distillation time was 8 hours. After, the oil extracted was collected and weighed.

The oil yield was calculated with *Equation 5*,

$$Oil\ yield\% = \left(\frac{m_{EO}}{m_{dry}}\right) * 100 \quad (5)$$

where m_{EO} is the mass of essential oil extracted (g), and m_{dry} is the mass of dry plant material (g).

4.3.4. Scanning Electron Microscopy

To evaluate whether the trichomes were preserved or destroyed during the solar drying, scanning electron microscopy (SEM) was used to produce images of the surface of the solar-dried lemongrass leaves.

SEM imaging was conducted on solar-dried and shade-dried lemongrass leaves at Lund University, Sweden. Fresh leaf samples could not be analyzed since they could not be brought back to Sweden.

Carbon adhesive tape was put onto a stub. A small part of the cut leaves were put on the adhesive (around 0.5 cm). These were then coated with metal.

The metal covered leaves were placed into the SEM microscopy, which was installed at a pressure of 9e-005 Pa, voltage of 10 kV, and a distance of 8 mm. The scan was collected with lower secondary electron (LIE) detector.

4.3.5. Sensory Evaluation

A focus group was used to evaluate the aroma and acceptability of the final product, focusing on comparing different types of lemongrass to assess the acceptability of the solar-dried samples.

One focus group was made in Nepal, and one in Sweden, to explore potential differences in sensory perception and consumer acceptance across cultural backgrounds.

The questions asked and discussed during the focus group sessions can be found in *Appendix A.1.*

4.3.5.1. Preparation of Tea

1.8 g (dry matter) leaves were cut into smaller pieces and placed in 300 mL boiling water for 5 minutes. After 5 minutes, the leaves were taken out of the water, and the water was poured into paper cups.

4.3.5.2. Focus Group in Nepal

The focus group consisted of 6 Nepalese students.

Solar-dried lemongrass was compared with fresh lemongrass grown from plants bought in Kathmandu, and shade-dried leaves from the same source as the solar-dried samples, and commercially dried lemongrass bought in Pokhara.

4.3.5.3. Focus Group in Sweden

The focus group in Sweden consisted of 5 Swedish students.

Solar-dried lemongrass was compared with shade-dried leaves, commercially dried lemongrass tea with ginger (teabags: Kung Markatta, Roobios) bought in Sweden, and commercially bought lemongrass tea bought in Nepal.

4.3.6 Microbial Evaluation

A total plate count was used to estimate the number of viable, culturable microorganisms on the dried samples. It was made for both the dried leaves, and the tea made from the dried leaves, to assess the hygienic quality of the dried product and the safety of the brewed tea.

Tryptic soy agar (TSA) was used as a non-selective medium to enumerate the total bacterial count. The agar was prepared following the manufacturer's instructions.

Ten grams leaves, both solar-dried and shade-dried, were each mixed with 90 mL peptone water (0.1%). The mixture was then placed in a stomacher for approximately 2-3 minutes, to homogenize the mixture. The solution was then diluted 4 times (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}). An undiluted control (10^{0}) was also plated.

Tea was prepared for the two types of leaves, accordingly to the previously described procedure. The tea water was used for the plates, without dilutions.

The plates were inoculated using glass bead spreading method. Duplicates were made for all the samples/dilutions. The plates were incubated for 72 hours at 30 °C in aerobic and anaerobic conditions.

After incubation, the colonies were counted and the dilution with 30-300 colonies were chosen for the calculation of results, which was made with *Equation 6,*

$$CFU/g = \frac{mean\ colony\ count\ \cdot df^{-1}}{volume\ plated} \tag{6}$$

where mean colony count (*CFU*) is the mean value of the colonies of the duplicates, the df^{-1} the dilution factor inversed, and volume plated (mL) the added amount to each plate.

5. Results

The results from the solar drying, shade drying, and subsequent quality analyses of lemongrass (*Cymbopogon citratus*) conducted in Dhulikhel, Nepal and Lund, Sweden are presented below.

5.1. Solar Drying

Figure 8 shows the lemongrass leaves after solar drying.

Figure 8: *Solar-dried Cymbopogon citratus leaves.*

5.1.1. Initial Drying Experiment

The drying curve from the first drying experiment is presented in *Figure 9*. Tray 1 was placed above tray 2, in the middle of the right column of the solar dryer.

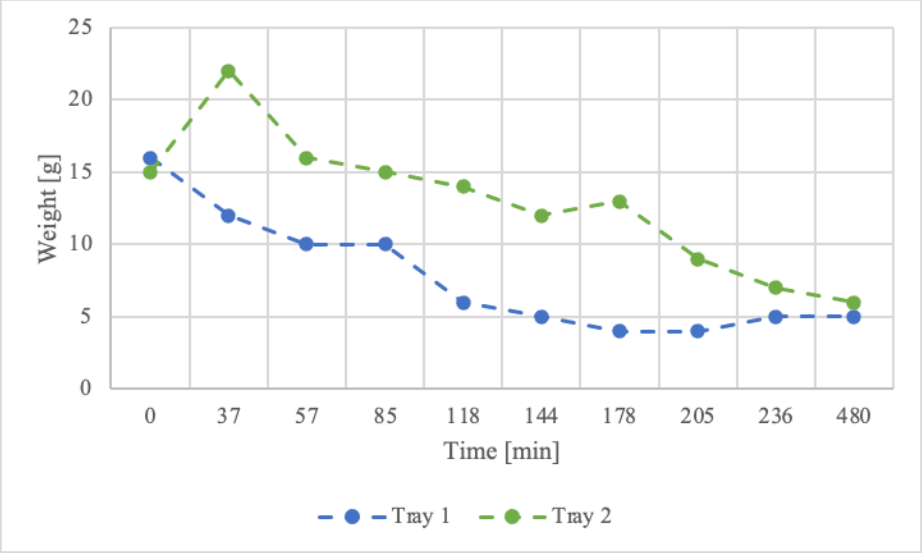

Figure 9: *Drying curves for two trays with lemongrass (Cymbopogon citratus), showing weight loss [g] over time [min].*

The lemongrass was dried for approximately 8 hours. As seen in *Figure 9*, the drying curve for tray 2 exhibits irregular fluctuations, likely due to scale uncertainty given the small sample mass or disturbing wind. Tray 1, placed above tray 2, are decreasing in weight quicker compared to tray 2.

The temperature and relative humidity within the dryer are presented in *Figure 10* (See *Figure 6* for positions of dataloggers).

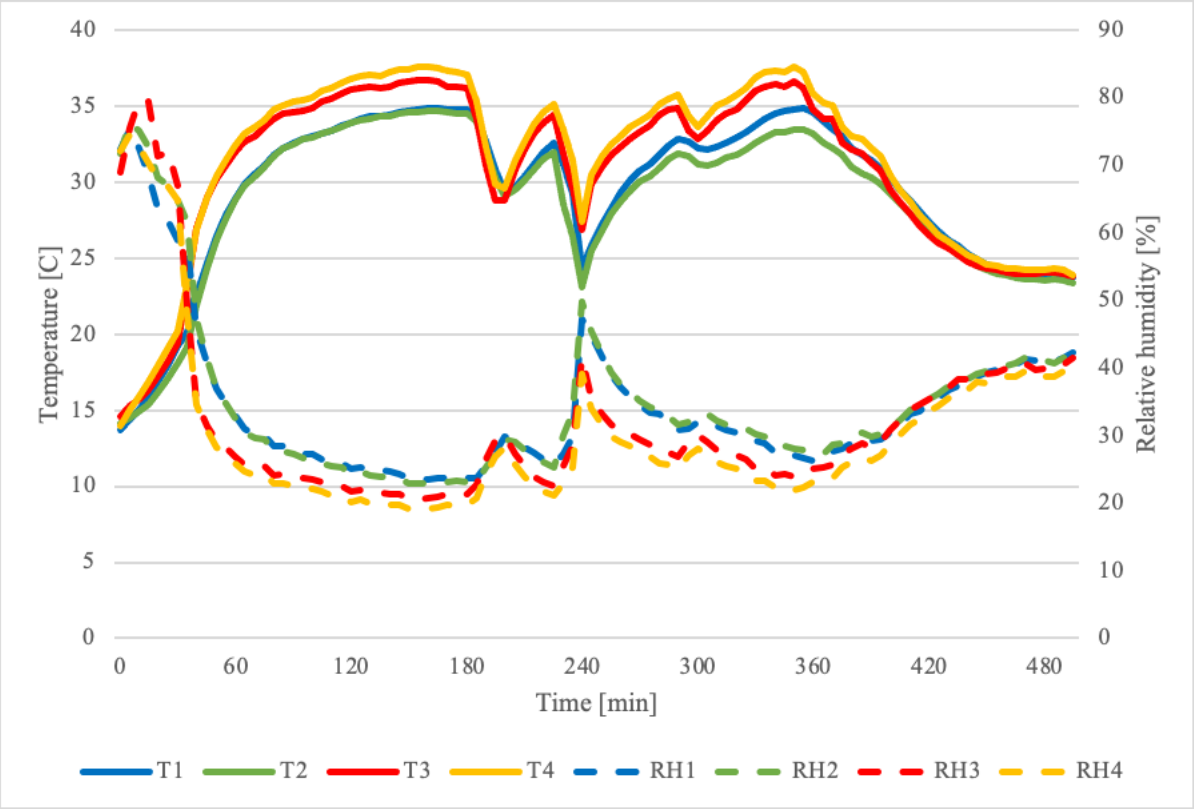

Figure 10: *Temperature [℃] and relative humidity [%] recorded at four positions inside the solar dryer during the drying experiment.*

As seen in *Figure 10* the temperature is varying between 15 °C to 37 °C, where the highest temperature is achieved in the middle of the day. The relative humidity is varying between 18% to 80%, where the highest is achieved in the beginning of the first day, and the lowest in the middle of the day.

When comparing the different dataloggers, the temperature is generally higher for T3 (red) and T4 (yellow), which are placed in the right column of the solar dryer, compared to T1 (blue) and T2 (green) which are placed in the left column. For the relative humidity, it is seen to be higher in the left column compared to the right column of the solar dryer.

During the next drying experiment, the scale malfunctioned, so no drying curve could be done, but it was dried for approximately 5 hours, and the temperature and relative humidity is shown in *Figure 11*.

