Research Article

# Disease-free and Organic Okra (*Abelmoschus esculentus L. Moench*) Production Through Treatments Combination of Mulching types and Weeding Regimes

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**Abstract** | The production and consumption of disease-free and organic food have recently gained increased focus despite the lower productivity of organic crops. Okra is an important economic vegetable crop that can reach optimum production in the absence of fertilizers/chemicals application and produce promising yields within a short period. However, several elements along with pathogens, pests, and very importantly viral diseases, restrict the belief of these intended goals. The current experiment assessed the effects of mulching materials and weeding regimes on the severity and incidence of not unusual viral diseases on okra without fertilizers/chemicals application. The treatments were (3×4) factorially designed and fitted into RCBD in field conditions. Weeding consisted of four levels *i.e.* no weeding, weeding once, weeding twice, and weeding thrice, whereas mulching types comprised of three levels i.e., no mulching, dry grasses mulching, and polythene mulching. The findings revealed that all of the okra plants tested were susceptible to virus infections regardless of treatment. Those who had a treatment combination of three weedings and polythene mulching, on the other hand, had the lowest incidence and severity of viral infection, while those who received no weeding and no mulching had the highest. At the 7th week after planting, the treatment combination of thrice weeding with polythene mulching had the lowest viral incidence of 18.75 percent, whereas the treatment combination of no mulch application and no weeding had the highest viral incidence of 89.63 percent. Similarly, the treatment combination of thrice weeding and polythene mulch resulted in significantly less disease severity (7.41%), whereas the treatment combination of no weeding and no mulching application resulted in significantly more disease severity (99.98%). In comparison to other treatment combinations, the treatment combination of weeding thrice and polythene mulching produced the highest yield characteristics at harvest. Okra, an important vegetable crop in Nigeria where viruses cause severe yield loss due to tropical climate. This study will help in the production of disease-free okra crop without chemicals application. Moreover, our study will contribute to the organic production of this important vegetable crop.

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## Introduction

The demand for disease and chemicals free food production has steadily increased worldwide despite the lower productivity of organic crops. Organic crops are generally more natural products and involve less or no synthetic pesticides or fertilizers (Hurtado-Barroso *et al*., 2017; Khan *et al*., 2020). Okra is a widely planted vegetable crop, particularly in the tropics that has the potential to produce higher yields without chemicals application (Alegbejo, 2015; Edet and Etim, 2007; Abdulraheem and Moshood, 2019a).

India is the world's leading producer of okra, producing 3.5 million tonnes (70% of total global production) on approximately 0.35 million hectares of land while Nigeria ranked first in Africa with 1.53 million tonnes (80% of global production) of total generated from 0.15 million hectares of land (FAOSTAT, 2008; Fudzagbo and Abdulraheem, 2020). The production and consumption of okra in Nigeria have rapidly increased in recent years (Alegbejo, 2015; Christo and Onuh, 2005; Katung and Kashina, 2005). According to CBN (2004), between 2001 and 2003, the average growth rate of the vegetable crop in Nigeria, including okra, was 14.0 percent, compared to 6.4 percent for cassava, 18 percent for palm oil, and 3.8 percent for maize. Okra in various variety are extensively cultivated throughout the year, both in the home garden and commercial plots in Nigeria CBN (2004), Abdulraheem (2018) and Farinde *et al*. (2001).

Okra, being a temperate crop is adaptable to hot weather, drought, less soil fertility, and is widely cultivated across the globe Hamon and Hamon (2001) and Abdulraheem *et al*. (2017). Despite its tolerance to stringent conditions, weed, insect pests, and poor cultural practices still pose a severe threat to achieving optimum yields. Besides, the high productivity of okra is also challenged by a wide variety of pests and pathogens that attack the crop at all stages of development Christo and Onuh (2005). These include bacteria, viruses, fungi, and nematodes, of which viruses constitute the major group of pathogens affecting okra production Abdulraheem and Moshood (2019a). Okra farmers in the dry savannah areas of sub-Sahara Africa obtain low yields estimated at 250kg $ha^{-1}$ due to complex biotic and abiotic factors FAOSTAT (2008). Poor soil fertility, excessive drought, heat, acidity and stress due to intercropping are biotic variables that induce yield decrease while biotic factors include pests, parasitic weeds as well as viruses, fungi, nematodes, and bacterial diseases (Thakur *et al*., 2000). Numerous plant viruses are transmitted by vectors from one host to another, among which weed and insects are the major pests of okra in all agroecological zones of Nigeria constituting the major constrain in large-scale production of okra (Christo and Onuh, 2005; Abdulraheem and Moshood, 2019b).

