Power System Protection and Control
ISSN:1674-3415

EFFECT OF ZINC OXIDE AND SULPHUR NANOPARTICLES ON STORAGE INTEGRITY AND QUALITY TRAITS OF STORED ALLIUM CEPA L UNDER CONTROLLED ENVIRONMENT CONDITIONS

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Received: 07 March 2025 **Revised**: 20 April 2025 **Accepted**: 27 May 2025

***ABSTRACT*:**

Onion (Allium cepa L.) is one of the most important vegetable crops grown across India, and yet, every year a large share of the harvest is lost during storage. Sprouting, rotting, weight loss, and quality drop are the most common problems, and traditional chemical sprout suppressants are slowly losing favour because of residue concerns. This study, carried out under the discipline of Olericulture (Vegetable Science), explored whether nanoparticles of zinc oxide (ZnO) and sulphur (S), applied as a post-harvest dip, can help keep stored onion bulbs in better shape for a longer time under controlled storage conditions. Freshly cured bulbs of the Nasik Red variety were treated with three concentrations of ZnO (50, 100, 150 ppm), three concentrations of sulphur nanoparticles (100, 200, 300 ppm), a combined treatment of ZnO 100 ppm and sulphur 200 ppm, and an untreated control. The bulbs were stored at 25 ± 2 °C and 65 ± 5% relative humidity for 120 days, with observations recorded every 30 days. Parameters studied included physiological loss in weight, sprouting and rotting percentage, total soluble solids, ascorbic acid content, and pyruvic acid content. The results showed that the combination treatment performed the best, cutting weight loss by nearly 41% and sprouting by close to 58% compared to the control. Quality traits like vitamin C and pungency were also better retained. The study suggests that ZnO and sulphur nanoparticles, especially when used together at moderate doses, can serve as a safer and effective alternative for extending onion shelf life in vegetable post-harvest management.

Keywords: *Olericulture, Onion Storage, ZnO Nanoparticles, Sulphur Nanoparticles, Post-Harvest Quality, Vegetable Science*

INTRODUCTION

Onion is a crop that almost every Indian household depends on, and it is also one of the most traded vegetables in the country. Within the broader discipline of Olericulture, which deals with the science of vegetable crops, onion holds a very special place because of its commercial importance and its long supply chain. India ranks second in the world in onion production, but unfortunately also among the leaders in post-harvest losses for this crop [1]. Different studies have estimated that between one-fourth and nearly two-fifths of the total onion harvest is lost between the farm and the consumer, mostly during storage. The main reasons are sprouting after a couple of months, fungal and bacterial rotting, and steady weight loss because of moisture leaving the bulb [2].

For decades, vegetable growers have tried to deal with this through traditional storage structures like ventilated chawls and bottom-and-top ventilated sheds. These methods work to a certain extent but cannot keep temperature and humidity in a stable range, especially during the hot and humid months. Chemical treatments such as maleic hydrazide sprays in the field, and gamma irradiation in some advanced units, have helped, but worries about chemical residues, consumer health, and stricter export rules have made vegetable scientists look for safer options [3].

Nanotechnology has slowly opened a new window in post-harvest vegetable science. Because nanoparticles are extremely small and have a large surface area, they interact with biological systems in ways that bulk materials do not. Zinc oxide nanoparticles have shown strong antimicrobial action in several food-related studies, and

 DOI: 10.46121/pspc.53.2.33

sulphur in nano form has shown promise as a natural fungus controller, especially against the moulds that attack stored *Allium* bulbs [4]. Both zinc and sulphur are also nutrients that the onion plant naturally uses, so there is a feeling within the vegetable science community that these are gentler choices than synthetic chemicals.

Even so, most published work on nanoparticles in horticulture has focused on fruits like tomato, mango, and strawberry, while bulb vegetables have received less attention [5]. The few studies done on onion have looked at one nanoparticle at a time, and the combined use of ZnO and sulphur nanoparticles is still not well understood. This is an important gap in Olericulture research because, in practice, sprouting and rotting often happen together, and a single treatment may not handle both problems equally well [6].

