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Javanese long pepper (*Piper retrofractum* Vahl.): botanical, cultivation, post-harvest and utilization review

Diana Nurus Sholehah [1*], Millatul Ulya [2]
[1] Study Program of Agroecotechnology, Faculty of Agriculture, University of Trunojoyo Madura, Jl. Raya Telang, Bangkalan 69162, Indonesia
[2] Study Program of Agroindustrial Technology, Faculty of Agriculture, University of Trunojoyo Madura, Jl. Raya Telang, Bangkalan 69162, Indonesia
* Corresponding Author

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ABSTRACT

The relevance of researching Javanese long pepper from several aspects has increased due to the growing number of medicinal plants used for industrial and personal purposes. Knowledge of botany, agronomy, growth, chemistry, and their utilization is expected to aid in developing and using long pepper. The purpose of this study is to compile the knowledge currently accessible on their botany, agronomy, growth, and chemistry, and their benefits are expected to help the future development and utilization of Javanese long pepper. Scientific publications from electronic databases, including Scopus, Web of Science, Science Direct, PubMed, and Google Scholar, comprise the literature review. These studies make it possible to justify the usage of herbal plants and discover new chemical compositions and pharmacological activities. However, further study on cultivation improvements to increase production and the content of efficacious active compounds is needed, and their detailed usage in the industrial sector is still rare. Furthermore, additional study on isolating active compounds and pharmacological testing from plant components other than long pepper fruit is required.

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1. INTRODUCTION

Piper retrofractum Vahl belongs to the *Piperaceae* family, widespread in tropical areas. Over a thousand species belong to the Piper genus [1]. The species of *Piperaceae* well-known in rituals and traditional medicine in Indonesia is betel (*Piper betel* L.). Along with pepper (*Piper nigrum* L.), *P. retrofractum* is a member of Piper with high economic value. Both *P. retrofractum* and pepper are aromatic herbs. However, *P. retrofractum* has a harsher aroma than pepper and is famous as a medicinal plant, while pepper is a food spice [2]. Southeast Asian countries like Indonesia, Thailand, Malaysia, Philippines, and Vietnam are the origins of this plant. Additionally, it can be found in Yunnan and the Ryukyu Islands in Japan, Guangdong in China, and Kampuchea [3].

Synonyms of Piper retrofractum are Chavica maritima Miquel, Chavica officinarum Miquel, Chavica peepuloides Wight, Chavica retrofracta (Vahl) Miq., Piper chaba Hunter, Piper longum Blume non L, Piper officinarum (Miquel) C. DC. The vernacular name for P. retrofractum is India: cabya, Indonesia: cabe jamu (general), Lada Panjang (Sumatra), Cabia (Sulawesi), Cabe jamu, Cabe Jawa (Java), Malaysia: Lada Panjang and Thailand: Dipli. The common names are Balinese Pepper, Jaborandi Pepper, Java Pepper, Long Pepper, Java Long Pepper, and Javanese Long Pepper [3]. Long pepper is a frequently used common name. The naming was given due to its pungency, like pepper, but has an elongated shape with an upward growth direction resembling chilies [4], [5], [2]. Although it is stated that P. longum is a synonym of P. retrofractum, Babu et al. [6] stated that there are differences between the two. P. longum is the Indian long pepper, while P. retrofractum is the Javanese long pepper. The fruits of the Javanese long pepper (P. retrofractum) are larger and less pungent than the Indian long pepper (P. longum). It also has sparser-appearing foliage than those of P. longum. The spike of P. retrofractum is conical, while P. longum is cylindrical [6], [2].

The long pepper fruit has unique properties. Despite its sweet and aromatic scent, the flavor is bitingly hot, persistent, and dull. Long pepper is three times more popular than black pepper and was likely known in Europe long before it became the main spice. Roman cuisine benefited greatly from this ingredient's spicy and sweet combination because the Romans loved both flavors. Long pepper cannot be replaced by regular black pepper because terpene compounds are absent from its scent [6].

Long pepper is one of about 22 Piper species listed as herbal medicines and herbs worldwide [5]. As a traditional medicine, it is considered by the Indonesian Agency of Drug and Food Control (NA-DFC / BPOM) to be one of nine primary medicinal plants [7]. The utilization of long pepper fruit in simplicia is ranked sixth in the top 10 primary raw materials used by the Indonesian traditional medicine industry, approximately 9.5% of the total simplicia. The use of this simplicia shows an average annual increase of 20.81% in the period 1985-1990. The need for long pepper for the variety uses of medicinal plants is 47.73% [8]. Indonesia supplies one-third of the 6 million people who need long pepper [9]. The cultivation in Indonesia has been widely held in the yard and a large farm for commercial trade on the market [10] in some areas, including Java, Sumatra, Bali, Nusa Tenggara, Kalimantan, and Sulawesi. The main cultivated centers of Indonesia are Madura Island, Lamongan, and Lampung [11]. The exports of this commodity reach Malaysia, Singapore, China, Europe, and the United States as spices [2].