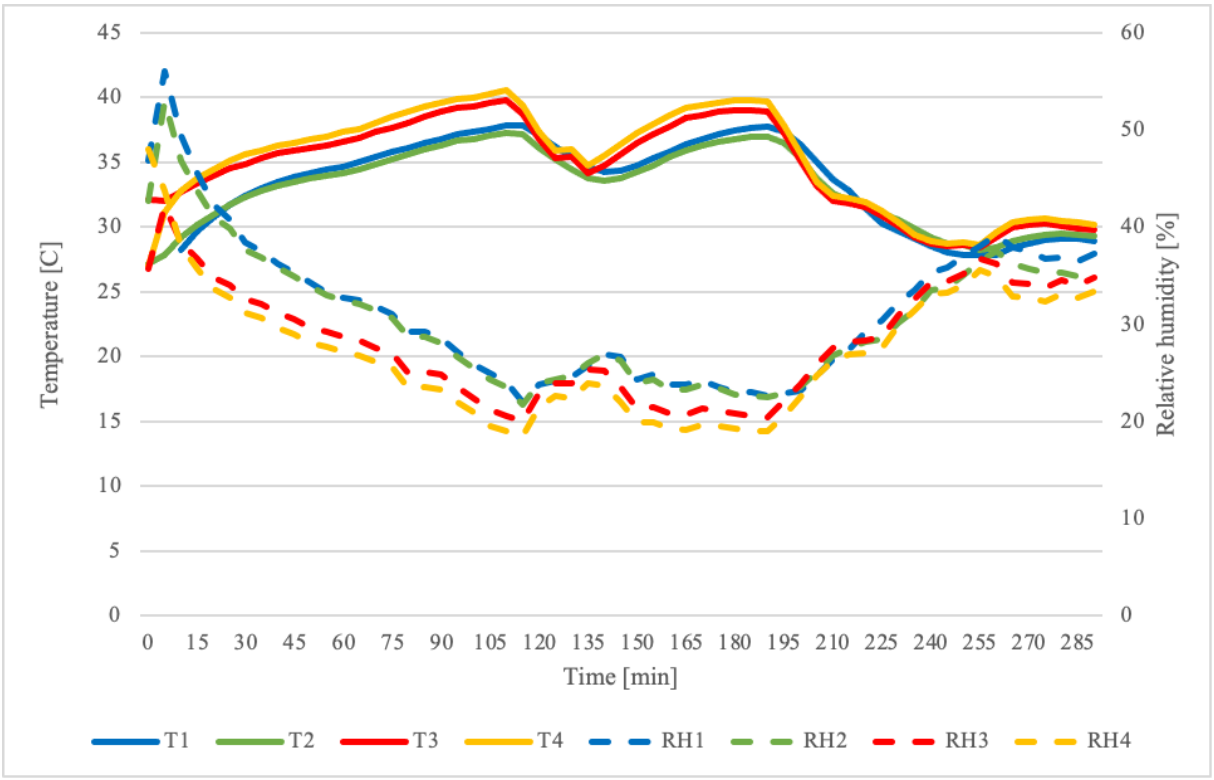

Figure 11: *Temperature (℃) and relative humidity (%) recorded at four positions inside the solar dryer during the drying experiment.*

As seen in *Figure 11*, the temperature is generally higher in the right column compared to the left column. Also, the relative humidity is higher in the left column compared to the right column. Therefore, these results show comparability to the earlier experiment.

5.1.2. Uniformity of the Solar Dryer

The drying curve to evaluate the uniformity of drying is presented in *Figure 12*. The positions of the trays are shown in *Figure 7*.

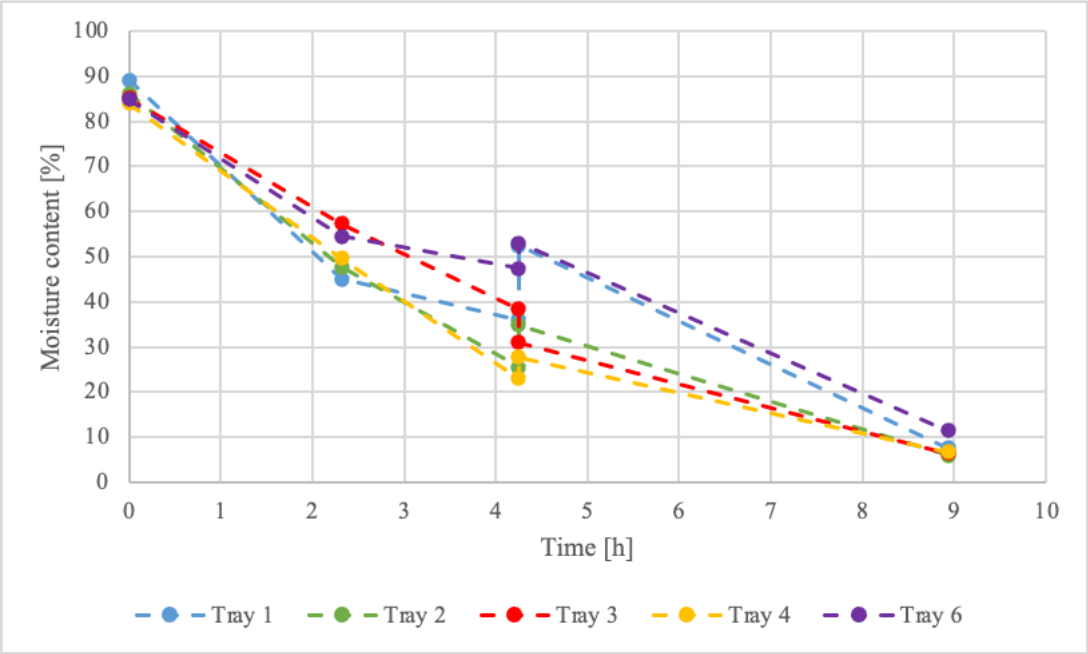

Figure 12: *Drying curves for lemongrass on 5 different trays placed in the solar dryer.*

As shown in *Figure 12.,* the moisture content decreasing over time for all trays. The largest reduction occurred during the first day of drying (first 4.3 hours). A slight increase in moisture content was observed between the first and second drying day for some trays. At 4.3 hours, tray 2 and 4 exhibited the lowest moisture contents, while tray 6 retained the highest moisture content. Although the moisture contents became more similar towards the end of drying, tray 6 continued to show slightly higher moisture levels than the other trays.

The drying curve for weight (g) over time for each tray is shown in *Figure A.1*., and the estimated drying rate over time is shown in *Figure A.3*. in *Appendix A.2.*The temperature and relative humidity within the solar dryer, and at ambient conditions, are presented in *Figure 13*.

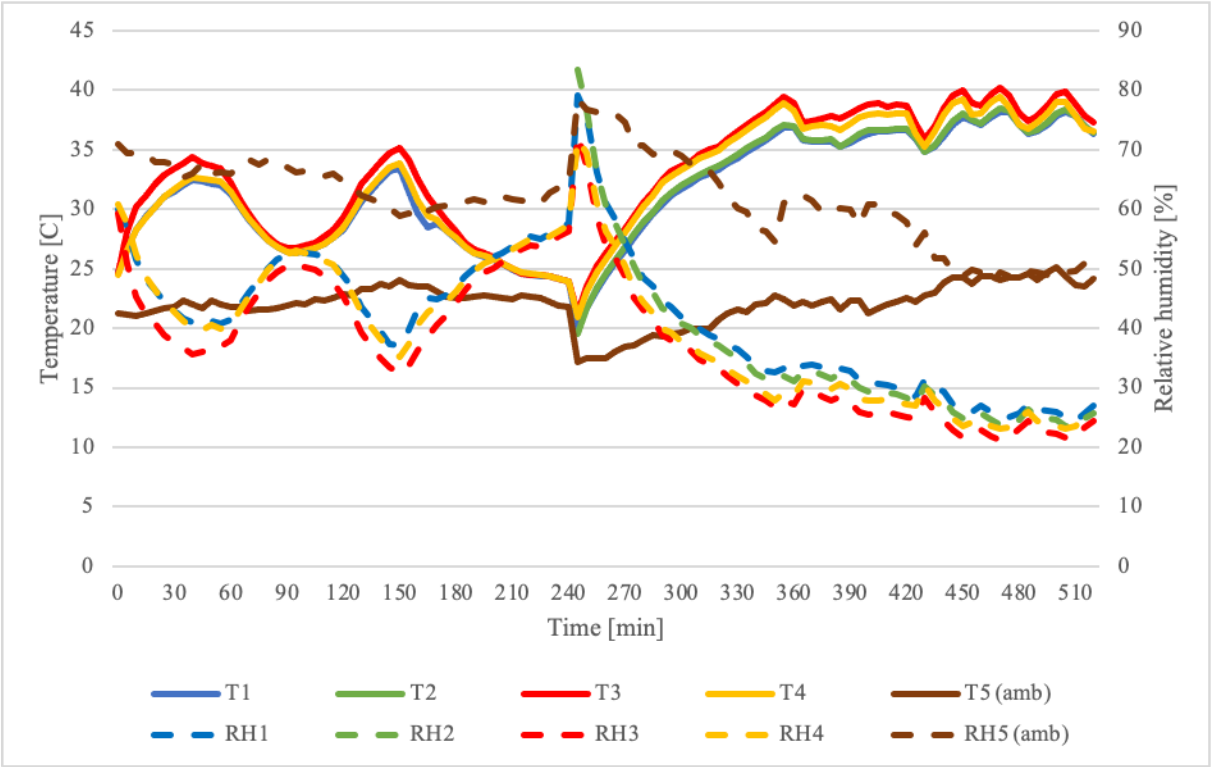

Figure 13: *Temperature (℃) and relative humidity (%) measured with 5 dataloggers. amb = ambient.*

During the first day, the temperature within the solar dryer is fluctuating, and it is not going over 35 °C. However, during the second day the temperature goes up to 40 °C. For both days, the ambient temperature is between 17-25 °C, which means that the temperature within the dryer is around 20 °C higher than outside.

The final moisture content of samples dried with the same drying time was measured for the five different trays, and the results are presented in *Table 5*.

Table 5: *Moisture content (%) for the fresh lemongrass collected in Chitwan, and for the five different trays placed in the solar drier, at different columns and levels.*

	Fresh	Tray 1	Tray 2	Tray 3	Tray 4	Tray 6
Moisture content (%)	75.5	7.6	6.0	6.4	6.7	11.5

As shown in *Table 5*, the moisture content of the solar-dried leaves differs between the trays. Tray 2, placed in the bottom of the left column has the lowest moisture content, while tray 6, placed in the bottom of the right column, has the highest moisture content.