This study tries to address that gap by testing ZnO and sulphur nanoparticles, alone and in combination, on stored onion bulbs of the Nasik Red variety. The main questions guiding the work are: Do these nanoparticles really help extend onion storage life under controlled conditions? Which combination and dose works best? And do the treatments affect the eating quality of the bulb, especially its pungency and vitamin C content? The findings are expected to be useful for vegetable growers, cold storage operators, and exporters who are looking for cleaner and more reliable storage options for one of India's most important vegetable crops [7].

LITERATURE REVIEW

The science of keeping onions fresh after harvest has a long story behind it within the field of Olericulture. Early researchers focused on the physical side of storage, like field curing the bulbs in the sun to harden the outer skin, which acts as a natural shield against moisture loss and pathogens [8]. This was followed by work on ventilated structures and later on controlled atmosphere storage, where oxygen and carbon dioxide levels are adjusted to slow down respiration. These methods do work, but the cost and complexity put them out of reach for most small and medium vegetable growers.

Chemical sprout suppressants such as maleic hydrazide became common in many countries from the late twentieth century onwards. They are still used today, but residue worries and growing pressure from organic and export markets have pushed vegetable scientists to look for cleaner alternatives. Essential oils, plant extracts, and bio-control agents have been tested, with mixed results, often working well in laboratory trials but failing to scale up in real storage conditions [9].

The use of nanoparticles in vegetable production and storage is a much newer area. Studies on ZnO nanoparticles have shown that they have strong antimicrobial action because they produce reactive oxygen species that damage the cell walls of bacteria and fungi. When applied on tomato and other vegetables, ZnO nanoparticles reduced decay and helped maintain firmness during storage [10]. Sulphur has been used by vegetable farmers for centuries as a fungicide, and recent research suggests that in nano form, it is even more effective at lower doses. One study on garlic, which is a close relative of onion in the *Allium* group of vegetables, reported that sulphur nanoparticles reduced black mould incidence by more than half, which is a meaningful drop in commercial terms [11].

Work directly on onions within Olericulture has been limited but encouraging. An Indian study using ZnO nanoparticles at 150 ppm reported lower weight loss in stored bulbs, although the trial did not look at combinations with sulphur [12]. Another Egyptian study used sulphur nanoparticles to manage *Aspergillus niger* on onion and showed clear control of black mould, but only disease parameters were measured, not the full quality profile. So while the building blocks are there in the literature, the combined use of ZnO and sulphur nanoparticles on onion, covering both storage losses and quality traits, has not been properly studied [13].

This study tries to bring these pieces together. It also adds value by working with a popular Indian variety (Nasik Red) and using storage conditions that are realistic for Indian onion stores, rather than highly artificial laboratory conditions.

METHODOLOGY

The experiment was carried out in the Post-Harvest Technology Laboratory of the Department of Vegetable Science, using freshly harvested onion bulbs of the Nasik Red variety, sourced from a single farm in the Lasalgaon belt of Nashik district to keep agronomic variation low. Bulbs of medium size (60 to 80 grams) and free from any visible damage were selected after field curing of three days and shade curing of four days [14]. ZnO nanoparticles and sulphur nanoparticles, both with an average particle size of less than 50 nanometres, were obtained from a certified supplier. Particle size and zeta potential were checked using dynamic light scattering before the trial began, to confirm that the material was within the expected nano range.

The trial followed a Completely Randomised Design (CRD) with eight treatments and three replications. The treatments were T0 (control, distilled water dip), T1 (ZnO 50 ppm), T2 (ZnO 100 ppm), T3 (ZnO 150 ppm), T4 (sulphur 100 ppm), T5 (sulphur 200 ppm), T6 (sulphur 300 ppm), and T7 (ZnO 100 ppm + sulphur 200 ppm). For each treatment, bulbs were dipped in the respective suspension for five minutes, air-dried for two hours in the shade, and then placed in ventilated plastic crates [15].

