Conventional and advanced packaging and storage technology of leek (*Allium ampeloprasum* var. *porrum*): A Review

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Abstract. Leek (*Allium porrum* L.), belonging to the Alliaceae family, is a biennial herbaceous plant. It is a tetraploid (2n=32). They are native to Middle Asia, while its secondary centres of development and spread were in Western Asia and the Mediterranean region. Kaempferol is the most significant flavonoid aglycone found in leeks. Leeks are also used as medicine in addition to being a food. The primary health advantages include anti-asthma, antiseptic, diuretic, antioxidant, antibacterial, and antifungal properties. Additionally, it helps shield skin from harm and lowers the risk of gastrointestinal disorders. Leek roots also contain alliin which is non-toxic to the human body and can be used to preserve food and increase its shelf life. Recent studies also reported that leek portions ultrasonic extracts can be used in the food sector to preserve products from oxidation. Furthermore, when frozen unblanched leek slices are packaged with nitrogen after a year in frozen storage, the amount of sulfur compounds in the slices does not increase and the development of an off flavor is inhibited. It can also be stored up to 14 days when stored at modified atmosphere. In conclusion, using contemporary biotechnology techniques, new leek cultivars with increased productivity and adaptability must be created. Other health-related substances like folates and polyphenols, as well as the quantitative assessment of enzyme activities should all be included in future research as they contribute to the potential health benefits of vegetable products.

Keywords: *Allium*; Leek; Nutritional value; Pharmaceutical property; Packaging: Storage

1 Introduction

Leek (*Allium porrum* L.), belonging to the Alliaceae family, is a biennial herbaceous plant [1]. Globally, Allium genus is one of the most significant crops of field vegetables. This genus, which contains over 700 species, is known to be a significant source of biologically active secondary metabolites [2]. With a vast distribution over the holarctic, from the arid subtropics to the boreal zone, the genus is primarily composed of perennial and bulbous plants [3]. According to Keller et al., (2012) [4], leek is a polyploid complex with diverse morphological and cytological characteristics that includes both wild and cultivated species.

It is a highly versatile vegetable crop that is grown all over the world due to its ability to withstand low temperatures and lack of reliance on photoperiod or bulb resting stage [5]. They complement meals subtly without overpowering other flavors because of their sweeter, more delicate flavor than onions. Grown leeks have a fragrant flavor akin to shallots, but with a slight sweetness [6]. They are propagated using seeds [7]. Leeks can be harvested after growing for 120 to 210 days, or when they are around half an inch and two inches (one to six centimeters) thick [8]. Less than ideal for long-term preservation, leeks must be consumed quickly or preserved using a variety of techniques, including freezing, drying, or cold storage [9,10]. Leek roots were also found to contain large amount of diallyl sulfides of the volatile oil, which were found to be responsible for antibacterial action [11-13]. Furthermore, it was found that the leaves of leeks have a rather high concentration of certain carotenoids [14].

1.1 Botany

Leek is a tetraploid (2n=32). Its reduced propensity to develop bulbs is the primary difference between onion and garlic. It is a robust herbaceous biennial plant that doesn't develop bulbs or produce cloves, but instead...
resembles big onion plants with flat leaves. Leeks are composed of basal leaf sheaths, which can range in length from 15 to 25 cm and a diameter of 5 cm. It is a tall, hardy biennial plant with broad leaves and white, narrowly ovoid bulbs [6]. Since leeks are self-compatible, emasculation of the flowers of plants to be used as female parents is required before hybridization in order to avoid selfing [15].

Fig 2: Botanical description of leek
Source: [17]

Rather than producing bulb like onion, leek produces a long cylinder of bundled leaf sheaths, and these are typically blanched by pushing soil around them (a process known as trenching). They are hardy plants that can be left in the ground throughout the winter and picked as needed. In their second year, leeks produce attractive flowers during the spring season. These flowers form in perfectly round clusters atop tall, leafless stems. Each flower cluster typically consists of numerous white, star-shaped flowers. On occasion, these flower clusters may contain small bulbs instead of flowers, which can be planted to yield leeks in the following year [16].

