CHEMICAL INPUTS FOR SUSTAINABLE PLANT DISEASE MANAGEMENT IN ORGANIC AGRICULTURE

Abstract

Organic farming can be defined as an environmentally, economically, and socially sustainable method of producing safe and nutritious foods and fibres with the least amount of nutrients and energy lost and the least amount of negative environmental impact. Plant protection that is both efficient and sustainable is critical for worldwide agricultural production on both economic and ecological levels. Climate change, population increase and global commerce are just few of the problems that will place growing demands on future crop output and crop protection. This involves increasing crop output while reducing environmental effect and hence preserving food quality and security. Though the use of chemical inputs in agriculture is unavoidable in order to combat hated pests, diseases and fulfil the growing need for food in a populated country like India, there are chances to increase organic production to meet domestic and export demand for fresh fruits and vegetables. Organic farming is a pioneering endeavour to create sustainable development based on a variety of ideas. Keeping in view the health of environment, we can use chemicals that are acceptable in organic culture. These chemicals are cost effective in nature and provide us simultaneously significant control of pests and diseases. Organic farming (OF) has become increasingly popular in recent decades. Disease control in organic farming is mostly centred on maintaining biological diversity and soil health through balanced crop rotations, which include nitrogen-fixing and cover crops, intercrops, manure and compost additions, and reduced soil tillage along with some permitted chemicals in a specified quantities in different crops.

Keywords: Chemicals, Disease, Organic farming, Plant protection, Sustainable agriculture, Disease control.

Authors

Shahid Mushtaq
Division of Plant Pathology
FoA Wadura SKUAST-K
Kashmir, India.

F. A Bhat
Division of Plant Pathology
FoA Wadura SKUAST-K
Kashmir, India.

Ali Anwar
Division of Plant Pathology
FoA Wadura SKUAST-K
Kashmir, India.

Fazil Fayaz Wani
Division of Plant Pathology
FoA Wadura SKUAST-K
Kashmir, India.

I. INTRODUCTION

The ultimate objective of sustainable agriculture is to assist farmers and producers in producing pesticide-free agriculture products at every stage of the process, however on severe outbreak of pests and diseases they are allowed to use few chemicals which are having considerable maximum residual limit (MRL) and these are the chemicals that are acceptable in organic agriculture. For example; EU organic agriculture under EU Regulation (EC) No 889/2008: has allowed to use copper fungicides 6kg/ha per year in case of few fruit and vegetable crops. Plants and their pathogens are constantly engaged in adaptive changes, and long-term disease control necessitates the development of innovative systems to generate environments that are favourable to short and long-term disease management, which can be achieved through sustainable disease management (Anwar *et al.*, 2008). The majority of soil-borne illnesses are naturally suppressed, however foliar diseases can be troublesome at times. Pesticides licenced for organic farming are only used when a serious disease outbreak is expected. Pesticides that are regulated can be used in sustainable agriculture. In crop protection, many pesticides are particularly effective against a particular pathogen group (fungal infections) so we conclude that a systemic approach to disease management is necessary. The widespread use of synthetic pesticides in conventional fruit farming, on the other hand, clearly demonstrates that pesticides have a number of drawbacks as well as major negative consequences for the environment and human health. This produced a severe need for a more ecologic friendly approach in the practice of crop cultivation, notably in plant protection, in order to synchronize the quality produce with better yield as well healthy environment for better life (Bhat *et al.*, 2009). The current state, options and approaches to fungal disease and other diseases management for organic and integrated crop production systems, which are the most widely used, are discussed in this review paper. European Union organic agriculture has approved use of chemicals like sulphur, potassium bicarbonate, copper oxychloride, copper sulphate, lime sulphur, calcium hydroxide, diammonium phosphate, etc. (Anonymous, 2020). Holb (2009) reported six inorganic chemicals *viz.*, Copper, lime sulphur, elemental sulphur, bicarbonates, hydrated lime and kaolin for organic apple production. Non-chemical and chemical control measures are then combined into a multiple management tactic across all fungal diseases and are defined for integrated and organic apple production systems. The use of several plant protection inputs of mineral origin, such as copper, sulphur or mineral oils is seen as contentious by many consumers and stakeholders within the organic sector (Katsoulas *et al.*, 2020). Copper oxychloride 50 WP, copper hydroxide 77 WP, potassium bicarbonate (AR), wettable sulphur 80 WP were used for eco-friendly management of tomato late blight (Gopi *et al.*, 2020).

