Evaluation of production practices to minimize diseases and postharvest losses of soybean (*Glycine max* L. (Merr.))

Clive Neba Akongnwi[1], Chuyong George Bindeh[2], Neba Godlove Ambe[2], Christopher Suh[1]
[1]Institute of Agricultural Research for Development, Cameroon
[2]University of Buea, Cameroon
*** Correspondence:** suhchristopher@yahoo.com

ABSTRACT

Soybean (Glycine max (L.) Merr.) is a leguminous crop which is a very important source of dietary protein and oil in animal feed, and a staple for human consumption. It is the fourth most important crop in the world in terms of area harvested and production. The stored products are usually subjected to postharvest losses, most of which begin from the field. These losses can be due to poor field or postharvest practices, which can lead to total grain loss. The objectives of this study were to determine appropriate field practices and postharvest storage practices that minimize the infection and spoilage of soybean grains. The field was laid out in an RCBD with 3 blocks of 6 treatments and the storage experiment was laid in a CRD, based on the 6 field treatments, subjected to two drying methods and stored under 5 storage systems. Results showed that plants that were mulched, produced more nodules and had higher yields compared to non-mulched. Plants that received chemical treatments before harvest showed less disease incidence at storage than the untreated and plants stored in packages with or without botanicals showed less disease incidence at storage than those stored in open air.

Key Words: Evaluation, Production Practices, Disease, Soybean (*Glycine max* L. (Merr))

RESUME

Le soja (*Glycine max* (L.) Merr.) est une légumineuse qui est une source très importante de protéines alimentaires et d'huile dans l'alimentation animale, et un aliment de base pour la consommation humaine. C'est la quatrième culture la plus importante au monde en termes de superficie récoltée et de production. Les produits stockés sont généralement soumis à des pertes post-récolte, dont la plupart commencent au champ. Ces pertes peuvent être dues à de mauvaises pratiques sur le terrain ou après la récolte, ce qui peut entraîner une perte totale de grains. Les objectifs de cette étude étaient de déterminer les pratiques de terrain appropriées et les pratiques de stockage post-récolte qui minimisent l'infection et la détérioration des grains de soja. L'essai a été disposé dans un RCBD avec 3 blocs de 6 traitements et l'essai de stockage a été disposée dans un RCB, basée sur les 6 traitements du champ, soumis à deux méthodes de séchage et stockés sous 5 systèmes de stockage. Les résultats ont montré que les plantes paillées

Received: 10/02/2023
Accepted: 31/03/2023
DOI: https://dx.doi.org/10.4314/jcas.v19i1.4

produisaient plus de nodules et avaient des rendements plus élevés que les plantes non paillées. Les plantes qui ont reçu des traitements chimiques avant la récolte ont montré une incidence de maladie moindre au stockage que les plantes non traitées et les plantes stockées dans des emballages avec ou sans plantes ont montré une incidence de maladie moindre au stockage que celles stockées à l'air libre.

Mots clés : évaluation, pratiques de production, maladie, soja (*Glycine max* L. (Merr))

INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is a leguminous crop that is a very important source of dietary protein and oil in animal feed, as well as a staple for human consumption (Hartman *et al.*, 2011). Soybean is the fourth most important crop in the world in terms of area harvested and production and it is the most important oilseed and least expensive but important protein source produced worldwide (Fried *et al.*, 2018; Julia *et al.*, 2019). Soybean cultivation is successful in warm climates with optimum growing mean temperatures of 20 to 30°C. Temperatures that fall below 20°C and over 40°C may significantly stunt growth. Soybean can grow in a wide range of soils, with best growth rates in moist alluvial soils of high organic content. Modern day soybean crop cultivars often reach a height of around 1m and take between 80–120days from sowing to harvesting (Kanchana *et al.*, 2016).

Agricultural production is generally seasonal, while demands for agricultural products are more evenly spread all year round. Thus, storage is particularly important in agricultural production. Consequently, there is thus a need to meet average demands by storing the harvested grains during the harvest season in order to gradually release them to the market during off-seasons (Okoruwa *et al.*, 2013). However, there are always diseases present at storage causing both qualitative and quantitative losses. Protecting crops from different pests and diseases through appropriate techniques can reduce, if not eliminate these losses. Presently, crop protection in agriculture plays an important role and is, however, a challenging process than before, as there has been emergence of so-called resistant species, which have to be brought under control. Failure to control them appropriately leads to a drastic reduction in the yield of many crops. To successfully carry out postharvest operations, it is important to first carry out good pre-harvest operations (Ashish et al., 2018; FAO, 2002). The use of new technologies, better cultivation practices, coordination and investment in infrastructure from food production to consumption are very important for reducing food losses and waste at different postharvest stages (FAO, 2002; Rajeshree *et al.*, 2013; Zubaida *et al.*, 2016; Sharma *et al.*, 2015).

Over the years, there has been an increase in soybean production in Cameroon. However, high incidence of diseases can lead to losses of grains, which greatly reduces yield (Rajeshree *et al.*, 2013; Rupe and Luttrell, 2020). Generally, the problem often begins in the field and is then transmitted to storage (Ashish *et al.*, 2018).

The objectives of this work were to: determine field agronomic practices which will minimize field disease infection of soybean plants and grain infection at harvest, and to determine the best local postharvest storage system to reduce soybean grain spoilage.

