Tuber Sprout Suppressants

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To avoid tuber sprouting, increased storage and transportation of potatoes demands either the retention of their dormant state or the application of sprout growth suppressants.

Tuber Sprout Suppressants | sprout inhibition | potato

1. 1,4-Dimethyl Naphthalene

1,4-dimethyl naphthalene (1,4-DMN), a naturally occurring and endogenous methyl-substituted naphthalene in potatoes, is an alternate sprout inhibitor [1][2][3]. It is a volatile compound that contributes to the flavor and aroma of baked potatoes [2] and was isolated from potato skins and then synthesized for use as a plant growth regulator [4]. In particular, the chemical suppresses sprout production and etiolated development in stored potato tubers, thereby prolonging the effective storage period and preserving tuber quality [1][3]. Because the chemical has reversible effects, it may also be utilized on seed potatoes [2]. 1,4-DMN is commercialized in synthetic form as 1,4Sight®, 1,4SHIP®, and 1,4SEED®.

1.1. Mode of Action of 1,4-Dimethyl Naphthalene

Meigh, et al. [5] demonstrated the availability of 1,4-DMN isomers and how they exhibit sprout-inhibiting properties. Studies conducted by [6] revealed the potential of 1,4- and 1,6-DMN to reduce the rate at which potato sprouting occurs, and these findings were confirmed by [7]. The mechanism of action of 1,4-DMN is yet to be fully characterized. However, because it is a naturally occurring substance that is readily available in potato tubers, it is thought to suppress sprout development by extending endogenous dormancy conditions and via hormonal actions [1][2]. Although emerging, reports suggest that 1,4-DMN inhibits sprouting by repressing meristem cell proliferation [1][3]. Analysis of the changes in transcriptional profiles of meristems isolated from 1,4-DMN- treated potato tubers showed the repression of cyclin or cyclin-like transcripts, thus suggesting that 1,4 DMN modifies genes involved in the maintenance of a G1/S phase block, most likely via the stimulation of the cell cycle inhibitors [1]. A recent report shows that sensitivity to 1,4-DMN changes as potato tubers age and transition from endo-dormant to eco-dormant in storage [3]. These are clear indications that 1,4-DMN may regulate sprouting by integrating external/ambient cues.

1.2. Evaluation of 1,4-Dimethyl Naphthalene as a Sprout Inhibitor

The efficacy of 1,4-DMN as a sprout inhibitor has been the subject of much of the published studies available in the public domain. Many of these studies have indicated the efficacy of the 1,4-DMN based on how long the

experiments ran for, which is the storage period, rather than how long 1,4-DMN was able to extend and suppress sprouting (which would be shelf-life extension). For instance, a study by Kalt, Prange, Daniels-Lake, Walsh, Dean and Coffin [8] revealed that a dosage application of 0.02 mL/kg of 1,4-DMN did not result in any significant shelf-life extension. These are shown in **Table 1**. Compared to CIPC, Russet Burbank cultivars did not achieve any shelf-life extension. In addition, controls were not used in this study.

Table 1. Shelf-life studies showing the efficacy of 1,4-DMN and 1,4Sight® as alternative sprout suppressants.

Treatment	Dosage	Temp.	Type of Cultivar	Application			Shelf-Life Extension (±) + Extended − Did Not Extend	Ref.
				Number	Stage	Method		
1,4Sight®	0.02 mL/kg	9 °C	Russet Burbank	1 Repeated after 9 weeks	After curing	Applied as an aqueous spray	Russet Burbank −70 days compared to CIPC	[8]
1,4-DMN	0.1 mL/kg	23 °C	Shangi Asante Kenya Mpya	1	After curing	Liquid fog	Asante +10 days compared to control. −70 days compared to CIPC. Kenya Mpya +18 days compared to control. −48 days compared to CIPC. Shangi 0 days compared to control. −105 days compared to control.	[9]

Potato varieties were stored for up to 200 days at 4 °C at a dosage of 0.04 mL/kg as conducted by Richard Knowles, Knowles, and Haines [2]. However, the suppressant dosage used was lower than the dose (0.1 mL/kg) used in the study conducted by Beveridge, Dalziel, and Duncan [12], where potato tubers were only stored for 98 days at a higher temperature of 10+/0.5 °C.