Table of MRLs in Foods and comparison of Copper and Sulphur Compounds MRLs with some of important fungitoxicants *(By: Japanese Food Chemical Research Foundation)*

Chemical	MRLs (ppm)
Captan	5
Carbendazim	2
Thiophanate Methyl	2
Copper	**30**
Sulphur	**30**
Metalaxyl	1
Difenocozole	1
Tricyclazole	0.02
Dodine	0.2
Tebuconozole	1

II. COPPER

Copper is commonly employed by Mediterranean organic growers in citrus, olive, tomato and potato production, according to the findings. The 6 kg/ha/year annual restriction was not always adhered to their orchards. They also discovered that tomato growers utilize lot of copper in their greenhouse winter harvests (Katsoulas *et al*., 2020). The grapevine is one of the most extensively grown and economically significant fruit species on the planet is attacked by downy mildew caused by *Plasmopora viticola*. This disease is one of the most damaging of all grapevine diseases, found almost all over the world. Copper is the sole substance effective against this disease in organic farming, according to European organic farming regulation EC 889/2008. In field testing, the efficacy of prophylactic low copper dosages was confirmed. In the field, rates of 200 and 400 g Cu/ha (equivalent to 5 and 10 mg Cu/m^2, respectively) were found to significantly reduce downy mildew (72–89 percent efficacy), correlating with results from leaf disc assays (Alba *et al*., 2017). Late blight of potatoes, caused by *Phytophthora infestans*, is particularly difficult to prevent or control in organic agriculture. The copper fungicide treatment reduced foliar blight severity by 27% on average in all varieties tested in England for two years and boosted yield by 20% on average, but it had no effect on tuber blight. A transition to blight-resistant cultivars should be heavily encouraged in organic farming, albeit this is unlikely to eliminate the requirement for copper fungicides (Speiser *et al*., 2006).Copper is an important component in the organic control of late blight in potatoes and tomatoes. When compared to crops that aren't protected by copper, this is expected to result in yield increases of 10 to 40%.Zamani *et al*. (2011) recommended copper fungi toxicants during early spring for the control of walnut anthracnose.Stone (2017) said that copper fungicides are expected to extend the growing time (before the potato foliage has to be eliminated to prevent blight from spreading to the tubers and neighbouring fields) by 2 to 4 weeks. Morando and Lavezzaro (2014) reported that with a full dose application copper performance was upto the mark against downy mildew of grapevine and one of the copper gluconates and copper gluconate+algae showed statistically sufficient results. de Resende, *et al*. (2021) while highlighting “Strategies for Coffee Leaf Rust Management in Organic Crop Systems” advocated use ofcupric fungicides as disease management for rust control in coffee.

1. **Copper Oxychloride :** Copper oxychloride @ 0.25 % was found to be the most effective against leaf blast (20.58% and 16.36 %) and neck blast (18.33 % and 19.20 %) while evaluating a number of chemicals against rice blast (Gopi et al., 2016).Movsesyan (1978) advocated 0.5 % copper oxychloride for controlling walnut anthracnose. Nasir (2017) reported that copper oxychloride was much effective in the management of anthracnose and powdery mildew of mango. Rimfeldt (1979) recommended that copper oxychloride at 2500 ppm can be very effective in the management of *Marssonina salicicola*. Devappa *et al*. (2006) advocated that copper oxychloride (0.3%) were very effective in managing the black spot of rose.Donne *et al*. (2020)reported that fungal foliar diseases caused by *Alternaria dauci* and *Cercospora carotae* in carrot caused blight and weakened leaves and petioles every year. They evaluated some organic materials and conventional fungicides approved by Organic Materials Review Institute (OMRI) against *C. carotae* and *A. dauci* to update existing disease management techniques for both organic and conventional agriculture. In field trials conducted in 2015 and 2016, it was discovered that copper-based fungicides (copper hydroxide and copper hydroxide/copper oxychloride) were the only OMRI-approved products that consistently limited foliar blight, as evidence from relative area under the disease progress curve (AUDPC) data. Fani *et al*. (2021)evaluated different copper oxychloride-based fungicides against cucumber downy mildew in green house conditions, they reported that at the first disease evaluation, Copertox® and Oksavit® were much more effective than the other products, with Copertox® being the most effective fungicide at the second disease assessment. There were also significant disparities between the control plots. Commercial brands of copper oxychloride were shown to be 53-67 per cent effective in controlling cucumber downy mildew.

2. **Copper Hydroxide:** Ali (2016)proved that Copper hydroxide (Kocide 2000) was more effective than copper oxychloride in suppressing the olive fruit-fly, resulting in infestation reductions of (55.9%, 59.0% and 59.9%) and (48.0, 52.8 and 58.5%), respectively. Sugar (2010) reported fruit scab infections in pear were suppressed by 94.3 and 87.5%, respectively, by potassium bicarbonate one percent and copper hydroxide (Kocide-3000, 1.0 gL^{-1}).