MATERIALS AND METHODS

Study site:

The research was carried out at the Institute of Agricultural Research for Development (IRAD), Nkolbisson, Yaounde. Nkolbisson lies between Latitudes 03°51' and 03°62' North, and Longitudes 011°27' and 011°43' East. It is at an elevation of 710m above sea level and is characterized by tropical climate with a fairly constant temperature throughout the year (Mballa *et al.*, 2017; CLIMATE-DATA.ORG, 2012).

MATERIALS

The pesticides used were: PENNCOZEB 80 WP (with active ingredient: zinc ion + ethylenebisdithio carbamate), a broad- spectrum contact Fungicide at a dose of 100g/16L of water and LAMIDA GOLD 90 EC (with active ingredient: 30g/L Imidaclopride + 60g/L Lambda cyhalothrine), a broad spectrum Systemic and Contact Insecticide at a dose of 60ml/16L of water. The variety used was TGX 2004-3F and the botanical used were powdered leaves of *Chenopodium ambrosoides*. The containers used for storage included plastic bottles, woven polythene bags and open-air storage.

METHODS

Field layout

The experimental design was a Randomized Complete Block Design (RCBD), composed of 3 Blocks with each block having 6 experimental units, laid out in a rectangular array. Each block had 6 experimental units. Each unit measured 2.5m X 2m, with an alley of 1m between units and an alley of 2m between blocks. The field treatments (T0: No mulch (Control); T1: Plastic Mulch only; T2: Combination of Grass Mulch + Pesticide treatment before harvest; T3: Combination of Plastic Mulch + Pesticide treatment before harvest; T4: Grass Mulch Only; T5: Pesticide treatment before harvest Only).

Sowing

Sowing was done at a density of 200 grains per plot, with each plot having 4 columns and 50 rows, with one plant per stand. Giving a plant population of 3600 for the experiment.

At sowing, the treatments T1, T2, T3, T4, were applied. For the plastic mulch treatments, polythene was placed on the entire plot and perforated at points where the grains were to be sown. For the grass mulch, dry grass straw (mainly composed of *Penicetum caudatum* and *Panicum maximus*) were used as the mulch (at a rate of 10Kg of mulch material per plot), by spreading all over the experimental unit. However, for T3, T4 and T5, pesticides were applied one week before harvest on the crops using a knapsack sprayer. The pesticides were applied 3 weeks before harvest to control the diseases before harvest. This was to determine whether the diseases at harvest are transmitted to storage.

Harvesting and Storage

Grains harvested from each field treatment were separated into two lots, two drying (sun drying and oven drying) methods applied to them, and five storage treatments (S0: Open air storage S1: Combination of tight containers and botanicals; S2: Storage in a tight container; S3: Combination of botanicals and bags; S4: Storage in bags) were then applied to each of the dried samples, giving a total of 60 experimental units. The botanical used was *Chenopodium ambrosioides*.

Drying

All the grains that were obtained from the different field treatments were separated into two different lots, with respect to the various treatments and one of each lot was subjected to a particular form of drying (either sun or oven drying). Thus, at drying, there were a total of 12 lots, 6 (from each field treatment) of which were oven dried and the other 6 sun dried.

Oven Drying: The seeds were dried in an oven, under hot air at a temperature of 40oC till they attained a moisture content of 12%.

Sun Drying: The seeds were dried under the sun till they attained a moisture content of 12%. The moisture content of the grains was determined using a grain moisture meter.

Twenty-five grams (25g) of the powder was measured out and used for each treatment that needed storage with the powder. The storage was such that all the grains were completely covered with the powder.

The diseases of interest included: *Cercospora* leaf spot caused by *Cercospora kikuchii*, bacteria pustule caused by *Xanthomonas axonopodis* pv. *glycines*, red-leaf blotch caused by *Phoma glycinicola*, Frog-eye leaf spot caused by *Cerospora sojina* and Soybean mosaic (Soybean mosaic virus) and Soybean rust, caused by *Phakopsora pachyrhizi*.

Data collection and Analyses

In the field, data was collected on plant height and disease incidence on the crop starting at 3 weeks after planting. The plant height was measured by using a ruler. The ruler was placed on the ground next to the stem, and the height of the tallest stem measured.

The disease incidence of the grains. At storage, data was collected fortnightly on the disease incidence at storage. The disease was assessed visually using the semi-quantitative scale of Kemerait *et al.*, 2009 (with modifications) that ranges from 1 to 5 depending on the severity of symptoms, where each number corresponds to:

1) Plants show no symptoms upon inspection.
2) 25% of the plants are covered with symptoms.
3) 50% of the plants are covered with symptoms.
4) 75% of the plant are covered with symptoms.
5) More than 75% of the plants are covered with symptoms.

At harvest, data was collected on number of nodules. The number of nodules from each plant from which data was collected in each treatment was counted. The plant was uprooted and the nodules counted and recorded.

All the data collected for this study were analyzed using the SAS statistical software, where summary statistics were first done and one-way Analysis of Variance (one-way ANOVA) was performed to determine if there existed a significant difference between the various field treatments and their effects on the field and storage parameters. The results from the analyses were presented on bar charts and tables.

