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*(Original Article)*

# Impact of Phosphine Fumigation Treatments on the Vitality of Wheat Grains at Different Storage Periods

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## Abstract

To study the effect of phosphine fumigation treatments (two tablet/ton exposure for 24, 48, 72 hours; four tablet/ton exposure for 24, 48,72 hours; six tablet/ton exposure for 24, 48, 72 hours ) on the vitality of bread wheat grains cv. Giza 171 at different storage periods (fresh grains, 3, 6, and 9 months) using a complete randomized design with three replications at the laboratory of Prof. Dr. Youssef Mohamed Omar, Plant Protection Department, Agriculture Faculty, Assiut University during the period from 26 May 2022 to 3 March 2023. Grains of Giza 171 cv. were obtained from the Agronomy Department Farm, Agriculture Faculty, Assiut University. The obtained result showed that the tested storage periods had a highly significant effect on all studied traits. Thus, the maximum mean values of germination power (%), germination percentage (%), roots and shoot length (cm), and seedling dry weight (g) traits were recorded at the begging of storage then a gradual decrease occurred. In addition, treating wheat grains with phosphine at different doses for different periods gained a significant increase in all studied traits compared to the control treatment (without fumigation), while there were no noticeable differences between most of the phosphine treatments themselves were found. Therefore, we suggest under the conditions of this study, wheat grains could be treated with 2 tablets of phosphine for a period of 72 hours to reduce the dose and increase the exposure time which could reduce the harmful effects of excessive doses of phosphine.

***Keywords**: Viability, Biotic, Triticum, PH3.*

## Introduction

Wheat (*Triticum spp*. L.) is considered as one of the most important strategic crops in the world, and in Egypt, it ranks first in terms of area as compared with other cereal crops. in Egypt, the total harvested area of wheat in 2021 reached about 1,394,558 hectares and the total production exceeded 9 million tons with an average of 6.454 t/ha. While its consumption reached about 19 million tons in the same year which means that we need to import more than 10 million tons (FAO, 2021).

During storage wheat grains face a loss could exceed 10 % due to biotic and abiotic factors and insects are contributing by about 2.5 to 5.0 percent to these losses. The loss of stored grain due to insects is one of the main factors

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which need to be understood well to control the reduction of stored grain. Insects may also cause damage to the stored grains by many indirect ways, such as their remaining droppings, dead insects, and the toxins they secrete, making the grains unfit for human consumption. It may also change the storage environment to be hotter causing hot spots or increasing the moisture content, which leads to the rapid spread of fungus that causes damage to the stored grains. Moreover, insects caused damage to stored grains and their products range from 5-10% in the temperate zones and the damage could reach 20-30% in tropical countries (Badawi *et al*., 2017). Therefore, our primary goal is to reduce the spread of insects in grain stores from harvest time using the best insect control management that limits the spread of insects and their harmful effects on the loss, vitality, and quality of grain.

Because of their presence of a broad spectrum of activity and no or low residuals on the central processing unit, fumigants are one of the most powerful weapons in managing stored grain insect pests. Therefore, Phosphine fumigants have largely replaced most other fumigants to overcome the damage caused by insects in stored cereals (Malavika and Yadava, 2023). The efficiency of using phosphine in smoking stored grain depends on several factors, including the dose used, exposure time, and storage conditions such as temperature and humidity.

Ramadan (2016) reported that fumigation of wheat grains before beginning of storage with phosphine at the rates of 3, 5, and 7 Tablet phosphine/m3 had a significant effect on storage efficacy characters (insect infestation and weight loss percentages) and germination % as compared to control treatment. In addition, Badawi *et al*. (2017) revealed that the high germination percentage of wheat grains was obtained from grains that were treated with phosphine at the rate of 8 ppm. Furthermore, Seadh *et al*. (2021) stated that the highest final germination percentage, shoot and root length, and seedlings dry weight in addition to the lowest, and speed germination index were recorded with phosphine fumigation at the rate of 3 tablets m-3 after 15 days from beginning the storage. Moreover, Kandil *et al*. (2022) revealed that phosphine fumigation of storage wheat grains with five tablets m-3 significantly increased final germination percentage, root length, shoot length, and seedling dry weight.

The main objective of this study was to evaluate the effect of phosphine fumigation doses and exposure time as well as the length of storage period on the vitality of bread wheat.