   Copper hydroxide @ 0.25% was found to be the most effective against leaf blast (21.80% and19.26 %) and neck blast (20.50 % and 23.63 %) severity, respectively (Gopi *et al*., 2016).It has long been recognised that applying 0.2 per cent copper hydroxide to sour cherry and apricot clusters during the tight cluster stage can considerably minimise the probability of brown rot infection (Holb, 2006).Romanazzii *et al*. (2020) said that instead of a mixture of laminarin and *Saccharomyces* spp. extract, copper hydroxide was used in conjunction with the 0.5 %/0.8 % chitosan formulation. For both high-pressure and low-pressure disease, 0.5 %/0.8 % chitosan formulation alone and with copper hydroxide provided effective protection against grapevine downy mildew.Holb (2005) reported copper hydroxide and lime sulphur, alone or in combination with micronized wettable sulphur, were the most effective fungicide treatments for controlling blossom blight when treated twice (at closed blossom and full bloom) or three times (at closed blossom, full bloom, and petal fall) during bloom. Park *et al*., (2012) while evaluating 20 agricultural organic materials reported that among inorganic compounds, only copper hydroxide was able to inhibit growth of both *Phytophthora capsici* causing phytophthora blight and *Colletotrichum acutatum* causing anthracnose in chilli.

3. **Copper Oxide:** Cuprous oxide is often used a fungicide (for seed dressings), and an antirust protective agent. Copper is readily available on the market copper (II) oxides having a copper concentration of roughly 78% (Rusjan, 2012). It has been reported that CuO nanoparticles helps in disease suppression while using against *Fusarium* in chrysanthemum, thus improving yield (Elmer *et al*., 2021).For the management of European canker caused by *Neonectria ditissima* in pip fruit crops in New Zealand, postharvest fungicides are required.Single applications of copper oxychloride and copper oxide were used to suppress the disease in artificially infected leaf scars.Copper oxide had equivalent control of leaf scar infections as captan had control on leaf scars (Walter *et al*., 2015).While studying various antibacterial mechanisms of biosynthesized copper oxide nanoparticles against *Ralstonia solanacearum*, copper oxide nanoparticles exhibited dose-dependent bacteriostatic action, with high concentrations significantly lowering bacterial viability and killing microorganisms. Copper oxide nanoparticles contact with bacterial cells resulted in reduced bacterial motility and biofilm development, as well as disrupted ATP synthesis in cells, which was confirmed from to antibacterial testing (Chen *et al*., 2019). El-Abeid *et al*. (2020) had done spectroscopic and microscopic investigations, validated the effective synthesis of the rGO-CuO NPs (reduced graphene oxide-copper oxide nanoparticles) as well as their antifungal efficacy against wild *Fusarium oxysporum* strains that harm tomato and pepper plants. Hardy *et al*. (2007) besides other copper fungicides, recommended 500 to 750 g CuO per hectare for the management of coastal diseases such as melanose, citrus scab, alternaria brown spot and citrus black spot, as well as greasy spot, brown rot and septoria spot, which are also found in southern inland growing areas.

III. HORTICULTURAL MINERAL OIL

Horticultural mineral oils have long been used as adjuvants in the application of conventional pesticides (such as insecticides and copper-based compounds) to increase their efficacy. Petroleum spray oils (PSOs) have been successfully employed to manage powdery mildew diseases on a variety of crops, including black sigatoka of bananas, greasy spot of citrus and black sigatoka of bananas. PSOs are useful in powdery mildew management programmes for apple, cherry, cucurbits, grapes, peach, rose and tomatoes (Walsh *et al*., 2000).Oils provided moderate protection for 4 days against grape powdery mildew, pre and post-harvest curative effect, and excellent antisporulant efficacy (Northover and Schneider, 1996). Scales, mites and whiteflies are all controlled by mineral oils (Katsoulas *et al*., 2020). Horticultural mineral oil (HMO) has been used many times in plant disease management. Horticultural mineral oil was found very effective at preventing and suppressing tomato powdery mildew (Nicetic *et al*., 2002). It was also reported that 0.3%-0.5% v/v horticultural mineral oil (HMO) sprays were excellent at curing infections of rose powdery mildew (Nicetic *et al*., 2002).Horticultural mineral oils (HMO) are one of the most efficient insecticides for controlling non-persistent aphid viruses (Yang *et al*., 2019). Horticultural Mineral oil play a significant role in eco-friendly and integrated pest management providing synergism in the efficacy of other pesticides. These oilsplay a crucial role in pest and disease management and are suitable to fit in spray schedule as having following characteristics; non-toxic to both plants and animals, easy to apply, low risk properties, cost-effective. (Nile *et al*.,2019). Vidal *et al*. (2013) reported that use of horticultural mineral oil (HMO) treatments in prunus nurseries as a feasible control approach for reducing plum pox virus (PPV) incidence.Zhang *et al*. (2016) reported that in field trials, regalia SC and HMO 736 each reduced disease severity in one of two field trials during the early stages of disease development, but not during the later stages of disease when disease pressure became high. When regalia SC and HMO 736 were used in combination with procure 480SC, the control efficacy was significantly higher than when procure 480SC was used alone.Leong *et al*. (2021) reported that horticultural mineral oil (HMO) has been shown to limit the spread ofHuanglongbing disease (HLB), on spraying with HMO, only 11.43 % citrus trees were infected compared to 42.20 % trees in untreated control plot.