The storage room was held at 25 ± 2 °C and 65 ± 5% relative humidity, conditions which are close to what most Indian onion stores aim for. Observations were taken at 0, 30, 60, 90, and 120 days. Physiological loss in weight (PLW) was calculated using the standard formula:

$$\text{PLW (%)} = \frac{W_0 - W_t}{W_0} \times 100$$
where W_0 is the initial weight of the bulbs and W_t is the weight at the time of observation [16]. Sprouting and rotting percentages were measured by counting affected bulbs and expressing them as:

$$\text{Sprouting (%)} = \frac{\text{Number of sprouted bulbs}}{\text{Total number of bulbs}} \times 100$$
Total soluble solids (TSS) were measured using a hand refractometer, ascorbic acid was estimated using the 2,6-dichlorophenol indophenol titration method, and pungency was measured as pyruvic acid content following the modified Schwimmer and Weston method [17]. Data was analysed using Analysis of Variance (ANOVA) at a 5% significance level, and critical difference values were calculated to compare treatment means.

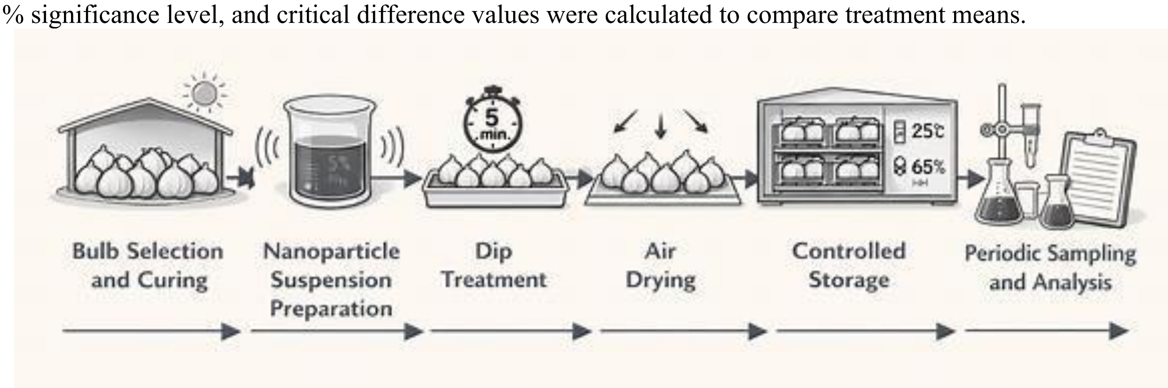

Figure 1: Experimental Layout and Treatment Plan for the Onion Storage Trial

EXPERIMENTAL SETUP

A total of 960 onion bulbs were used in the trial, with 40 bulbs per replication and three replications per treatment. The nanoparticle suspensions were prepared fresh on the day of treatment. The required amount of ZnO or sulphur nanoparticle powder was weighed on a digital balance and dispersed in distilled water using an ultrasonic bath for 20 minutes. This step was important because nano powders tend to clump together if just stirred by hand, which reduces their effective surface contact with the bulb skin [18].

The pH of each suspension was adjusted to around 6.5, close to the natural surface pH of onion skin, using dilute citric acid or sodium bicarbonate as needed. The dip treatment was carried out at room temperature, with each batch of bulbs held under the suspension for exactly five minutes. After dipping, the bulbs were placed on clean trays and air-dried in a shaded area for two hours before being moved into the storage crates.

The crates were stacked in the storage room with enough spacing on all sides to allow free air circulation, since poor airflow is a well-known cause of rapid spoilage in stored vegetables, particularly onions [19]. Temperature and humidity were monitored daily using a calibrated digital data logger.