Flea beetles (Podagrica sp. ), cotton stainer (Dysdercus superstitus), whitefly (Bemisia tabaci), and green stink bug (Nezera viridula) are among the insect pests found infesting okra in Nigeria, according to Asare-Bediako *et al*. (2014). Flea beetles (Podagrica species.) are the most devastating of these pests in Nigeria (Asare-Bediako *et al*., 2014). The feeding activity of Podagrica sp. causes damage to the leaves, which includes typical perforations and irregular holes that diminish photosynthetic surface area, resulting in a significant drop in yield (Echezona and Offordile, 2011).

Okra is infected by roughly 19 different plant viruses around the world, according to Christo and Onuh (2005), with only three of these being reported in Nigeria (Alegbejo, 2015). Okra Mosaic Virus (OkMV), Okra Leaf Curl Virus (OkLCV), Cucumber Mosaic Virus (CMV), Yellow Vein Mosaic Virus (YVMV), and Sida Golden Mosaic Virus (SiGMV) are some of the plant viruses that attack okra plants in the field (Unseld, 2010). However, the okra plant is frequently affected with many virus diseases, which can result in significant economic losses (Christo and Onuh, 2005). In the field-grown to okra crops (Alegbejo, 2015; Alegbejo, 2000), losses owing to viral infections are expected to be 10% and 100%, respectively. The virus has a destructive effect and can easily have an impact on household food security, either directly or indirectly. The Covid-19 pandemic has exacerbated the situation, with consumers more anxious about consuming virus-free food (Khan *et al*., 2020; Oyetoro *et al*., 2020).

Most importantly, weeds are plants that compete for nutrients, space, water, and light with crops while exerting many harmful effects that reduce crop quality and quantity (Ronald *et al*., 2006). They are also reservoir or alternative hosts for insects, diseases, and pathogens (Ronald *et al*., 2006). Weed-related crop losses could be exacerbated if weeding is delayed or impossible over the full crop growth cycle (Ossom *et al*., 2001). Weeds competition can lower vegetative growth, flowering, fruiting, and seed production which will determine the yield (Slippers, 2009). Besides, losses from inadequate cultural practices that lower crop yield include the use of contaminated farm tools, diseased seeds, weed seeds on farmer's clothes, and other erroneous cultural practices (Ronald *et al*., 2006). Weeds and inappropriate cultural practices that aggravate insects and other pests often coexist and reduce yield in the agricultural system (Ronald *et al*., 2006; Abdulraheem and Charles, 2018). Yield losses due to parasitic weed have been reported to range from 12.7-60%, 82%, 41-80% (Li *et al*., 2004) while damage caused by inappropriate cultural practices on okra can be as high as 80% to 100% (Ossom *et al*., 2001). However, weed control without adequate cultural practices like the use of mulching materials (polythene and dry grasses) may lead to more than 60% reduction in growth and yield component especially in the savannah of the tropics and sub-tropic in Africa and Asia (Ronald *et al*., 2006). Meanwhile, insect pest control in cultural practices without weed control results in about 98% to 100% loss in okra yield (Alegbejo, 2000).

As a result, managing these viral illnesses and pest infestations effectively is critical to increasing okra yields. The establishment of appropriate and successful management techniques will require information on the severity and incidence of these viral illnesses. This study tends to research using mulching as a cultural exercise in lowering the prevalence and severity of viral diseases on okra; to assess the primary outcomes of mulching materials and weeding regimes at the occurrence and severity of viral diseses on okra; and to evaluate the effect of treatment combos of mulching materials (dry grasses and polythene film) and weeding regimes on the occurrence and severity of viral diseases on okra.