1.2 Origin and distribution

The origin of the leek can be traced back to the eastern Mediterranean region, where it was cultivated by ancient civilizations such as the Egyptians, Greeks, and Romans. Over time, it's cultivation spread to the middle of Europe. Some theories propose that the leek may also be indigenous to Europe and central Asia [18]. Although it thrives at higher elevations in India and Sri Lanka, humid weather is detrimental to its growth [6]. Leeks prefer optimal growth conditions characterized by abundant sunlight and well-drained soil enriched with organic nutrients. Sandy loam soil is considered ideal for their cultivation. They flourish in areas with mild, temperate climates during summer and benefit from minimal nitrogen supplementation [8]. It is grown extensively in Turkey, France, Belgium, and Poland [19]. In Wales, leeks are so highly regarded that they are used as the national symbol, and people wear them on St David's Day. Legend has it that in an old fight in a leek field against the Saxons, Saint David commanded his Welsh warriors to distinguish themselves by wearing the vegetable on their helmets. Leek is made up of four gene pools: Egyptian kurrat, great-headed garlic, European leek cultivars, and wild leek. The great-headed garlic plant has a robust appearance [20].

2 Nutritional value

According to Shubha et al., (2023) [21], leek offers significant amounts of vitamin C and folate, along with beneficial amounts of vitamin B, vitamin A, calcium, and iron. Anti-hepatotoxic and antifungal activities are also believed to be possessed by leeks [22]. The amino acids found in leek that are most abundant are arginine, alanine, glutamine, glutamic acid, and aspartic acid [23]. The high potassium and iron content of leek pseudo stem contributes to its excellent nutritional value [24] and significant biological activity linked to the exceptional concentration of antioxidants, including polyphenols [25], glucosinolates, S-alkenyl-L-cysteine sulfoxides which have antioxidant and anti-diabetic effects [26], and pectic polysaccharides [27], that are comparable to that of Allium cepa [28]. As a result, leek exhibits antimicrobial, cardioprotective, hypcholesteremic, hypoglycemic, antirheumatic, hypotensive, anti-anemia, and anticancer properties; additionally, it also enhances the functionality of the liver, intestines, and brain; lowers blood pressure; prevents platelet aggregation; and wards off prostate and neural tube disorders [29]. In a study conducted by [30], leek leaves exhibited higher levels of polyphenol content and antioxidant activity compared to the white and green stems. Research has indicated that the primary flavonoid aglycone in leek is kaempferol [31,32]. Agrobiological analysis of Allium ampeloprasum L. variety samples compared to Allium sativum L. cultivars was conducted by [33]. They found that garlic cultivars had significantly higher protein content and higher fat content compared to both Allium ampeloprasum variety samples, while Allium ampeloprasum variety samples had higher ash and carbohydrate content, which depended more on calorie content concluding that the Allium ampeloprasum L. had a higher nutritional value and an enhanced chemical composition. Owing to a potential correlation between sunshine exposure and the formation of polyphenols, extracts from green leek leaves had a higher total phenolic content than extracts from white leek stems [34]. Although leeks are considered as a common food, their health advantages are not well understood, and there isn't a comprehensive list of studies on leeks. In light of this, it is beneficial to look into recent developments and provide referrals to researchers in the subject, which will encourage leek applications and research in the future.

3 Pharmaceutical sciences

Leek is used as medicine in addition to being a food. Allicin, a compound found in leeks and other allium vegetables, has been related to better cardiovascular health and a lower risk of heart disease. The bulbs are utilized in traditional Brazilian medicine to cure symptoms of inflammation and the fresh juice is consumed raw and is said to have digestive qualities in addition to being an antispasmodic and stomachic [35].
Leek is also used as an aphrodisiac and as an appetizer. It has been reported that leek has been used to treat hemoptysis, headaches, constipation, obesity, asthma, and hemorrhoids [36]. The leek leaf extract (LLE), according to Ibrahim and Kenawy (2017) [37], has potent anthelmintic action and can be used to eradicate or inactivate fish infections caused by metacercairial parasites. [38] also demonstrated that leek extract can suppress immunological and non-immunological stimuli that may help stabilize mast cells in allergic reactions. The consumption of Allium could also reduce cardiac problems in future [39]. The expectorant properties of the saponins found in leek root bulbs can stimulate the mucosa in the stomach and subsequently increase the production of mucosa in the respiratory system allowing sputum to be diluted and eliminated [40,41]. Leeks have a complex yet beneficial health function that people are now aware of. In order to optimize their full potentiality, further research on their biological activity function and an examination of the interrelationships between various activity functions are still needed.