Baker [10] showed that the Russet Burbank variety was stored for up to 330 days with a 0.2 mL/kg dosage of 1,4Sight® at 7–8 °C. This dosage tends to be more efficient when compared to the results from other studies. In contrast, de Weerd, Thornton, and Shaw [11] demonstrated stored potatoes could be maintained for just 60 days at a higher temperature of 15 °C +/2 °C with a lower dose of 0.058 mL/kg. This shows that a higher dosage concentration worked better at increasing the storage period of potato varieties. Discrepancies in some important parameters exist in these two studies. While Baker [10] employed a swing fogger to apply a higher dosage, the

Lewis, Kleinkopf, and Shetty [4] evaluated 1,4-DMN, diisopropyl naphthalene (DIPN), and CIPC for reducing sprouting in Russet Burbank potatoes and discovered that DIPN was the most efficient of the two naphthalene derivatives when two applications of the suppressant were used. They found that 1,4-DMN or DIPN was an effective sprout suppressant on a short-term basis, which is very high compared to the rates recommended. The

Weber conducted by Baker [10][11], with the least amount of 1,4-DMN gauze to apply the same chemical. Overall, it is challenging to decide the best potential sprout suppressant because treated with 1,4-DMN were critical parameters did not consider such as dosage application, temperature, methods applied, and what genetic type of potatoes is used. These could have contributed to the significantly different outcomes of both studies.

2. 1,4 SIGHT®

1,4-DMN has acquired registrations for use in different European countries as of 2018. In that way, the synthetic form has been marketed with the trademark 1,4Sight® [14], among others. On short-dormancy potato varieties, 1,4SIGHT® can be applied as a stand-alone to maintain dormancy (inhibit sprouting) and quality while keeping moisture loss at a bearable minimum immediately postharvest.

2.1. Mode of Action of 1,4SIGHT®

1,4SIGHT® is a 'therapy' that is based on genetics. It regulates genes involved in water-holding proteins, which may aid in weight reduction [15]. Pathogen resistance genes are also regulated, resulting in greater resistance to fungal infection [15][16]. The method of action of 1,4SIGHT® is fungistatic, which means that the fungus is prevented from growing, allowing non-pathogenic bacteria and fungi to proliferate [17].

2.2. Evaluation of 1,4SIGHT® as a Sprout Inhibitor

1,4Sight® has been used in a shelf-life study conducted by Kalt, Prange, Daniels-Lake, Walsh, Dean, and Coffin [8], where extension of shelf-life was not achieved at all compared to CIPC (**Table 1**). However, there is a greater chance that shelf-life would have been achievable with a control other than CIPC. Another study conducted by Baker [10] showed the most extended storage period of 330 days at a dosage application of 0.2 mL/kg at 7–8 using a Swing fogger apparatus. However, this was not a shelf-life extension study. Studies that compare the effects of varying temperatures and modes of application on the efficacy of 1,4Sight® are not available.

3. S-carvone

Plant organs, such as leaves, roots, stems, and flowers, contain high concentrations of essential oils. Volatile oils, also known as ethereal oils, obtain their names from their ability to evaporate quickly when exposed to air at room temperature. Secondary metabolites, such as sesquiterpenes and phenylpropanoids, make up most of these oils. They are well-known for their antimicrobial and sprout-inhibiting properties [18]. Both *S*-carvone, 2-methyl-5-(1-methylethenyl)-2-cyclohexene-1-one, and its enantiomer, *R*-carvone, are volatile monoterpenes in the essential oils of caraway (*Carum carvi* L.), mint (*Mentha spicata* L.), and dill (*Anethum graveolens* L.), which have potent inhibitory bioactivities on the sprouting of potato tubers at continuous low headspace concentrations [19][20][21]. In addition to its sprout suppression bioactivities, *S*-carvone inhibits bacterial and fungal growth, thereby presenting secondary benefits, such as suppressing storage pathogens such as *Fusarium* and *Rhizoctonia* species [21][22]. Other notable advantages of *S*-carvone over CIPC include its strong odor, which is transmitted to foods when used

as a flavoring agent, it is non-toxic and safe for humans, and it contributes less to ozone depletion compared to CIPC [22][23]. Some European nations have commercialized *S*-carvone and market it under tradenames such as Talent™ [24].

3.1. Mode of Action of *S*-carvone

The precise mechanism of sprout suppression employed by *S*-carvone is yet to be fully resolved. However, *S*-carvone is believed to influence potato tuber sprouting by interfering with isoprenoid metabolism. The mevalonate pathway, which employs the enzyme 3-hydroxy-3-methylglutaryl coenzyme A reductase (HMGR), is implicated in the process that prevents sprouts from growing [25]. *S*-carvone interferes with sprouting by inhibiting HMGR activity [26] through repression at the post-translational level [27]. Another model proposes the inhibition of the 2-C-methyl-D-erythritol 4-phosphate (MEP) isoprenoid pathway, which affects the mevalonate pathway downstream and isoprenoid metabolism by blocking protein isoprenylation. Here, *S*-carvone blocks an MEP pathway-dependent protein geranylgeranylation that is required for signaling [28]. The mevalonate pathway partakes mainly is the provision of metabolites for the biosynthesis of hormones that are important for plant growth.