## Materials and Methods

The experiment was conducted at the University of Ilorin's Teaching and Research Farm (Crops division) in Kwara State, Nigeria located at latitude $8^{0}29^{1}$N and $9^{0}30^{1}$N and longitude $4^{0}30^{1}$E and $6^{0}25^{1}$E during September and November 2016. Ilorin's rainfall pattern is bimodal, with a four-month wet season from June to October, and a quick dry spell, which occurs in maximum cases within the 2nd part of August. The wettest months are June/July and September/October, with a quick dry season from November via December. The daily mean temperature varies from 26 and 49°C (FAOSTAT, 2008; Abdulraheem and Moshood, 2019b) and it is classified as AEZ-II (Agro-Ecological zone). Balogun and Odutola (2003) had a medium-high topography with sandy loam soil that had been found to be ideal for okra growing. Land preparation commenced with bush clearing followed by the conventional method of plowing, harrowing, and ridging, followed by weeds, volunteers, and other major stubbles. The land was then exposed to natural weathering for 7 days after plowing. Then the field was marked into plots of 30meters/ weeding regime and 12 treatment combinations in three blocks/replicate with 2-meters distance between replicates. The experiment was set up as a 3 X 4 factorial design with three (3) replicates in a randomized complete block design (RCBD). There are 12 treatment combinations in each block. The total land area planted was 15m X 30m, with block sizes ranging from 5 to 15m and 1m within replicates.

Weeding regimes, as well as the blocks and mulching kinds within the plots, were used to divide the experimental field into three blocks. Each experimental plot had 24 ridges, each measuring 5m in length. Weeding and mulching were the two most important elements. No weeding, weeding once, weeding twice, and weeding thrice were the four levels of weeding, whereas mulching was divided into three categories: no mulching, plastic (polythene) mulching, and organic mulching (dry grasses). Each treatment was carried out three times and a different plot was assigned to each one at random.

The growth, yield, and disorder parameters were gathered weekly as of when they had been due in the morning, and a file become stored on the chosen samples of the populace in every that had already been tagged. Starting from four weeks after plantation, the sick leaves found on the selected samples were counted and documented. The amount of unwell end result turned into calculated by counting the quantity of okra yields from selected sparkling harvest pattern vegetation that had over 80% viral signs based on visual inspection. The virus was located at Ibadan's International Institute of Tropical Agriculture (IITA). Each block collected samples from the 12 treatment mixtures that revealed viral signs and ran them through an Antigen Coated Plate - Enzymes Linked Immunosorbent Assay (ACP-ELISA).

The mean values of ACP-ELISA were collected after 1 hour of analysis based on absorbance value (OD*405nm) and overnight analysis of the samples collected using ACP-ELISA. The antibodies used were for Cucumber Mosaic Mosaic Virus (CMV), Okra Leaf Curl Virus (OkLCV), Okra Mosaic Virus (OkMV), and Blackeye Cowpea Mosaic (BiCMV) Virus. The percentage of disease incidence was obtained using Sharma's measurement of disease approach that states: the percentage of diseased plants or parts in a sample or population of plants could be the proportion or percentage of sick leaves in a plant, infected stalks or a tiller, or diseased seedlings in a field.

$$\text{Disease incidence} = \frac{\text{No.of infected plants}}{\text{Total no.of plant assessed}} \times 100$$

The percentage of disease severity was obtained using visual assessment methods with a standard severity scale. The scale ranges from 0-9.

The percentage of important host tissues or organs covered by symptom/lesion or harmed by the disease is referred to as disease severity. The following formula was used to calculate the severity of the lesions based on their number and size.

$$\text{Disease severity or Infection index} = \frac{SD}{TR \times MD} \times 100$$

Where;
SD=Sum of all disease rating, TR=Total no. of rating, and MD=Maximum disease grade.

An analysis of variance (ANOVA) was performed on the data collected. SPSS 16.0 (statistics packages for social sciences) was used in connection with Duncan's Multiple Range Test (DMRT) to separate the means.

## Results and Discussion

Figure 1 shows the analytical results of pre-cropping surface soil at the experiment site. Abdulraheem *et al.* (2012) and Abdulraheem and Ojeniyi (2015) found that the studied soil had marginal organic matter (OM), was enough in nitrogen, calcium, magnesium, and potassium but deficient in phosphorus, and was somewhat acidic. As a result, the soil requires the application of a fertilizer amendment that is rich in P for the growth of okra.

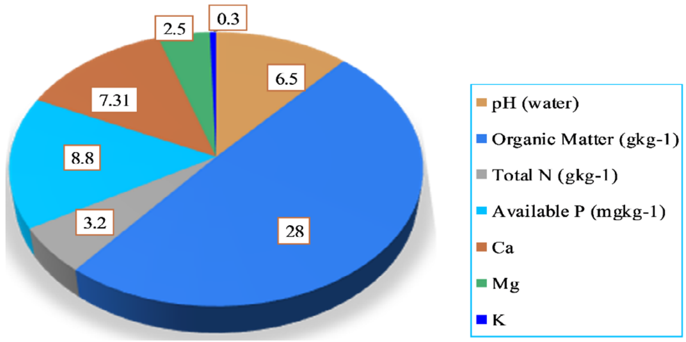


**Figure 1:** *Pre-cropping soil chemical properties.*

**Table 1:** *Effect of weeding regimes and mulching types of combinations on percentage incidence of viral diseases on okra at different times after planting.*

