Storage Conditions Deteriorate Cotton and Wheat Seeds Quality: An Assessment of Farmers’ Awareness in Pakistan

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Received: 6 July 2020; Accepted: 17 August 2020; Published: 24 August 2020

Abstract: Seed quality is assessed by appropriate seed germination, seed moisture contents, insect/pathogen infestations and seed vigor. Seed storage conditions are essential to protect from deterioration. In this study, knowledge and practices of wheat and cotton seeds storage were accessed among commercial seed growers (CSGs) and non-commercial seeds growers (NCSGs) in the Vehari District of Pakistan, while samples of stored wheat and cotton seeds were also collected to assess the quality of stored seeds. Stored seeds in the study area were contaminated by a variety of fungi, with infestation percentages reaching 13% for wheat and 20.7% for cotton in seeds from NCSGs, compared to 9% (wheat) and 9.5% (cotton) in seeds from CSGs. The majority of seed growers (75.0%) did not have any training on seed storage. The growers (60.9%) were unaware that seed should not be stored in closed polythene bags and most (62.2%) were not well aware about seed-borne crop diseases. Most growers did not maintain the temperature and humidity of storage rooms (82.7%) and did not calculate the seed rate before sowing after seed germination tests (87.2%). However, seed dressing with fungicides was implemented by most farmers (69.9%). Controlling the temperature of the seed storage was significantly influenced by growers’ age, while controlling the humidity of the seed storage was significantly influenced by growers’ farming experience. Seed dressing with fungicides was positively associated with the graduation level of growers, while checking seed maturity was positively associated with the higher education (Master’s level) of growers. There was a lack of active information centers in the study areas and a lack of agricultural information provision to farmers. Awareness regarding bad-quality seeds should be initiated to increase growers’ knowledge. Training programs for providing adequate knowledge to growers and skills in seed storage should be organized. Legislation regarding the seed business and seed storage protective measures should be enforced to minimize problems by a seed-borne inoculum and deterioration of seed quality.

Keywords: awareness; practices; seed quality; seed storage; seed-borne diseases; training
1. Introduction

Agricultural production depends on the quality of seeds stored under controlled conditions until the next growing season. Some of the crops can maintain 50% seed germination at least for two years under different conditions of storage [1]. Important factors that can influence seed quality under storage are the climate of the location in a specific geographical area or the prevailing environmental conditions in the storage place, e.g., non-ventilated, damp and hot warehouses. Moreover, for appropriate seed storage, proper drying of seed to a desirable moisture content [2], seed packing and protection from rain [3], dust, snow, rodents [4] and insects [5], seed-borne pathogens and gaseous atmosphere [6] of storerooms are crucial. All these factors affect seed germination. Appropriate conditions for seed storage largely depend on the period of time the seeds must to be stored [7]. Usually, the seeds deteriorate in the field or get damaged during harvest or drying, so that low-quality seeds are often placed under storage. The quality is reduced further in poorly ventilated, damp and hot warehouses. Companies of seed and farmers store seed material under open storage conditions. According to Nagel and Börner, 2010 [8], an important issue is how long propagation material can survive maintaining high germination (e.g., >80%). Long-term storage of seeds is associated with viability loss [9]. It can also cause long-term persistence of pathogens in seed lots and easy spread of disease. Proper management of seed-borne diseases could increase seed quality and crop yields. Bad seed storage rooms can promote these problems. The problem of food insecurity in developing countries remains a serious concern because of severe constraints in food production. Farmers cultivate crops either for commercial purposes (e.g., to sell seeds in local markets) or non-commercial purposes (e.g., own consumption of seeds). Therefore, lack in knowledge about seed storage influences crop production in agriculture, especially in less developed regions of the world [10].

A previous study showed that traditional seed storage methods deteriorate the vigor of maize seed in three to six months and higher insect damages were recorded [11]. Seed insecurity has been reported among rural farmers due to poor facilities and inappropriate methods for seed storage. Another investigation reported that poverty, and insufficient technical and financial support is also causing poor storage problems in farmer communities [12]. Seed business is a source of income in farming, but storage problems reduce the seasonal crop yields of buyers and reduce the seller’s income [13]. Inappropriate seed storage causes up to 10% loss in quality due to poor germination [14,15]. It had been reported that 20–30% of losses resulting from poor storage of maize grains caused the loss of more than USD 4 billion annually [16]. These losses had been reported due to the infestations of insects and fungi. The percentage of losses increased if the environmental conditions favored the spread of insects and fungi [17]. Each season, the African region lost 10–88% of the total maize produced due to field and storage pests [18–20]. Grain temperature and moisture contents rose because of insect presence and feeding. This condition creates warm moist spots which increases grain respiration or humidity, ultimately accelerating grain deterioration and further fungal contaminations [21]. Therefore, favorable conditions and inappropriate storage systems often result in considerable losses [22].