RESULTS

Effects of different treatments on growth and yield of the crops

1.Plant height

As observed from the field, T1 (Plastic Mulch only) and T3 (Combination of Plastic Mulch + Pesticide treatment before harvest) had the tallest plants (with means of 84.2±2.1 and 83.0±1.6 respectively), while T0 and T5 had the shortest plants (with means of 32.4±0.9 and 33.0±1.2). A one way-ANOVA on plant heights showed that the treatments mulched with plastic (T1 and T3) were the tallest plants (significant at (P = 0.000) 0.05%). The plants were taller than those of treatments mulched with grass T2 (Combination of Grass Mulch + Pesticide treatment at harvest) and T4 (Grass Mulch Only), which were also taller than the treatments not mulched T0 (Control) and T5 (Pesticide treatment before harvest) as seen in Fig 1 below.

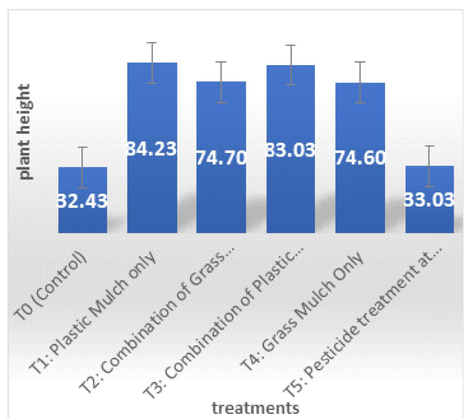

Fig 1. Mean plant height per treatment

2. Root nodules

As observed from the field, T1 (Plastic Mulch only) and T3 (Combination of Plastic Mulch + Pesticide treatment before harvest) had the highest number of nodules (with means of 516.3±49.9 and 512±49.3 respectively), while T0 (Control) and T5 (Pesticide treatment before harvest) had the least number of nodules (with means of 263.0±24.3 and 271.0±32.3 respectively) as seen in Fig 2 below.

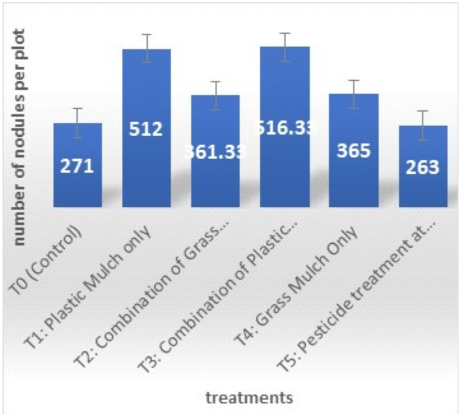

Fig 2. Mean number of nodules per treatment

3. Cercospora leaf blight

As observed from the field, T1 (Plastic Mulch only) had the highest incidence of *Cercospora* leaf blight (with means of 61.3±4.7), while T5 (Pesticide treatment before harvest) had the least *Cercospora* leaf blight incidence (with an overall mean of 29.0±5.6). T2 (grass mulch), T3 (Combination of Plastic Mulch and Pesticide treatment before harvest), T4 (Combination of Grass Mulch and Pesticide treatment before harvest), and T0 (Tillage only) had means of 38.0±, 58.6±3.5 31.0±4.2 respectively. This is shown in fig 3 below.

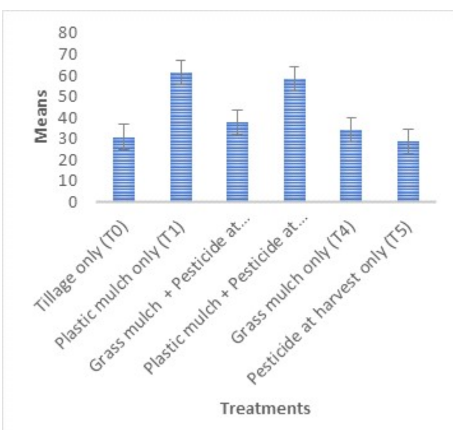

Fig 3. Mean Cercospora leaf blight incidence per treatment

4. Grain yield at harvest

At harvest, it was observed that, T1 (Plastic Mulch) had the highest grain yield (with an overall mean of 614.6±115.9Kg and a corresponding grain yield per hectare of 1229.6±231.9Kg), while T0 (tillage only) had the least grain yield (with mean of 228.4±66.3Kg, and a corresponding grain yield per hectare of 456.8±132.6Kg). These results are presented in fig 4 below.

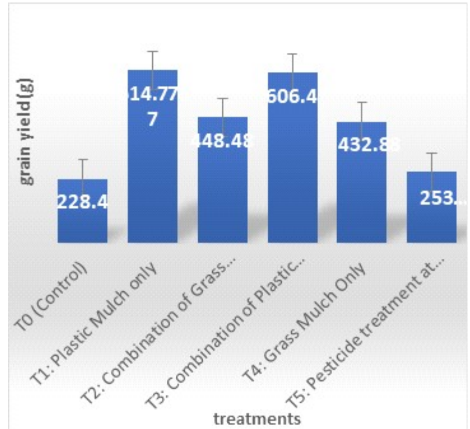

Fig 4. Means of grain yield

A) Effects of different treatments on grain infection.

Grain disease incidence

As observed at harvest, T1 (Plastic Mulch) had the highest grain disease incidence (with an overall mean of 38.7±20.9), while T5 (Pesticide treatment before harvest) had the least grain disease incidence, as shown in fig 5.