The percentage of marketable bulbs at the end of the storage period was calculated as:
$$\text{Marketable Bulbs (%)} = 100 - (\text{Sprouting % + Rotting % + Severe PLW %})$$

Statistical analysis was done using OPSTAT software. Critical Difference (CD) at p = 0.05 was used to compare means, and the coefficient of variation (CV) was calculated to check the reliability of the trial [20]. All laboratory instruments were calibrated before each round of measurement, and titration values were taken in duplicate to reduce reading error.

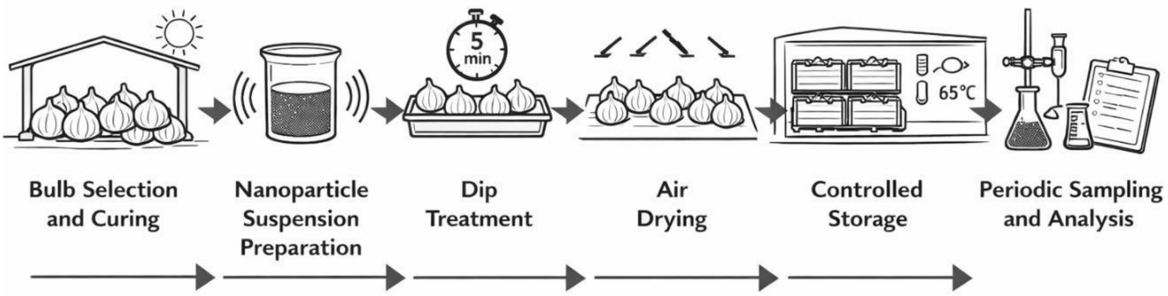

Figure 2: Schematic of Nanoparticle Treatment and Storage Workflow

RESULTS

The data collected across the five sampling intervals showed clear and meaningful differences between the treatments. The control bulbs (T0) showed the highest physiological loss in weight, reaching nearly 28.6% by the end of 120 days, while the combination treatment (T7) limited it to about 16.9%, which is a reduction of close to 41%. Among the single treatments, ZnO 100 ppm and sulphur 200 ppm performed better than their respective higher and lower doses, suggesting that the relationship between concentration and effectiveness is not strictly linear.

Table 1: Physiological Loss in Weight (%) at Different Storage Intervals

Treatment	30 days	60 days	90 days	120 days
T0 (Control)	7.4	14.2	21.6	28.6
T1 (ZnO 50 ppm)	6.8	13.1	19.8	25.7
T2 (ZnO 100 ppm)	5.9	11.4	16.7	21.2
T3 (ZnO 150 ppm)	6.2	12.0	17.5	22.3
T4 (S 100 ppm)	6.7	12.8	18.9	24.6
T5 (S 200 ppm)	5.8	11.2	16.2	20.8
T6 (S 300 ppm)	6.0	11.7	17.0	21.9
T7 (ZnO 100 + S 200)	4.6	8.9	13.1	16.9
CD (p=0.05)	0.41	0.52	0.63	0.78

Sprouting started showing up clearly only after about 60 days of storage. By the end of 120 days, the control had a sprouting percentage of around 46.2%, while the combination treatment kept it down to just 19.4%. Rotting followed a similar pattern, with the combination treatment showing the lowest rotting percentage of 11.7% against 31.5% in the control. The percentage of marketable bulbs at the end of storage was nearly twice as high in the combination treatment compared to the control.