Plant disease management is becoming an increasingly complex process, especially among farmers. In modern and sustainable crop production approaches, crop disease management requires the full co-operation of the different stakeholders dealing with seed distribution, with positive return for the local micro-economy and for the environment [21–23]. These management approaches include biophysical aspects, farmers’ knowledge and training, socio-economic prospects and policies, resources and technologies that are available in a rural area [24]. Nevertheless, adaptation of these practices to local needs is essential for sustainable agricultural development [25]. Therefore, understanding local knowledge and finding the most effective practices in relation to the extraneous technologies for the further promotions are essential for scientists and extension workers [26,27] and enhance their willingness, as a key condition to the adoption of new innovations and techniques [28]. Devkota et al., 2018 [29], reported in Nepal several wheat seed storage options including farmer practices such as reused fertilizer bags, polythene bags, household metal containers and mud bins. Advanced storage materials that were investigated included plastic bags (with and without pesticide),
metal bins and the hermetic “SuperGrain Bag” (SGB). Seed quality and losses were assessed after six
months of storage with parameters such as grain moisture content, insect damage, seed germination
and seedling vigor. It was found that SGBs were a good option to maintain seed quality and were more
economical. Furthermore, the farmers can maintain seed quality under ordinary storage structures to
some extent in high-temperature and low-rainfall areas if they frequently check and dry their seed and
grain during storage [29]. In this context, accessing farmers’ knowledge of seed storage and current
storage practices for designing strategies to empower them as competent decision makers of their
farm operations is essential. Governmental agriculture advice and policies exist in our study area,
but seed-growing farmers are less competent in seed storage techniques to control seed-borne diseases
and maintain a high quality of seeds. In a study, Nepali farmers excoriated a lack of training and
extension services on storage pests and their management, underlining the need to develop extension
services [30]. Seed growers usually market their seeds in the local farming communities, but those
seeds are potentially infested with seed-borne contamination or may be of low quality due to a lack of
appropriate knowledge, training and experience in seed storage.

Seeds storage, in particular for wheat, does not affect only seed quality and yield. Particularly,
it has a significant effect on flour quality, dough rheological properties and on bread and bakery
products characteristics. Regarding the production of wheat flours, the milling of contaminated wheat
could generate significant problems for consumers’ health and might worsen the milling process,
which is a crucial operation for the production of flour and bakery products [31,32]. Moreover, in the
case of whole wheat bread, poor management of wheat storage could adversely affect dough rheological
properties and bread quality [33]. This highlights the need to expand the knowledge regarding optimal
seeds storage strategies.

In Pakistan, there had been no study reported to access the knowledge and practices of farming
community regarding seed storage. This work aimed to generate primary information from farming
communities of the Vehari District of Pakistan that are related to common seed storage practices.
In this context, farmers’ knowledge of various seed storage methods and practices was assessed from
available seed growers based on a farmers’ survey by using structured questionnaires. The specific
objectives of the study were to: (1) assess farmers’ knowledge and practices of seed storage of wheat
and cotton; and (2) compare commercial seed growers (CSGs) and non-commercial seed growers
(NCSGs) regarding seeds storage practices with respect to seed moisture contents, seed germination
percentages and seed-borne fungal infestations levels.

2. Materials and Methods

2.1. Study Area

The study took place at COMSATS University Islamabad in the Vehari District of Punjab Province,
Pakistan. This area has intensive agricultural activities with cultivation of a variety of field crops
(wheat, cotton, rice, maize and sugarcane), but the wheat–cotton rotation scheme is usually adopted
in this region. Vehari city is located between the rivers Sutlej and Ravi (30°04’19” N, 72°35’28” E),
at an altitude of 135 m. The climate of the area is characterized by hot summers (from April to August,
with temperatures up to 50 °C) and cold winters (from November to January, with temperatures
up to 1 °C). The average annual rainfall is about 127 mm, occurring mainly during the monsoon
season (July and August), while dust storms commonly occur in the period of summer (Pakistan
Meteorological Department).

2.2. Seed Sampling, Temperature and Humidity Measurements

The study area was divided into three parts based on the three tehsils of Vehari District (i.e., Mailsi,
Vehari and Burewala). Therefore, a stratified random sampling was followed, using the three tehsils
of Vehari District as strata. The main advantage of this sampling is that it secures better coverage of
the target population and captures key population characteristics in the sample. Moreover, a smaller
sample size can reach with a stratified sample rather than a simple random sample, which can save a lot of time and money. In total, 156 growers were involved in this study, commercial seed growers (CSGs) (48) and non-commercial seed growers (NCSGs) (108) from the above areas of study (Table 1). Each grower provided one sample of cotton and one sample of wheat seeds. Total collected seed samples of wheat and cotton were (CSGs $48 \times 2 = 96$) and (NCSGs $108 \times 2 = 216$). The samples were taken in eight different points of stored seed lots from storage places of each seed grower. Sampled seeds were stored in paper bags at a temperature 8–10 °C and then placed at room temperature for 24 h before processing.

Table 1. Basic demographic profile of the farmers surveyed.

| Variable               | Frequency | Percentage |
|------------------------|-----------|------------|
| Area                   |           |            |
| Vehari (VE)            | 48        | 30.8       |
| Mailsi (MA)            | 56        | 35.9       |
| Burewala (BU)          | 52        | 33.3       |
| Growers                |           |            |
| Non-commercial seed growers | 108    | 69.2       |
| Commercial seed growers | 48       | 30.8       |
| Age                    |           |            |
| 20–30 years            | 42        | 26.9       |
| 31–40 years            | 57        | 36.5       |
| 41–50 years            | 26        | 16.7       |
| 51–60 years            | 31        | 19.9       |
| Education              |           |            |
| Primary                | 58        | 37.2       |
| Middle to intermediate | 36        | 23.1       |
| University graduate    | 45        | 28.8       |
| Master and above       | 17        | 10.9       |
| Farming experience     |           |            |
| 1 to 10 years          | 57        | 36.5       |
| 11 to 20 years         | 80        | 51.3       |
| 21 to 30 years         | 19        | 12.2       |
| Total farmland         |           |            |
| 1 to 10 acres          | 55        | 35.3       |
| 11 to 20 acres         | 90        | 57.7       |
| 21 to 30 acres         | 6         | 3.8        |
| Above 30 acres         | 5         | 3.2        |

The temperature and humidity of the storage room (where seeds were stored) of each seed grower were measured. Measurements of temperature and relative humidity in the stores were recorded on a monthly basis using a digital humidity/temperature meter recorder [34–36]. Temperature and humidity measurements were done at eight different points in each seed storage room.