IV. SULPHUR

Elemental sulphur without a doubt is the most ancient of all pesticides. Although much of the pesticide early history is lost, its pesticidal effects were understood by the ancient Greeks as early as 1000 B.C. Sulphur was first recommended for disease control by Forsyth (1802). Quicklime and sulphur were his recommendations for controlling powdery mildew on fruit plants. According to Robertson, (1824) sulphur was the only efficient cure he knew for controlling mildew on peaches (Tweety, 1981). Organic vegetable growers, particularly in greenhouses, frequently employ sulphur (Katsoulas *et al*., 2020). Root-knot nematodes (*Meloidogyne* spp.) are one of the main pests of cucumber production in greenhouses. The findings of two trials revealed that using 50 mg/kg sulphur in pots (45-day old plants) filled with non-sterilized soil and placed within plastic bags increased shoot dry weight by 36% and yield by 114% on average (Rumaini *et al*., 2016).Jamar *et al*. (2017) reported that wettable sulphur (1%) considerably reduced pear scab. Bloem *et al*. (2005) while studying the significance of sulphur in the protection of plants against pests and diseases said that the fungicidal effect of foliar S has been in operation from end of 19th century, however its importance as a soil applied S for disease resistance became clear only 100 years later. By knowing the mechanism of nutrient-induced resistance we can substantially increase plant health in organic culture and reduce the input of pesticides in conventional agriculture. Koch *et al*. (2014) advocated the need and results of a change of the unit of wettable sulphur dose to kg/m^2 leaf area from kg/ground area against powdery mildew in organic vine farming for sustainable uses.Heneklaus *et al*. (2007) while studying the effect of repeated foliar sulphur(S_0) treatments on the infection rate of barley inoculated with *Fusarium culmorum* causing fusarium head blight, it was discovered that this conventional fungicide is also efficient against this pathogen.Culbreath *et al*. (2019) reported that control obtained by combining elemental sulphur with either cyproconazole or a premix of prothioconazole + tebuconazole was superior to either of the DMI (demethylation inhibitor) treatments alone. Ahiladeva *et al*. (2019)investigated that a sulphur dosage of 1875 to 2500 g ha^{-1} successfully suppressed pea powdery mildew disease. This dosage was comparable to larger doses and yielded higher results than the other therapies. Upto a sulphur dosage of 5000 g ha^{-1}, or double the effective amount, no phytotoxicity was detected. Hussain and Leitech (2005) while studying the control of powdery mildew in spring wheat reported that use of foliar S was linked to a decrease in the amount of mildew (*Erysiphe graminis*) found on the top leaves and ears in the canopy.Ajithkumar *et al.* (2017) reported that successful treatment of powdery mildew disease in linseed was achieved by two sprays of wettable sulphur (0.4 percent) or soil application of sulphur (30 kg/ha) through gypsum at the time of sowing followed by two sprays of 0.3 per cent wettable sulphur.Dehigaspitiya *et al.* (2016) observed that sulphur when sprayed as a foliar on an okra can increase photosynthetic leaf area and reduce insect and disease damage. The pace of plant growth was also greatly boosted as a result of the sulphur treatment. Rao and Paria (2013)usedsulphur nanoparticles (SNPs) against two phytopathogens, *Fusarium solani* (isolated from an infected tomato leaf and responsible for early blight and Fusarium wilt infections) and *Venturia inaequalis* (responsible for the apple scab disease) to checktheir fungicidal effectiveness. Different characteristics that impact the efficacy of the fungicidal action, such as particle size, particle concentration, surfactant medium and so on, were investigated. Small particles (35 nm) have been discovered to be particularly effective in suppressing fungal growth.SNP-based fungicides can be used to protect essential crops including as tomatoes, potatoes, apples, grapes and other fruits and vegetables against various diseases, primarily for organic farming.