3.2. Evaluation of *S*-carvone as a Sprout Inhibitor

Sprout growth inhibition was achievable for the Bintje cultivar only for 15 days compared to CIPC and the Agria cultivar, 0 days compared to CIPC. Sprout suppression for treated Russet Burbank cultivar was achievable for 70 days with a dosage of 0.080 mL/kg [8]. An in vitro study demonstrated the effectiveness of the essential oils and clearly showed that sprout growth and extension of shelf-life were achievable [29]. Using mint (*M. spicata*) essential oil, which contains a significant amount of carvones (51–73%) [19][30], and synthetic *R*-carvone, Teper-Bamnolker et al. [19] noted a significant decrease in sprouting and weight loss in tubers of eight different potato cultivars that were stored for six months. However, these studies were not shelf-life extension studies as they only demonstrated the effectiveness of the essential oil at reducing sprout growth.

With a dosage application of 0.6 mL/kg, sprout suppression for the Monalisa cultivar compared to the control was achieved 21 days [31]. Dosage application of 155 mL/kg extended tuber shelf-life by 25 days compared to the control for both Agria and Kennebec cultivars [25]. Using the Agria cultivar, [24] demonstrated that the tuber shelf-life extension at different temperatures was achieved with a dosage application of 0.6 mL/kg. Compared to the control and CIPC, different results were achieved with *S*-carvone. CIPC performed better than *S*-carvone at shelf-life extension. At 5 °C, they noted 60 days of the shelf-life extension was achieved compared to the control, whereas 0 days compared to CIPC. At 10 °C, 75 days extension was noted compared to the control, whereas 0 days was achieved compared to CIPC and at 15 °C, 90 days compared to the control and 15 days compared to CIPC.

4. SmartBlock®

SmartBlock is a biopesticide, i.e., it is a naturally occurring chemical with minimal detrimental environmental impacts. The active compound in SmartBlock® is 3-decen-2-one, a naturally occurring 10-carbon unsaturated

ketone [32] that has been tested on several potato species and under a variety of storage settings. Along with other *α,β*-unsaturated ketones, 3-decen-2-one is produced in higher plants as components of their aroma profiles [33]. Many industrialized nations have accepted and approved 3-decen-2-one as a food additive and flavoring agent in different processed foods. SmartBlock® is intended for use in thermal fogging systems in potato storage facilities, especially for fresh market potatoes. It delivers a safe, quick sprout burn-off on fresh potato types without harming potato quality, and it is simply administered using fogging equipment [34].

4.1. Mode of Action of SmartBlock®

For regulating postharvest sprouting in potatoes, SmartBlock® has a unique mode of operation known as sprout 'burn out'. When used as a hot or cold fog, the active 3-decen-2-one vaporizes quickly and easily, destroying the meristematic tissues of rapidly developing sprouts [35][32]. These *α,β*-unsaturated ketones are electrophiles, with carbonyl and conjugated double bonds, forming adducts with cellular amino and sulfhydryl groups, such as those in glutathione, proteins, and DNA, which is toxic and lethal to tissues [32]. 3-decen-2-one is also known to induce the disruption of internal cell structures and cell content leakage, interference with oxidative stress control, and rapid desiccation of sprouts [35][32][36].

Another notable mechanism of action of SmartBlock® is the induction of a transient increase in respiration that mobilizes available reducing sugars before tuber respiration rate is decreased to similar levels as observed in dormant, non-sprouted tubers [36]. Sprout control bioactivities are also present in the first two breakdown products, 2-decanone and 2-decanol, which together provide extended sprout control. According to data, fresh market potatoes stored at colder temperatures (3–4 °C) can be safely stored with only one application during the storage season. For processing potatoes, which are usually stored at higher temperatures (7–10 °C), two–three applications are typically needed during the storage season [14].

4.2. Evaluating SmartBlock® as a Sprouting Inhibitor

According to the European Food Safety Authority [37], SmartBlock® has shown the potential to be used as a sprout inhibitor. Immaraju and Zatylny [38] demonstrated that using SmartBlock® for successful sprout suppression for 21 days, at an application rate of 0.115 g/kg, with only one treatment, and at a higher temperature, is feasible for already sprouted potatoes. They noted that 100% of sprout eyes were burnt off until the last day of observation, whereas 94% of potato studies were blackened. SmartBlock® can be perceived as a very effective sprout inhibitor as it can perform well at even higher ambient temperatures. The active component of SmartBlock® (3-decen-2-one) has been suggested as a valuable alternative to CIPC for controlling sprouting in potato tubers [35].