2.3. Knowledge and Perceptions Assessment

Knowledge of CSGs to sell and market the seeds in the local markets and knowledge of NCSGs to grow their own seeds and use them by themselves were assessed based on simple questions with reference to seed storage practices and knowledge to see whether the reported practices agree with national/international standard practices (or suggestions of the national agriculture department). This information is important for understanding common practices of seed growers regarding storage of seeds and increasing awareness about improved storage practices [37,38]. The questionnaire included items with dichotomous options and multiple options (Table 1). Growers were asked to complete this structured questionnaire to assess their knowledge/perceptions about seed storage.
(dichotomous variables, 8 questions) and practicing methods of seed storage (dichotomous variables, 13 questions). Scores were computed by summing the individual scores of the given response for each component item, using the integral values 0 = no or 1 = yes. Some of the structured questions covered multiple choice options (6 questions). The respondents were asked to select one answer that fitted best to each question among the given multiple options. Farmers who were unable to read and write were interviewed directly and their responses were added to the questionnaire by the enumerators. Information about farmers’ age, education, farming experience, professional trainings, participation in farmers’ social gatherings and contact with agriculture extensions were also collected.

2.4. Germination Tests

Seed germination tests were carried out following standard procedures of ISTA (International Seed Testing Association). Three layers of blotter (Whatman No. 1) in sterilized Petri dishes were moistened with sterile distilled water. Sub-samples of seeds (300 seeds) were placed on the moistened blotters at the rate of 10 seeds per plate. The plates were incubated at 28 ± 2 °C for 7 days. Germination counts were taken on blotter plates and seed germination percentages were calculated. Seeds were considered germinated if the plumule length was longer than 5 mm.

2.5. Seed Moisture Content

Seed moisture levels were determined using the gravimetric method. A sub-sample of 5 g seed from each sample was dried for 17 h in a drying oven with the temperature set at 103 °C. The test was performed in triplicates [39,40]. Seed moisture was determined using the following formula:

\[
\text{Seed moisture (\%)} = \left(\frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Oven dry weight}}\right) \times 100
\]

2.6. Identification of Seed-Borne Pathogens

A standard blotter method according to ISTA (International Seed Testing Association) [40] was used to determine the occurrence of seed-borne fungi in wheat and cotton seeds. Seeds were surface-sterilized with 3% NaOCl for 5 min followed by washing twice with distilled water and then dried in a laminar flow chamber. Ten seeds were placed per Petri plate. Petri plates were incubated at 25 ± 1 °C with a 12-h photoperiod of white light and 12-h period of dark. Pathogens were identified on the basis growth characteristics [41–43]. When multiple fungal growths occurred, colonies were isolated from a single seed (wheat or cotton), recorded and then pure cultures were preserved on PDA slants (pH 5.6). All pathogenic fungi that appeared on seeds were evaluated on each single seed and then the fungi occurrence percentage was calculated for each seed sample [38]. Pathogen identifications were done twice: after 7 days and then after 10 days of incubation. According to ISTA rules, 400 seeds were tested per sample and the test was performed thrice for replications (400 + 400 + 400). The percentage of infected seeds was calculated by the counting number of seeds infected with seed-borne pathogens divided by the total number of tested seeds and multiplied by hundred. The seed-borne pathogens were isolated and identified at the Plant Pathology Research Division, Barani Agriculture Research Institute, Chakwal, Pakistan.

\[
\text{Infected seeds (\%)} = \frac{\text{No of seeds infected by pathogens}}{\text{Total no of seeds tested}} \times 100
\]

2.7. Data Analysis

Knowledge of CSGs and NCSGs was expressed as percentages of correct responses for each item tested. In addition, dichotomous variables were subjected to binomial logistic regression to determine
factors influencing knowledge of seed storage. For binomial logistic regression, the possibility (P) for the dependent variable (y) is determined as a function of the independent variables (x_i) as follows:

\[ P_i = \frac{e^{b_0 + b_i x_i}}{1 + e^{b_0 + b_i x_i}} \]

where \( b_i \) is the coefficient of each independent variable \( x_i \) [44]. For each type of practice of seed storage, age, education, farming experience, total farmland, training on seed storage, contact with extension agents and participation in farmers’ social gatherings (dummy variable) were added in the model as independent variables. A multinomial logistic regression model (MLR) was also used to examine the relationship between farmers’ perceptions of seed storage practices [45,46]. The multinomial logistic regression model with a baseline category is expressed as follows:

\[ \log \left( \frac{y}{1 - y} \right) = a_i + b_i x \]

The multinomial logistic model uses the baseline category logits with a predictor x. A predictor x with k categories generates \( k - 1 \) equations and each of the \( k - 1 \) equations is a binary logistic regression comparing a group with the reference group. The analysis addressed the question of how well farmers knew seed storage practices compared with the reference group. The outcomes of interest were the rating of farmers’ ability to manage their stores with a possible factor of their best choice depending on their knowledge or perceptions in multiple choice options.

An analysis of variance (ANOVA) was performed to find differences in means of seed germination tests, moisture contents of seeds and percentages of pathogens isolated from stored seed of wheat and cotton. Differences between means were compared with the Tukey’s honestly significant difference (HSD) test at \( p < 0.05 \).

3. Results

Seed moisture contents, germination and seed-borne infestations were accessed for stored seeds of cotton and wheat. Seed samples collected from NCSGs and CSGs from Vehari had significantly higher moisture contents compared to Mailsi and Burewala, whereas seed samples from Vehari had significantly low germination percentages in both cotton and wheat seeds (Figure 1). Seed samples collected from CSGs had no significant differences for seed germination in all sampled sites both for cotton and wheat seeds (Figure 1).