One more replicate was made to investigate the uniformity of the drying within the solar dryer. The positions of the trays are shown in *Figure 7.* The weight of the lemongrass on each tray over time is shown in *Figure 14.*

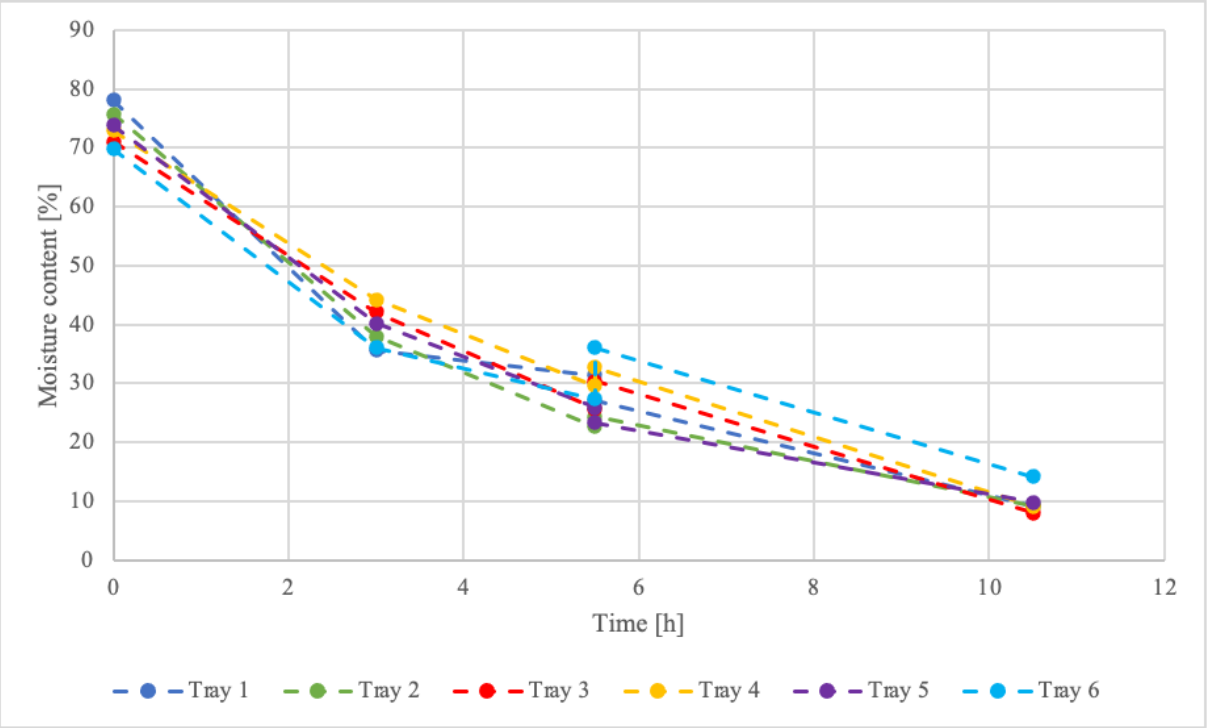

Figure 14: *Drying curves of six different trays placed in the solar dryer.*

As shown in *Figure 14.,* the moisture content decreased over time for all trays. During the first day of drying, the drying profiles were relatively similar across all trays. However, during the second day, tray 6 retained a higher moisture content than the other trays, similar to the trend observed in the previous drying replicate.

The drying curve for weight (g) over time for each tray is shown in *Figure A.2.* and the estimated drying rate over time is shown in *Figure A.4.* in *Appendix.* The temperature within the dryer, the ambient temperature, and the relative humidity are presented in *Figure 15.*

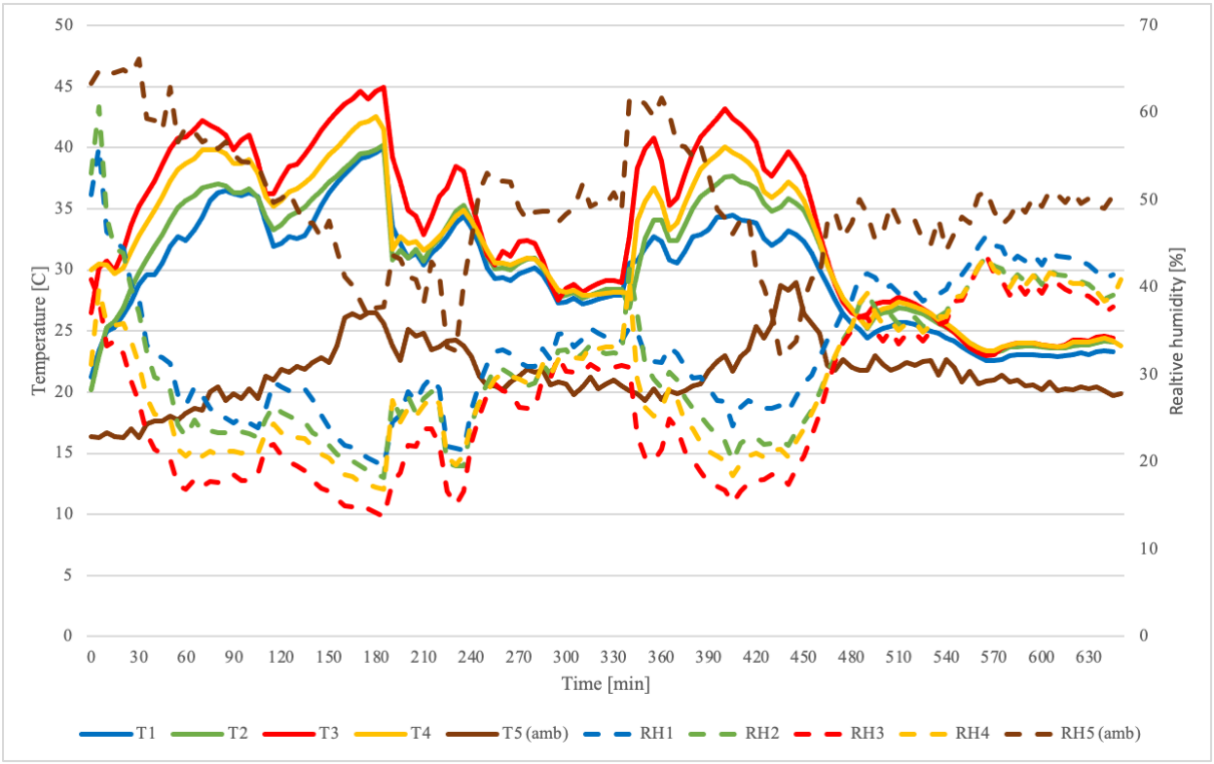

Figure 15: *Relative humidity (%) and temperature (℃) measured with 5 dataloggers. amb = ambient.*

As seen in *Figure 15,* the temperature in the solar dryer was around 5-20 °C higher compared to the ambient temperature. For the relative humidity, the ambient one was around 10-30% higher compared to inside of the dryer.

The final moisture content of samples dried with the same drying time for the six trays was measured, and the results are presented in *Table 6.*

Table 6: *Moisture content (%) for the fresh lemongrass, and for the solar-dried lemongrass placed in different places within the solar dryer.*

	Fresh	Tray 1	Tray 2	Tray 3	Tray 4	Tray 5	Tray 6
Moisture content (%)	67.9	9.2	9.1	8.0	9.1	9.8	14.2

As shown in *Table 6,* the moisture content of the lemongrass dried on tray 6, located in the bottom of the right column, has the highest moisture content, while the lemongrass with the lowest moisture content was located on Tray 3, in the bottom of the left column. These results align with the results from the first replicate, where the uniformity within the dryer was investigated.

4.1.2.1. Moisture Content

Figure 16 shows the average moisture content for each tray, at their position in the solar dryer.

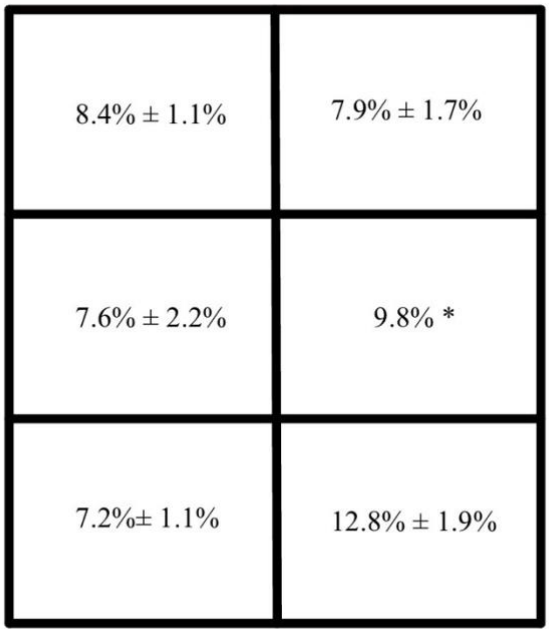

Figure 16: *Average moisture content (%) and standard deviation for the 6 trays at their positions in the solar dryer, from two replicates. * = only one replicate made.*

As seen in *Figure 16*, the moisture content is higher for the tray positioned in the bottom of the right column compared to the other trays.

5.2. Shade Drying

Two replicates of shade drying were made. The lemongrass leaves were placed at room temperature, away from direct sunlight, for approximately 8-9 days. The drying curves for the shade drying are shown in *Figure 17.*

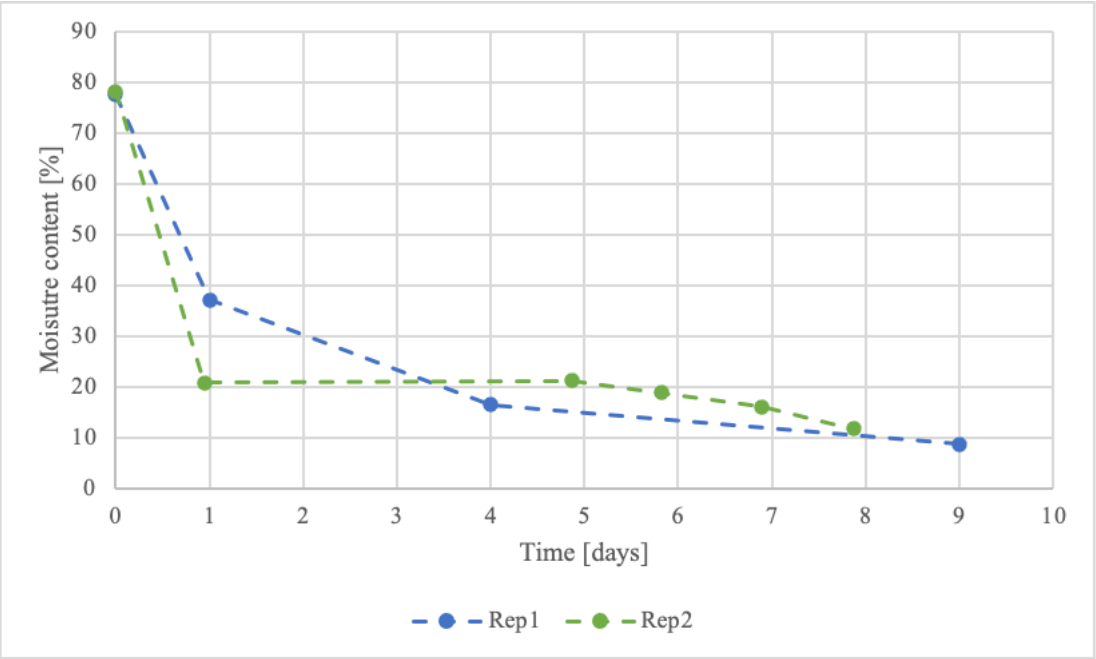

Figure 17: *Moisture content (%) over time (days), for two replicates of shade drying.*

As seen in *Figure 17*, the leaves were drying most during the first day, for both the replicates. It is then decreasing slowly for the rest 7-8 days.

5.3. Moisture Content & Water Activity

The moisture content was measured in Nepal, while the water activity was measured on the lemongrass transported back to Sweden.