## Materials and Methods

### Experiment description and design

To investigate the influence of phosphine fumigation treatments (two tablet/ton exposure for 24, 48, 72 hours; four tablet/ton exposure for 24, 48,72 hours; six tablet/ton exposure for 24, 48, 72 hours ) on the vitality of bread wheat grains cv. Giza 171 at different storage periods (fresh grains, 3, 6, and 9 months) using a complete randomized design with three replications at the laboratory of Prof. Dr. Youssef Mohamed Omar, Plant Protection Department, on the middle fifth floor of the educational building of the Agriculture Faculty, Assiut University during the period from 26 May 2022 to 3 March 2023. The wheat grain, Giza 171, was obtained from the Agronomy Department Farm, Faculty of Agriculture, Assiut University. Glass jars were used and sealed with metal clips with a capacity of 1.5 kg. Tablets of aluminum phosphide were crushed in a crucible under isolation conditions from moisture. Dosses were prepared for each jar and placed in cotton, then the jars were closed until the end of the exposure period, and then opened for ventilation for 24 hours, then re-sealed until the measurements began.

**Measurements vitality traits**

After each tested storage period, 100 grains were randomized collected for each treatment and germinated according to International Seed Testing Association (ISTA, 1996) on top filter paper in sterilized Petri-dishes (14 cm diameter); each Petri-dish contains 25 seeds.

The germinated grains were counted, and the first count was defined as the number of germinated grains on the fourth day. After that, the number of germinated grains was counted every 24 hours until the end of the germination test (after ten days). The recorded traits were:

**Germination power percentage (GP %)**

It was calculated by counting the germinating grains at the first count (4 days after sowing) and relative them to the total number of tested seeds as described by Ruan *et al*. (2002).

**Final germination percentage (FG %)**

Normal seedlings of each replicate were counted at the end of the standard germination test and expressed as a percentage according to the following equation:

$$\text{FG \%} = \frac{\text{Number of normal seedlings}}{\text{Number of total grains}} \times 100$$

**Root length (cm)**

At the end of the standard germination test, averages of the root length of ten seedlings randomly per replicate were measured from the root origin in seeds to the tip of the root and recorded in centimeters (cm) as the root length.

**Shoot length (cm)**

Averages of the shoot length of ten seedlings were taken at random per each replicate from the seed to the tip of the leaf blade and expressed in centimeters (cm) as the shoot length at the end of the standard germination test.

**Seedlings dry weight (g)**

Ten random seedlings for each replicate were dried in the oven at 70 º C until constant weight. Seedlings were weighted in grams (g).

## Statistical analysis

Data were statistically analyzed using the analysis of variance (ANOVA) for the f completely randomized design (CRD) as published by Gomez and Gomez (1984) using a computer software package "SAS". Revised Least significant difference (RLSD) method was used to test the differences between treatment means at a 5% level of probability as described by Snedecor and Cochran (1980).

## Results and Discussion

### Germination power (%)

Data exhibited in Table 1 show that studied storage periods had a significant ($P \geq 0.01$) effect on the germination power trait. The maximum average value of the germination power trait (95.9 %) was recorded from fresh grains without storage treatment. In addition, the gradual decrease in germination power percent occurred with increasing the storage period from control (without storage) to nine months of storage. The decrease percentage in germination power from the beginning of storage to 3, 6, and 9 months were 3.68, 6.44, and 12.52 %, respectively. The previous results may be due to the lack of vitality of wheat grains and the lack of nutrients stored in grains due to the long storage period because of the infection with insects and fungi. These results were in the same line with those obtained by Abdelgwad (2021).

**Table 1. Means of germination power (%) as affected by phosphine treatments, Storage periods, and their interaction**

| Phosphine Treatments (P) | | Storage Periods (S) | | | | Mean |
|---|---|---|---|---|---|---|
| | | Without storage | 3 months | 6 months | 9 months | |
| Control | | 95.00 | 88.00 | 82.00 | 78.33 | 85.83 |
| **2 tablets Ton$^{-1}$** | 24 h | 94.67 | 91.67 | 89.67 | 84.67 | 90.17 |
| | 48 h | 94.00 | 91.00 | 89.00 | 84.00 | 89.50 |
| | 72 h | 97.33 | 94.67 | 91.33 | 87.00 | 92.58 |
| **4 tablets Ton$^{-1}$** | 24 h | 96.67 | 93.67 | 91.67 | 86.67 | 92.17 |
| | 48 h | 96.00 | 93.00 | 91.00 | 86.00 | 91.50 |
| | 72 h | 98.00 | 95.00 | 93.00 | 88.00 | 93.50 |
| **6 tablets Ton$^{-1}$** | 24 h | 97.33 | 94.33 | 92.33 | 87.33 | 92.83 |
| | 48 h | 94.67 | 91.67 | 89.67 | 84.67 | 90.17 |
| | 72 h | 96.00 | 93.00 | 91.00 | 86.00 | 91.50 |
| **Mean** | | 95.97 | 92.60 | 90.07 | 85.27 | ------ |
| **F test and R. L.S.D 0.05** | | F test | | R.L.S.D. 0.05 | | |
| **S** | | ** | | 0.71 | | |
| **P** | | ** | | 1.85 | | |
| **S × P** | | N.S | | - | | |