The outcome of a recent study on the efficacy of SmartBlock® in sprout inhibition indicated that this chemical is viable for use on various cultivars [36]. It was noted that multiple applications (three times) were required for effective sprout inhibition at higher temperatures whereas, for a lower temperature, only one application was enough to suppress sprouting for 168 days. When fresh potatoes are stored at 4 °C, a single application of dosage,

ranging from 0.100 mL/kg to 0.135 mL/kg can provide season-long sprout control for many varieties. Processing varieties stored at 7.5 °C would require three applications.

5. Caraway Seeds and Essential Oils as Alternative Sprout Suppressants

Caraway seeds were used to inhibit sprout formation in the Monalisa cultivar. Using seed essential oils, sprout suppression was achievable for 25 days at a 155 mL/kg dosage application in both Agria and Kennebec cultivars [25]. Similarly, at 5 °C storage temperature, dill essential oil suppressed sprouting by 90 days compared to the control whereas 30 days compared to CIPC [24]. At 10 °C, 135 days of the shelf-life extension was achieved with dill essential oil compared to the control, while 60 days was achieved compared to CIPC. Lastly, at 15 °C, 150 days of the shelf-life extension was achieved with dill essential oil compared to the control and 75 days compared to CIPC.

The potato tuber sprouting suppression bioactivities of essential oils is partly attributed to the abundance of diverse monoterpenes in these oils [19][25][39][40]. Monoterpenes are known to compromise membrane integrity because of their lipophilic nature [41]. Mint essential oil induced tuber bud necrosis by damaging apical meristem and vascular tissues [19]. Monoterpenes may influence phytohormones synthesis and activities to elicit sprouting suppression. For instance, 1,8-cineole-mediated inhibition of tuber sprout growth was found to be mediated via the alteration of key gibberellin metabolism gene expression, impaired gibberellin biosynthesis, and reduced gibberellin content [42]. Other essential oils with reported potato sprout suppression activities include those obtained from eucalyptus and coriander [25][40].

With essential oils, several treatments are necessary during storage to sustain sprouting inhibition, and because the essential oil manufacturing process is quite expensive, these types of sprout suppressants are challenging to put on the market [43]. However, compared to CIPC, essential oils provide no difficulty when storing potato seeds in the same facility as the treated potatoes since their impact is reversible, and their volatility makes it easy to clean the storage facility's air of any chemical residues [39]. They also provide secondary benefits as they can diminish the rate of accumulation of reducing sugars in stored tubers, which are responsible for browning in processed potato products [44]. Another important consideration for promoting and adopting essential oils, or their components, is their safety. Since these compounds are from natural sources and biodegradable, they are safe for human consumption and do not pose any threat to the environment. Using essential oils will also encourage the cultivation of plants from which they are extracted, thereby contributing to job provisions and the agricultural economy.

6. Aloe Vera Gel

Due to its unique nutritional profile, Aloe vera is extensively used in the food, health, and nutraceutical sectors. As an edible coating, Aloe vera gel has grabbed the curiosity of researchers who wish to look at its potential for

increasing the shelf and storage life of fresh fruit due to its organic origin [45][46]. Edible coating is a preservative technology that involves the application of a thin layer of edible material, which may be hydrophobic or hydrophilic or an integration of both, around the farm produce to restrict respiratory gas exchange [47][48][49][50][51]. This increases carbon dioxide accumulation and decreases oxygen supply while limiting water loss, thus extending the storage life of fresh commodities [45]. Edible coating is gaining popularity for controlling the ripening of vegetables and climacteric fruits because it is easy to prepare, widely available, relatively inexpensive, and does not require the use of sophisticated instruments [45][46].

Extrapolating from results obtained in studies that used *Aloe vera* gel as edible coatings on fruits and vegetables, the potential outcomes and benefits of testing and adopting *Aloe vera* gel for use as a sprout suppressant for potato tuber storage can be glimpsed. Edible coatings made from *Aloe vera* gel have been found to prevent weight loss by reducing moisture loss and retaining fruit firmness, lowered respiration and delayed oxidative browning, and inhibit microbial growth in diverse fruits and vegetables [45][48][51]. However, there is hardly any data on the usage of *Aloe vera* gel as a sprout suppressant or its application on potato cultivars for tuber shelf-life extension.

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