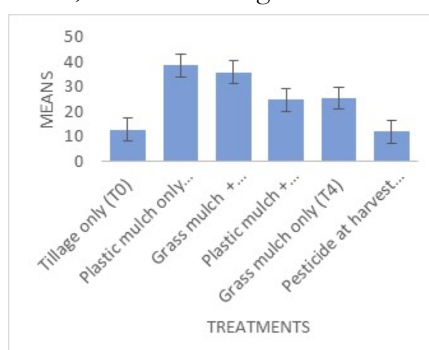

Fig 5. Means of grain diseases incidence

Field Treatments, Dried in the Sun

Disease incidence of grains harvested from field treatments, dried in the sun and stored with the different storage methods (S):

Grains harvested from T0 (Tillage only plots). Observations showed that, grains harvested from T0 and stored in open air (S0) had the highest disease incidence (with a mean of 43.4±0.8), while grains harvested from T0 and stored in a bag with botanical extract (S3) had the least incidence (with an overall mean of 10.1±0.3). This is presented in table 1.

Grains harvested from T1 (Plastic mulch only).

Grains harvested from T1 and stored in open air (S0) had the highest disease incidence (with a mean of 35.3±0.9), while grains harvested from T1 and stored in S1 had the least incidence (with an overall mean of 10.9±0.6). This is shown in table 1.

Grains harvested from T2 (Grass mulch only).

Grains harvested from T2 and stored in open air (S0) had the highest disease incidence with mean of 40.8±0.6), while grains harvested from T2 and stored in S3 (bag with botanical extract) had the least incidence (with an overall mean of 10.3±0.6). This is shown in table 1 below

Grains harvested from T3 (Combination of Plastic mulch and pesticide treatments before harvest).

Grains harvested from T3 and stored in open air (S0) had the highest disease incidence (with mean of 42.0±1.1), while grains harvested from T3 and stored in S2 (Storage in a tight container) had the least incidence (with an overall mean of 12.6±0.0). Grains harvested from T3 and stored in S1 (Combination of tight containers and botanicals), S3 (Combination of botanicals and bags) and S4 (Storage in bags) all had means of 12.9±0.3, 13.2±0.6 and 21.0±1.4, respectively. This is shown in table 1.

Grains harvested from T4 (Grass mulch and pesticide treatments before harvest).

Grains harvested from T4 and stored in open air (S0) had the highest disease incidence (with a mean of 48.0±1.4), while grains harvested from T4 and stored in S3 had the least incidence (with an overall mean of 10.1±0.3). Grains harvested from T3 and stored in S1 (Combination of tight containers and botanicals), S3 (Combination of botanicals and bags) and S4 (Storage in bags) all had means of 10.9±0.9, 12.9±0.3 and 15.5±0.6, 61 respectively. This is shown in table 1.

Grains harvested from T5 (tillage and pesticide treatments before harvest).

Grains harvested from T5 and stored in open air (S0) had the highest disease incidence (with a mean of 34.8±3.7), while grains harvested from T5 and

Table 1: Disease incidence at storage for all field treatments, harvested and dried under the sun and stored under all the different storage treatments.

SUN	T0	T1	T2	T3	T4	T5
S0: Open air storage	$43.4±0.8^{a}$	$35.3±0.9^{a}$	$40.8±0.6^{a}$	$42.0±1.1^{a}$	$48.0±1.4^{a}$	$34.8±3.7^{a}$
S1: Combination of tight containers and botanicals	$11.5±1.2^{bc}$	$10.9±0.6^{c}$	$12.9±0.3^{b}$	$12.9±0.3^{c}$	$10.1±0.9^{c}$	$10.9±0.0^{b}$
S2: Storage in tight container	$12.5±0.6^{bc}$	$11.2±0.3^{bc}$	$10.9±0.0^{b}$	$12.6±0.0^{c}$	$12.9±0.3^{bc}$	$14.1±0.9^{b}$
S3: Combination of botanicals and bags	$10.1±0.3^{c}$	$11.5±0.0^{bc}$	$10.3±0.6^{b}$	$13.2±0.6^{c}$	$10.1±0.3^{c}$	$13.2±0.6^{b}$
S4: Storage in bags	$13.2±0.6^{b}$	$14.9±0.6^{b}$	$17.8±1.7^{b}$	$21.0±1.4^{b}$	$15.5±0.6^{b}$	$12.6±0.0^{b}$

Each value is the mean of two replications. Means in the same column followed by the same letters are not significantly different (Pd"0.05) according to Duncan's test.

stored in S1 had the least incidence (with a mean of 10.9±0.0). Grains harvested from T5 and stored in S3 (Combination of botanicals and bags), S4 (Storage in bags) and S2 (Storage in a tight container) all had means of 12.6±0.0, 13.2±0.6 and 14.1±0.9, respectively. This is shown in table 1.

Field Treatments, Dried in the Oven

Disease incidence of grains harvested from field treatments, dried in the oven and stored with the different storage methods (S).

Grains harvested from T0 (Tillage only).

Grains harvested from T0 and stored in open air (S0) had the highest disease incidence (with mean of 39.9±0.9), while grains harvested from T0 and stored in S2 and S3 had the least incidence (with an overall mean of 12.9±0.3). Grains harvested from T0 and stored in S1, and S4 all had means of ranging from 13.5±0.9 and 13.5±0.3, as shown in table 2.

Grains harvested from T1 (Plastic mulch only).