V. LIME SULPHUR

Lime sulphur was far more effective than wettable sulphur and it has been observed effective at temperatures below 10°C, although its efficacy against apple scab was reduced if treatments were delivered 12-24 hours later than in the 'during-infection' spray method (Jammar *et al.*, 2010). Holb, (2005) reported that compared to wettable sulphur treatments, lime sulphur treatments resulted in much less scab damage on both the leaves and fruits of apple and pear.(Jammar *et al.*, 2017) reported lime sulphur, one of the few alternative plant protection solutions to prevent scab infestation. Lime sulphur was studied in varied dose rates and timings during the infection process and demonstrated extremely good protective, halting, and even curative benefits in field experiments. The degrees of efficiency were constantly high to very high, especially during the germination period. Lime sulphur consistently outperformed the rival product wettable sulphur.A lime sulphur and wettable sulphur spray schedule against brown rot blossom was developed by Holb and Schnabel (2005). Daniel *et al.* (2020) reported that lime sulphur was found to be effective in reducing the severity of citrus leprosy and increasing citrus output. Trapman (2002)found that after application of lime sulphur in case of apple scab infection minimize the number of spray rounds, allowing for the use of less pesticides and less harm to beneficial insects and mites.Applications 30 to 72 hours after the start of rain were effective in controlling the disease. In 1999, 2000 and 2001, field trials in the Netherlands revealed that post-infection lime sulphur sprays are effective under field conditions for at least 20 hours after the commencement of the infection. Trapman *et al.* (2004)reported that by the use of lime sulphur against sooty blotch of apple, disease incidence was reduced by 28 and 48 % respectively. Weber *et al.* (2016) recommendedspraying with lime-sulphur and potassium bicarbonate to reduce sooty blotch and fly speck diseases in apple to produce better organic output throughout the season and they claimed that it is effective and necessary for management against disease under study. Tate *et al.* (2000) reported that use of lime sulphur in organic apple production showed acceptable results in management of diseases in apple.Lime sulphuris most beneficial,when sprayed to moist vegetation within 300 hours of infection start.These products can effectively control apple scab, according to their findings. Kitani *et al.* (1960) reportedagainst the wheat brown rust and the soybean rust pathogens in

Japan, lime sulphur provided effective control at first, but its efficacy quickly deteriorated.The effectiveness of lime sulphur was improved by adding polyethylene polysulfide.Jelev and Marinov (2018)investigatedthree different lime sulphur treatment combinations against cherry leaf spot (CLS) and shoot hole disease (SH). Treatments were carried out in a sweet cherry orchard without rain shields (cv. Van). All lime sulphur treatments showed significant cherry leaf spot (CLS) suppression and good shoot hole (SH) control. Sprays "between rain and spore germination" provide equally effective control as sprays "before rain" or within a 7-day interval, according to their findings.

VI. BORDEAUX MIXTURE

Reznikova (1977) reported that 2-6 sprays of treatments with Bordeaux mixture and urea results in best control of walnut anthracnose than 1 % Bordeaux mixture alone. When the Bordeaux mixture was sprayed to foliage of omija medicinal plants in various ways, it showed powerful control efficacy against powdery mildew disease, with control values ranging from 87 to 96 % (Lee *et al*., 2009). Zakhov (1980) reported spraying with Bordeaux mixture (2%) during winter and 1% before flowering and after flowering once was very effective against *G. leptostyla*. Zamani *et al*. (2011) recommended Bordeaux mixture in winter against walnut anthracnose. Rosnev and Tsanova (1980) recommended 1% Bordeaux mixture for management of anthracnose in walnut. Vega (2013) reportedtreatment with 0.5 kilogram of $CuSO_4$ in 100 litres of water administered every 21 days has been shown to be effective in controlling grey mold. At 75 days after starting treatment, the Botrytis was completely gone. Treatments with a greater dose level and the same application frequency did not improve the outcomes.Sengupta *et al*. (2011)sprayed betlevine with a Bordeaux combination (4 drenches+ 8 sprays at monthly and fortnightly intervals, respectively) and four split dosages of uninoculated Mustard oil cake (MOC) at 500 kg/split/ha at quarterly intervals against *Phytopthora parasitica* which causes foot rot in it and reported that all other therapies are statistically inferior to this one. Ravikumar *et al*. (2019) conducted research in 2015-16, 2016-17 and 2017-18 with Bordeaux mixture and stabilised Blue Bordo at 1.0, 1.5, 2.0, and 2.5 % respectively along with control.The treatment Bordeaux mixture 1.0 % produced the highest number of healthy bunches (3.05), the lowest number of infected bunches (1.05), the lowest number of fallen nuts (15.92), the lowest number of infected nuts (12.10), the lowest weight of fallen nuts (143.15g), and the highest green nut weight (14.12 kg) per palm. The untreated control had the lowest number of healthy bunches (2.59), the largest number of fallen nuts (33.41), the highest number of infected nuts (30.10), the highest weight of fallen nuts (366.78g) and the lowest green nut weight per palm (10.46 kg).Khalequzzaman (2015) while studying effect of Trichoderma and safe chemicals in controlling anthracnose of hyacinth bean, found thatTilt 250 EC sprayed plot had the highest yield (9.17 t/ha), followed by Bordeaux mixture (7.37 t/ha), baking powder (6.25 t/ha) and Trichoderma (6.25 t/ha).