The increasing number of medicinal plants for industrial and personal needs has encouraged the importance of studying long pepper from Indonesia from various aspects. Knowledge of botany, agronomy, growth, chemistry, and their benefits is expected to help the future development and utilization of Javanese long pepper. Scientific publications from electronic databases including Scopus, Web of Science, Science Direct, PubMed, and Google Scholar make up the literature used in the review.

2. BOTANY

Most of the Piper Genus are climbers, although some are shrubs and a few are trees. Like pepper, this plant is a perennial, climber, or creeper on rocks or soil, with branches reaching up to 0.5 m and a height reaching up to 10 m [1], [2]. This plant has fibrous roots [12].

The distribution of long pepper in several regions in Indonesia allows for diversity, which can be caused by genotype, growing environment, and cultivation technology [13] The diversity of long peppers can be seen from the characteristics of their leaves and fruit [4].

The stem is cylindrical, soft, woody and striated. The color of the stem varies greatly, from black and brown to blackish brown. The stem color that is often found in every location is blackish brown. The length of the main stem is 2.93-9.82 cm, with a diameter of 2-7 mm [11], [14], [12]. The stem nodes have adhesive roots with a firm adhesion to concrete walls or rock. The adhesive roots are between 0.7-1.0 mm in diameter and 1-2.5 cm long, with a numbering between 4-9 pieces. The newly emerged adhesive roots are white and turn brown. Roots that do not find an attachment place will dry out [12]. Long pepper has monopodial branching with two types of branches: orthotropic and plagiotropic. Orthotropic branches or climbing branches grow vertically with 6-8 cm length, have more adhesive roots at the nodes, and, when mature, have rough spots. Plagiotroph branches or fruit branches grow horizontally, have shorter segments of 2,08 – 8,02 cm in length, and are fruit-bearing branches. The colors are green, dark green, and dark green. The green color is often found in most locations. Apart from these two branches, there are ground branches, which are branches from the main stem that grows along the ground and have adventitious roots at each node. It has leaves and stems that are smaller than both branches. If it finds a climbing spot, this branch will return to a normal orthotropic branch and form a new tree [11], [8].

Leaves' characteristics show variations in leaf shape, length, width, thickness, length of leaf stalks, and number of leaves per branch [8]. The number of leaves on this plant is 3.95-14.46 per branch. It is correlated with the probability of fruit forming, so the growth in the number of leaves can be used to predict fruit number. The leaves are green to dark green, glabrous, simple, and alternate [2], [14]. The shape is generally lanceolate, but some are ovate and oblong, measuring 4,33 – 14,22 cm long and 2.35 – 8,28 cm wide. The size of the leaves is broader and shorter than the long pepper leaves found in Thailand [1], India [6], other countries in Southeast Asia [15], and Asia [3]. The petiole is 0.2-1,72 cm long. The basal part of the leaf is cordate, acute, or obtuse, with the apex of the leaf being acute to acuminate. Leaf veins pinnate. The leaves on orthotropic branches are symmetrically curved, while those on plagiotropic branches are asymmetrically curved [11], [4].

The flower is monoecious or dioecious. The flower is erect or slightly pendulous and has a slightly fragrant aroma. The inflorescence is a pedunculated spike of unisexual, tiny, densely packed flowers. The spike grows on the node of the plagiotroph branched stem opposing the leaf with a 1-2 cm long peduncle [4], [2]. The spike has a diameter of 0.3-0.5 cm, while the length of the male and female spikes has different lengths. However, there is insufficient data regarding the size of male and female spikes originating from Indonesia [12], [2]. The flower emergence to fertilization, indicated by dried-up flowers, takes 15-30 days [12].

The fruit grows in a variety of sizes and shapes, including short, round (globular), elliptical (conical), flat length (filiform), and petite lengths (cylindrical) [14]. Cylindrical fruit has a length of 2 - 8.24 and a 3 - 11 mm diameter. The largest fruit size was obtained from Sumenep Regency, Madura Island [11]. The rest of the petals of this species are prominent, which is a distinction from other pepper species. Young fruit is green, then turns brown, orange, and red when ripe. The fruit will fall after it is ripe, characterized by its dark red color and soft flesh. The right harvested time will produce suitable fruit hardness with a distinctive spicy taste [4], [2]. The fruit contains 10-101 globose and yellowish-white seeds with a diameter of up to 1 mm. The fruit ripening process can take 1.5-2 months [12].