Table 2: Sprouting, Rotting, and Marketable Bulbs (%) at 120 Days of Storage

Treatment	Sprouting (%)	Rotting (%)	Marketable Bulbs (%)
T0 (Control)	46.2	31.5	38.3
T1 (ZnO 50 ppm)	38.7	26.4	47.6
T2 (ZnO 100 ppm)	25.6	17.2	63.4
T3 (ZnO 150 ppm)	28.1	18.9	60.2
T4 (S 100 ppm)	35.4	23.7	51.8
T5 (S 200 ppm)	24.8	16.1	65.7
T6 (S 300 ppm)	27.3	17.9	61.5

T7 (ZnO 100 + S 200)	19.4	11.7	73.6
CD (p=0.05)	1.12	0.94	1.45

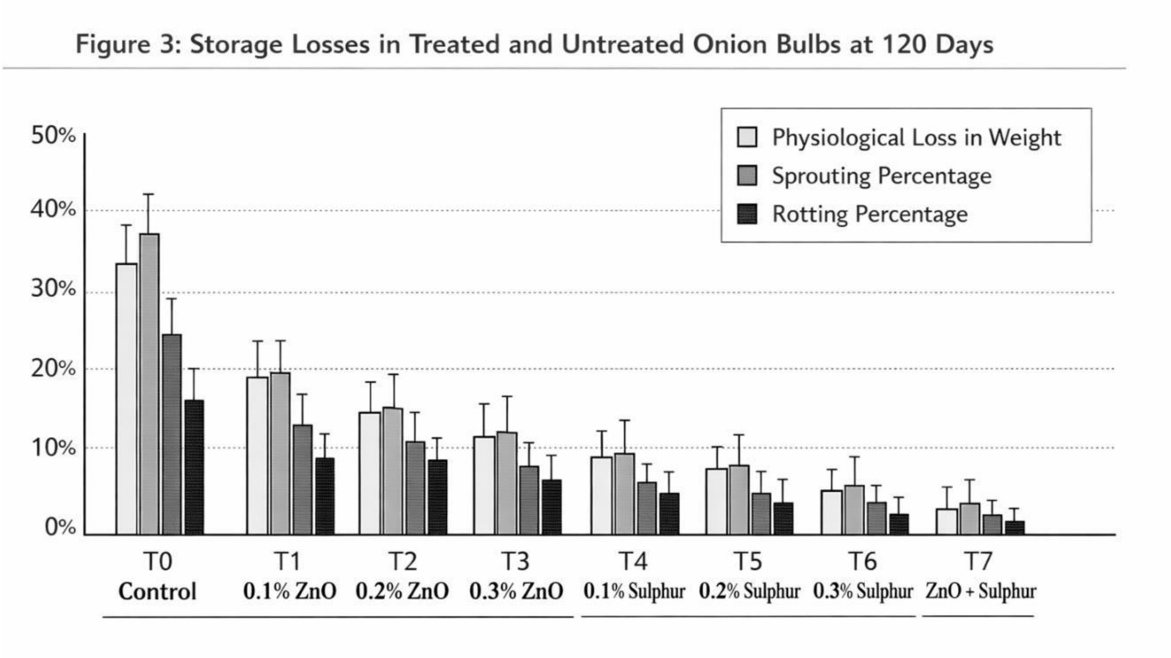

Figure 3: Comparative Bar Chart of Weight Loss, Sprouting, and Rotting Percentage Across Treatments at 120 Days

The quality parameters also showed clear patterns. Total soluble solids stayed reasonably stable in treated bulbs but dropped noticeably in the control. Ascorbic acid content fell in all treatments over time, which is expected with prolonged storage, but the drop was slower in nanoparticle-treated bulbs. Pyruvic acid, which gives onion its characteristic pungency, was best retained in the combination treatment, suggesting that the internal sulphur chemistry of the bulb was kept more active.