Grains harvested from T1 and stored in open air (S0) had the highest disease incidence (with mean of 36.5±2.0), while grains harvested from T1 and stored in S2 had the least incidence (with an overall mean of 11.5±0.6). Grains harvested from T1 and stored in S1, S3 and S4 all had means of 11.7±0.3, 11.7±0.3 and 14.1±0.3, respectively, as shown in table 2.

Grains harvested from T2 (grass mulch only).

Grains harvested from T2 and stored in open air (S0) had the highest disease incidence (with mean of 39.9±0.3), while grains harvested from T2 and stored in S3 had the least incidence (with an overall mean of 10.3±0.6). Grains harvested from T2 and stored in S1, S2 and S4 all had means of 11.8±0.9, 11.5±0.6 and 15.2±0.9, respectively, as shown in table 2 below.

Grains harvested from T3 (Combination of plastic mulch and pesticide treatment before harvest).

Grains harvested from T3 and stored in open air (S0) had the highest disease incidence (with mean of 40.5±0.3), while grains harvested from T3 and stored in S1 had the least incidence (with a mean of 11.2±0.9), as shown in table 2.

Grains harvested from T4 (Combination of grass mulch and pesticide treatment before harvest).

Grains harvested from T4 and stored in open air (S0) had the highest disease incidence (with mean of 47.1±0.1), while grains harvested from T4 and stored in S1 had the least incidence (with an overall mean of 8.9±0.3). Grains harvested from T4 and stored in S3, S2 and S4 all had means of ranging from 11.2±0.3, 12.9±0.3 and 14.4±0.6, respectively. This is shown in table 2 below.

Grains harvested from T5 (tillage and pesticide treatment before harvest).

Grains harvested from T5 and stored in open air (S0) had the highest disease incidence (with mean of 34.7±3.7), while grains harvested from T5 and stored in S1 had the least incidence (with an overall mean of 10.6±0.3). Grains harvested from T5 and stored in S3, S4 and S2 all had means of ranging from 12.9±0.3, 13.5±0.3 and 15.5±0.6, respectively. This is shown in table 2 below.

Table 2: Disease incidence at storage for all field treatments, harvested and dried in the oven and stored under all the different storage treatments.

OVEN	T0	T1	T2	T3	T4	T5
S0: Open air storage	39.9±0.9[a]	36.5±2.0[a]	39.9±0.3[a]	40.5±0.3[a]	47.1±0.6[a]	34.7±3.7[a]
S1: Combination of tight containers and botanicals	13.5±0.9[b]	11.8±0.4[b]	11.8±0.9[bc]	11.2±0.9[c]	8.9±0.3[b]	10.0±0.3[b]
S2: Storage in tight container	12.9±0.3[b]	11.5±0.6[b]	11.5±0.6[bc]	12.4±0.3[c]	12.9±0.3[b]	15.5±0.6[b]
S3: Combination of botanicals and bags	12.9±0.3[b]	11.7±0.3[b]	10.3±0.6[c]	12.6±0.0[c]	11.2±0.3[c]	12.9±0.3[b]
S4: Storage in bags	13.5±0.3[b]	14.1±0.3[b]	15.2±0.9[b]	20.9±1.4[b]	14.4±0.6[b]	13.5±0.3[b]

Each value is the mean of two replications. Means in the same column followed by the same letter are not significantly different (Pd"0.05) according to Duncan's test.

Disease incidence in relation to drying method at storage

The following figures (fig 6-fig 11) are bar charts showing results of disease incidence of grains harvested from different field treatments (T0: No mulch (Control); T1: Plastic Mulch only; T2: Combination of Grass Mulch + Pesticide treatment before harvest; T3: Combination of Plastic Mulch + Pesticide treatment before harvest; T4: Grass Mulch Only; T5: Pesticide treatment before harvest Only), dried with different drying methods (sun drying and oven drying) and stored under different storage conditions (S0: Open air storage; S1: Combination of tight containers and botanicals; S2: Storage in a tight container; S3: Combination of botanicals and bags; S4: Storage in bags).

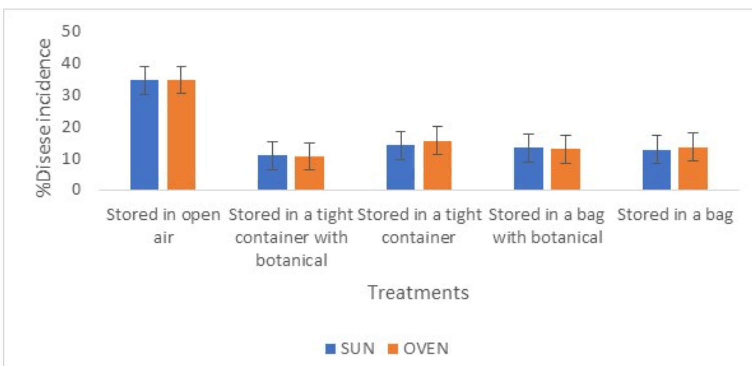

Fig 6. Bar chart showing disease incidence in relation to drying method from T0 (tillage only)