| Mulching Types | Weeding Regimes | 3WAP | 4WAP | 5WAP | 6WAP | 7WAP |
|---|---|---|---|---|---|---|
| | | Incidence (%) | | | | |
| Dry Grasses | No-Weeding | 20.48 | 36.87 | 55.30 | 63.34 | 84.71 |
| | Once | 14.32 | 25.78 | 38.67 | 46.65 | 67.62 |
| | Twice | 11.74 | 21.13 | 31.70 | 38.19 | 59.61 |
| | Thrice | 9.40 | 16.92 | 25.37 | 33.00 | 52.11 |
| No Mulch | No-Weeding | 17.22 | 30.99 | 46.49 | 59.44 | 89.63 |
| | Once | 16.25 | 29.24 | 43.87 | 48.06 | 75.00 |
| | Twice | 10.54 | 18.97 | 28.46 | 32.22 | 59.16 |
| | Thrice | 8.83 | 15.90 | 23.85 | 28.53 | 53.78 |
| Polythene | No-Weeding | 4.97 | 8.95 | 13.65 | 17.37 | 31.71 |
| | Once | 5.06 | 7.10 | 12.44 | 14.11 | 25.83 |
| | Twice | 1.81 | 3.25 | 10.65 | 13.99 | 23.16 |
| | Thrice | 1.33 | 1.33 | 4.88 | 7.67 | 18.75 |
| S.E ± | | 1.87 | 3.32 | 4.94 | 4.98 | 5.99 |

*S.E= Standard Error of Mean, WAP = Week After Planting*

Percentage occurrence with viral infections on okra at different stages after planting is illustrated in the effect of weeding regimes and mulching type treatment combinations (Table 1). The results showed that treatment combination of no-weeding with dry grasses, no-mulching, and polythene at all the tested weeks after planting had significantly highest incidence% respectively.

Table 2 shows the results of the effect of treatment combination on disease percentage severity of viral diseases on okra plants at various stages after plantation. Where the analysis of the treatment combination of the weeding regime and mulching types on the incidence percentage showed that at weeks 3, 4, 5, 6 and 7, a treatment combination of dry grasses, no mulch, and polythene at no-weeding had significantly highest severity percentage of 23.32, 37.03, 62.95, 77.76 and 92.58 respectively while a treatment combination regime of thrice weeding at polythene and no mulching was significantly the lowest in severity percentage of 1.33, 2.33, 3.55, 1.23 and 7.41 which had the same trend with week 3, 4, 5, 6 and 7 weeks after planting.

**Table 2:** *Effect of weeding regimes and mulching type treatment combinations on percentage severity of viral diseases on okra at different times after planting.*

| Mulching Types | Weeding Regimes | 3WAP | 4WAP | 5WAP | 6WAP | 7WAP |
|---|---|---|---|---|---|---|
| | | Severity (%) | | | | |
| Dry Grasses | No-Weeding | 23.32 | 37.03 | 62.95 | 77.76 | 92.58 |
| | Once | 15.54 | 24.69 | 41.97 | 64.19 | 80.23 |
| | Twice | 12.80 | 20.33 | 34.56 | 56.78 | 80.23 |
| | Thrice | 14.62 | 23.60 | 39.49 | 64.19 | 83.93 |
| No Mulch | No-Weeding | 26.97 | 42.84 | 72.83 | 88.87 | 99.98 |
| | Once | 17.37 | 27.59 | 46.91 | 62.95 | 79.00 |
| | Twice | 13.71 | 21.78 | 37.03 | 41.97 | 56.79 |
| | Thrice | 12.80 | 20.33 | 34.56 | 53.08 | 70.36 |
| Polythene | No-Weeding | 7.78 | 12.81 | 20.94 | 35.80 | 59.25 |
| | Once | 6.86 | 10.89 | 18.52 | 32.09 | 51.84 |
| | Twice | 5.49 | 8.71 | 14.81 | 28.39 | 45.67 |
| | Thrice | 1.33 | 2.33 | 3.55 | 1.23 | 7.41 |
| S.E ± | | 2.91 | 4.62 | 7.79 | 6.70 | 6.68 |