VII. CARBONATES AND BICARBONATES

Holb and Kunz (2016) reported that potassium carbonate decreases the apple scab and powdery mildew infestation during primary infection interval in organic apple orchard.Olivier *et al*. (1998) investigated silver scurf, a postharvest disease of potato tubers caused by *Helminthosporium solani*, using seven organic and inorganic salts. At concentrations of 0.06-0.2 M, potassium sorbate, calcium propionate, sodium carbonate, sodium bicarbonate, potassium carbonate, potassium bicarbonate and ammonium bicarbonate were introduced to V8 agar. All salts, at all doses, greatly slowed the radial development of *H. solani* (P 0.05). Jamar *et al*. (2008) reported that armicarb (a new formulation of potassium bicarbonate) decreased the apple scab severity on the leaves and fruits significantly on the three different cultivars. Hemelrijck *et al*. (2012) investigated efficacy of potassium bicarbonate to manage apple scab in organic farming, they confirmed mode of action of potassium bicarbonate on conidial infection as well as the timing of applications in relation to the infection phase. According to the results of their experiment, potassium bicarbonate has fungistatic action and has the best effectiveness against apple scab when given curatively. Bellingeri *et al*. (2018) said that Armicarb® 85 is a multisite fungicide that is based on potassium bicarbonate.Between 2016 and 2017, it was evaluated in five trials, either alone or in a tank mix with some biological standard references. In all of the studies, the product demonstrated good efficacy against grapevine powdery mildew at various infection pressures. It worked well throughout the early stages of infection as well as when pest pressure was high. Armicarb has proven to be highly useful in tank mixes with other products to reduce resistance risks.Park *et al*. (2014) reported that application of 0.5 % bicarbonates will effectively control grapevine leaf spot. Gamagae *et al*. (2003)confirmed sodium bicarbonate at 2% along with antagonist *Candida oleophila* as an alternative to pesticides for controlling anthracnose, a severe postharvest disease in papaya during storage. Reuveni *et al*. (1995)investigated single spray of aqueous solutions (25 mm) comprising different phosphates and potassium salts effectively suppressed powdery mildew in cucumber produced by *Sphaerotheca fuliginea*.

VIII. CALCIUM HYDROXIDE

Among different chemicals evaluated calcium hydroxide was the most effective in reducing brown rot incidence in peach caused by *Molilina fructicola* (Biggs *et al*., 2007). Rao and Tewari (1998) performed a study on American leaf spot of coffee byspraying with $Ca(OH)_2$ suspensions on scratched and unscratched coffee leaves. After inoculating the scratched places with *Mycena citricolor* gemmae, the leaves were graded for lesion formation 1 and 2 weeks later. Spraying dramatically reduced the number and diameter of lesions and delayed their formation, with a 0.1 mg/cm^2 spray fully inhibiting lesion development. Heijne *et al*. (2005) reported that when slaked lime applied at 50-100 kg/ha thrice during leaf fall to manage the European fruit tree canker in organic apple cultivation, their experiment showed a reduction of 57, 35 and 60 % in newly appeared cankers in comparison to untreated check for three years. According to Yoon *et al*. (2010) seven different calcium compounds were used to check their relative effectiveness against *Botrytis cineria*. Among seven compounds calcium hydroxide, calcium oxide, calcium hydride and calcium carbonate inhibited the growth of *Botrytris cineria* effectively. Najarpour *et al*. (2018) reported that calcium salts reduce the number of zoospores, sporangia, germination percentage of cysts while studying the efficacy of calcium salts in controlling gummosis of Pistachio, during this study they also investigated that calcium hydroxide and calcium oxide reduced the hyphal growth and also caused deformation of sporangia.