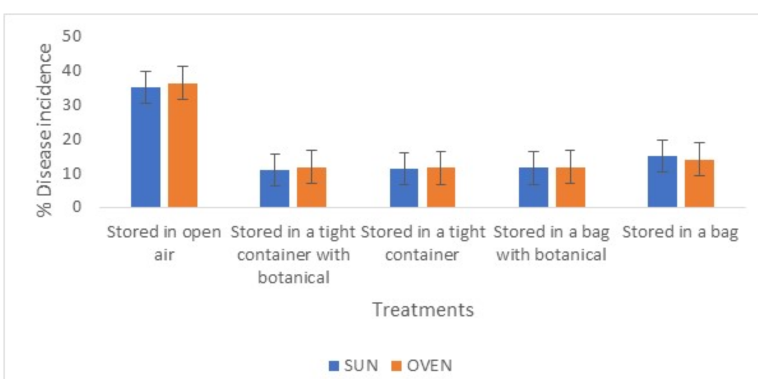

Fig 7. Bar chart showing disease incidence in relation to drying method from T1 (plastic mulch only)

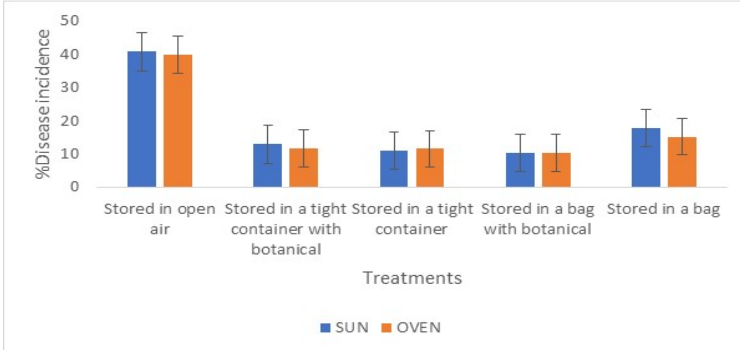

Fig 8. Bar chart showing disease incidence in relation to drying method from T2 (grass mulch only)

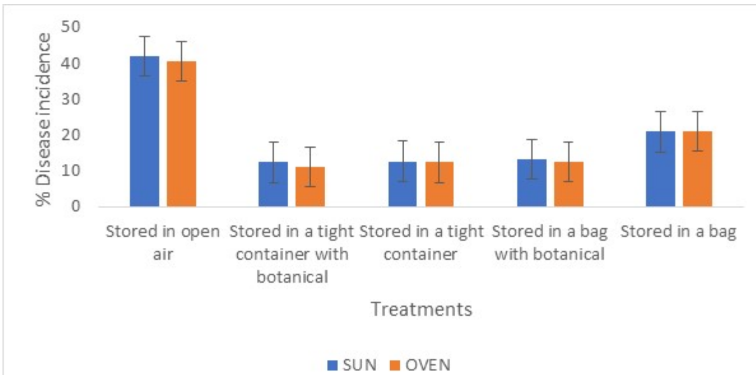

Fig 9. Bar chart showing disease incidence in relation to drying method from T3 (combination of plastic mulch and pesticide treatment before harvest)

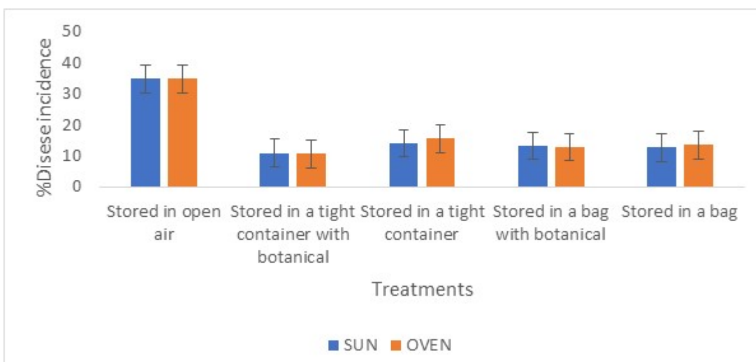

Fig 10. Bar chart showing disease incidence in relation to drying method from T4 (combination of grass mulch and pesticide treatment at harvest)

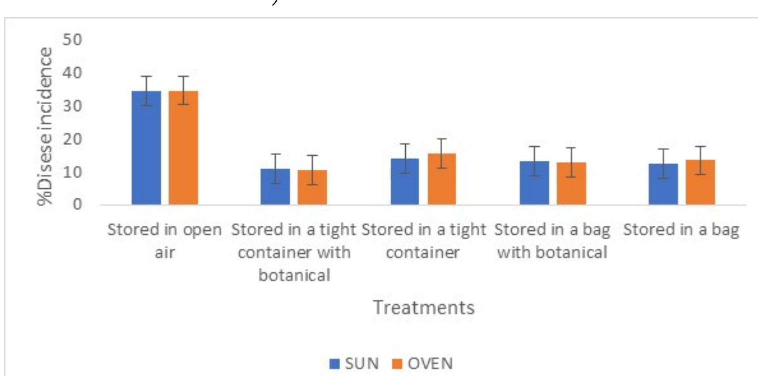

Fig 11. Bar chart showing disease incidence in relation to drying method from T5 (pesticide treatment before harvest)

DISCUSSION

Effects of different treatments on growth and yield of the crops

1. Plant height

The difference in the heights of the plants with respect to the different treatments could be attributed to the fact that the different mulches change the micro climate around the plants, thus, influencing their growths differently. These mulches help in conserving soil moisture, temperature, soil texture and conserving soil fertility (Kavutu, 2018; Melek and Atilla, 2009). All these properties are essential for proper plant growth thus suggesting why the treatments which were mulched had taller plants. Under the plastic mulch system, soils are loose, friable and well aerated and also roots have easy access to adequate oxygen which promotes high microbial activity (Lalitha *et al.*,2010). The soil fertility is conserved due to the fact that the mulch serves as a barrier, inhibiting the leaching of nitrates, especially produced during N-fixation. Consequently, treatments mulched with plastic had the tallest plants and this result is in conformity with those of Siczek *et al.*, 2015 and Kader *et al.*, 2017.