**Table 3:** *Effect of weeding regimes and mulching type treatment combinations on the height of okra at different times after planting.*

| Plant height interactions (cm) | | | | | | |
|---|---|---|---|---|---|---|
| Mulching Types | Weeding Regimes | 3WAP | 4WAP | 5WAP | 6WAP | 7WAP |
| Dry Grasses | No-Weeding | 13.64 | 20.00 | 30.00 | 32.22 | 38.78 |
| | Once | 13.89 | 20.37 | 30.56 | 32.00 | 39.78 |
| | Twice | 13.43 | 19.70 | 29.56 | 31.00 | 35.78 |
| | Thrice | 14.60 | 21.41 | 32.11 | 34.78 | 37.22 |
| No Mulch | No-Weeding | 15.15 | 22.22 | 33.33 | 34.89 | 42.44 |
| | Once | 14.24 | 20.89 | 31.33 | 33.00 | 35.22 |
| | Twice | 14.09 | 20.66 | 32.00 | 32.67 | 39.44 |
| | Thrice | 14.14 | 20.74 | 31.11 | 32.89 | 38.78 |
| Polythene | No-Weeding | 15.15 | 22.17 | 33.33 | 36.22 | 37.11 |
| | Once | 16.21 | 23.78 | 35.67 | 37.00 | 37.89 |
| | Twice | 19.65 | 28.82 | 43.22 | 43.94 | 49.00 |
| | Thrice | 19.19 | 28.15 | 42.22 | 46.00 | 51.67 |
| S.E ± | | 1.15 | 1.68 | 2.53 | 2.49 | 3.37 |

Table 3 shows that effect of weeding regimes and mulching type treatment combinations on the height of okra plants at different times after plantation. Where the analysis of the treatment combination of the weeding regime and mulching types on the plant height showed that at week 7, a treatment combination of polythene weeded thrice had the significantly highest plant height of 51.67 and a treatment combination regime of once weeding and no mulching was significantly the lowest plant height of 35.22 which had the same trend with week 3, 4, 5, and 6 after planting.

Table 4 shows the effect of mulching type and weeding regimes treatment combinations on the number of leaves of okra at different times after plantation. Where the analysis of the treatment combination of the weeding regime and mulching types on the number of leaves interactions at thrice weeding showed the significant highest leaves number at weeks 3, 4, 5, and 6. However, the weeding regimes and mulching types at 7 weeks were significantly higher than other treatment combinations.

**Table 4:** *Effect of weeding regimes and mulching type treatment combinations on the number of leaves of okra at different times after planting.*

| Number of leaves interactions (cm) | | | | | | |
|---|---|---|---|---|---|---|
| Mulching Types | Weeding Regimes | 3WAP | 4WAP | 5WAP | 6WAP | 7WAP |
| Dry Grasses | No-Weeding | 4.15 | 7.56 | 11.33 | 13.33 | 6.89 |
| | Once | 4.80 | 7.04 | 10.56 | 12.44 | 6.56 |
| | Twice | 5.25 | 7.70 | 11.56 | 14.00 | 5.78 |
| | Thrice | 5.40 | 7.93 | 11.89 | 14.11 | 4.67 |
| No Mulch | No-Weeding | 5.25 | 7.70 | 11.56 | 13.67 | 3.22 |
| | Once | 4.85 | 7.11 | 10.67 | 12.44 | 3.56 |
| | Twice | 5.46 | 8.00 | 12.00 | 13.78 | 5.89 |
| | Thrice | 5.81 | 8.52 | 12.78 | 14.22 | 6.89 |
| Polythene | No-Weeding | 5.81 | 8.52 | 12.78 | 15.44 | 8.56 |
| | Once | 5.46 | 8.00 | 12.00 | 14.00 | 5.44 |
| | Twice | 6.97 | 10.22 | 15.33 | 17.67 | 5.22 |
| | Thrice | 7.78 | 11.41 | 17.11 | 22.23 | 8.11 |
| S.E ± | | 0.46 | 0.73 | 1.10 | 1.29 | 1.45 |

The effect of weeding regimes and mulching type treatment combinations on the quantity of flowers, edible fruits, and diseased fruits in okra was shown in Table 5. The data for the number of flowers, diseased fruits, and edible fruits revealed that there was a significant difference in the effect of the polythene mulching type of the regime weeded thrice with the highest number of flowers while the data for the number of diseased fruits and edible fruits revealed that there was a significant difference in the effect of the polythene mulching type of the regime weeded thrice with the lowest number of flowers while treatment combination of no mulch no weeding had the lowest number of flowers, polythene mulching types combined with thrice weeding regimes have the highest amount of fruits while the regime of no mulch no weeding had the lowest number of edible fruits. Analyzed results also showed that dry grasses mulch of no-weeding regime had the lowest number of diseased fruits of meanwhile polythene weeded thrice had the minimum amount of damaged fruits.