5.3.1. Moisture Content

An average of the moisture content measured for all the replicates for the fresh, solar-dried, and shade-dried lemongrass leaves are presented in *Table 7*. The average moisture content is calculated between each batch, and for the solar-dried includes the values for the different trays too, the shade-dried was only made two times.

Table 7: *Average moisture content (%) calculated from the fresh, solar-dried, and shade-dried lemongrass leaves, with calculated standard deviation and number of replicates.*

	Fresh	Solar-dried	Shade-dried
Moisture content (%)	72.7 ± 0.081 (n = 5)	9.66 ± 0.032 (n = 13)	10.1 ± 0.022 (n = 2)

As seen in *Table 7,* the solar-dried and shade-dried has comparable moisture contents. During both the solar drying and shade drying, the moisture content has been decreased from 72.7% to approximately 10%.

5.3.2. Water Activity

The water activity for solar-dried and shade-dried lemongrass leaves are presented in *Table 8*.

Table 8: *Water activity of solar-dried and shade-dried lemongrass leaves, and standard deviation from three replicates each.*

	Water activity (%)
Solar-dried	0.287 ± 0.012
Shade-dried	0.297 ± 0.009

As seen in *Table 8*, the water activity of both samples are highly comparable.

5.4. Antioxidant Capacity

The antioxidant capacity was measured for fresh, solar-dried, and shade-dried lemongrass leaves for comparison.

The IC50-values, calculated from a curve made from different dilutions of the extractions, are presented in *Table 9*. The curves used to get the linear equation for the IC50-values are shown in *Appendix A.3*.

Table 9: *IC50-values (µg/mL) for fresh, solar-dried, and shade-dried lemongrass leaves, from three different biological batches, with calculated mean and standard error. "-" indicates no measurement was done.*

	IC50 (µg/mL))			
	Batch 1	**Batch 2**	**Batch 3**	**Mean ± se**
Fresh	165	154	79	133 ± 27.1
Solar-dried	189	149	171	171 ± 11.5
Shade-dried	-	155	196	176 ± 21.2

As presented in *Table 9.*, the IC50-values differs between the batches, with higher standard error for the fresh leaves compared to the solar-dried and shade-dried. For the first batch, the IC50 value is 14.5% higher for the solar-dried leaves compared to the fresh lemongrass leaves, which means that the antioxidant capacity is 14.5% lower for the solar-dried leaves.

For the second batch, the IC50 values are comparable between the solar-dried, shade-dried, and fresh lemongrass leaves, meaning that the antioxidant capacity is similar between the different types.

During the third batch, the IC50 value for the solar-dried leaves was 116.5% higher than the fresh, meaning 116.5% lower antioxidant capacity. The IC50 value for the shade-dried leaves was 148.1% higher than for the fresh leaves, meaning 148.1% lower antioxidant capacity.

5.5. Essential Oil Extraction

The measured oil yield for the fresh and solar-dried lemongrass are shown in *Table 10*.

Table 10: *Essential oil yield (%) for fresh and solar-dried Cymbopogon citratus leaves, from two biological batches.*

	Oil yield (%)	
	Batch 1	**Batch 2**
Fresh leaves	4.5	1.1
Solar-dried leaves	1.39 ± 0.94 (n = 2)	-

As presented in *Table 10*, the oil yield varies considerably between the fresh and solar-dried lemongrass leaves, but also between the different batches. For the fresh lemongrass leaves, it varies with approximately 75% between the two biological batches. For the first batch, the oil yield for the solar-dried leaves is approximately 70% lower compared to the fresh leaves.

5.6. SEM

Pictures captured of the solar-dried and shade-dried lemongrass leaves with the SEM microscopy are shown below. *Figure 18* shows zoomed in pictures of an intact and disrupted glandular trichome.

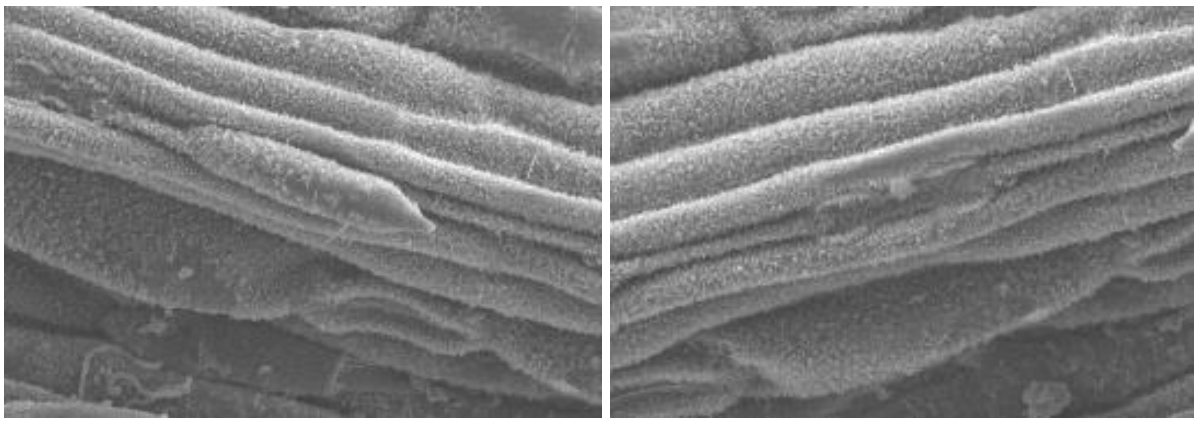

Figure 18: Intact trichome (left), disrupted trichome (right), of a shade-dried leaf.

Pictures with solar-dried and shade-dried are in *Figure 19*. The images reveal that the trichomes follow a linear arrangement along the leaf surface. Red circles indicate intact glandular trichomes, while blue rectangles highlight potentially disrupted trichomes.

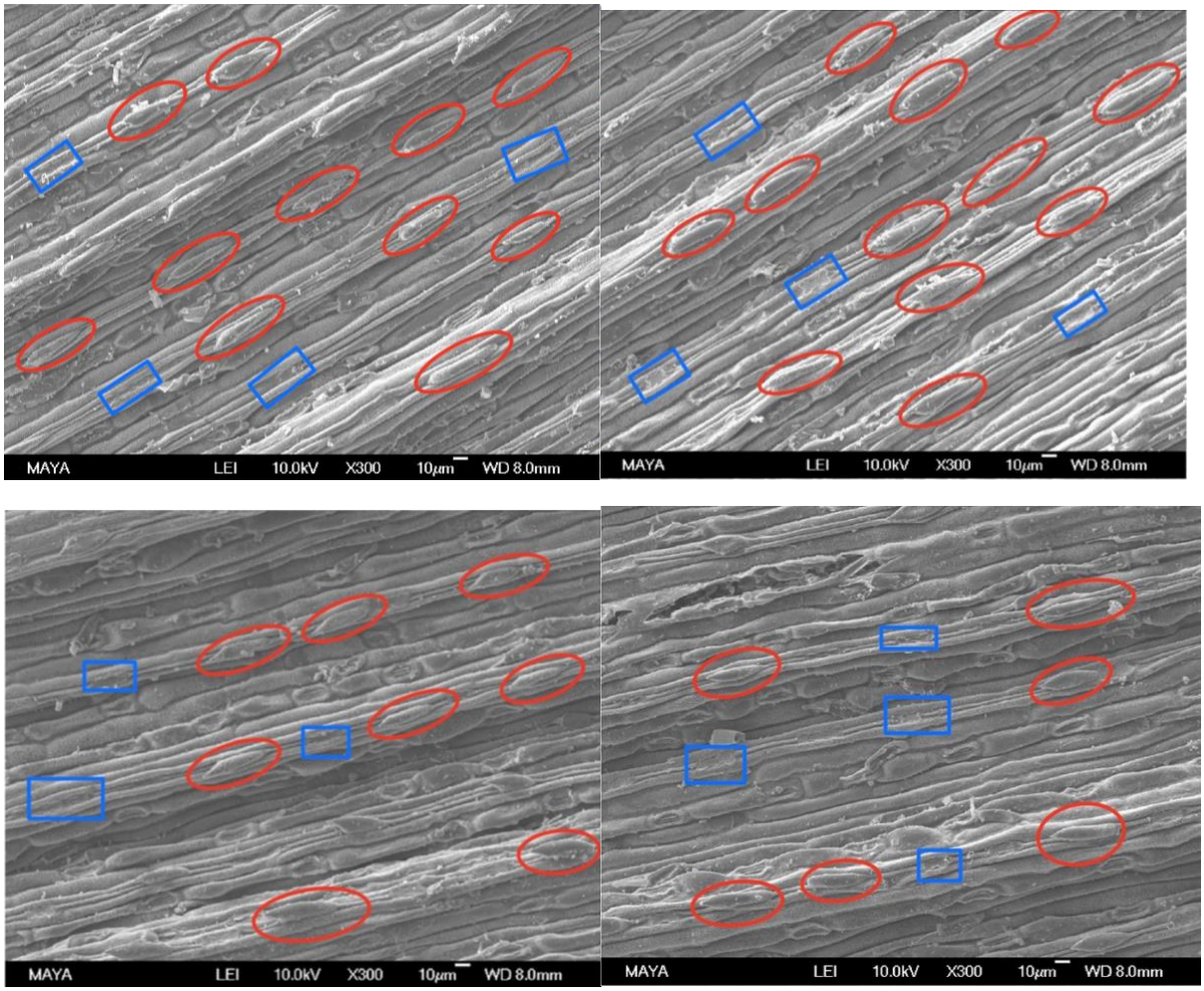

Figure 19: *SEM-images of solar-dried lemongrass leaves (top) and shade-dried lemongrass leaves (bottom) captures by SEM microscope. The red circles represent identified glandular trichomes, and the blue rectangles represent potentially disrupted glandular trichomes.*

Solar-dried samples show a higher number of intact trichomes compared to shade-dried samples. The shade-dried samples do potentially have more disrupted trichomes.

Additional photos taken are shown in *Appendix A.4.*

5.7. Sensory Evaluation

Pictures of the four prepared teas are shown in *Figure 20.*

Figure 20: *Prepared teas for the focus group, where the leaves have been placed in hot water for 5 minutes. From the left: Shade-dried, solar-dried, commercial Nepal, Swedish tea bag.*

As seen in *Figure 20*., the commercially bought lemongrass tea from Nepal, shade-dried and solar-dried lemongrass tea have similar colors, while the Swedish tea bag exhibited a darker red color. It should be noted that the figure serves as an illustrative example, and variation in color may occur between different batches and preparations.

5.7.1. Focus Group in Nepal

All participants in the Nepalese focus group reported consuming tea regularly, ranging from daily to a few times per week. Only one participant had previously tried lemongrass tea, however all were familiar with lemon tea and consumed it regularly. When asked about the most important factors when drinking tea, all participants rated flavor as the most important, followed by aroma and color.

The average ratings for color, aroma and flavor are presented in *Table 11*.