2. Root nodules

The difference in number of root nodules per plot could be due to the fact that, soil compaction affects nodulation and nitrogen fixation of soybean (Anna and Jerzy, 2011). This could be the reason why T0 (Control) and T5 (Pesticide treatment before harvest) plants had the least number of nodules, while plants which were mulched had more nodules per plot as well as a corresponding weight of nodules. The compaction limits the space required for the nodules to be formed. These nodules help in the nitrogen fixing ability of the plant, which provides the plants with nitrogen for growth. Consequently, plants mulched with plastic had the highest number of nodules and this result is in conformity with those of Siczek *et al.*, 2015 and Kader *et al.*, 2017

3. Cercospora leaf blight

All treatments mulched with plastic had the highest incidence, which could be attributed to the fact that the spores of the fungi are easily spread among plants of these treatments. In this case, the spores were easily blown off by the wind once they fell on the plastic or washed off by rain splashes once they are on the plastic. This probably enhanced the easy spread of the diseases among these treatments, whereas, for treatments not mulched or mulched with grass, once the spores touched the bare ground or grass mulch, it became difficult for them to be blown easily by the wind or dispersed by rain splashes. This result is in conformity with that of Madden, who did a similar trial 1997, to see the effects of plastic mulch on disease spread

4. Grain yield at harvest

Mulching is an effective method of improving crop growth and yield through manipulation of the crop's growing environment by ameliorating soil temperature, conserving soil moisture content, reducing soil erosion, improving soil structure and enhancing organic matter content (Kareem *et al.*, 2012). Since mulch increases plant growth, it is likely that the yield of the crops will be high with respect to their growth. These tall plants usually have bigger canopies and higher rates of photosynthesis. These large head sizes and high chlorophyll contents may be associated with high grain yield (Lawlor *et al.*, 2001; Vikrant and Dhillon, 2015). Consequently, treatments mulched with plastic had the tallest plants, more nodulation, which were translated into yield. Thus, plants which were mulched especially with plastic had the highest yield. This result is in conformity with those reported by Siczek *et al.*, 2015 and Kader *et al.*, 2017.

Effects of different treatments on grain infection.

Pre-harvest chemical desiccation provides some significant advantages (Touhidul and Anowarul, 2018). Chemical applications may advance the harvest date, eliminate seed losses, and improve quality (Yong-qi et al., 2015). This could be why the grains harvested from T5 (Pesticide treatment before harvest) had the least diseased grains. It could still be as a function of the proportion of disease grains to the quantity of grains per treatment, whereby, treatments with a high yield could likely have a higher quantity of disease grains. However, treatments which had a higher infection rate in the field also had a higher disease incidence in the grains, which could be suggested that the diseases were transmitted to the grains in the field.

All grains harvested from the field treatments and stored in open air had a high disease incidence rate, irrespective of the drying method. This can be attributed to the fact that the grains stored in open air were open to moisture absorption which increased their moisture contents, thus providing a favourable moisture content for disease growth and spread. Moisture content is known to be the primary contributing factor in determining the kinds of fungi that invade stored seed and the degree to which they invade it, thus it could be a justification in the rapid spread of disease among the grains stored in open air (Marek *et al.*, 2018; Danilo *et al.*, 1997). An increase in moisture content could also mean an increase in rate of respiration, thus a further increase moisture, which is favourable for fungi growth and reproduction (Dillahunty *et al.*, 2000). Grains harvested from various treatments and stored in bags with botanicals showed a reduced rate of disease incidence at storage, irrespective of the drying method. This could be due to the fact that the bags had small air pores which could help in small air circulation within the packages, thus a reduced rate of moisture accumulation within the bag. This also could have helped in the regulation of the temperature within the packages. This regulation in temperature and humidity within the bags could possibly have led to a reduced rate of moisture accumulation, thus limiting the growth and development of fungi diseases within the packages. The reduced disease incidences could also be as a result of the use of the botanicals. The powder of the botanicals could either be acting directly by inhibiting the growth and reproduction (fungi static) of the pathogens causing the diseases, or by killing the pathogens causing the diseases (fungicidal effect) or it could also be absorbing the moisture produced, thus reducing the rate of disease spread. The grains stored in tight containers equally showed a reduced rate of disease incidence irrespective of the field treatment or the drying method. However, the grains stored in tight containers with botanicals had an even lesser rate of disease incidence, when compared with those not stored in botanicals. However, unlike those stored in bags, there could be a possibility moisture accumulation within the containers in the long run, thus favouring the growth and spread of the diseases.

Disease incidence in relation to drying method at storage

When comparing the different samples dried with different methods, there was no significant change in the rate of infection among the different storage treatments. This could be because all the samples were dried to 12% moisture, which is an ideal moisture content for storage. However, the different storage treatments had different rates if infection but similar treatments dried under the different drying methods did not show a big difference.