**Table 5:** *Effect of weeding regimes and mulching type treatment combinations on the number of flowers, edible fruits, and diseased fruit at different times after planting.*

| Mulching Types | Weeding Regimes | No. of flowers | No. of diseased fruits | No. of Edible fruits |
|---|---|---|---|---|
| Dry Grasses | No-Weeding | 5.44 | 2.44 | 2.67 |
| | Once | 5.44 | 2.33 | 2.22 |
| | Twice | 5.56 | 2.21 | 2.44 |
| | Thrice | 6.00 | 2.10 | 2.56 |
| No Mulch | No-Weeding | 5.78 | 2.11 | 2.11 |
| | Once | 5.33 | 2.11 | 2.44 |
| | Twice | 6.11 | 2.08 | 2.67 |
| | Thrice | 4.89 | 1.97 | 2.44 |
| Polythene | No-Weeding | 7.00 | 1.67 | 2.78 |
| | Once | 6.55 | 1.00 | 2.22 |
| | Twice | 7.78 | 0.67 | 3.56 |
| | Thrice | 10.55 | 0.35 | 5.44 |
| S.E ± | | 0.46 | 0.73 | 1.10 |

**Table 6:** *Effect of weeding regimes and mulching type treatment combinations on the okra fresh yield.*

| Mulching Types | Weeding Regimes | Fresh Yield (g) |
|---|---|---|
| **Dry Grasses** | **No - Weeding** | **40.00** |
| | Once | 45.99 |
| | Twice | 46.76 |
| | Thrice | 41.66 |
| No Mulch | No-Weeding | 32.81 |
| | Once | 36.97 |
| | Twice | 36.86 |
| | Thrice | 33.79 |
| Polythene | No-Weeding | 33.39 |
| | Once | 39.43 |
| | Twice | 43.61 |
| | Thrice | 50.60 |
| S.E ± | | 4.26 |

Table 6 showed the effect of weeding regimes and mulching type treatment combinations on the okra fresh yield. The polythene that weeded thrice had the highest fresh weight of 50.60g while the no mulch that was not weeded had the lowest fresh weight of 32.81g. However, the twice weeding regimes in both the dry grasses and no-mulch had the highest fresh weight of 46.76g and 36.86g respectively.

Table 7 showed the diagnostic result of the viruses using ACP-ELISA. Whereby, identities of the viruses were confirmed using specific antiserum to each virus with four antibodies (CMV, OkLCV, OkMV, and BCMV). The results indicated the presence of viruses in all the okra leaf samples of each treatment combination. The results indicated that CMV was detected as one of the most prevalent viruses and it occurred in all the treatment combinations except the okra treatment combination of polythene weeded twice and thrice. The treatment combination of dry grasses and regimes of no-weeding, weeding once, and weeding twice were positive on CMV, OkLCV, and OkMV while negative on BiCMV. However, when dry grasses were combined with regime weeded thrice was positive on CMV and OkMV but negative on antibodies of OkLCV and BiCMV. Moreover, the treatment combination of no-mulch with the regime not weeded and regime weeded once showed positive on antibodies of CMV, OkLCV, and OkMV while both were negative on BiCMV. However, when no-mulch was weeded twice and thrice, it was detected that OkLCV and BiLCV were negative while CMV and OkMV were positive.

Finally, the okra that had the treatment combination of polythene and no weeding detected positive on CMV and OkMV while negative on OkLCV and BiCMV. Treatment combinations of polythene weeded once, twice, and thrice were negative when tested with CMV, OkLCV and BiCMV. Even though OKLCV was detected in all treatment combinations in this experiment, the okra plants of all mulching types and regimes weeded thrice tested to be negative alongside all the combinations that involved polythene foil while BiCMV was not detected in all treatment combinations be weeded thrice and all forms of mulching combinations. OKMV was most detected in all treatment combinations with the highest virulent strain in treatment combination of dry grasses and no mulch followed by treatment combination of no mulch and no weeding regime while treatment combination of polythene mulch and weeding thrice regime had lowest strain value.