2.1. Growing condition

The environment is an essential abiotic factor in plant growth and production. Climate influences 82% of long pepper production [16]. Long pepper requires high humidity, high rainfall, frequent irrigation, and partial shade for good growth [6]. However, it has good adaptability to unfavorable environmental conditions such as dry climate, less fertile soil, and acid to alkaline soil pH (pH 4-8) [4], [3].

In Indonesia, Long pepper grows in coastal areas up to 600 m above sea level. It is also found at an altitude of 50-700 meters above sea level in Thailand [1] and 0-1000 meters above sea level in India [6]. Most of the cultivation centers of long pepper in Indonesia are dry areas such as East Lampung, Lamongan, and Madura Island. The climate type (Schmidt and Ferguson) of Lamongan is C and D, Madura is C, D, to E [12] while East Lampung is C [4]. In these cultivation areas, sometimes there are long dry months with 6-7 months, but generally, they have 5.7-6.8 wet months [8]. The desired rainfall ranges from 1250-2500 mm per year, but it can survive well at lower rainfall, 960 mm/year [16].

The growth occurs at 40-80%, but optimal humidity is 80-90%. The optimal light intensity is 50% ± 75% [6], [9], [16]. This plant requires sandy loam, light, porous, rich in organic content, and well-drained soil. Long pepper cultivation in Madura is carried out on sandy soil and sandy clay [12], while in Lampung, it is carried out on red and yellow podzolic soil. In India, these plants are grown on acidic soil such as laterite soil, which has abundant organic matter and moisture-holding ability, black cotton soil with good drainage, and alkaline soil such as limestone soil [6]. Long pepper also grows well in other soil types, namely andosol, grumusol, latosol, and regosol, including shallow and rocky soil layers [17].

2.2. Agronomic aspect

The plant utilization as raw materials of pharmaceutical preparations need to be supported by adequate upstream technology so that the quality of the simplicia and extracts used in the pharmaceutical industry is qualified and standardized. Upstream technology includes the plant species/varieties, growing environment, plant parts, cultivation technology, harvest time, and post-harvest treatment [18].

a. Propagation

Propagation is carried out generatively and vegetatively. Vegetative propagation is preferred because of its lower genetic variations than generative propagation [5]. Vegetative propagation is generally carried out by cuttings from climbing, fruit, and ground branches [19]. Seedlings originating from climbing branches have the highest seedling growth rates. The success rate for breeding climbing branch cuttings is around 75%, ground branch cuttings 66%, and fruit branch cuttings 38%. The climbing branch cuttings have broader leaves and longer roots than other branches [8], [19]. Seedlings from ground branch cutting give a higher elongation rate, but the stems have slower enlargement and fruit branch formation [4]. However, it is easy to obtain in all seasons, especially during the rainy season, and their collection does not interfere with plant production [20], more resistant to drought and has a longer lifespan than cuttings from another branch [17].

Fruit branch cuttings have the lowest seeding rate. However, [4] stated that using treaded fruit branch cuttings containing climbing branch nodes may increase the seedling rate [8]. This seeding uses a fruit branch containing 3-7 segment spike buds in its shoots [17].

Cuttings from fruit branches for seedlings are rarely used in large-scale planting because their productivity is low, even though they bear fruit quickly. Seeds from fruit branches are suitable for ornamental plants in pots.

Apart from that, another difference in the characteristics of these planting materials is that climbing branches require shade to grow optimally, while fruit branches grow better in sufficient light [17], [20].

The cutting plant material usually comes from a year-old long pepper. The cuttings used are 3 internodes long, and the time required for the seeds to be ready for planting is 1-3 months. Apart from the type of branch, the part of the branch used for cuttings also affects the seedling growth rate. It is related to the growth hormone content contained in plants. The shoot and top parts of plants contain higher levels of the hormone auxin than other parts to stimulate tip growth [21].