4 Application in food industry

The mild flavour and mucilaginous texture of leek makes them a versatile ingredient in soups and stews. In addition to being used as a garnishing agent in salads, it can also be substituted for garlic in Indian cuisines. According to the findings by Biernacka et al. (2022) [47], GL (green leek powder), at a maximum of 3 g per 100 g, can serve as a beneficial supplement to semolina flour for making pasta that has improved nutritional and health benefits along with palatable texture. [48] confirmed that AD (air dried) leek powder controlled the crumb hardness of the bread during storage when fortified by 1 g leek powder per 100 g flour. Furthermore, potato-based pellets that are enhanced with fresh leek pulp when fried results in less fat being absorbed [49]. Leek extracts can also be used to preserve products from oxidation [50]. Recent studies have also reported that leeks can also be used as a preservative to lengthen the shelf life of the cheese [51]. Moreover, leek roots contain alliin which is non-toxic to the human body and can be used to preserve food and increase its shelf life [52]. It has also been suggested that Allium ampeloprasum L. may enhance the tissue and sensory qualities of the product and help probiotics and helpful bacteria survive in inappropriate storage environments [53]. In conclusion, leek holds significant importance in the food industry due to its nutritional value, culinary versatility, and potential health benefits. However, further research endeavors are warranted to explore its full spectrum of properties and potential applications, thereby enhancing its utilization and contribution to the food industry.

5 Post-harvest technology

After harvesting, leeks should be quickly cooled to almost 0°C using vacuum cooling, crushed ice, or hydro cooling along with a relative humidity of 95-100%. Using a controlled environment (CA) at 0°C, they can be stored for 4-5 months with carbon dioxide content of 5–10% and an oxygen content of 1-3 percent. During sorting, they are categorized based on criteria such as size, stem thickness, straightness, leaf colour, surface blemishes, and uniformity within the bunch. Following sorting, the leeks undergo a thorough washing process using chilled water containing 150 ppm of hypochlorous acid, maintaining a pH of 6.5. Trimmed to a length of 12 inches, they are often bundled according to their diameter and packaged with polyethylene film bags. Typically, leeks come in wire-bound crates or 5 kg cartons that may hold 10 film bags each weighing 500 grams. Cutting the roots, removing the outer layer of rotted leaves, clipping the leaves and precisely cutting the stalks to length are examples of minimal processing for leeks.
5.1 Storage for shelf life

Leeks are perishable and they require proper storage conditions. If not handled and kept properly, they are susceptible to post harvest losses. They need specific conditions to stay fresh and high quality, including temperature, humidity, and airflow. Wilting, decaying and flavour loss can result from improper storage. Consequently, to increase the shelf life of leek and reduce food waste, proper storage condition must be maintained, including refrigeration at ideal temperatures and suitable packaging. [54], stated that the shelf life of the shredded leeks was extended when stored at low temperatures: 10 days at 10 °C and 20 days at 5 °C; the optimal shelf life of shredded leek was found to be 14 days when the ambient composition was 3-5% CO₂ and 3-5% O₂. When stored at ambient temperature, the shelf life was decreased to 3 days.

Table 2: Storage requirements for shelf life of leek

<table>
<thead>
<tr>
<th>Storage</th>
<th>Requirements</th>
<th>Shelf-life</th>
<th>References</th>
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</thead>
<tbody>
<tr>
<td>Cold storage</td>
<td>Ascorbic acid treatment (AA) (1%-2%) stored at 0 ± 1 °C and 90 ± 5% relative humidity (RH)</td>
<td>30 days</td>
<td>[59]</td>
</tr>
<tr>
<td>Low temperature storage</td>
<td>4°C</td>
<td>9 days</td>
<td>[60]</td>
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<tr>
<td>Cold storage</td>
<td>0 °C and 90 ± 5% relative humidity, leeks treated with oxalic acid</td>
<td>50 days</td>
<td>[61]</td>
</tr>
<tr>
<td>Refrigerated storage</td>
<td>Carboxymethyl cellulose (CMC) coating at 5 ±1°C and 85-90% relative humidity</td>
<td>20 days</td>
<td>[62]</td>
</tr>
<tr>
<td>Refrigerated storage</td>
<td>Leeks treated with salep based coating stored at 4°C</td>
<td>6 days</td>
<td>[63]</td>
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[55] further disclosed that the green leaves and white shaft of the whole packaged leek did not suffer any adverse effects from 13 days of refrigerated storage at 4 °C in terms of their antioxidant capability or total phenolic content. According to Gariepy et al. (1994) [56], in comparison to regular atmosphere (RA) and high relative humidity (HRA) storage, leek yields minimally processed leek such as inner leaf growth, discoloured cut surface and fresh weight loss can be minimized when stored at 0°C [58]. Therefore, delving deeper into the physiological and biochemical changes occurring during storage, particularly regarding moisture content, respiration rate, and enzymatic activity, can provide valuable insights into optimal storage conditions and preservation methods.