Overall, NCSGs had a high percentage of seed-borne infestations (Figure 2). High infestations were found in cotton and wheat seeds samples collected from both growers’ groups (NCSGs and CSGs) in Vehari. Wheat seed samples had higher percentages of *Fusarium* spp., *Alternaria alternata* and *Stemphylium botryosum* in all samples, irrespective of area and growers’ group. A higher percentage of cotton seeds of NCSGs were infected by *Fusarium* spp. (6%), while wheat seeds had >2% infestation, but only seeds collected from NCSGs of Vehari had >4% *Fusarium* spp. *Alternaria alternata* was second in percentages in wheat seeds of all growers (Figure 2).
Figure 1. Percentages of seed moisture contents, seed germination and seed-borne infestations of cotton and wheat seeds from stored samples collected from non-commercial seeds growers (NCSGs) and commercial seeds growers (CSGs) in Vehari (Pakistan). Data presented in the graphs are means with standard deviation, bars sharing same letter(s) within each parameter are statistically non-significant according to HSD Tukey test at $p < 0.05$. 

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*Alternaria alternata* was second in percentages in wheat seeds of all growers (Figure 2).
The sample of the study covered almost equal proportions of respondents from each tehsil (Table 1). Most respondents (69.2%) were NCSGs, while 30.8% were CSGs. The greatest proportion of growers (37.2%) had primary education, while having a high level of education (i.e., university graduates and MSc) was noted for 39.7% of the respondents. Almost half of the respondents (51.3%) had 11 to 20 years of farming experience, while almost 6 out of 10 respondents (57.7%) had total farmland between 10 and 20 acres.

Overall, a high percentage of farmers were storing seeds in their living rooms (33.2%) and in open areas (28.8%), with CSGs noting higher percentages than NCSGs (Table 2). Only 29.1% of the growers were storing seeds in proper storage rooms, with NCSGs noting higher percentages than CSGs. Growers used different containers for seed storage (Table 2). Cotton bags were the most preferred container for CSGs (54.1%), while polythene bags were the most preferred container for NCSGs (29.7%). Overall, almost one-third of the growers (34.4%) had knowledge of the appropriate temperature for seed storage (0–10 °C), while the respective proportion was lower (16.7%) among NCSGs. However,
A higher percentage of the farmers (69.4%) were aware of the appropriate humidity for seed storage (50–60%), with the respective proportion being lower (53.7%) among NCSGs (Table 1). Half of the total growers (48.5%) were also aware that seed should be harvested at low moisture contents. Usually, most seed growers (84.9%) had bad conditions of their stores in terms of proper basic facilities for seed storage, while this was dominant among NCSGs (92.6%) (Table 2).

Many growers did not have any training for seed storage (75.0%), while most thought that seeds can be stored in closed polythene bags (60.9%) (Table 3). Nevertheless, growers were not well informed about seed-borne diseases (62.2%) and most thought that seed-borne diseases do not reduce crop yield (66.0%). Moreover, growers thought that crop diseases are not spread through seeds (59.6%) and most did not mention any disease problems in their crops (71.2%). Usually, growers cleaned the seeds before storage (58.3%), but a higher percentage of the growers did not sort and eliminate the infected and damaged seeds (84.6%). The growers did not maintain the temperature and humidity of stores (82.7%). Moreover, growers cleaned the store before seed storage (63.5%), but most of them did not calculate the seed rate for sowing after testing seed germination percentages (87.2%) (Table 2). High percentages of growers had contact with extension workers (69.9%) and participated in activities of social groups (social participation) (59.0%). Most growers did not control the temperature (90.4%), but some growers controlled the humidity in storerooms (38.5%) (Table 2). High percentages of growers checked moisture

Table 2. Farmers’ practices and knowledge of seed storage.

| Variable                          | CSGs (n = 48) | NCSGs (n = 108) |
|-----------------------------------|--------------|-----------------|
|                                   | BU | MA | VE | BU | MA | VE |
| Place of seed storage             |    |    |    |    |    |    |
| Living room                       | 22.9 | 8.3 | 0.0 | 14.8 | 12.0 | 8.3 |
| Open area                         | 10.4 | 8.3 | 8.3 | 11.1 | 12.0 | 7.4 |
| Kitchen                           | 0.0 | 2.1 | 0.0 | 3.7  | 4.6  | 7.4 |
| Store                             | 0.0 | 16.7 | 22.9 | 3.7 | 7.4 | 7.4 |
| Storage container                 |    |    |    |    |    |    |
| Polythene bags                    | 0.0 | 0.0 | 0.0 | 10.2 | 9.3 | 10.2 |
| Jute bags                         | 6.3 | 10.4 | 6.3 | 8.3 | 7.4 | 8.3 |
| Cotton bags                       | 12.5 | 20.8 | 20.8 | 3.7 | 7.4 | 4.6 |
| Closed bins                       | 14.6 | 4.2 | 4.2 | 4.6 | 6.5 | 3.7 |
| Covered heaps                     | 0.0 | 0.0 | 0.0 | 6.5 | 5.6 | 3.7 |
| Appropriate temperature for seed storage |    |    |    |    |    |    |
| 0 to 10                            | 18.8 | 22.9 | 10.4 | 6.5 | 5.6 | 4.6 |
| 11 to 20                           | 12.5 | 8.3 | 14.6 | 8.3 | 7.4 | 6.5 |
| 21 to 30                           | 2.1 | 4.2 | 6.3 | 18.5 | 23.1 | 19.4 |
| Appropriate humidity for seed storage |    |    |    |    |    |    |
| 50 to 60                           | 32.5 | 30.0 | 22.5 | 18.5 | 21.3 | 13.9 |
| 61 to 70                           | 7.5 | 10.0 | 10.0 | 8.3 | 7.4 | 6.5 |
| 71 to 80                           | 0.0 | 2.5 | 5.0 | 3.7 | 7.4 | 3.7 |
| 81 to 90                           | 0.0 | 0.0 | 0.0 | 2.8 | 0.0 | 6.5 |
| Appropriate seed moisture for harvest |    |    |    |    |    |    |
| 5 to 10                            | 22.9 | 22.9 | 18.8 | 14.8 | 13.0 | 4.6 |
| 11 to 15                           | 10.4 | 12.5 | 12.5 | 4.6 | 17.6 | 10.2 |
| 16 to 20                           | 0.0 | 0.0 | 0.0 | 8.3 | 4.6 | 13.0 |
| 21 to 25                           | 0.0 | 0.0 | 0.0 | 5.6 | 0.9 | 2.8 |
| Grading of storage conditions      |    |    |    |    |    |    |
| Bad                                | 33.3 | 29.2 | 14.6 | 31.5 | 35.2 | 25.9 |
| Moderate                           | 0.0 | 6.3 | 10.4 | 0.0 | 0.9 | 2.8 |
| Good                               | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 1.9 |