b. Cultivation

Long peppers are climbers and require 25-50% shade for optimal vegetative growth [9]. Its cultivation requires other plants as climbing poles as well as shade. The diameter and height of climbing poles correlate with canopy growth and production. The larger a climbing tree's diameter, the greater the attachment area of its attached roots, thereby increasing the formation of branches and crowns [22]. The climbing trees used can be existing productive trees or trees deliberately planted by vegetative propagation [4]. Types of trees commonly used as climbing trees on the island of Java include moringa (*Moringa oleifera* Lamk), kelandingan (*Leucaena leucocephala*), dadap (*Erythrina* sp), kedondong (*Spondias dulcis*), jaranan (*Dolichandrone spathaceae* (L.) f.K. Schum), soursop (*Annona muricata*), palm fruit, coconut, neem (*Azadirachta indica*), noni (*Morinda citrifolia* Linn.). Research shows high fruit productivity is obtained from siwalan and coconut climbing poles. However, these plants are not an option for intensive cultivation because of the difficulty of controlling plant height and the long planting time [22]. Currently, the climbing trees often chosen in Madura are Moringa and Jaranan trees because of their ease of propagation pruning and their high level of use other than for climbing poles, for example, as animal feed, vegetables and traditional medicine [22], [23]. Meanwhile, the climbing trees widely used in Lampung include pepper and vanilla climbing trees such as the gamal (*Gliricidae sepium*), usually used as a pepper climbing plant. Apart from that, other plants that are often used include kapok (*Ceiba pentandra*), petai (*Perkia speciosa*), kedaung (*Parkia roxburghi*), coconut (*Cocos nucifera*), and cloves (*Syzygium aromaticum*).

The preparation for approximately 2 m high climbing trees is simultaneous during seedling but ideally carried out 10-12 months before the cuttings are transplanted to the field. It is useful for climbing trees with deep roots and sufficient shading effect. Climbing trees are planted at a space of 1.5-2.0 m. Each climbing tree contains 1 – 3 long peppers. Preparation for climbing trees approximately 2 m high can be done at the same time as seeding, but ideally, 10-12 months before the seeds are transferred to the field. It helps climb trees with deep roots and sufficient shading effect. Climbing trees are planted at a distance of 1.5-2.0 m from each other. Seedlings are planted near climbing trees at 20 – 30 cm from climbing trees. Each climbing tree contains 1 - 3 herbal chili plants [17].

Increasing plant productivity can be done by pruning long peppers and climbing trees. Long pepper pruning aims to increase the number of productive branches by climbing branches and ground branches pruning. Climbing branches should be kept at a height of 2 m to facilitate maintenance and harvesting. Climbing branches not attached to the climbing tree and growth hanging from the canopy are unproductive and must be pruned [17]. The planting of climbing trees must be done regularly, especially during the rainy season, to prevent pest and disease transmission, prevent excessive shade, and maintain a suitable microclimate for plants [8].

Fertilizing long pepper still uses the recommendations for pepper fertilization with several modifications based on previous research. Fertilization is often done by providing cow dung fertilizer. Ruhnayat et al. [18] reported that applying 15 kg drum fertilizer/tree/ year can increase dry fruit production by 6.3 tonnes/Ha/year. Fertilizing with doses of Urea, SP36, and KCl of 0.25 kg/ha each and 25 kg/ha of manure will increase yields more than twofold [8]. Hasanah and Setiawan [24] reported that giving 60 g NPK/climbing tree to 1 and 2-year-old long peppers increased fruit number wet and dry fruit weight.

Pest and disease attacks on long pepper are similar to pepper but have relatively low intensity. The foot rot disease caused by *Phytophthora* sp occurs in months with high rainfall, high air humidity, and high moisture content in planting media due to the coverage of the canopy to the planting media [20]. Long pepper from Lampung is the most susceptible to pest and disease attacks, while the Javanese long pepper from Lamongan is the most resistant. Another disease is the nematode *Radhopholus similis,* which significantly inhibits plant growth. Symptoms of this attack on the leaves are yellowing, stiffness, drying, and falling leaves. In severe attacks, similar symptoms also occur on the stems, damaging root hairs and increasing susceptibility to Fusarium sp. infection, increasing sensitivity to drought and nutrient deficiencies [25]. Pest and disease prevention attacks can be made by maintaining the microclimate around plants by adjusting the canopy, pruning climbing plants regularly, and weeding.

Long pepper is often intercropped with other plants. In Lampung, it is generally planted together with pepper. Intercropping is done between rows of long pepper with secondary crop species. This cultivation method increases land productivity effectively [8]. Meanwhile, intercropping on Madura Island is done with a combination of green beans-long pepper-siwalan and eggplant-banana-papaya-long pepper-coconut-moringa [16].

c. Harvest

The plant bears fruit all year round. The type of branch used for propagation cuttings determines the timing of the first harvest. The first harvest of plants from climbing branches occurs faster at 1-2 years compared to plants from ground branches, which occurs at 3-4 years of age [17], [24]. Before bearing fruit, plant material from ground branches undergoes two stages of branch formation, including climbing branches and fruit branches. The use of climbing branches is only one stage of branch formation, namely fruit branches before fruiting [11].

