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Research article

Effects of storage strategies on physicochemical properties of stored wheat in Ethiopia

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Abstract: A postharvest management intervention of wheat grain needs to be examined from technological quality perspectives before its introduction to users. This study was conducted to evaluate the effects of different grain storage strategies on the physicochemical properties of stored wheat. The experiment included six treatments: Filter-cake treated wheat in a polypropylene bag, triplex treated wheat in a polypropylene bag, metal silo, Purdue Improved Crop Storage (PICS) bag, Super GrainPro bag, and polypropylene bag (control). Data on water activity, protein, ash, wet gluten, sedimentation value, and farinograph were determined at two months interval for six months. Mean ash contents of wheat after six months of storage had ranged from 1.58% in Super GrainPro bag to 1.79% in the control while filter-cake and triplex treated wheat exhibited higher ash than wheat in other interventions. Mean wet gluten content after six months had ranged from 24.7% in the control to 27.8% in the Super GrainPro bag. Baseline wet gluten and sedimentation values of wheat in the control, triplex, and filter-cake treatment diminished unlike those in the hermetic containers. Mean farinograph water absorption of wheat after six months had ranged from 54.1% in PICS bag to 61.2% in the control. Storage period did not affect all the measured parameters, except farinograph water absorption, of wheat stored in hermetic containers. Hermetic containers are better options to maintain physicochemical properties of stored wheat compared to the commonly used polypropylene bag. However, the application of filter-cake and triplex powders resulted in increased water absorption and ash content apart from diminished wet gluten content and sedimentation values. This condition may pose a negative influence on the baking performance of flour from wheat treated with the powders. Hence, effective removal of filter-cake and triplex from the treated wheat needs further investigation.

Keywords: filter-cake; physicochemical change; triplex; wheat storage; Ethiopia

1. Introduction

Wheat accounts for 13.8% of African cereal production, and Ethiopia ranks first in wheat production among the countries of sub-Saharan Africa [1]. During the major production season of 2017/18, 4.6 million tons of wheat was produced on 1.7 million hectares [2]. However, the country is currently a net importer of wheat [3], and the overall postharvest loss of wheat in the country is estimated to be about 14.2% [4]. Recently, Kalsa et al. [1] pointed out that insect alone caused a 9.6% grain weight loss and a 14.6% grain damage of wheat stored in polypropylene bag for six months under ambient condition. Therefore, to satisfy the local demand, improvement of postharvest management of wheat is an essential step to be taken along with the attempt for increased productivity [5].

Wheat is subject to both biological and physical factors that deteriorate its quality during farm storage [3]. Insects are among critical biological factors that cause quality deterioration of stored wheat. Insects such as the granary weevil *Sitophilus granarius* (L.), the lesser grain borer *Rhyzopertha dominica* (F.), rice weevil *Sitophilus oryzae* (L.), and maize weevil, *Sitophilus zeamais* Motschulsky commonly damage farm-stored wheat [6]. A recent report by Kalsa et al. [7] indicated that the *Sitophilus* spp. and the Angoumois grain moth *Sitotroga cerealella* are common in farm-stored wheat samples of Ethiopia.

Insect infestation of stored grains generally contributes to a reduction in the quantity of the grain such as grain weight loss and decreased flour yield [1,8,9]. Unlike in other grains, insect damage to wheat results in an additional dimension of adverse consequences. Insect damage can change the physicochemical properties of wheat, which is manifested in unfavorable technological properties [9]. Wheat seed possesses unique characteristics compared to all others in the plant kingdom in that it has the gluten proteins capable of forming the elastic dough necessary to bake leavened bread [10]. Therefore, effective insect control of stored wheat is necessary not only to prevent grain weight loss but also to maintain the grain's unique technological properties.