CONCLUSIONS

From the results of this study, the following conclusions were derived: One of the most effective ways to improve yield of soybeans, while minimizing disease infection is by mulching. With the high costs of polythene and the adverse environmental effects of plastics, using grass mulches will be the best option as they are readily available, cheap and biodegradable. However, applying pesticides before harvest can further reduce the infection transmission from leaves to pods and subsequently to grains. Storing grains in clean containers or packages, especially with botanicals can reduce the rate of disease spread at storage. Storing grains in open air enhances infection and disease spread during storage due to the exposure of the grains to favourable environmental conditions for disease growth. Therefore, to adequately minimize grain spoilage at storage, it is important to apply the best field practices to first minimize infection from the field, followed by applying the best storage treatments to enable the longer storage of grains.

ACKNOWLEDGEMENTS

We acknowledge the assistance of the Institute of Agricultural Research for Development, IRAD for providing space for the field research. We also acknowledge the University of Buea for granting the laboratory for analysis.

CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

REFERENCES

Ashish, M., Paschal, M. and Ajay, S. (2018). An overview of the post-harvest grain storage practices of smallholder farmers in developing countries agriculture. *Agriculture*, 8(57), 12-40.

Anna, S. and Jerzy, L. (2011). Soybean nodulation and nitrogen fixation in response to soil compaction and surface straw mulching. *Soil and Tillage Research*, 114(1), 50-56.

Danilo, E., Mew, T. and Lina, L. (1997). *Influence of moisture content and length of storage on fungal invasion of paddy rice*. New York: Guilford Press.

Dillahunty, L., Siebenmorgen, T., Buescher, R., Smith, D. ad Mauromoustakos, A. (2000). *Effect of Moisture Content and Temperature on Respiration Rate of Rice*. BIO Web of Conferences 10. Retrieved from; https://doi.org/10.1051/bioconf/20181002001.

Food Agriculture Organization of the United Nations (FAO) (2002). *Soybeans: Postharvest operations*. Rome: FAO.

Fried, H., Narayanan, S. and Fallen, B. (2018). Characterization of a soybean (Glycine max L. Merr.) germplasm collection for root traits. *PLoS ONE*, 13(7).

Hartman, L., West, E. and Herman, T. (2011). Crops that feed the world 2: Soybean worldwide production, use, and constraints caused by pathogens and pests. *Food Security*, 3(5), 1–17.

Kader, A., Masateru, S., Mojid, M., Takeo, O. and Kengo, I. (2017). Effects of plastichole mulching on effective rainfall and readily available soil moisture under soybean (Glycine max) cultivation. *Paddy and Water Environment*, 10.1007/s10333-017-0585-z.

Kanchana, M., Lakshmi, S. and Dilip, R. (2015). A review on *Glycine max* (L.) Merr. (Soybean). *World Journal of Pharmacy and Pharmaceutical Sciences*, 5(1), 356-371.

Kareem, T., Alamu, O., Egberongbe, R. and Arogundade, R. (2012). Effect of different mulch materials on the incidence and severity of okra mosaic virus (OMV) in okra plants. *Journal of Applied Horticulture*, 14(1): 1-12.

Kavutu, A. and Mwangi, M. (2018). Effects of Grass and Plastic Mulch on Growth and Yield of Strawberries (Fragaria x ananassa) in Kiambu

County, Kenya. *Journal of Animal and Plant Sciences*, 38(1), 6129-6137.

Marek A., Koloman K., Ján J., Pavol F. and Milan K. (2018). *The effect of conditions and storage time on course of moisture and temperature of maize grains*. BIO Web of Conferences, 10, 02001.

Mballa, T., Ngonkeu1, M., Malaa, D., Mouen, J., Meppe, P., Petmi, C., Nanda, V., Tekeu, H. and Noe W. (2017). Field Evaluation of NERICA 8 (Oryza sativa L.) and JL24 (*Arachis hypogaea* L.) Spatial Arrangement on Agronomic Traits Performance in Humid Forest Zone of Cameroon. *Annual Research and Review in Biology*, 12(1), 1-14.

Melek, E. and Atilla D. (2009). Effects of different ulch materials on plant growth, some quality parameters and yield in melon (Cucumis Melo L.) cultivars in high altitude environmental condition. *Pakistan Journal of Botany*, 41(4), 1891-1901.

Okoruwa, V., Ojo, O., Akintola, M., Ologhobo, D. and Ewete, K. (2013). Post-harvest grain management storage techniques and pesticides use by farmers in SouthWest Nigeria. *Journal of Economics and Rural Development*, 18(53), 53-72.

Rajeshree, A., Manish, M. and Himanshu, P. (2013). *Assessment of pre and postharvest losses in soybean crop in Rajasthan. Rajasthan: Agro-Economic Research Centre for the states of Gujarat and Rajasthan*.
Rupe, J. and Luttrell, R. (2020). *Effect of Pests and Diseases on Soybean Quality*. London: Researchgare Publications.

Sharma, K., Singh, S., Sharma, P., Kumar, P., and Lalan, S. (2015). Seed treatments for sustainable agriculture-a review. *Journal of Applied and Natural Science*, 7(1), 521 – 539.

Siczek, A. and Lipiec, J. (2011) Soybean nodulation and nitrogen fixation in response to soil compaction and surface straw mulching. *Soil Tillage Research*, 114,50– 56.

Touhidul, I. and Anowarul, H. (2018). Evaluation of pre-harvest interval for pesticides on different vegetables in Bangladesh. *Journal of Bangladesh Agricultural University*, 16(3), 444–447.