6 Packaging for shelf life

Packaging methods aim to prolong the shelf life of food items, thereby increasing their accessibility, affordability, and appeal to consumers. Enhanced shelf life, ensured safety, and improved quality are key attributes of packaging materials, which can help mitigate postharvest losses of fruits and vegetables [64]. Leeks are highly sensitive to their choice of packaging materials due to their perishable nature, making them susceptible to quality deterioration that can significantly affect their shelf life. Commonly used packaging materials for vegetables include HDPE and LDPE, among others. Low-density polyethylene (LDPE) is preferred for flexible films due to its softness, flexibility, and stretchability. LDPE films find application in packing various foods such as fresh and frozen produce. In contrast, high-density polyethylene (HDPE) offers high stiffness and hardness, providing effective barriers against gas and water permeation [65]. Modified atmosphere packaging (MAP) was initially developed for preserving fresh produce. It can be viewed as either an active or passive system for adjusting the gas concentration within food packages. In the passive method, the natural gases present in the package initially interact with the product's respiration rate and the packaging's gas permeability to achieve the desired atmosphere. In contrast, the active approach involves introducing specific gases into the packaging to quickly establish the desired atmosphere [66]. According to Mei-ting et., al (2023) [67], leeks stored in MAP at 4°C showed reduced respiration rates, maintained elevated chlorophyll levels, and experienced an increase in peroxidase activity. [68] examined the microbiological, physicochemical, and sensory characteristics of raw, ready-to-eat leek in relation to modified atmosphere packaging (MAP) and disinfection. The findings demonstrated that leek quality might be well preserved during storage by using MAP along with disinfection. Another finding by [69] stated that P-Plus films (made of polypropylene), which have a lower permeability than PVC film (polyvinylchloride), might be better at preserving the quality of leeks during storage. Polypropylene is a type of plastic material created through the catalytic addition of propylene monomers to form a polymer [70]. The P-Plus films did not significantly lose weight when packed in batches, and the films’ light-exposure characteristics remained the same (18 days). When leeks were transported in wooden bulk packaging, they exhibited lower percentages of wilting, physical damage, and weight loss (%) with low respiration rate thereby leading to low ethylene production while maintaining a higher visual quality grade [71]. Leeks packed in moisture-retentive polyethylene bags, whether perforated or not, can significantly reduce weight losses and ward off wilting [72]. Furthermore, [73] study revealed that when frozen unblanched leek slices are
packaged with nitrogen after a year in frozen storage, the amount of sulfur compounds in the slices does not increase and the development of an off flavor is inhibited. Future research endeavors should focus on exploring novel packaging materials, such as biodegradable films and smart packaging systems, tailored specifically to the unique characteristics of leeks. In conclusion, more research on packaging of leek holds tremendous promise and significance in enhancing the overall quality, safety, and sustainability of this versatile vegetable throughout the supply chain.

7 Future prospects

In the realm of future prospects, leek stands as a promising subject warranting further exploration and research across various domains. It is increasing its importance in various countries. From its nutritional value to its pharmacological benefits, leek presents a plethora of avenues for investigation. Firstly, studies into the pharmacological properties of leek constituents have shown potential in areas such as anticarcinogenic, antidiabetic, and antimicrobial effects. These properties could pave the way for the development of novel therapeutic interventions in areas ranging from chronic disease management to skincare products. Moreover, leek’s rich nutritional profile, including vitamins K, vitamin A and folate highlights its potential in addressing nutritional deficiencies. Further research into the quantitative assessment of enzyme activities, its specific nutritional benefits, bioavailability of nutrients, and potential role in disease prevention could provide valuable insights for public health initiatives. Also, using contemporary biotechnology techniques, new leek cultivars with increased productivity and adaptability must be created. Additionally, exploring the culinary and gastronomic aspects of leek could lead to innovative food formulations and culinary techniques, enhancing its appeal and consumption.

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Conflict of interest

There is no conflict of interest.

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