Table 11: *Average ratings ± standard deviation (scale 1-5, where 1 = lowest and 5 = highest) for color, aroma and flavor of four lemongrass teas, evaluated by six Nepalese participants. P-values from one-way ANOVA are presented in the bottom row. * = significant. Different subscript letters within a clumn indicate significant differences between samples according to Tukey's HSD test ($p < 0.05$).*

	Color	**Aroma**	**Flavor**
A: Shade-dried	2.7 ± 0.5^{a}	5.0 ± 0.0^{a}	3.9 ± 0.5^{a}
B: Commercial Nepal	2.0 ± 0.6^{a}	2.3 ± 0.5^{c}	2.0 ± 0.6^{b}
C: Solar-dried	4.8 ± 0.4^{b}	4.7 ± 0.5^{a}	4.0 ± 0.3^{a}
D: Fresh	2.3 ± 0.5^{a}	3.8 ± 0.4^{b}	3.3 ± 0.5^{a}
p-value	< 0.001*	< 0.001*	< 0.001*

For color, the solar-dried tea received the highest rating (4.8) and was rated significantly higher than all other samples ($p < 0.05$). Participants described its appearance as a satisfactory color that matched their expectations. The shade-dried, commercial, and fresh teas did not differ significantly from each other and were generally described as having little visible color

compared to hot water. However, participants noted that the shade-dried tea exhibited a more noticeable color than the commercial and fresh teas.

For aroma, the shade-dried (5.0) and solar-dried (4.7) teas received the highest ratings and did not differ significantly from each other. Both were described as having a strong lemon aroma. The fresh tea (3.8) received significantly lower ratings than the dried samples and was described as lemony but less intense. The commercial tea (2.3) received the lowest ratings and differed significantly from all other samples, being described as weak with little difference from hot water.

For flavor, the shade-dried (3.9), solar-dried (4.0), and fresh (3.3) teas did not differ significantly from each other and were all described as having a lemony flavor. The commercial tea (2.0) received significantly lower ratings than all other samples and was described as having little taste beyond water. Some participants noted that the solar-dried tea had a stronger and slightly more bitter aftertaste than the other teas.

When asked about consumption, all participants stated they would consider drinking lemongrass tea if offered at cafes or restaurants, and would be willing to prepare it at home. Some participants indicated a preference for sweetened tea, adding sugar or honey, while others described it as suitable as an unsweetened calming drink in the evening.

5.7.2. Focus Group in Sweden

Three of the five Swedish participants reported drinking tea almost daily, while the remaining two noted that their consumption varies by season, being higher in winter than summer. None of the participants had previously tried pure lemongrass tea, though some noted they may have encountered it as an ingredient in blended tea bags.

All participants rated flavor as the most important factor when choosing a tea, while noting that color and aroma also contribute to the overall experience.

The average calculated values for color, aroma and flavor are presented in *Table 12*. A statistically significant difference between the teas was found for color ($p = 0.004$), while no significant differences were found for aroma ($p = 0.633$) or flavor ($p = 0.092$).

Table 12: *Average ratings ± standard deviation (scale 1-5, where 1 = lowest and 5 = highest) for color, aroma and flavor of four lemongrass teas, evaluated by five Swedish participants. P-values from one-way ANOVA are presented in the bottom row. ns = not significant. * = significant. Different subscript letters within a column indicate significant differences between samples according to Tukey's HSD test ($p < 0.05$).*

	Color	**Aroma**	**Flavor**
A: Commercial Nepal	2.4 ± 1.1^{a}	4.3 ± 1.1	2.0 ± 0.7
B: Shade-dried	2.3 ± 0.8^{a}	3.9 ± 0.2	2.9 ± 0.7
C: Solar-dried	3.1 ± 0.5^{a}	4.0 ± 0.0	2.9 ± 0.2
D: Swedish tea bag	4.3 ± 0.4^{b}	4.3 ± 0.4	3.0 ± 0.8
p-value	0.004*	0.633 (ns)	0.092 (ns)

For the color, the Swedish tea bag received the highest rating (4.3) and was rated significantly higher than all other samples ($p < 0.05$). Participants described it as having a stronger red-orange color. The commercial Nepal tea (2.4), shade-dried tea (2.3), and solar-dried tea (3.1) did not differ significantly from each other. These samples were described as nearly colorless, greenish, and yellowish, respectively.

For aroma, all four teas received comparable scores ranging from 3.9 to 4.3, with no statistically significant difference between them. The commercial tea bought in Nepal was described as slightly sweet and lemony. Both the shade-dried and solar-dried teas were described as having a stronger lemon aroma, somewhat foresty, and reminiscent of lemonade. The Swedish tea bags was described as slightly sour with a spicy aroma water than lemony.

For flavor, the ratings ranged from 2.0 to 3.0, with no significant difference observed between the teas. The commercial Nepal tea received the lowest numerical rating and was described as largely tasteless, with less flavor than the aroma suggested. Both the shade-dried and solar-dried teas were described as having a stronger lemon flavor with a grassy or matcha-like aftertaste. The Swedish tea bags were described as slightly more watery than the color and aroma suggested, with a spicy flavor that participants could not precisely identify.

When asked about future consumption, participants indicated they would potentially purchase lemongrass tea to prepare at home, though several noted a preference for other teas they already consume regularly.

5.8. Microbial Evaluation

The results from the microbial evaluation by plate count is shown in *Table 13*. The plate count was made for both the leaves of the shade-dried and solar-dried lemongrass.

Table 13: *Number of bacteria (CFU/g) for solar-dried leaves, shade-dried leaves, and tea made from solar-dried leaves and shade-dried leaves. Values are presented as mean ± standard error (n = 2). n.d. = not detectable. *Only one replicate yielded a countable result.*

	Aerobic (10^4 CFU/g)	**Anaerobic (10^4 CFU/g)**
Shade-dried	2.05*	5.4 ± 0.3
Solar-dried	3.0 ± 0.1	3.3 ± 1.0
Shade-dried tea	n.d.	n.d.
Solar-dried tea	n.d.	n.d.

Under aerobic conditions, shade-dried leaves showed a slightly lower bacterial count compared to the solar-dried leaves. However, as only one replicate produced a countable plate for the shade-dried aerobic sample, this result should be interpreted with caution. Under anaerobic conditions, the shade-dried leaves exhibited a higher bacterial count than the solar-dried leaves.

No bacterial growth was detected on any of the tea plates under either aerobic or anaerobic conditions.

Pictures of the plates can be found in *Appendix A.5*.

6. Discussion

6.1. Solar Drying

From the experiments, it has been shown that the lemongrass leaves can be dried in the solar dryer within 8-10 hours. A fuller capacity with several trays needs around 9 hours to dry, while drying with only 2 trays needs around 8 hours. A fuller capacity takes more time since it has more mass, but also more restricted airflow between the trays.

The solar dryer reached temperatures of 40-45 °C during peak hours, which is 10-15 °C over the ambient temperature. This range is comparable to the 42-59°C reported by Bareen et al. (2023), who also used an indirect solar dryer and achieved improved quality and reduced mass losses. However, as established by Mabai et al. (2018), drying at 40 °C produced the best results for color and aroma retention, suggesting that the peak temperatures occasionally reached by the solar dryer may risk marginal degradation of these quality attributes. As highlighted by Hashim et al. (2019), volatile compounds such as citral and limonene are highly sensitive to elevated temperatures, meaning that controlling peak drying temperatures remains important for preserving the characteristic aroma of lemongrass. Overall, the drying conditions achieved in these experiments are within a reasonable range for maintaining product quality.

With these conditions and drying duration, the leaves were dried to a moisture content of approximately 10%. The solar-dried leaves retained a green color, though with a slightly greyer tone compared to the fresh leaves (See *Figure 8*), suggesting minor color changes occurred during drying while overall color was reasonably preserved.

6.1.1. Uniformity of the Solar Dryer

When evaluating the drying uniformity of the solar dryer, the results indicate that the final moisture content was notably higher in the bottom tray of the right column compared to the other trays. This interpretation is further supported by the drying profiles shown in *Figures 12* and *14*, where this tray (tray 6) generally retained a higher moisture content than the other trays throughout the drying process and showed a tendency towards slower drying.

This suggests that drying was less effective in this position relative to the rest of the dryer. Since each column is equipped with three fans, and the bottom trays of both columns are symmetrically positioned relative to their respective fans, a difference in moisture content between the two bottom trays would not be expected if the airflow conditions were identical throughout the dryer. The fact that the left bottom tray does not show a similarity elevated moisture content therefore suggests that the issue may be related to variations in airflow between the two columns. This could be due to differences in fan performance between the columns or to uneven air distribution within the dryer caused by the dryer geometry or airflow patterns. However, neither fan speed nor airflow distribution was measured during this study. Investigating airflow characteristics throughout the dryer would therefore be a relevant area for future research, as uneven airflow could significantly affect drying uniformity.

6.1.2. Solar Drying vs Shade Drying

As shown in the figures in the results, it has taken over a week to dry the lemongrass leaves in the shade, to reach the comparable final moisture content as drying it in the solar drying within 10 hours. So, it is more time-effective to dry it in the solar dryer than in the shade. However, shade drying is less weather-dependent compared to solar drying. Solar drying relies heavily on sunlight, whereas shade drying is only slightly affected by weather conditions, mainly through variations in room temperature during the drying process. Additionally, the extended drying duration and open-air drying may pose a risk of microbial growth, which will be further discussed in *Section 6.6*.

Despite this advantage, the dramatically longer drying time and associated quality risks suggest that solar drying is the more practical and efficient method for processing lemongrass.

6.2. Antioxidant Capacity

When comparing the experimental IC50 values with literature values (*Table 1*), the results fall within the range across several studies, which spans from 61.5 to 258.9 μg/ml for various conditions and solvents. However, direct comparison is limited by methodological differences between studies, including variations in extraction solvent, sample preparation, and drying conditions. Furthermore, as discussed in *Section 3.3.2.,* IC50 values for lemongrass can vary considerably depending on biological batch, geographical origin, and season of harvest, making batch-to-batch comparisons unreliable due to large biological variation.

Overall, the antioxidant capacity appears to decrease upon drying, regardless of method. When comparing solar drying and shade drying, the difference in antioxidant capacity retention is small, with solar drying appearing to preserve antioxidant capacity marginally better. However, the results are largely comparable between the two methods.

The observed decrease in antioxidant capacity following drying is consistent with Sucipto et al. (2022), who demonstrated that both temperature and drying time directly influence the antioxidant capacity of dried lemongrass products. However, the comparable antioxidant capacity between solar and shade-dried samples suggests that solar drying does not cause greater degradation of antioxidants than shade drying, indicating that the elevated temperatures and solar radiation associated with solar drying do not appear to significantly increase antioxidant loss.

In batch 3, the difference between fresh and dried leaves is notably larger than in the other batches. This is likely attributable to the considerably higher baseline antioxidant capacity of the fresh leaves in that batch, rather than a difference in drying conditions, as a similar loss was observed for both solar- and shade-dried samples. Alternatively, since the fresh and dried subsamples were taken from the same biological batch but not from identical plant material, natural variation in antioxidant content within the batch itself may have contributed to the observed difference. As lemongrass composition can vary between individual plants and within a harvest, the fresh subsample may not be perfectly representative of the material used for drying.