**Table 7:** *Virus detected in the okra leaf samples using enzymes lined immunosorbent Assay (ELISA).*

| **(ACP-ELISA)** | | | | | |
|---|---|---|---|---|---|
| **Okra Treatment Combinations** | | **Elisa values** | | | |
| | | **Overnight** | | | |
| Mulching Types | Weeding Regimes | CMV | OkLCV | OkMV | BiCMV |
| Dry Grasses | No-Weeding | 5.112(+) | 4.590(+) | 4.594(+) | 0.793(-) |
| | Once | 4.675(+) | 3.985(+) | 3.685(+) | 0.685(-) |
| | Twice | 3.705(+) | 3.709(+) | 3.715(+) | 0.515(-) |
| | Thrice | 3.613(+) | 2.638(-) | 3.638(+) | 0.338(-) |
| No Mulch | No-Weeding | 5.677(+) | 4.671(+) | 4.671(+) | 0.971(-) |
| | Once | 5.637(+) | 3.667(+) | 4.667(+) | 0.567(-) |
| | Twice | 4.739(+) | 0.506(-) | 3.706(+) | 0.606(-) |
| | Thrice | 4.607(+) | 0.448(-) | 3.649(+) | 0.547(-) |
| Polythene | No-Weeding | 2.537(+) | 3.467(-) | 3.567(+) | 0.479(-) |
| | Once | 1.518(-) | 2.538(-) | 3.538(+) | 0.425(-) |
| | Twice | 1.458(-) | 1.498(-) | 3.499(+) | 0.391(-) |
| | Thrice | 0.517(-) | 0.537(-) | 3.337(+) | 0.302(-) |
| Disease | | 2.535(+) | 3.405(+) | 2.415(+) | 3.491(+) |
| Healthy Buffer | | 0.95(-) | 0.45(-) | 1.55(-) | 0.79(-) |

*Key: (-) signifies negative, (+) signifies positive. Antibodies Used: CMV = Cucumber mosaic virus; OkLCV = Okra leaf curl virus; OkMV=Okra mosaic virus; BiCMV= Blackeye cowpea mosaic virus*

Additionally, BCMV was not detected in all the leaf samples of all treatment combinations subjected to (ACP-ELISA), however, all treatment combinations relatively displayed higher viral strain when compared with treatment combination regimes that involve polythene mulch.

Because maximum plant viruses rely upon vectors for survival and dissemination, combining herbicides, an artificial insecticide, and cultural weed control that interferes with vector landing feeding might be the only approach to control viruses. In these three methods, cultural control is the most acceptable and widely adopted method which promotes organic production and sustains agricultural as well as environmental sustainability.

Taking the data into account, all okra plants in the experiment were sensitive to virus diseases, as they displayed indications of viral diseases, though their susceptibility varied depending on the treatment combinations used. However, okra plants that received a treatment combination of thrice weeding and polythene mulch appeared to be the most resistant to viral diseases, while those plants that received a treatment combination of no weeding and no mulching appeared to be the most susceptible to viral diseases, based on yield and growth parameters. The most evident viral indications include yellowing of the foliage, vein banding, light and dark green patches on the leaves, crinkling, curling, and severe stunting of select immature plants. However, the weeding and mulching treatment combinations utilized in this study had an effect on the incidence and severity of viral infections. Polyethylene film as a mulch can improve plant growth and development, increase yield, reduce soil evaporation and nutrient leaching, reduce the incidence of pests and weeds, and improve fruit cleanliness and quality yield (Farias-Larios and Orozco-Santos, 2007; Decoteau, 2007; Diaz-Perez *et al*., 2007) and ultimately increase gross return, net return, and benefit: cost ratio of fruit and vegetable crops.

Our findings, which confirmed that low virus prevalence existed below the polythene mulch weeded three times and the highest on the no weeding regimes mixed with out a mulch, showed that low virus prevalence existed beneath the polythene mulch weeded thrice, and has the same opinion with (Alegbejo, 2015), who pronounced that viral occurrence decreases progressively with weeding regime. This have to have happened as a result of polythene suppressing the boom of weeds, which are commonly used as a domestic for possible virus vectors (Stapleton *et al*., 2005). However, some management strategies had been proffered to ameliorate CMV epidemics namely: early planting and close spacing, keeping field free of weeds, use of barrier crops such as maize or sorghum, and Integrated Diseases Management (IDM) (Alegbejo, 2015).