The interval between the first and next harvest ranges from 15 – 25 days, depending on rainfall. Harvesting is carried out continuously 3 – 5 times a year. If the rainfall is high, the harvest interval is closer. The lower the rainfall, the longer the harvest interval [24]. The first production reaches 0.5 kg of dried fruit per climbing tree. Peak fruit production produces 1.5 kg of dried fruit per climbing tree per season. Fruits are harvested at the orange stage. Harvest delay at red-stage fruit changes volatile compound compositions and reduces essential chemical compounds such as phenol, piperine, and other antioxidant compounds [26], [27], [28]. It has softened fruit flesh, having a short storage life and increasing post-harvest process difficulties [4].

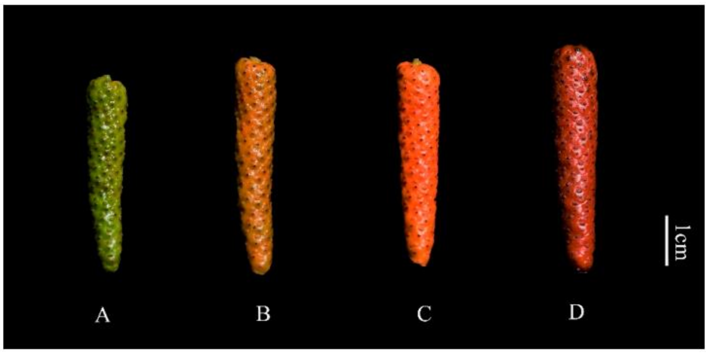

Fig. 1. Ripening stage of long pepper fruit. (A) Green stage, (B) Color-breaking stage, (C) Orange stage, (D) Red stage. Source: [28]

2.3. Post Harvest

a. Blanching

Because of their high moisture content (67-75% (wb), long pepper fruits are perishable and sensitive to quick damage when incorrectly managed after harvest [27]. Generally, the drying process is carried out to avoid fruit damage due to the activity of phytohormones in the form of ethylene gas in herbal chilies. In Indonesia, farmers harvest long pepper when it is ripe and reddish-orange, then blanch it as a pre-treatment, and then dry it with open sun drying. Farmers often handle long pepper fruit after harvest by drying it in the sun for three to four days after blanching it. Farmers claim that blanching in hot water accelerates the drying process. Due to its ease of use and low cost, hot water blanching is the most widely used and commercially adopted approach [29].

Fruit that undergoes pre-blanching treatment experiences a shorter drying time, thereby removing significantly more moisture from the fruit. For example, after six hours of drying, the fruit that underwent pre-blanching treatment had an average moisture content of 21.43±4.94% (wb), while the fruit that skipped the pre-blanching treatment had an average moisture content of 54.37±2.69% (wb). After 18 hours of open sun drying, the long pepper fruit's final average moisture content and drying rate were significantly impacted by the blanching pre-treatment; the fruit had a lower final average moisture content and a greater drying rate [30].

b. Drying

The harvest is then dried to obtain dried Javanese black chilies that can be stored for a long time. The yield of dried fruit compared to fresh fruit ranges from 25 to 33% [4]. The growth of spoilage bacteria and enzymatic and non-enzymatic chemical processes in the matrix can be inhibited by drying long pepper. Hot air drying is the most inexpensive and straightforward method of producing dried fruits and vegetables. As a result, it is frequently used for this purpose [31]. The drying process may reduce or remove potential issues, including the development of microorganisms and enzymatic and non-enzymatic chemical interactions. This procedure may also increase the product's shelf life. Table 1 shows a few kinds of research executed to assess the pepper fruit's drying process using different techniques.