Furthermore, shade drying was only evaluated across two biological batches compared to three for fresh and solar-dried leaves, which limits the reliability of comparison involving shade-dried samples.

Overall, a greater number of replicates would be required to draw reliable conclusions. Additionally, complementing the DPPH assay with an ABTS assay would improve the reliability of the results, as ABTS also scavenges lipophilic antioxidants, whereas DPPH is limited to hydrophilic antioxidants (Gulcin, 2020).

6.3. Oil Extraction

The oil yield varied considerably both between biological batches and between fresh and solar-dried leaves. As with the antioxidant capacity, this variation is likely due to differences in biological batch, and harvest seasons, as similarly large variations have been reported across studies in the literature *(Table 2.)*.

When comparing the experimental values with literature values, the fresh lemongrass oil yield reported by Hanaa et al. (2012) was 2.86%, while the experimental values ranged from 1.1% to 4.5% across the batches, suggesting that biological variation between batches is considerable. The solar-dried oil yield of 1.39% (batch 1) is comparable to the sun-dried value of 2.10% reported by Hanaa et al. (2012) and the sunshine dried value of 1.08% reported by Salimi et al. (2024), indicating that the solar dryer produces oil yields within a range consistent with similar drying methods in the literature.

The results indicate a 70% reduction in oil yield between fresh and solar-dried leaves in batch 1, which is notably higher than the approximately 26% reduction reported by Hanaa et al. (2012) between fresh and sun-dried lemongrass. However, given the large biological variation observed between batches, this difference may partly reflect variation in the raw material rather than solely drying-related losses. This is consistent with Hashim et al. (2019), who highlighted that volatile compounds such as citral and limonene are susceptible to loss during drying due to their high volatility, meaning some reduction in oil yield upon drying is expected.

Due to the limited number of replicates and the absence of solar-dried data for batch 2 and shade-dried data for both batches, reliable conclusions cannot be drawn from the current dataset alone. Additional replicates and inclusion of shade-dried samples would be valuable to determine whether the observed reduction is due to the drying process in general or specifically to the conditions of solar drying.

6.4. SEM

The SEM images suggests that the solar-dried samples has more intact glandular trichomes compared to the shade-dried samples. This may be attributed to the longer drying time associated with shade drying, which could have led to greater disruption of the trichomes over time. Additionally, this finding may indicate that the higher temperatures reached during solar drying do not negatively affect the glandular trichomes.

However, since only one sample of each leaf type was examined, the results should be interpreted with caution. A more reliable conclusion would require a larger number of samples

and replicates. Furthermore, as fresh lemongrass leaves could not be transported to Sweden for analysis, no baseline comparison was possible. Without a fresh leaf reference, it cannot be determined whether the trichomes in the dried samples were fully intact or only partially so, meaning that structurally intact trichomes may not necessarily retain their full oil content.

As the analysis was purely visual and qualitative, no quantitative data on trichome counts or size was obtained, which limits the strength of the conclusions that can be drawn. A quantitative approach, such as counting trichomes across multiple image areas, would provide stronger evidence for the observed differences between the two drying methods.

The lower essential oil yield of the solar-dried leaves, which was 70% lower compared to fresh leaves as discussed in *Section 6.3*, may partly be explained by trichome disruption or partial deflation of trichomes during drying, though this cannot be confirmed without a fresh leaf baseline for comparison.

6.5. Sensory Evaluation

6.5.1. Comparison between teas

Across both focus groups, the solar-dried and shade-dried teas generally received higher or comparable ratings to the commercial and fresh lemongrass teas for aroma and flavor. In the Nepalese focus group, statistically significant differences were found for all three attributes, while in the Swedish focus group, a significant difference was only found for color, with no significant differences detected for aroma or flavor.

The strong aroma and flavor of the solar- and shade-dried teas may be linked to the preservation of glandular trichomes during drying, as observed in the SEM analysis (*Section 5.6.*), since intact trichomes retain the essential oil compounds responsible for the characteristic lemon aroma of lemongrass (Ranade & Thiagarajan, 2015). The comparable performance between solar- and shade-dried teas across both panels is consistent with the antioxidant and microbial findings, further suggesting that solar drying does not cause greater quality loss than shade drying.

The commercial tea bought in Nepal received the lowest scores both aroma and flavor in both panels, although these differences were only statistically significant in the Nepalese focus group. This may be due to degradation of volatile compounds during high-temperature industrial drying, consistent with findings by Hashim et al. (2019). This was also reflected in the color ratings, where the commercial lemongrass tea was described as nearly colorless by both panels, which may indicate degradation of chlorophyll and other bioactive compounds during processing (Thamkaew et al., 2020).

The fresh lemongrass tea received surprisingly low flavor ratings despite its high aroma scores in the Nepalese panel. This may be attributed to its higher moisture content, which could reduce the diffusion of flavor compounds into the hot water during brewing compared to dried samples. Additionally, some Nepalese participants noted a stronger and more bitter aftertaste in the solar-dried tea compared to the shade-dried tea, which may reflect the effect of higher drying temperatures on certain flavor compounds beyond citral.

6.5.2. Overall and Cultural differences

Overall, the Nepalese participants responded more positively to the lemongrass teas, particularly the solar and shade-dried samples, and indicated a willingness to purchase and consume lemongrass tea regularly. The Swedish participants show a more moderate interest, with several noting that while they would potentially purchase lemongrass tea, they would likely consume it less frequently and would generally prefer other teas they already drink regularly.

These differences may reflect broader cultural differences in tea consumption habits between the two groups. However, given the small number of participants in each focus group, these observations should be interpreted as preliminary rather than representation of the Nepalese and Swedish populations as a whole. Herbal teas are more commonly consumed in Nepal, which may have made the strong lemon and herbal characteristics of the dried lemongrass teas more familiar and appealing to the Nepalese participants. In Sweden, tea consumption is more commonly associated with conventional tea bags, often blended with other ingredients, which may explain why the Swedish participants responded more favorably to the blended Swedish tea bags than to pure lemongrass tea.

From a market perspective, these findings suggest that lemongrass tea may have greater consumer acceptance in markets where herbal tea consumption is already established, while markets such as Sweden, blending lemongrass with other ingredients may be a more viable approach to increase consumer acceptance.

6.6. Microbial Evaluation

The aerobic plate count was 2.05 * 10^4 CFU/g for shade-dried leaves and 3.0 *10^4 CFU/g for solar-dried leaves, both well below the WHO limit of 10^7 CFU/g for total aerobic microbial count in herbal products. The anaerobic plate count was 5.4 * 10^4 CFU/g for shade-dried leaves and 3.3 *10^4 CFU/g for solar-dried leaves. No widely established specific limit for anaerobic counts in dried herbal products was identified, making direct assessment against a standard difficult. However, as discussed in *Section 3.2.1.2.,* water activity is an important factor affecting microbial growth in dried products (Belessiotis & Delyannis, 2011). The water activity of both the solar- and shade-dried samples was approximately 0.3, well below the critical threshold of 0.6, indicating that conditions were unfavorable for microbial proliferation in both samples.

The leaves were sanitized with chlorinated water prior to drying, which likely contributed to the initial microbial counts being within acceptable limits. However, the use of chlorine-based wash for fresh produce remains debated in Europe, and has been restricted in some countries due to concerns regarding the formation of potentially harmful disinfection by-products (Meireles et al., 2016). Therefore, alternative sanitation methods could be considered in future studies.

When comparing the two drying methods, the differences in bacterial counts are relatively small. Under aerobic conditions, the solar-dried leaves showed a 46.3% higher CFU/g than the shade-dried leaves. However, as only one replicate yielded a countable result for the shade-

dried aerobic sample, this comparison should be interpreted with caution. Under anaerobic conditions, the shade-dried leaves showed a 63.6% higher count than the solar-dried leaves. This may be due to the considerably longer drying duration of shade drying, during which the leaves were exposed to the surrounding environment for an extended period, allowing more contamination.

No bacterial growth was detected on any of the tea plates under either aerobic or anaerobic conditions for either drying method. The tea was prepared by steeping the leaves in boiling water at 100 °C for 5 minutes, consistent with previous research identifying 100 °C as an optimal brewing temperature for lemongrass tea (Udayana University, 2026). Exposure to boiling water likely contributed to the inactivation of viable microorganism, as heat treatment is known to inactivate microorganisms in foods (Cerbrián et al, 2017). This is a positive finding from a food safety perspective, as lemongrass is most commonly consumed as tea.

7. Conclusion

The aim of this thesis was to investigate how solar drying affects selected quality parameters of lemongrass (*Cymbopogon citratus*), including antioxidant capacity, essential oil content, microbiological safety, and sensory acceptability. Traditional shade drying was used as a reference method to evaluate the potential of solar drying as an alternative drying technique for lemongrass processing.

The results demonstrate that lemongrass can be effectively dried in the indirect solar dryer within 8-10 hours, reducing the moisture content from approximately 73% to 10%, comparable to the moisture content achieved by shade drying over more than a week. This highlights the significant time efficiency of solar drying over shade drying. However, some variation in drying uniformity was observed across tray positions, particularly in the bottom tray of the right column, suggesting that fan performance may affect drying consistency.

The antioxidant capacity was found to decrease slightly upon drying regardless of method, with solar and shade drying producing comparable results. The essential oil yield was approximately 70% lower in solar-dried leaves compared to fresh leaves, though considerable biological variation between batches limits the reliability of this conclusion. SEM analysis suggested that solar-dried samples retained more intact glandular trichomes than shade-dried samples, which may partly explain differences in aroma and flavor observed in the sensory evaluation.

Both the solar and shade-dried lemongrass met the WHO microbiological limits for herbal products, and no bacterial growth was detected in the brewed tea under either aerobic or anaerobic conditions, indicating that the final product is microbiologically safe for consumption.

In the sensory evaluation, the solar- and shade-dried teas were generally rated higher than the commercially dried and fresh lemongrass teas. Significant differences in color, aroma and flavor were observed among the Nepalese participants, whereas among the Swedish participants, significant differences were only observed for color. The Nepalese participants responded more positively overall and showed greater willingness to purchase lemongrass tea regularly, likely reflecting greater familiarity with herbal teas. The Swedish participants showed more moderate interest, suggesting that blending lemongrass with other ingredients may improve consumer acceptance in markets less accustomed to herbal teas.

Overall, solar drying appears to be a promising method for processing lemongrass, preserving quality parameters at a level comparable to shade drying while offering a dramatically shorter drying time. Further research should include a larger number of replicates, SEM imaging of fresh leaves as a baseline, and complementary antioxidant assays such as ABTS to improve reliability of the results.

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Appendix

A.1. Focus Group – Questions

The following questions were addressed and discussed during the discussion:

- Have you consumed lemongrass tea before (or lemon tea)?
- How often do you usually consume tea?
- When you drink tea, is color, flavor, or aroma the most important factor to you? Why?