Table 3: Quality Parameters of Onion Bulbs at 0 and 120 Days of Storage

Treatment	TSS (°Brix) Day 0	TSS (°Brix) Day 120	Ascorbic Acid (mg/100g) Day 0	Ascorbic Acid (mg/100g) Day 120	Pyruvic Acid (µmol/g) Day 120
T0 (Control)	12.4	9.2	9.8	4.6	6.1
T2 (ZnO 100 ppm)	12.4	11.1	9.8	6.8	7.9
T5 (S 200 ppm)	12.4	11.3	9.8	7.0	8.2
T7 (ZnO 100 + S 200)	12.4	11.8	9.8	7.6	8.9
CD (p=0.05)	NS	0.31	NS	0.42	0.38

DISCUSSION

The results bring out a few interesting points about how these two nanoparticles behave on stored onion bulbs. The first is that the combination of ZnO and sulphur worked better than either of them alone. This is most likely because the two nanoparticles attack different storage problems through different routes. ZnO is known to produce reactive oxygen species at its surface, which damage the cell walls of fungi and bacteria, while sulphur nanoparticles seem to interfere with fungal enzymes and may also act as a mild brake on the bulb's respiration. When used together, they appear to complement each other rather than overlap, which is why the combination treatment came out clearly ahead.

DOI: 10.46121/pspc.53.2.33

The second point is that higher doses did not give better results. Both ZnO at 150 ppm and sulphur at 300 ppm performed slightly worse than their mid-range doses. This is most likely because, at very high concentrations, nanoparticles tend to clump together, which lowers their effective surface area. From a practical point of view, this is actually good news for vegetable growers, because it means farmers do not need to use very high doses to get the best benefit. This keeps the cost down and also reduces any chance of unwanted residue on the bulbs.

The retention of pungency, measured as pyruvic acid content, is worth a closer look. Pungency is not just about taste, but it is also linked to the natural defence chemistry of the onion. The fact that nanoparticle-treated bulbs kept more of their pungency suggests that the internal sulphur metabolism of the bulb stayed more active, which indirectly means the bulb was better able to resist decay rather than sitting passively in storage. This is a useful side effect that goes beyond just appearance.

Vitamin C retention also followed a clear pattern. The slow drop in ascorbic acid in treated bulbs suggests that nanoparticle treatment may be slowing down the oxidative processes inside the bulb. From a nutrition angle, this matters because onion is often one of the few steady sources of vitamin C in many Indian households during the lean vegetable months. Keeping more of this vitamin alive during storage is a quiet but real public health benefit. One limitation of this study is that it was done under controlled laboratory storage conditions, which not every Indian vegetable grower has access to. Field-level chawls and sheds see bigger swings in temperature and humidity, and results there may be somewhat different. The trial also focused on just one variety, Nasik Red, and other varieties such as Bhima Super or Agrifound Light Red may behave differently. A multi-location and multi-variety trial would help strengthen the conclusions and make the findings more useful for wider adoption in Indian Olericulture.

CONCLUSION

This study set out to test whether ZnO and sulphur nanoparticles, used alone or together, can improve the storage life and quality of onion bulbs under controlled conditions. The results give a fairly clear answer. The combination of 100 ppm ZnO and 200 ppm sulphur nanoparticles gave the best outcome across all major parameters, holding the percentage of marketable bulbs at around 73.6% at the end of 120 days, compared to just 38.3% in the untreated control. This is a meaningful jump and could translate into real income gains for vegetable growers and traders if the technology is scaled up properly.

The main contribution of this paper lies in showing that two well-known agricultural inputs, zinc and sulphur, when used in their nano form and in combination, can work as a safer and more effective alternative to traditional sprout suppressants in vegetable storage. The doses needed are small, the residues are expected to be low, and the treatment process is simple enough to be carried out at the village level with basic equipment such as a small ultrasonic bath and a dipping tank. For onion exporters, who face stricter residue norms in international markets, this approach could be especially useful.

That said, more work is needed before this can be recommended on a wide scale. Long-term consumer safety studies, residue analysis on the edible portion of the bulb, and trials under real farm storage conditions are the obvious next steps. It would also be useful to test the same treatments on other *Allium* vegetables like garlic and shallots, which face similar storage problems. If those studies also turn out positive, nano-based post-harvest treatments could quietly become an important tool in the wider effort to reduce vegetable losses in Indian Olericulture. For the present, this study provides a strong starting point and a clear direction for further work in this area.

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