CSGs: commercial seed growers; NCSGs: non-commercial seed growers; BU: Burewala tehsil; MA: Mailsi tehsil; VE: Vehari tehsil.
(82.1%), weather (86.5%) and seed maturity (87.8%) before harvest. High percentages of growers (86%) did not perform germination tests before sowing (66.7%), did not keep the records of stored seeds (85.9%) and they also do not adopt new varieties (66.7%) at early stages of market (Table 3).

Table 3. Knowledge-based awareness of seed growers for seed storage (N = 156).

| Variable                                      | Yes | No  | Yes | No  |
|-----------------------------------------------|-----|-----|-----|-----|
| **Knowledge**                                 |     |     |     |     |
| Do you have training on seed storage?         | 39  | 117 | 25.0| 75.0|
| Can we use sealed containers/closed polythene bags? | 95  | 61  | 60.9| 39.1|
| Do you know about seed-borne diseases?        | 59  | 97  | 37.8| 62.2|
| Do seed-borne diseases reduce crop yield?     | 53  | 103 | 34.0| 66.0|
| Are crop diseases spread through seeds?       | 63  | 93  | 40.4| 59.6|
| Do you have a diseases problem in your crops? | 45  | 111 | 28.8| 71.2|
| **Practice**                                  |     |     |     |     |
| Do you clean seeds before storing them?       | 91  | 65  | 58.3| 41.7|
| Do you perform sorting of seeds damaged/diseased? | 24  | 132 | 15.4| 84.6|
| Do you maintain varieties separately?         | 86  | 70  | 55.1| 44.9|
| Do you maintain temperature in the store?     | 27  | 129 | 17.3| 82.7|
| Do maintain moisture/humidity in the store    | 27  | 129 | 17.3| 82.7|
| Do you clean/spray the store before storage?  | 99  | 57  | 63.5| 36.5|
| Do you calculate the seed rate after the germination test? | 20  | 136 | 12.8| 87.2|
| Do you contact the extension agents?          | 47  | 109 | 30.1| 69.9|
| Social participation to update knowledge       | 64  | 92  | 410 | 59.0|
| Do you control the temperature of the storeroom? | 15  | 141 | 9.6 | 90.4|
| Do you control the humidity of the storeroom? | 60  | 96  | 38.5| 61.5|
| Do you dress seeds with fungicides before storage? | 109 | 47  | 69.9| 30.1|
| Do you check the seed moisture at harvest of seeds? | 128 | 28  | 82.1| 17.9|
| Do you check the weather before seed harvest?  | 135 | 21  | 86.5| 13.5|
| Do you check the level of seed maturity at harvest? | 137 | 19  | 87.5| 12.5|
| Do you perform germination tests before sowing? | 52  | 104 | 33.3| 66.7|
| Do you keep records of the stored seeds?      | 22  | 134 | 14.1| 85.9|
| Do you adopt new varieties immediately if available in market? | 52  | 104 | 33.3| 66.7|

Controlling the temperature of the seed store was positively associated with growers’ age ($p < 0.01$), namely older farmers showed a tendency for controlling the temperature of seed storage (Table 4). Controlling humidity during seed storage was positively associated with growers’ farming experience, namely experienced farmers showed a tendency for controlling the temperature of stored seeds. Seed dressing fungicides use was positively associated with growers’ education (graduation level), while checking seed maturity was positively associated with grower’s education (Master level). Controlling the temperature of the seed store was positively associated with growers’ total farmland ($p < 0.01$) and using sealed containers/polythene bags was positively associated with growers’ training for seed storage ($p < 0.001$) (Table 5). In addition, keeping records of seed storage and seed sorting were positively associated with total farmland ($p < 0.05$). Cleaning of the seed store was negatively associated with growers’ total farmland ($p < 0.01$) and positively with contact with extension agents ($p < 0.01$).
Table 4. Factors influencing farmers' practices of seed storage (N = 156).

| Practice                                      | Age (Years)       | Education (Level) | Farming Experience (Years) |
|-----------------------------------------------|-------------------|-------------------|-----------------------------|
|                                               | Graduation        | Master            |                              |
| Controlling the temperature of the storeroom  | 0.025 (0.045) **  | -1.8 (1.476)      | 0.594 (0.991)               |
|                                               |                   |                   | 0.075 (0.059)              |
| Controlling the humidity of the storeroom     | 0.002 (0.023)     | -1.094 (0.757)    | -0.388 (0.667)              |
|                                               |                   |                   | 0.088 (0.034) **           |
| Seed dressing fungicides before storage       | -0.014 (0.02)     | 1.547 (0.778) *   | 0.466 (0.679)               |
|                                               |                   |                   | -0.013 (0.029)             |
| Checking seed maturity before harvesting      | 0.01 (0.28)       | 0.85 (1.096)      | 2.39 (1.234) *              |
|                                               |                   |                   | -0.022 (0.04)              |

* Significant at p < 0.05, ** significant at p < 0.01; values in parenthesis show standard errors.