Table 1. The studies of long pepper drying methods and pre-treatment

Drying methods and pre-treatment	Research goal	Results	References
Hot water blanching under an indirect forced convection solar dryer	evaluates the drying behavior, drying kinetics model, and shrinkage of the long pepper fruit	The moisture content of long pepper fruit decreased to 6% (wb) and 9% (wb) with and without hot water blanching.	[31]
Blanching pre-treatment and open sun drying	evaluate moisture removal characteristics and develop a thin layer drying kinetics model that represents the drying behavior of long pepper fruit when dried in the open sun	Blanching pre-treatment significantly impacted drying behavior, including final moisture content, drying rate, and drying kinetics. Midilli et al.'s model was determined to be the best at depicting long pepper fruit drying kinetics among the twelve drying kinetics models examined.	[30]
Hot air-drying method at 70°C for 18 hours	examine the water content and drying rate of long pepper at three distinct phases of maturity, denoted by the colors green, orange, and red, as well as the piperine, antioxidant, and reducing sugar after drying.	Dried red long pepper has the most extensive water content, fastest drying rate, and maximum reducing sugar level, whereas green and orange long pepper have fewer piperine and antioxidant activity.	[26]
Sun-drying, oven-drying, roasting and steaming	investigate the effects of processing on the volatile aroma elements of hihatsumodoki fruits (sun-drying, oven-drying, roasting, and steaming).	The aroma properties of roasted (180°C), steamed, and steamed-dried fruits differed from the control. Maillard reaction products like furans and furanone were produced during high-temperature roasting, which might give delicious caramel aromas.	[32]
Blanching and oven-drying	to investigate physical (dimension, weight loss) changes of long pepper dried in the oven-drying at 80 °C for 2, 4, and 6 h.	The drying method resulted in significant changes in long pepper between pre- and post-drying (color image, length, diameter, and water activity)	[33]
Blanching and solar drying	to investigate drying rate, mathematical modeling of drying curve, and physical features as parameters for developing the drying method of long pepper fruit using a solar dryer.	Blanching pre-treatment causes long pepper fruit to lose moisture more quickly than nontreatment long pepper fruit. The drying rate of long pepper fruit reduced as drying duration and moisture content were increased. Midilli et al. were the best-fitting model in this study.	[34]
Freeze drying	investigated the freeze-drying characteristics of medicinal plants and assessed the quality of freeze-dried products.	The drying time was affected more by chamber pressure and freezing rate than by the product's surface temperature. Higher chamber pressures and higher freezing rates tended to reduce the primary drying time while increasing the secondary drying time. The freeze-dried product was somewhat lower in quality than the raw material but higher than when oven-dried at 35-40°C, and it met the MMI criteria.	[35]
Solar and oven-drying	Evaluated effects of solar and oven-drying on physicochemical and antioxidant characteristics of fruit	The drying circumstances affected the fruits' color characteristics (Hunter a* and b* values). Solar drying for 18 hours and oven drying at 90 °C for 6 hours significantly reduced total phenol content and DPPH radical scavenging capabilities.	[36]

c. Chemical content

The principal chemical compounds isolated and identified from *P. retrofractum* include amides, alkaloids, phenylpropanoids, alkyl glycosides, and lignans [37]. Jadid et al. [38] have reported that the long pepper fruit included 63.4% of carbohydrates, 11.4% of crude protein, 4.29% of total ash, 28.8% of dietary fiber, and 2.97% of total fat. Calcium, copper, iron, magnesium, phosphor, potassium, sodium, and zinc were also found in varying amounts in the fruit. Both n-hexane and ethyl acetate extracts included quinone, sterol, glycosides, and alkaloids. Furthermore, tannin was found in ethylacetate and methanol extracts. Meanwhile, sterols, glycosides, flavones, tannins, and alkaloids were found in methanol extract. The results also demonstrated that the fruit's methanol extract had the most phenol compared to other extracts.

Extracted bioactive metabolites from long pepper fruits have been identified as having an alkaloid component and an amide derivative with antifungal, antiflatulent, antitussive, expectorant, and appetizing characteristics. Furthermore, it has been discovered to have gastroprotective and cholesterol-lowering characteristics, which may be valuable in traditional medicine [39], [40], [41].

Javanese long pepper from Sumenep Regency has an oil content of 1.56-1.66% [42]. Meanwhile, the results of exploration in 2003 [43] showed that the piperine, oleoresin, and essential oil content of Javanese long pepper from several production centers also varied. The highest piperine content (17.24%) was obtained from Bali province, with oval, flat, and small fruit with yellow color. Meanwhile, the highest essential oil content (1.40%) was obtained from Pamekasan Regency. Javanese long pepper from Sumenep has the most incredible oleoresin level, at 6.10% [11] [43].

Several previous studies have discussed the chemical content of *Piper retrofractum* vahl, which is summarized in Table 2. Almost all parts of the long pepper plant contain beneficial active compounds.

Table 2. Several previous studies of long pepper chemical content

Plant parts	Method	Chemical content	References
Leaves	Aqueous extract	Flavonoids and saponins	[44]
	Dried leaves	Terpenoid compounds	[45]
		Flavonoids, tannin, quinone, and steroid/triterpenoid	[46]
Fruits	Fruit extract	Three new amides, (2E,14Z)-N-isobutyleicosa-2,14-dienamide, dipiperamides F and G together with 30 known compounds	[47]
		Piperine, methyl piperate, sylvatin, and piperlonguminine	[48]
		32 compounds, including 24 known compounds, two new amides ((E)-N-cinnamoyl-2-methoxy piperidine and (R)-1-(2-oxopyrrolidin-3-yl)-5,6-dihydropyridine-2(1H)-one), four new amide glucosides (retrofractosides A–D) And two new phenylpropanoid glucosides (retrofractosides E and F)	[49]
Stem	n-hexane and methanol extract	Sesamin (lignans), pellitorine (amide), piplartine (amide) compounds	[50]
Essential Oils	Extracted Fruit	*germacrene D* (24.20%), *tetramethylcyclo [5.3.1.0 (4.11)] undec-8-ene* (17.73%), *Ar-turmerone* (11.55%) and *benzyl benzoate* (6.28%), *α-cubebene* (3.55%), *β-cubebene* (2.59%), and *β-cadinene* (2.49%) as well as sesquiterpene alcohol curlone (2.67%) and derivatives of phenyl propanoate, 2-methoxy-4- (2-propenyl) –phenol (2.05%) showed a content between 2-4%	[51]
	Dried seeds and fresh leaves	Caryophyllene, beta-selinene, germacrene D, naphthalene, undecane, 5-octadecene, cyclohexene, limonene, and 2-beta-pinene. Both essential oils included limonene, linalool, caryophyllene, and naphthalene.	[52]
	Leaves	The major components were monoterpene hydrocarbons (34.4%) and benzyl benzoate (14.4%) as the major. component	[53]
	Leaves	21 components and dominated by ocimene (15.6%) and linalool (12.9%)	[54]