For each tea, the following questions were asked:

- How would you describe the color? Is it what you expecting?
- How would you rate the color from 1-5*?
- How would you describe the aroma? Does it remind you of anything? Is it what you are expecting?
- How would you rate the aroma from 1-5*?
- How would you describe the flavor? Does it remind you of? Is it what you are expecting?
- How would you rate the flavor from 1-5*?

*5 is representing high and 1 low

After, the following questions were addressed in the end:

- Would you consider buying lemongrass tea and making tea at home?
- Would you consider ordering lemongrass tea at a cafe or restaurant?

A.2. Solar Drying

A.2.1. Drying curves

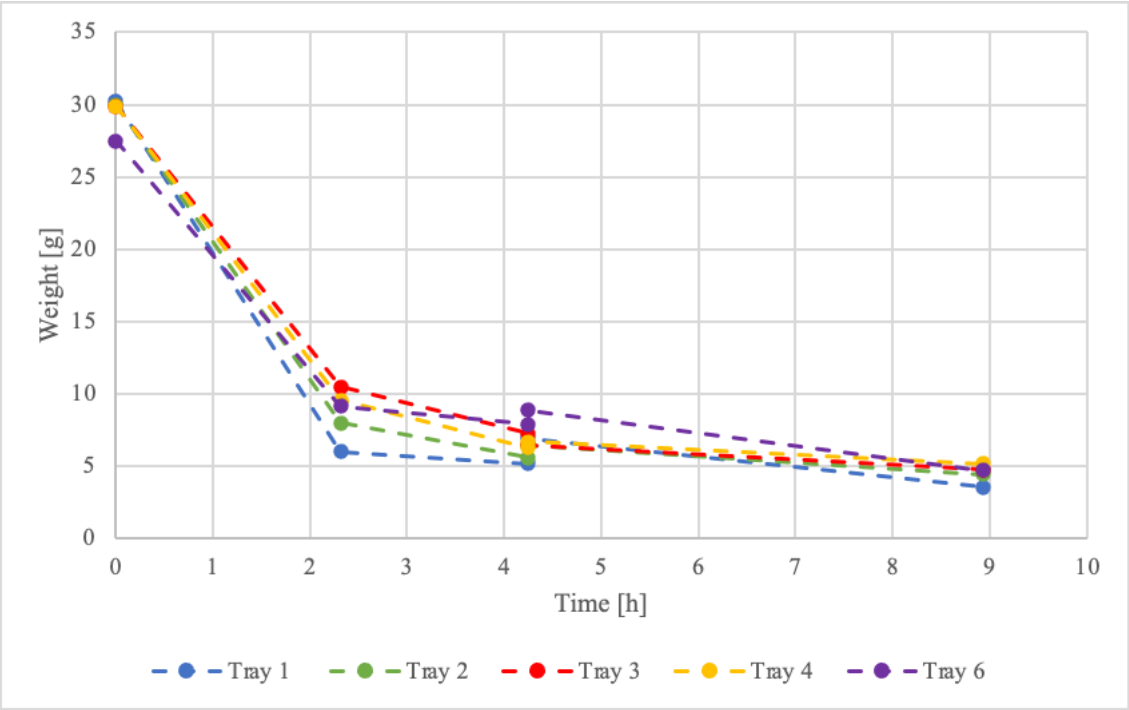

Figure A.1: *Drying curve with weight [g] over time [h] for five trays on different positions within the solar dryer (First replicate of drying uniformity).*

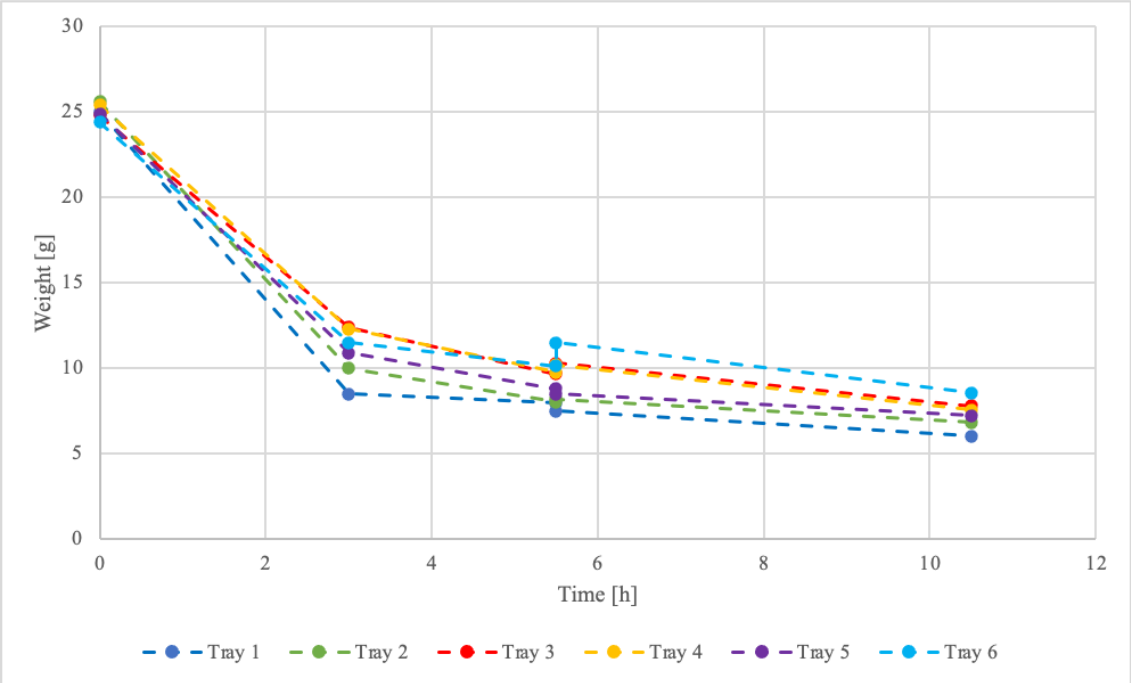

Figure A.2: *Drying curve with weight [g] over time [h] for six trays on different positions within the solar dryer (Second replicate of drying uniformity).*

A.1.1. Drying rate

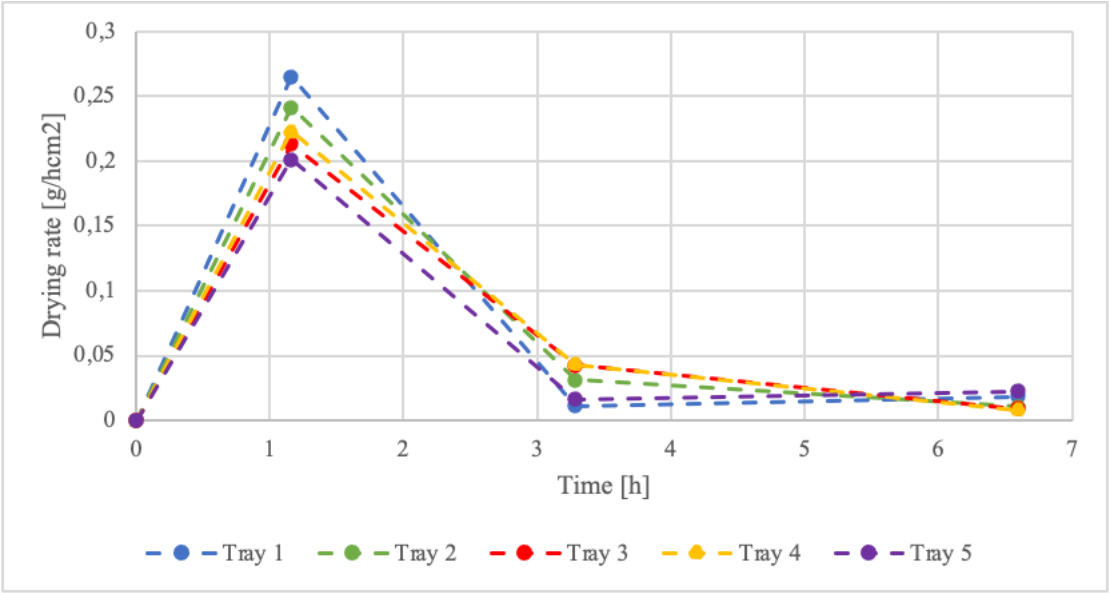

Figure A.3: *Drying rate over time for 5 trays placed in the solar dryer at different levels. Tray 1 was placed in top of the left column, tray 2 in the bottom of the left column, tray 3 in the top of the right column, tray 4 in the middle of the right column, and tray 5 in the bottom of the right column (First replicate of uniformity).*

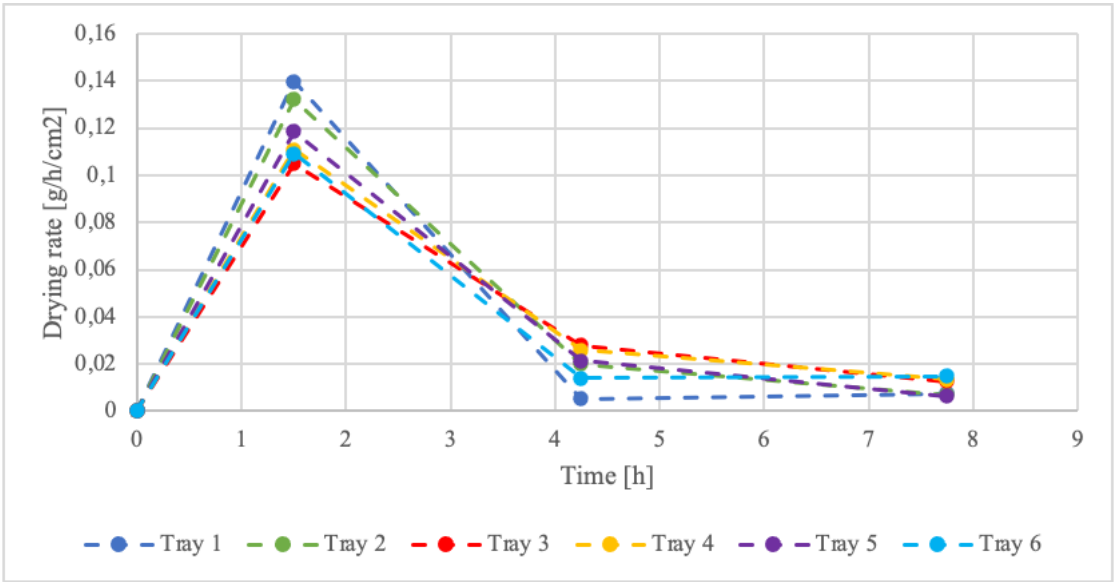

Figure A.4: *Estimated drying rate over time for each tray with lemongrass in the solar dryer, placed on different levels and columns. Tray 1 is placed in the top of the left column, tray 2 in the middle of the left column, tray 3 in the bottom of the left column, tray 4 in the top of the right column, tray 5 in the middle of the right column, and tray 6 in the bottom of the right column (Second replicate of uniformity).*