Where, N.S and ** men non-significant and significant at 1 % level of probability, respectively

Here too, the presented data in Table 1 reveal that phosphine treatments had a significant ($P \geq 0.01$) influence on the power of germination. Treatment of wheat grains before storage by 4 tablets for 72 hours exposure period gave the maximum germination power trait (93.50 %) with non-significant differences between this treatment and treatment of 6 tablets/24h (92.83%), 4 tablets/24h (92.17%), and 2 tablets/72h exposure period (92.17%). Otherwise, the minimum mean value of the germination power (85.83 %) was recorded from the control treatment. These results may explain the effect of phosphine in resistant insect pests and maintain their embryo and stored nutrients safe until germination time. These results are in harmony with those detected by Kandil *et al*. (2022).

Concerning the interaction between storage periods and phosphine treatments, the obtained data in the same previous table focus that the interaction failed to be significant at a 5 % level of probability.

**Germination percentage (%)**

Data illustrated in Table 2 denotes that the germination percentage was affected highly significantly ($P \geq 0.01$) by the studied storage periods. Thus, the highest mean value of the germination percentage (98.50 %) was recorded without storage treatment. Furthermore, a gradual decrease in germination percentage occurred with increasing the storage period from control (without storage) to nine months of storage. The level of decrease in germination percentage from begging of storage to 3, 6, and 9 months were 3.17, 5.46, and 9.20 %, respectively. These results may explain to the effect of storage was due to the damage to the membrane, nucleic acid, proteins, and enzyme, Ultimately, this leads to the death of the embryo and the loss of germination. The obtained results are in good line with those obtained by Badawi *et al*. (2017).

Meanwhile, the obtained results in Table 2 reveal that the germination percentage was affected highly significantly ($P \geq 0.01$) by the studied phosphine treatments. Wheat grains that were treated to 2 tablets/ton for 72 h or 6 tablets/ton for 48 h gave the highest percentage of germination (96.33%), but the lowest percentage of final germination (88.42%) was produced from the control treatment. In addition, although these aforementioned treatments gave the highest average values of germination percentage, they did not differ significantly from 4 tablets/ton for 72 h (95.67 %), 4 tablets/ton for 48 h (95.58 %), and 2 tablets/ton for 48 h (95.58 %). These results confirm the effect of the exposure period on germination percentage, as the longer the exposure period, the lower the dose used. These results are in harmony with Osama *et al*. (2020).

Moreover, the interaction between storage periods and phosphine treatment doses significantly affected the final germination percentage as presented in Table 2. Treatment of wheat grains by 2 tablets /ton for 72 h without storage (storage starter) gave the highest mean value of germination percentage (100 %) and the phosphine treatments during the different storage periods were continued the highest in the average values of the germination percentage compared to the control treatment under the different storage periods. This means that phosphine reduced the deterioration of the grain by preserving the nutrients in it and reducing the metabolic reactions. These results confirmed those obtained by Osama *et al*. (2020) and Badawi *et al*. (2017).

**Table 2. Means of germination percentage (%) as affected by phosphine treatments, Storage periods, and their interaction.**