3. UTILIZATION

3.1. Health

The Long pepper has antioxidant, hepatoprotective, cytotoxic, larvicidal, antiproliferation, antitubercular, antileishmanial, antiphotoaging, and anti-obesity effects [37]. It has potential nutritional and phytochemical properties, supporting its pharmacological use. The plant's medical uses are linked to its phytochemical composition, which includes alkaloids, saponins, tannins, flavonoids, steroids, terpenoids, and glycosides [1]. Flavonoid compounds identified from other Piper plants, such as *Piper crocatum*, have anticancer, antimicrobial, and anti-inflammatory properties. Alkaloid compounds have also been discovered to have powerful antineoplastic effects, inhibiting the uncontrolled proliferation of cancer cells [55]. Regarding biological activity, *P. retrofractum* has been utilized to stimulate blood circulation and treat influenza and hypertension [3]. *P. retrofractum* has also been employed for its antiobesity activity [56] (Kim et al., 2011), expectorant, antifungal, and palatable properties [57]. Recent research has also shown that *P. retrofractum* is an anti-inflammatory agent [56].

In Indonesian traditional medicine (*jamu*), the long pepper fruits are used as a tonic to treat intestinal, stimulant, hypnotic, and digestive diseases [47]. Because of its biologically therapeutic properties, long pepper is also used to treat rheumatoid arthritis, diarrhea, and other general diseases [58]. Long pepper's potential nutritional and phytochemical benefits support its traditional use as a sedative, anti-irritant, expectorant, and antiflatulent medicinal [59], [38]. According to a study by [60], the *Piper rectofractum* Vahl was shown to be effective in suppressing the proliferation of MCF-7 breast cancer cells. Table 3 showed studies on utilization of long pepper in the health sector.

Table 3. The research on the utilization of long pepper in the health sector

Parts	Function	Secondary metabolites	References
Fruits	anticancer	Piperine, piplartin	[61], [62], [63], [64]
	Antioxidant	Phenolic compounds (piperine, piplartin)	[65], [66]
	Hepatoprotective activity	Phenolic content	[66]
	Anti-obesity	piperine	[56]
	Antibacterial activity	Amides and lignan compounds	[67], [68]
	Antiphotoaging effects	dehydropipernonaline	[59]
	Aphrodisiac	Piperine alkaloids, ethanol, and essential oils	[69], [70]
	Antitubercular activity	Antibacterial activity of *Mycobacterium tuberculosis*	[48]
Leaves	Antibacterial activity	Essential oil components	[71]

3.2. Industry

The long pepper essential oil is frequently utilized in nutritional supplements, cosmetics, phytotherapy, aromatherapy, perfumes, and scents [28]. It is an essential oil-bearing industrial crop in tropical regions, and its unique scent and therapeutic potential benefit the food industry and herbal medicine [72]. Wang et al. [28] used GC-MS to examine the variance in long pepper fruit aroma components throughout four developmental phases. There were 60 aroma components found and categorized into six functional groups: 12 alcohols, 4 phenols, 5 acids, 34 alkanes, 28 alkenes, and 9 esters. The main distinctive components of red long pepper were alkenes and alcohols, with the alkenes, especially sesquiterpenes, contributing significantly to scent and having anti-inflammatory and anti-cancer properties, with potential uses in medical biotherapy and commercial fragrance applications.