A.3. Antioxidant Analysis

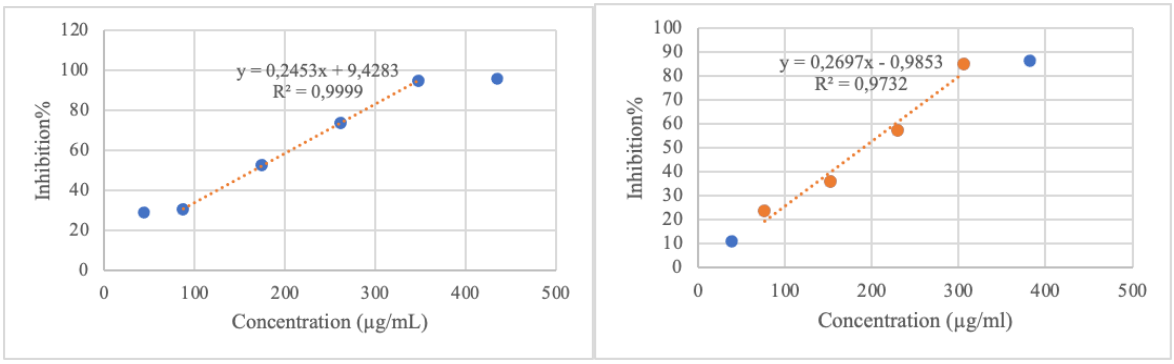

Figure A.5: *Inhibition curve for antioxidant capacity for fresh (left) and solar-dried (right) lemongrass leaves, with linear equation and R^2 value, lemongrass leaves from batch 1.*

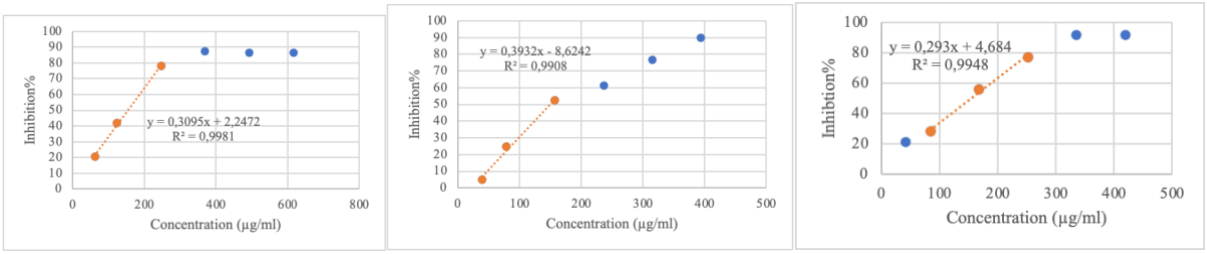

Figure A.6: *Inhibition curve for antioxidant capacity for fresh (left), solar-dried (middle), and shade-dried (right) lemongrass leaves, with linear equation and R^2 value, from batch 2.*

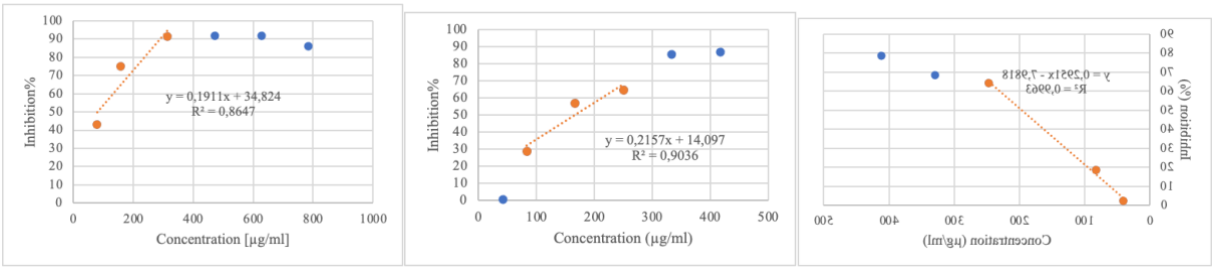

Figure A.7: *Inhibition curve for antioxidant capacity for fresh (left), solar-dried (middle), and shade-dried (right) lemongrass leaves, with linear equation and R^2 value, from batch 3.*

A.4. SEM

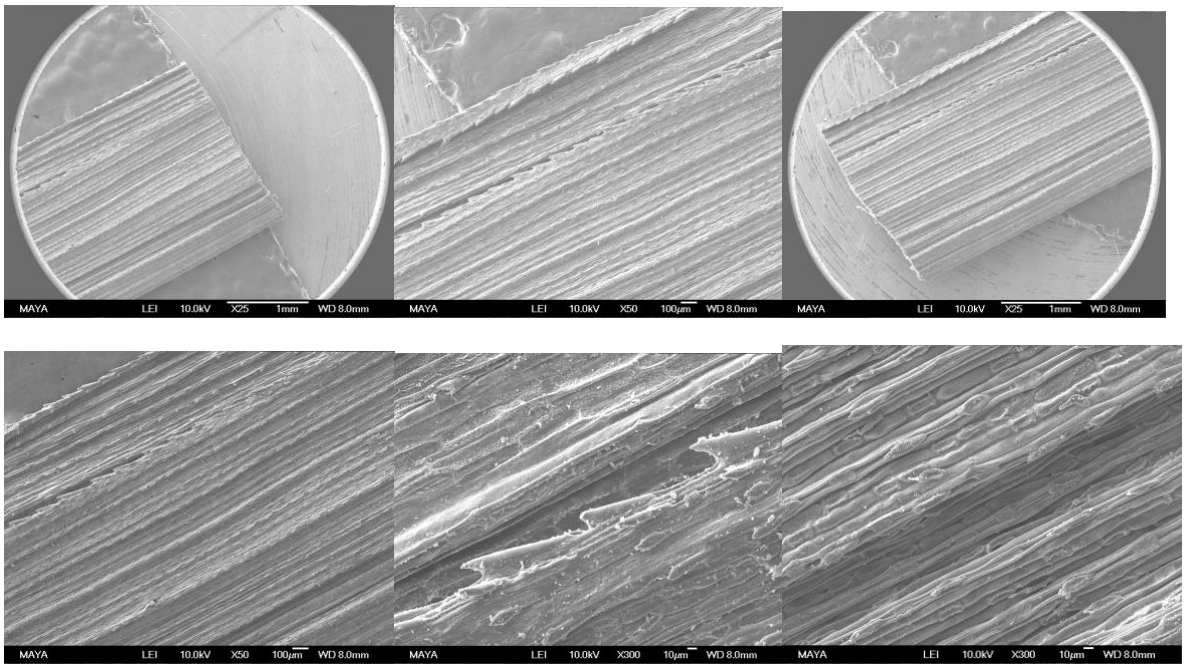

Figure A.8: *Additional SEM-images of the solar-dried sample*

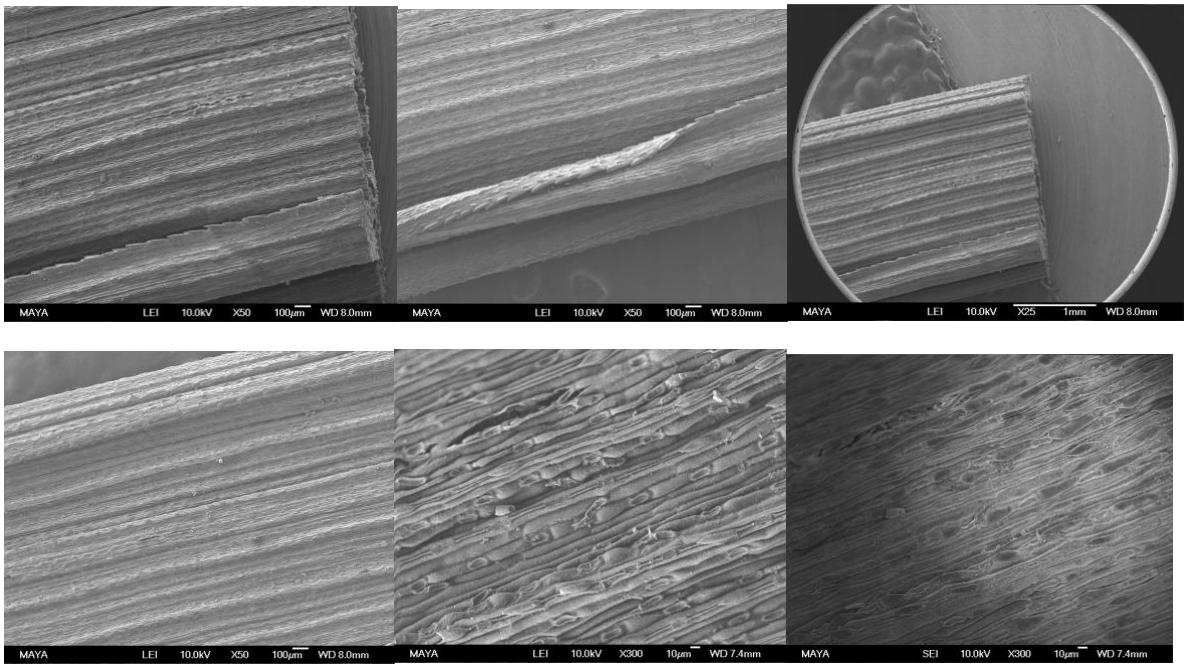

Figure A.9: *Additional SEM-images of the shade-dried sample.*

A.5. Microbial Evaluation

Figure A.10: *Countable plates used for calculated of CFU/g.*

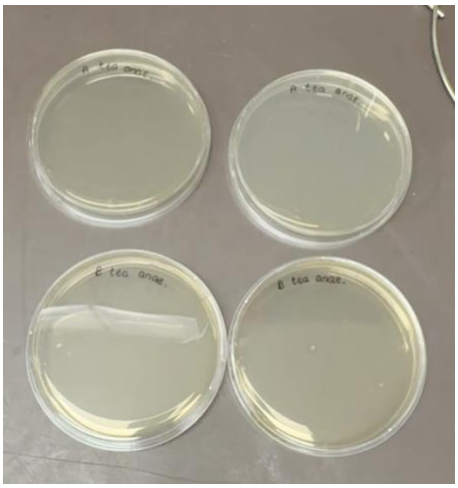

Figure A.11: *Plates of shade-dried and solar-dried teas incubated.*

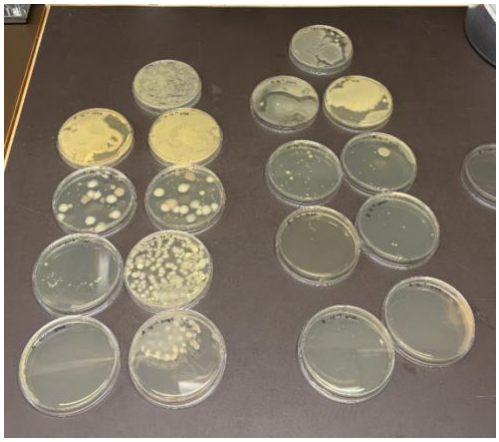

Figure A.12: *All plates of lemongrass leaves, including non-countable plates.*