| phosphine Treatments (P) | | Storage Periods (S) | | | | Mean |
|---|---|---|---|---|---|---|
| | | Without storage | 3 months | 6 months | 9 months | |
| Control | | 96.67 | 92.33 | 88.67 | 76.00 | 88.42 |
| **2 tablets Ton$^{-1}$** | 24 h | 99.33 | 96.33 | 94.33 | 92.33 | 95.58 |
| | 48 h | 98.00 | 95.00 | 93.00 | 91.00 | 94.25 |
| | 72 h | 100.00 | 97.00 | 95.33 | 93.00 | 96.33 |
| **4 tablets Ton$^{-1}$** | 24 h | 98.33 | 95.33 | 93.33 | 91.33 | 94.58 |
| | 48 h | 99.33 | 96.67 | 94.33 | 92.00 | 95.58 |
| | 72 h | 99.67 | 96.00 | 94.67 | 92.33 | 95.67 |
| **6 tablets Ton$^{-1}$** | 24 h | 97.33 | 94.33 | 92.33 | 90.33 | 93.58 |
| | 48 h | 99.00 | 97.33 | 95.67 | 93.33 | 96.33 |
| | 72 h | 97.33 | 94.33 | 92.33 | 90.33 | 93.58 |
| **Mean** | | 98.50 | 95.47 | 93.40 | 90.20 | ------ |
| **F test and R. L.S.D 0.05** | | F test | | R.L.S.D. 0.05 | | |
| **S** | | ** | | 0.72 | | |
| **P** | | ** | | 1.07 | | |
| **S × P** | | ** | | 2.39 | | |

Where, ** men significant at 1 % level of probability

## Root length (cm)

The data presented in Table 3 focus that the length of primary roots being significantly (P ≥ 0.01) affected by studied storage periods. The highest mean value of root length was recorded from fresh grains (without storage) (14.93 cm), which did not differ significantly from the average value obtained at a 3-month storage period (14,22 cm). It could be noticed that the length of the primary roots was decreased by increasing storage periods of wheat grains from the beginning of storage to 3, 6, and 9 months. These results can be attributed to poor growth due to the weak embryo and the consumption of nutrients during storage periods. A similar trend was observed by Salama *et al*. (2016) and Mahmud (2017).

Moreover, fumigation with phosphine significantly (P ≥ 0.01) affected the length of primary roots. The longest root of wheat seedlings (14.93 cm) resulted from 6 tablets/ton for 48 h treatments. Furthermore, the previous treatment had non-significant differences with treatments of 2 tablets/ton for 48 h (14.50 cm), 4 tablets/ton for 48 h (14.29 cm), 6 tablets/ton for 24 h (14.18 cm), 6 tablets/ton for 72 h (14.17 cm). These results may indicate that phosphine treatments preserved the contents of the inner grains from damage and deterioration due to insect infestation or consumption of nutrients during studied storage periods. These results are in accordance with those reported by Osama et al. (2020).

on the contrary, the interaction between storage periods and phosphine treatments had not recorded any significant effects on the length of primary roots.

**Table 3. Means of Root length (cm) as affected by phosphine treatments and storage**

| Phosphine Treatments (P) | | Storage Periods (S) | | | | Mean |
|---|---|---|---|---|---|---|
| | | **Without storage** | **3 months** | **6 months** | **9 months** | |
| Control | | 15.47 | 13.33 | 12.33 | 10.33 | 12.87 |
| **2 tablets Ton$^{-1}$** | 24 h | 14.27 | 14 | 13.67 | 13.33 | 13.82 |
| | 48 h | 15.00 | 14.67 | 14.33 | 14.00 | 14.50 |
| | 72 h | 14.17 | 14.03 | 13.67 | 13.33 | 13.80 |
| **4 tablets Ton$^{-1}$** | 24 h | 14.27 | 14 | 13.67 | 13.33 | 13.82 |
| | 48 h | 15.01 | 14.67 | 13.94 | 13.54 | 14.29 |
| | 72 h | 13.73 | 13.6 | 13.27 | 13.17 | 13.44 |
| **6 tablets Ton$^{-1}$** | 24 h | 14.67 | 14.33 | 14.00 | 13.67 | 14.17 |
| | 48 h | 15.13 | 15.13 | 14.8 | 14.67 | 14.93 |
| | 72 h | 14.47 | 14.4 | 14 | 13.87 | 14.18 |
| **Mean** | | 14.62 | 14.22 | 13.77 | 13.32 | ------ |
| **F test and R. L.S.D 0.05** | | F test | | | R.L.S.D. 0.05 | |
| **S** | | ** | | | 0.58 | |
| **P** | | ** | | | 0.83 | |
| **S × P** | | N.S | | | - | |

Where, N.S and ** men non-significant and significant at 1 % level of probability, respectively

## Shoot length (cm)

The presented data in Table 4 show that the average shoot length of the wheat seedlings significantly ($P \geq 0.01$) was affected by studied storage periods. It could be noticed that the shoot length was decreased by increasing storage periods from begging of storage to 3, 6, and 9 months around 1.50, 4.00, and 8.14%, respectively. The highest value of shoot length was recorded by fresh grains (without storage) (12.22 cm), and this treatment had non-significant differences with treatments of 3-month storage (12.04 cm). This may be due to decreasing of nutrients in the grains that had been affected by storage periods. These results confirmed those obtained by Salama et al. (2016) and Mahmud (2017).