3.3. Agricultural use

The strong insecticidal activity of long pepper has been documented against various insect pests (Table 4). The viability limit for utilizing extracts with organic solvents in the field, which is a concentration of 0.50% with mortality reaching a minimum of 80% of the test insects, is met by the LC95 value of long pepper extract against many insects. According to [73], this further implies that the extracts exhibited potent insecticidal action. Seed film coating from fruit extracts effectively kills and repels bruchid beetle attacks during six months of seed storage without germination effect. It has a similar effectivity to the fipronil insecticide group [74]. Insect toxicity can be caused by neurotoxins that have quick knockdown effects, severe and lethal contact effects, suppression of oviposition, and adult emergence [75], [52]. Following [76], there is no significant difference in the efficacy of this pesticide against brown plant hoppers compared to commercial abamectin.

Fruit has the highest level of insecticidal action, while leaf extract is known to have a moderate level of plant antifungal activity [77]. The insecticidal activity of hexane and ethyl acetate extracts is greater than that of their corresponding methanol extracts. Compared to the other known insecticidal components of long pepper, the semipolar and nonpolar active, including guineensine, piperine, hydrocarbon, and terpenoids, appear more active [78], [73]. It is also a potent compound to suppress and hinder germination and seedling growth of agricultural weeds, suggesting that they might be new prospects for bioherbicides [79]. Applying the extract to hydroponic vegetables does not show any symptoms of phytotoxicity in the form of spots or brown spots, wilting, or death of leaf tissue. Hence, it is safe to use as a plant insecticide [80].

Table 4. Agricultural use of long pepper

Long pepper part of the use	Activity and Dose	Responsible chemical constituents	References
The essential oil extracted from dried seeds and fresh leaves	Insecticidal activity against C. maculatus. Essential oil of fruit at 10 µl/L has a higher oviposition effect and adult emergence, while essential oil of leaves has higher fumigant toxicity with LC50 39,56 µl/L.	limonene, linalool, caryophyllene, and naphthalene	[52]
Nanoemulsion formulations derived from essential oils of fruit	Insecticidal activity against Brown Plant Hopper nymphs with LC50 and LC90 0.02% and 0.19%, respectively.	Piperamide compounds such as guininsin, pelitorin, pipericides, piperin, and retrofractamide A	[81]
Hexane extract from fruit	strong insecticidal activity against C. pavonana larvae at LC50 and LC95 of 0,12 and 0,31 %, respectively, at 72 hr after treatment	The alkaloids including (2E,4E,14Z)-N-isobutylicosa-2,4,14-trienamide, guineensine, retrofractamide D, pipernonaline, piperine, piperanine, and methyl piperate.	[82], [83], [73]
Hexane extract from fruit.	Film coating on mungbean seed has high toxicity and repels bruchid beetles (Callosobruchus maculatus and Callosobruchus chinensis) with LC50 values of 5.57–6.75 µg/cm^2 during 6 months of storage	pentadecane, heptadecane, 1-heptadecene, 8-heptadecene, 1-tetradecanol, 1-tridecene, and tridecan	[74]
Methyl chloride extract from fruit	Mortality of 98% and growth inhibition of 70-80% green stinky bug (N. viridula L.) at a concentration of 12% extract		[84]
Ethanolic extract of the fruit	Contact toxicity and antifeedant activity against Spodoptera litura at LC50 5,5 µg/larva	Piperine and (2E,4E,14Z)-N-isobutylicosa-2,4,14-trienamide	[85]
Ethyl acetate extract from fruit	Imago, nymphs, and oviposition mortality and toxicity against Helopeltis antonii at LC50 and LC95 0,20 and 0,49 %, respectively		[75]
Ethyl acetate extract from the leaf	Growth inhibition of *Pyricularia oryzae* at a concentration of 50 mg/ml	Flavonoids, alkaloids, terpenoids, steroids	[76]
Dried whole plant	completely inhibited the hypocotyl growth and 93.5% of the radicle growth at a dose of 50 mg		[86]
Ethyl acetate and hexane fractions from methanolic extract of fruit	Effective against the seed germination and seedling growth of cress and barnyard grass, with the lowest I50 being 11 µM	3-Phenylpropanoic acid, piperlonguminine, dihydro piperine, isochavicine, piperine	[79]

4. CONCLUSION

Several studies have been conducted on Javanese long pepper which focus on several aspects, such as botany, cultivation, post-harvest, and utilization in various fields. These studies made it possible to justify the use of herbal plants and discover new chemical compositions and pharmacological activities. However, research on innovations in cultivation to increase production and the content of efficacious active compounds needs to be increased and their use in the industrial sector in detail is still rarely reported. It is hoped that there will be more exploration of cultivation technology and use of long pepper in industry by utilizing information about chemical composition and pharmacological activity from previous studies. In addition, more research is needed on the isolation of active compounds and pharmacological tests from plant parts other than long pepper fruit.

Author Contribution

All authors contributed equally to the main contributor to this paper. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

Declare conflicts of interest or state "The authors declare no conflict of interest."

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