Table 5. Knowledge-based awareness of growers for seed storage (N = 156).

| Practice                                      | Total Farmland (Acres) | Training for Seed Storage | Contact Extension Agent |
|-----------------------------------------------|------------------------|---------------------------|-------------------------|
| Controlling the temperature of the storeroom  | 0.146 (0.051) **       | -1.629 (0.803) *          | -0.826 (0.837)          |
| Using sealed containers/closed polythene bags | 0.003 (0.026)          | 1.550 (0.453) ***         | 0.723 (0.469)           |
| Keeping records of stored seeds              | 0.059 (0.030) *        | 0.069 (0.607)             | 0.319 (0.648)           |
| Sorting damaged and diseased seeds           | 0.078 (0.030) **       | -0.361 (0.566)            | 0.478 (0.587)           |
| Cleaning or spraying the store to disinfect it| 0.163 (0.047) ***      | -1.918 (0.711) **         | 1.69 (0.623) **         |

* Significant at p < 0.05, ** significant at p < 0.01, *** significant at p < 0.001; values in parenthesis show standard errors.

Table 6 presents the multinomial logistic regression (MLR) coefficients obtained to gain insights into how the different aspects of seed storage were associated with growers' characteristics. The results present the outcome of coefficients comparing the relationship between selected variables regarding seed storage and growers' variables that were used as dependent variables, such as total farmland, training on seed storage, contact with extension agents and participation in social events to improve and update knowledge. As indicated, each factor has the respective reference category. The storage place was negatively associated with growers' total farmland compared with the reference category (store), while the type of containers used for seed storage was positively associated with growers' total farmland compared with the reference category (polyethylene bags) (Table 6). Knowledge regarding different temperature ranges, i.e., 16–30 and 31–45 °C, was significantly associated with training and social participation of growers. While the knowledge of storage humidity range 61–70% was negatively associated with contacting extension agents, the humidity range 71–80% was positively associated with social participation of growers (Table 6). Seed moisture at harvest in the range of 16–20% was positively associated with growers' seed storage training. Overall, bad condition of storage was negatively associated with total farmland.
Table 6. Multinomial logistic regression for growers’ perceptions of their abilities to manage seed storage.

| Variable                        | Total Farmland | Training for Seed Storage | Contact Extension Agent | Social Participation |
|---------------------------------|----------------|---------------------------|-------------------------|---------------------|
| Storage place                   |                |                           |                         |                     |
| Living room                     | −0.127 (0.046)** | 0.560 (0.560)             | 0.164 (0.610)           | −0.062 (0.480)      |
| Open area                       | −0.123 (0.048)** | 0.627 (0.600)             | 0.808 (0.670)           | −0.110 (0.494)      |
| Kitchen                         | −0.229 (0.071)*** | 0.027 (0.798)             | −0.198 (0.861)          | 0.783 (0.675)       |
| Store                           | Reference category |                         |                         |                     |
| Containers used for storage     |                |                           |                         |                     |
| Jute bags                       | 0.341 (0.081)*** | −0.513 (0.895)            | 0.909 (0.891)           | −0.343 (0.614)      |
| Cotton bags                     | 0.377 (0.081)*** | −0.624 (0.881)            | 1.163 (0.886)           | −1.091 (0.613)      |
| Closed bins                     | 0.348 (0.083)*** | −0.356 (0.946)            | 1.213 (0.944)           | −0.427 (0.661)      |
| Covered heap                    | 0.316 (0.089)*** | −1.670 (1.028)            | 0.740 (1.061)           | −0.341 (0.765)      |
| Polythene bags                  | Reference category |                         |                         |                     |
| Appropriate temperature for store |                |                           |                         |                     |
| 16–30 °C                        | −0.051 (0.033) | 0.537 (0.555)             | −1.058 (0.611)          | 1.500 (0.561) **    |
| 31–45 °C                        | −0.037 (0.042) | 3.344 (0.839)***          | −0.825 (0.722)          | 2.419 (0.624)***    |
| 0–15 °C                         | Reference category |                         |                         |                     |
| Appropriate humidity for store  |                |                           |                         |                     |
| 61–70%                          | −0.012 (0.029) | 0.178 (0.543)             | −1.753 (0.630)**        | 0.605 (0.440)       |
| 71–80%                          | 0.003 (0.042)  | 1.875 (1.162)             | −0.408 (0.876)          | 1.814 (0.688)**     |
| 81–90%                          | −0.036 (0.08)  | 1.088 (1.147)             | −1.958 (1.527)          | 0.694 (0.822)       |
| 50–60%                          | Reference category |                         |                         |                     |
| Knowledge of seed moisture at harvest |            |                           |                         |                     |
| 11–15%                          | 0.007 (0.027)  | 0.212 (0.487)             | 0.285 (0.552)           | −0.500 (0.399)      |
| 16–20%                          | −0.057 (0.047) | 2.504 (0.878)**           | 0.161 (0.648)           | 0.932 (0.575)       |
| 21–25%                          | −0.135 (0.091) | 0.408 (0.995)             | 0.109 (0.947)           | −0.430 (0.755)      |
| 5 to 10                          | Reference category |                         |                         |                     |
| Grading of store conditions     |                |                           |                         |                     |
| Bad                             | −0.159 (0.058)*** | 2.521 (1.35)             | −1.526 (1.317)          | −0.837 (1.378)      |
| Medium                          | −0.115 (0.063) | 1.275 (1.49)              | −1.48 (1.484)           | −0.675 (1.485)      |
| Good                            | Reference category |                         |                         |                     |