Concerning the effect of phosphine treatments, data exhibited in Table 4 clearly shows that the tested phosphine treatments significantly ($P \geq 0.01$) affected the shoot length. Fumigated wheat grains by 4 tablets/ton for 72 h exposure time recorded the highest mean value of shoot length (12.78 cm). It could be noticed that the mean value recorded from 4 tablets/ton for 72 h treatment did not differ significantly from the average values recorded from 4 tablets/ton for 24 h (12.75 cm), 2 tablets/ton for 72 h (12.48 cm), and 4 tablets/ton for 48 h (12.45 cm) treatments. Kandil et al. (2022) reported these results may explain the effect of phosphine in resistant insect pests and maintain their embryo and stored nutrients safe until occur of germination and seedling growth.

Here too, the interaction between storage periods and phosphine treatments had not recorded any significant effects on the length of shoots.

**Table 4. Means of shoot length (cm) as affected by phosphine treatments and**

| Phosphine Treatments (P) | | Storage Periods (S) | | | | Mean |
|---|---|---|---|---|---|---|
| | | Without storage | 3 months | 6 months | 9 months | |
| Control | | 11.37 | 11.17 | 10.33 | 8.67 | 10.38 |
| 2 tablets Ton$^{-1}$ | 24 h | 11.87 | 11.67 | 11.33 | 11.00 | 11.47 |
| | 48 h | 12.07 | 11.93 | 11.60 | 11.27 | 11.72 |
| | 72 h | 12.97 | 12.73 | 12.40 | 11.83 | 12.48 |
| 4 tablets Ton$^{-1}$ | 24 h | 13.13 | 12.97 | 12.63 | 12.27 | 12.75 |
| | 48 h | 13.00 | 12.60 | 12.27 | 11.93 | 12.45 |
| | 72 h | 12.87 | 12.87 | 12.87 | 12.53 | 12.78 |
| 6 tablets Ton$^{-1}$ | 24 h | 11.97 | 11.90 | 11.53 | 11.20 | 11.65 |
| | 48 h | 11.87 | 11.57 | 11.57 | 11.47 | 11.62 |
| | 72 h | 11.10 | 10.97 | 10.97 | 10.87 | 10.98 |
| Mean | | 12.22 | 12.04 | 11.75 | 11.30 | ------ |
| F test and R. L.S.D 0.05 | | F test | | R.L.S.D. 0.05 | | |
| S | | ** | | 0.34 | | |
| P | | ** | | 0.57 | | |
| S × P | | N.S | | - | | |

**Storage**

Where, N.S and ** men non-significant and significant at 1 % level of probability, respectively

## Seedlings dry weight (g)

Data obtained in Table 5 reveal that the studied storage periods had a significant (P ≥ 0.01) effect on the seedling dry weight trait. as the highest mean value of the seedling dry weight (0.031 g) was recorded without storage treatment. In addition, the gradual decrease in seedling dry weight trait occurred with increasing the storage period to nine months of storage. The decrease percentage in seedling dry weight from begging of storage to 3, 6, and 9 months were 3.33, 24.00, and 24.00 %, respectively. This result is expected to happen because of the same trend obtained by looking at the length of the roots and shoots, which is considered one of the main contributions to the increase in the weight of the seedlings (Tables 3 and 4). These results are in harmony with those obtained by Osama *et al*. (2020) and Salama *et al*. (2016).

Furthermore, data illustrated in Table 5 denotes that the tested phosphine treatments had a significant (P ≥ 0.05) influence on seedling dry weight trait. Treatment of wheat grains before storage by 6 tablets/ton for 48 hours exposure period gave the maximum seedling dry weight trait (0.030 g). Otherwise, the lowest mean value of seedling dry weight trait (0.024 g) was recorded from the control treatment (without fumigation by phosphine). This is to be logical since the same trend was recorded with regard to roots and shoot length. These results are in harmony with those reported by Seadh *et al*. (2021).

Moreover, the interaction between storage periods and phosphine treatments did not record any significant effects on seedling dry weight trait.