IX. HYDROGEN PEROXIDE

Hong *et al*. (2013) reported that H_2O_2 showed anti-bacterial activities during *in vitro* evaluation against *R. solanacearum* as well as in detached tomato leaves for bacterial wilt, they also reported that H_2O_2 + sodium nitroprusside (SNP) mixture reduced the disease severity significantly. With a lower relative area under disease progressive curve, the H_2O_2 + SNP combination proved to be very effective against *Ralstonia solanacearum* in tomato. These findings imply that H_2O_2 and SNP could be employed combined as bactericidal agents to reduce bacterial wilt in tomato plants. Kotchoni *et al*. (2007) investigated that use of H_2O_2 successfully reduced disease severity in cowpea against *Xanthomonas campestris* pv. *vignicola* when pre-treatment of cowpea seeds was done with 1mM H_2O_2 compared to untreated controls. However, in this experiment, combination of H_2O_2 and pyridinium chlorochromate resulted in a best suppression than individually of the two. Kortekamp (2006)made an*in-vitro* experiments, for post-harvest tobacco rot, revealed that calcium propionate, hydrogen peroxide, and azoxystrobin inhibited *R. oryzae* mycelial growth, spore formation, and germination. Whereas, only calcium chloride, hydrogen peroxide and azoxystrobin were chosen for rack treatments since calcium propionate proved phytotoxic when applied to leaves.Teniente *et al*. (2019) recorded thatat 6, 14, and 18 mM, hydrogen peroxide induced tolerance to pepper golden mosaic Gemini virus (PepGMV) by preventing, attenuating, and/or delaying symptoms. The level of protection seen was directly proportional to the amount of H_2O_2 sprayed on the plants. Hafez *et al*. (2008) conducted an experiment under the plastic housing, cucumber leaves were sprayed with a solution of hydrogen peroxide (H_2O_2) or pharmaplant-turbo mixed with organic or inorganic fertilisers. The H_2O_2 treatment made the leaves resistant to the *Podoshaera fusca* fungus, which causes cucumber powdery mildew. In two studies conducted over two seasons, H_2O_2 (15 mM) was able to reduce disease severity from 90.4 % to 12 %.Musetti *et al*. (2005) foundH_2O_2 and associated metabolites and enzymes to be involved in reducing pathogen virulence and disease symptom manifestation in European stone fruit yellows-infected apricot plants. Souza *et al*. (2021) reported that soybean rust was not effectively controlled with H_2O_2 and multi-site fungicides alone. In addition to improving disease control efficacy, the use of H_2O_2 in combination with commercial fungicide mixes has been proven to be a promising tool for managing fungicide resistance and reducing Asian soybean rust losses.

X. PERACETIC ACID

The citrus canker is caused by the plant pathogen *Xanthomonas citri* (*X. citri*). *X. citri* produces biofilms on the surface of plant tissues, particularly leaves and fruits and remains stuck there. As a result, all citrus fruits must be cleaned before they can be sold commercially. NaOCl is the most used sanitizer for decontaminating fruits around the world. Treatment with NaOCl is no longer accepted by some European Union countries due to its toxicity. The study was conducted to compare potassium bicarbonate ($KHCO_3$), calcium hydroxide ($Ca(OH)_2$), calcium hypochlorite ($Ca(OCl)_2$), and peracetic acid (CH_3CO_3H) to NaOCl for citrus fruit sanitization. It was found that peracetic acid as an effective and safer alternative to NaOCl among all the chemicals examined (Dillarli *et al*., 2021). For the sanitary washing of tomatoes, different peracetic acid (PAA) formulations and application techniques has been developed. This application also appears to be quite successful at reducing postharvest deterioration. On tomatoes, the postharvest treatment of Citrocide® PLUS was tested. Three different tomato cultivars were treated with Citrocide® PLUS