** significant at \( p < 0.01 \), *** significant at \( p < 0.001 \); values in parenthesis show standard errors.
4. Discussion

Moisture contents of seeds were higher in seed samples collected from Vehari (Pakistan) as compared to the other two tehsils in both NCSGs and CSGs. McDonald, 1999 [47] had reported that high temperatures during storage deteriorate seeds, just like a high seed moisture content does, but the impact of seed moisture and store temperature on seed quality varies among crop species. The structure and biochemical composition of the seeds also play a role to the extent of deterioration effects on stored seeds. Knowledge of seed moisture and storage temperature can predict patterns of seed viability losses [48]. In the studied areas, drastic fluctuations happened in temperature that caused conditions of very high temperatures, exacerbating the loss of germination in stored seeds.

Seed germination was significantly low in seed samples from Vehari (Pakistan) as compared to the other two tehsils among NCSGs. Stored seeds showed no loss of germination in higher percentages [49] and also onion seed germination has been reported at 91% after 180 days of storage in paper bags but in rose seed it declined to 84% [50]. Nevertheless, storage conditions play a critical role in seed quality. Storage factors like moisture and packaging materials affect the germination and vigor of seeds. Storage duration significantly affects radical elongation. Onion seeds that were dried to 5% seed moisture contents (SMC) and stored in aluminum foil packets and plastic bags were able to maintain more than 70% germination for 360 days [51], while seeds stored in sealed polyethylene bags with 8% SMC for 10 months showed 70% germination [52]. The longest germ inability up to seven years was reported in onion seeds (6.5% SMC) when stored with silica gel in a moisture-impervious container at 5–8 °C [53]. Germination loss in the storage of rice seeds in Ghana was rapid at high-moisture content and slow at low-moisture content [54]. Our results showed that seed drying is of major importance, besides low store temperature. It is better to decrease the seed moisture contents to the appropriate low levels. Moisture-absorbing materials (desiccants) can stabilize the seed moisture level during storage and they minimize the impact of fluctuating temperature on seed quality [55]. It has been experienced that the sampled seeds from Vehari were not excessively dried (Figure 1), and these seeds with bad drying practice can damage seeds in different ways. Therefore, low seed moisture contents maintain all physiological and biochemical reactions affecting deterioration in the dormant stage of seeds. However, over-drying is also harmful for seeds’ viability [56]. In our study, it has been found that the drying of seeds followed by packaging and low-temperature storage was not a common practice, especially among NCSGs under the hot and dry temperatures of this region. Low relative humidity in the store, i.e., 20–25% [57], temperature range 20–25 °C [58], and appropriate seed invigoration treatments [59] would promote seed longevity.

This study assessed growers’ knowledge and practices regarding wheat and cotton seeds storage among commercial seed growers (CSGs) and non-commercial seed growers (NCSGs) as well as factors affecting growers’ behavior in seed storage. Similar studies are lacking in the literature. Seed growers’ knowledge of storage temperature and humidity control and fungicide dressing of seeds and seed maturity at harvesting were linked with their age, education level and farming experience [60]. In a study, Midega et al., 2016 [30], reported that Farmers’ perceptions of pests were positively and significantly influenced by level of education and farming experience, indicating that education and experience improved farmers’ understanding of storage pests. Munyambonera et al., 2012 [61], also informed that on-time access to information is of great importance, especially to small-scale farmers. Our findings further revealed that farmers need appropriate information on seeds storage techniques. Despite the efforts of research institutions to disseminate information about the appropriate seed storage, it was noticed that very few farmers used better storage facilities for improved seeds [62]. This probably occurred because of the lack of awareness of such facilities or the lack of enough resources to purchase them. This finding is in accordance with previous findings of De Vitis et al., 2020 [9,63], who reported that most farmers were lacking knowledge on improved seeds storage and hence they usually stuck to traditionally preferred storage methods which are technically simple.

In our study, seed growers having higher land holdings were well aware of appropriate seed storage conditions and this awareness could be due to the availability of resources and economic
stability. Seed growers having relevant training, contact with extension agents and social participation had better knowledge of storage containers, and cleaning of stores by spraying. Knowledge about different ranges of temperature and humidity of the stores, as well as moisture of the seeds at harvest, was better among growers having relevant training, contact with extension agents and social participation. Lwoga, 2009 [64], reported that interpersonal sources, like friends, family members and neighbors, are considered main sources of agricultural information. This can be due to the reliability and credibility of those sources, but most of all, to the high confidence of those sources by the farmers. However, in our study modern technologies, like the Internet, are not used for agricultural advancements. The reason could be the low level of education among farmers in the studied areas, along with the lack of electricity, the lack of information centers and the lack of awareness of the role of the Internet as a convenient source of information. These regions do not have well-developed communication technologies. The findings of this study are in accordance with earlier studies [65–67]. For instance, farmers are unwilling to use advanced technology for reaching agricultural information. Usually, the farmers’ community in the studied areas has no access or knowledge to access Internet information sources for agricultural information, while most farmers do not have skills for using the advanced technology. Therefore, the agriculture institution must increase learning opportunities in a changing environment and advancement of technologies. The farmers need to use modern technology for access to the new advances in agricultural technologies. Knowledge about different types of storage containers was better among growers with higher land holdings probably because of more available resources and higher earnings that could support growers’ knowledge to store seeds in proper containers (e.g., cotton bags).