**Table 5: Means of Seedling dry weight (gm) as affected by phosphine treatments, Storage periods, and their interaction.**

| phosphine Treatments (P) | | Storage Periods (S) | | | | Mean |
|---|---|---|---|---|---|---|
| | | Without storage | 3 months | 6 months | 9 months | |
| **Control** | | 0.027 | 0.025 | 0.024 | 0.021 | 0.024 |
| **2 tablets Ton$^{-1}$** | **24 h** | 0.032 | 0.031 | 0.027 | 0.026 | 0.029 |
| | **48 h** | 0.032 | 0.025 | 0.030 | 0.024 | 0.028 |
| | **72 h** | 0.032 | 0.029 | 0.026 | 0.026 | 0.028 |
| **4 tablets Ton$^{-1}$** | **24 h** | 0.030 | 0.031 | 0.021 | 0.024 | 0.027 |
| | **48 h** | 0.032 | 0.030 | 0.025 | 0.020 | 0.027 |
| | **72 h** | 0.030 | 0.032 | 0.024 | 0.029 | 0.029 |
| **6 tablets Ton$^{-1}$** | **24 h** | 0.028 | 0.028 | 0.020 | 0.023 | 0.025 |
| | **48 h** | 0.033 | 0.034 | 0.027 | 0.025 | 0.030 |
| | **72 h** | 0.029 | 0.032 | 0.025 | 0.031 | 0.029 |
| **Mean** | | 0.031 | 0.030 | 0.025 | 0.025 | ------ |

| F test and R. L.S.D 0.05 | F test | R.L.S.D. 0.05 |
|---|---|---|
| **S** | ** | 0.001 |
| **P** | * | 0.001 |
| **S × P** | N.S | - |

Where, N.S and ** men non-significant and significant at 1 % level of probability, respectively

## Conclusion

Throw the findings of this study we could conclude that, to achieve the highest average values of the vital properties of wheat grains during storage, wheat grains should be fumigated with phosphine at a rate of 2 tablets/ton for an exposure period of 72 hours in the beginning of storage.

## Acknowledgment

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**تأثير معاملات التبخير بالفوسفين على حيوية حبوب القمح في فترات التخزين المختلفة**

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**الملخص**

لدراسة تأثير معاملات التبخير بالفوسفين (قرصان / طن لمدة تعرض 24 و 48 و72 ساعة؛ أربعة أقراص / طن لمدة تعرض 24 و 48 و72 ساعة، ستة أقراص / طن لمدة تعرض 24 و 48 و72 ساعة) على حيوية حبوب القمح في فترات التخزين المختلفة (بدون تخزين، 3، 6، 9 أشهر). تم تصميم تجربة باستخدام التصميم كامل العشوائية بثلاثة مكررات بمعمل الأستاذ الدكتور / يوسف محمد عمر بقسم وقاية النبات بالطابق الخامس الأوسط من المبنى التعليمي لكلية الزراعة بجامعة أسيوط خلال الفترة من 26 مايو 2022 إلى 3 مارس 2023. تم الحصول على حبوب القمح صنف جيزة 171 من مزرعة قسم المحاصيل بكلية الزراعة جامعة أسيوط.

أظهرت النتائج المتحصل عليها أن فترات التخزين المختبرة لها تأثير معنوي جدا على جميع الصفات المدروسة. وهكذا تم تسجيل اعلي متوسطات لقيم قوة الإنبات (٪) ونسبة الإنبات (٪) وطول الريشا والجذير (سم) والوزن الجاف للبادرات (جم) في بداية التخزين ثم حدث انخفاض تدريجي بزيادة فترة التخزين. بالإضافة إلى ذلك، أدت معاملة حبوب القمح بجرعات مختلفة من الفوسفين لفترات تعرض مختلفة إلى زيادة عالية المعنوية في جميع الصفات التي تم دراستها مقارنة بمعاملة الكنترول (بدون فوسفين)، في حين أن الفروق بين معظم معاملات الفوسفين نفسها لم تكن معنوية. لذلك وللحصول على أعلى متوسط قيم للصفات محل الدراسة وللحفاظ على حيوية الحبوب خلال فترات التخزين يمكن معاملة حبوب القمح بقرصين من الفوسفين لمدة 72 ساعة لتقليل الجرعة وزيادة وقت التعرض لتقليل الآثار الضارة لجرعات الفوسفين العالية.