The observed highest and lowest viral incidence at no and weeded thrice regimes respectively, were due to the reason of high weed interference. This attribution of viral incidence to high weeds operates as reservoirs for insects, disease agents, and nematodes, according to Hooks *et al*. (2004). This study also shown that the combined effects of weeding and mulching can successfully lower the frequency of virus illnesses, but that the type of polythene mulching utilized is more important, as agreed upon in the (Hooks *et al*., 2004) report where polythene mulched rhizosphere had the best potential for assisting herbaceous plant growth and development in the fight against viral infections Because majority of the plant diseases rely on hosts for existence and disperse, using herbicides, synthetic insecticides, and cultural weed control to disrupt vector landing feeding could be the most efficient way of controlling viruses (Abdulraheem *et al*., 2019a).

Furthermore, production reduction was attributed to uncontrolled weed development in okra, which was estimated to be 58.6-68.8% in comparison to the regime that was weeded twice and thrice. Katung and Kashina (2005) conclusions are supported by this research that losses of yield as a result of parasitic weeds vary from 50 to 80% and 41 to 80%, respectively. Weeding also reduces crop competition for space and gives plants a physiological boost (Sugiyato *et al*., 2009). Furthermore, in dry grasses regimes with polythene mulch, yield reduction due to insect pests was predicted to be 89.7-91.6% in compared to no mulch. Aiyelaagbe and Jolaoso (2012) found that insect pest damage to okra can be as high as 80-100% if not successfully controlled, which is similar to our findings.

Okra mosaic virus was discovered to be the most virulent virus that was positive independent of the control procedures utilized in this experiment because OkMV had the greatest host range (Alegbejo, 2015). According to Alegbejo (2002), other factors that support OkMV include warm weather and the availability of plentiful vectors and alternate hosts.

Finally, the study confirmed that a treatment combining polythene mulching and weeding three times resulted in the maximum yield metrics while lowering virus occurrence. This shows that weeding, in combination with polythene mulch, could be useful in suppressing viral infections. This could be explained by polythene's ability to protect the okra plant from insect/pest infestations in the alternate host (weed), which backs up Bhardwaj (2011) findings. These results could be further assessed in future studies for optimizing these treatment combinations, as recent studies have successfully optimized process parameters with higher yields and sustainability goals (Ihtisham *et al*. 2018; 2020). As a result, weed density decreases have resulted in a significant drop in the incidence and severity of viral infections.

## Conclusions and Recommendations

Based on our findings, we concluded that reducing weed density resulted in a considerable decrease in the incidence and severity of viral infections. The severity and incidence of virus infections on okra were dramatically reduced after weeding at least twice. This was most likely owing to a lack of area for vectors to live and reduced spatial competition within crops that ensured higher nutrients availability for okra plants and harvesting sunlight energy. The incidence and severity of viral infection on okra plants were dramatically impacted by polythene mulching. The incidence and severity of viral infections were dramatically reduced when polythene mulching was paired with at least two weedings. A considerable decline was most likely due to a diminished diseases amount that should be able to transfer the infection-causing viruses. Based on our results, we, therefore, suggest that a treatment combination of weeding thrice and polythene mulching type was found to be the most effective in reducing viral disease incidence percentage and severity on okra crop in the field conditions. However, given the high expense of insecticides, the time and effort required to prepare disease-free dry grasses mulch, and the back-breaking weeding, the grey polythene film is alternatively affordable and easily available can be applied in combination to achieve balance and increase okra yield, weed at least twice. This will not only ensure virus-free okra production but will contribute to sustainable and organic agriculture.

## Novelty Statement

Okra is an important vegetable crop in Nigeria. In Nigeria, viruses cause severe yield loss due to the tropical climate. This study helped in the production of reduced disease-free okra crop without chemicals application. Moreover, our study contributed to the organic production of this important vegetable crop.

## Author's Contribution

**Mukhtar Iderawumi Abdulraheem and Abiodun Yusuff Moshood:** Conducted research, collected data, literature review, data analysis and the first draft of manuscript writeup.
**Muhammad Ihtisham:** Writeup, literature review, revision, supervision, English editing, submission, correspondence.
**Nawab Khan, Muhammad Owais Shahid, Shafiq Hussain, Kumail Abbas and Fawad Zaman:**
Tables and graphs, literature collection, reference formatting, data analysis.
Mukhtar Iderawumi Abdulraheem and Muhammad Ihtisham contribute equally and are co first authors.

*Conflict of interest*
The authors have declared no conflict of interest.

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