Pure and abnormal seeds differed significantly between varieties and locations. Differences in seed physical qualities between locations could be attributed to the poor health status of seeds used for planting, prevailing weather conditions among different geographical positions and post-harvest management practices, including storage. Ingle, 1990 [68], studied the transmission and control of pearl millet seed-borne fungi and reported that seed samples collected from a farmer’s field were more diseased which was attributed to frequent rains during the seed development stages, high seed moisture content and a prolonged storage period deteriorating the seed quality. The quality of the seeds at the time of sowing depends on the quality of the seeds that entered storage and how well they were stored [69–71]. Seeds quality does not improve in storage, so inferior seeds in the store will finally end up as inferior seeds at sowing, no matter how much care is taken during storage [38,72,73]. Seed health is an important quality attribute and seeds used for planting should be free from abnormal seeds, inert matter and pests as reported by Bishaw et al., 2006; Gioria and Osborne, 2010 [74,75].

Investigations were carried out to evaluate the seed quality in relation to quality attributes and prevalence of seed-borne fungi as influenced by storage conditions. In our study, seed-borne contamination was observed in significantly higher percentages in seed samples collected from Vehari as compared to the other two tehsils in both NCSGs and CSGs (Figure 2). Higher percentages of *Fusarium* spp. were found in cotton seed samples of NCSGs from all three tehsils. Wheat seed samples had higher percentages of *Fusarium* spp., *Alternaria alternata* and *Stemphylium botryosum* in all samples, irrespective of area and growers’ group (Figure 2). This finding is in line with findings of other researchers [76–79]. With an increase in seed moisture content, seed-borne infestations increased, resulting in a reduction in seed germination. Containers used for seed storage could reduce *Fusarium* spp. infestations [76–79]. In Ethiopia, disease susceptibility of the existing wheat variety was a significant reason as to why most farmers (63.8%) purchased certified seed [80]. Seeds go under several processes after harvest and therefore damage caused by insect pests and seed-borne fungal pathogens affect the overall germination percentages of seed lots [81,82]. However, securing intact grains is essential for successful storing [81,83]. Dirty, cracked or broken grains provide an entry point for infestation by insects, pathogens and molds during storage [81,84]. Deterioration of seed quality can be due to improper post-harvest management practices of the seeds and unfavorable
storing conditions, which promote contamination by fungi or insect pest infestations, as reported by Gwinner et al., 1996 [81].

According to the Food and Agriculture Organization of the United Nations and United States Department of Agriculture [16–18], appropriate measures for grain and seed should start from the field (preharvest) and in the handling of the produce before storage (post-harvest handling). Farmers need to ensure standard harvesting, drying, threshing or cleaning, among other operations, and afterward to meet appropriate storage conditions which can reduce the risk of insects/fungi. Therefore, it should be ensured that seed storerooms have stable conditions of low temperature and relative humidity. The moisture content of the stored grain and seed should keep them under safe thresholds. Cottonseed may be artificially dried and cleaned at gins in storage. This process delays the development of free fatty acids, improves seed germination quality and reduces fungal contaminations [16–18]. The overall assessments showed that stored seeds in the study area were contaminated by a variety of fungi. Infestation percentages in seeds from NCSGs reached 13% for wheat and 20.7% for cotton, while the respective percentages in seeds from CSGs were 9% (wheat) and 9.5% (cotton). Seed deterioration in the study area was mainly caused by inappropriate storage practices that render seeds more prone to fungal contamination and infection. The study also revealed that most of the farmers (87.8%) in the area store their wheat and cotton grains in poor store conditions which allows contamination and infection by fungi. Timsina et al., 2014; 2018 [85,86], reported that poor seed quality results in huge crop losses. Farmers avoid trying new technologies, probably because they cannot handle the techniques and finally are blamed for their ignorance. However, this matter could be overcome with intensive extension activities [87]. Furthermore, appropriate interventions should aim to fit external technologies and strategies to the local environmental and cultural context [88].

5. Conclusions

Storage problems of farmers in the studied areas were drying and to maintain optimum conditions of seed storerooms. Unfavorable environment in storage was the major problem followed by higher seed moisture and higher infestations of seed-borne pathogens that deteriorate seed quality. In case of storage problems, “need to dry” several times was ranked as first followed by fluctuation in seed moisture content and incidence of insect pests. In this respect, a successful practical approach to sustainable disease management should be targeted. Extension workshops regarding seed storage techniques and awareness regarding potential losses due to bad-quality seeds should be initiated to increase public awareness. The government should organize training programs to provide adequate knowledge and skills for appropriate seed storage to growers. Legislation regarding the seed business and seed storage protective measures should be enforced to minimize problems by seed-borne contamination and deterioration of seed quality. The physiological status of the seed and the physical status of water within the seeds are important for the optimum seed storage. There are further needs to understand the relationship between the moisture content and physiological activities of seeds. Seed storage can be improved for the long-term storage of seeds by investigating the nature of seed aging under varying storage conditions.

Author Contributions: Conceptualization, M.F.S. and A.J.; methodology, I.A., S.A. and G.M.S.; formal analysis, M.F.S., A.F.; investigation, S.K.H. and S.A.; writing—original draft preparation, M.F.S. and A.J.; writing—review and editing, J.W.; funding acquisition, J.W. and M.F.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study has been funded for research work by Higher Education Commission, Pakistan (HEC), (Grant no. 21-254/SRGP/R&D/HEC/2016).

Acknowledgments: We would like to thank Higher Education Commission, Pakistan (HEC) for providing financial support for this research project.

Conflicts of Interest: The authors declare no conflict of interest.
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