(PAA-based product from Productos Citrosol S.A.), fruit was damaged to simulate cracking in two cultivars, while tomatoes were collected from a greenhouse with a high quantity of fungal inoculum in a third cultivar. The findings revealed that using Citrocide® PLUS correctly decreases tomato postharvest deterioration in all cultivars studied. In injured tomatoes, the decay reduction index ranges from 85 to 100 % after 10 days at 10°C and 85 % relative humidity (RH), whereas decay control was 100 % after 13 days at 10°C and 85 % RH in non-wounded tomatoes. Furthermore, the findings revealed that avoiding washing tomatoes is not a viable option for reducing postharvest deterioration. This research shows that applying Citrocide® PLUS after harvest is a dependable way to extend tomato postharvest life and as a result, reduce tomato economic losses due to postharvest decay (Mottura *et al*., 2017). Peracetic acid is efficient in treating *Fusarium oxysporum* f. sp *cubense* (Foc)-contaminated water, ozone would require large input expenditures, and chlorine can produce toxic disinfection by-products. Because of the enormous dosages required to remove Foc, UV would be impractical for field application (Ullah *et al*., 2021). On the germination of *Monilinia laxa* conidia, different concentrations of peracetic acid (PAA; 62.5, 125, 250, 500, and 1,000 g/ml) and chlorine dioxide (ClO_2; 12.5, 25, 50, 100, and 200 g/ml) were examined. Conidia germination was linked to the amount of chemical product utilised and the length of time it was exposed to it. After 5 minutes of contact with conidia, PAA at 500 g/ml completely inhibited germination, as did ClO_2 at 50 g/ml after 1 minute of contact with conidia. Inoculation of fruits with treated conidia verified the results of in vitro testing. The PAA therapy was similarly beneficial one hour after pathogen inoculation, but only on plums, where a 1,000 g/ml treatment reduced decay incidence by 50%. Pathogen conidia dipped for 20 minutes in PAA at 250 g/ml or ClO_2 at 10 g/ml, or for 5 minutes in PAA at 250 g/ml, were entirely inhibited in a semi-commercial test, and inoculated wounded nectarines and plums showed no brown rot (Mari *et al*., 1999).Sanitizing compounds such as acetic acid ($C_2H_4O_2$), peracetic acid ($C_2H_4O_3$), and hydrogen peroxide (H_2O_2) have been deemed a valuable tool in the treatment of various pathogens in the processing and marketing industries of fruits and vegetables. The usage of these chemicals has been permitted by the Food and Drug Administration (FDA) since their decomposition products are water, oxygen and acetic acid, which are nontoxic and environmentally beneficial. Because of their broad range of attack on bacteria, fungus, spores and viruses, chemicals such as acetic acid, peracetic acid, and hydrogen peroxide are regarded as antibacterial and antifungal agents. Human infections such as *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus* mutant and *Listeria monocytogenes* have been reduced *in vivo* experiments conducted on fresh and fresh-cut horticulture items. Microbial pollution of aerobic mesophiles, molds and yeast is also reduced by using acetic acid, peracetic acid and hydrogen peroxide, resulting in benefits and acceptable products for consumers. The antifungal activity of these sanitizers in fruits like guavas, peaches and tomatoes has been demonstrated by the inhibition of phytopathogens such *Rhizopus stolonifer*, *Monilinia fructicola*, *Alternaria alternata*, *Botrytis cinerea*, *Fusarium solani* and *Rhizoctonia solani* (González-Estrada *et al*., 2019). The linear development and spore germination of *Botrytis cinerea* were considerably reduced by peracetic acid, hence reduced the grey mold disease of strawberry fruits (Abd-Alla *et al*., 2011). Green mold, produced by *Penicillium digitatum*, is always found in citrus packaging factories in Australia. To kill conidia rinsed into the processing water, sanitizers are routinely used in high-pressure washers and added to fungicide drenches. Because it does not produce harmful disinfection by-products, peracetic acid (PAA) poses a lower nutritional risk than chlorine, but it requires longer exposure durations to limit conidia and has thus proven to be extremely efficient against green mould disease (Taverner *et al*., 2018). New commercial biocides containing peracetic acid (PAA), hydrogen peroxide (HP), phosphoric acid (PhA) and acetic acid are now available as stable matures in various concentrations. These compounds are powerful oxidizers, biodegradable and effective against a wide range of microorganisms, including bacteria and fungi. They can be used to protect living or growing plant tissues from microbial attack, including seeds, roots, tubers, seedlings, cuttings, rooting stock, growing plants, fruits and vegetables. PAA, HP and PhA could be utilised as alternative chemistries to control *Phytophthora* spp. infections in greenhouse production, not just for citrus but also for other vegetable crops, according to this study. Specific suggestions for greenhouse vegetable production and target diseases, on the other hand, must be devised.

XI. SUMMARY AND CONCLUSION

Increased production per unit of agricultural land has been the major aim of modern agriculture to guarantee the world food supply as the human population grows and arable land shrinks. This limited production target encourages the overuse of resources, such as agrochemicals and is one of the primary causes of unsustainable agricultural settings, which makes crop plants more susceptible to pathogen assault and plant diseases more difficult to control. As a result, in order to attain sustainability, the knowledge about chemicals such as their toxic effects, residual effect, persistence as well as their whole range of their negative consequences are prime importance in organic agriculture. Disease control methods that reflect the dynamic of pathogen population structure are critical for agricultural sustainability. The purpose of this article is to offer readers with relevant and clear information on this issue in a single document so that they are aware of the chemical inputs that are permissible in sustainable agriculture. All of the above-mentioned chemicals are permissible in organic farming and so may be used to manage disease without disrupting ecological balances in various habitats, as well as maintaining the environmental health. With adequate standards from state organic committees or international organizations like IFOAM, EU Organic, these chemicals can be employed in integrated organic disease management in order to reduce the losses caused by diseases on severe attacks. This study summed up all the chemicals inputs which has been used in organic production of various cereals, pulses, fruits, vegetablesand ornamental crops.

XII. FUTURE SCOPE

This study intends to bring together the literature on chemical inputs that are permissible in organic agriculture and to assist readers in understanding and using these chemicals, if required, to their crops in the case of serious disease infestation. Chemicals with a high MRL, such as copper fungicides, have a long history in conventional agriculture and a promising future in sustainable agriculture.

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