Among the methods used to protect insect infestation in stored grains in Ethiopia, application of synthetic insecticides is a common practice. However, improper use of pesticides coupled with poor regulatory oversight posed a significant risk to human health and the environment [11]. In recent years, there is increasing research to find alternatives to synthetic insecticides. Such alternatives are inert dust [1,12–14], hermetic bags, and airtight metal silos [1]. However, those findings did not consider the effects of the non-chemical insect control options on the technological properties of wheat. Changes in physicochemical characteristics and the associated reduction of flour technological quality were reported in wheat treated with diatomaceous earth for insect control during storage [15].

Hence, the objective of this study was to assess the effects of different postharvest preservation strategies on the physicochemical characteristics of wheat grains stored for six months.

2. Materials and methods

2.1. Wheat grain and source

The wheat grain of 'Kakaba' variety, harvested in March 2015, was purchased from Ethiopian Seed Enterprise, Bahir Dar, Ethiopia. It is the most widely grown wheat variety in the country. The wheat grain was obtained from the same lot as defined in International Rules of Seed Testing [16] and hence no need for additional homogenization. The grain had not been treated with pesticides and kept under ambient conditions until used for the experiment, as described in Kalsa et al. [1].

2.2. Experimental setup and design

The experiment was conducted for six months (April 22 to October 22, 2016) in the laboratory at the College of Agriculture and Environmental Sciences, Bahir Dar University, Ethiopia. The storage treatments were placed at the ambient condition in the grain quality laboratory room ($L \times W \times H \approx 1200\ m^3$).

The experiment included six storage strategies viz.: (1) filter-cake powder applied to wheat in polypropylene bag, (2) triplex powder applied to wheat in polypropylene bag, (3) metal silos, (4) Purdue Improved Crop Storage (PICS) bag, (5) Super GrainPro bag, and (6) polypropylene bag as control. All storage treatments, including the metal silo with a 100 kg grain holding capacity, were loaded with 50 kg wheat. Filter-cake and triplex were applied at a recommended 1% [12] and 0.25% [13] rates, respectively.

A randomized complete block design (RCBD) was employed with three separately treated replications. The relative humidity (RH) and temperature of the storage room were monitored as described in Kalsa et al. [1]. Detail description of the treatments can be obtained from Kalsa et al. [1].

2.3. Wheat sampling

Baseline samples were taken at the outset of the experiment. Consecutive sampling was done after two, four, and six months of storage periods, as indicated in Kalsa et al. [1].

2.4. Data collected

Water activity was measured using the chilled mirror dew point method [17] using an Aqualab 4TE (Decagon Devices, Inc Pullman, Washington, USA) following the manufacturer's instructions. The measurements were conducted at 25 °C on three replicates of randomly taken sub-samples of about 100 wheat kernels. Measurements were taken within an hour after sampling wheat from the storage containers.

Protein content and wet gluten content of wheat samples were measured using USDA-GIPSA approved method [18]: NIRT (Near Infrared Transmittance) using Infratec 1241 grain analyzer (Foss Analytical, 3400 Hilleroed, Denmark). The analysis was carried out at the grain quality laboratory of the Amhara Region Agricultural Research Institute, Bahir Dar, Ethiopia. Percentages of protein and wet gluten contents were reported on 12% and 14% moisture basis, respectively, as recommended in USDA-GIPSA [18].

For analyses requiring a ground sample, wheat grain was ground into flour using bench-top laboratory hammer mill (Sinograin, Sichuan, China) with an installed sieve of 0.5 mm size.

Ash content was determined according to AACC Method 08-12.01 [19]. The results were given in percentage dry weight basis. Water absorption, dough development time, dough stability, and degree of softening of whole-wheat flour were measured according to AACC Method 54-21.02 [20] using the 300 g bowl of an electronic Farinograph (toposun, Model: TPS-JMLD, Shanghai, China). Sedimentation value was measured according to AACC Method 56-61.02 [21] using a mechanical mixer (Model 3100, Bastak instruments, Ankara, Turkey) and reported on a 14% moisture basis.

2.5. Data analysis

Two-way ANOVA was conducted to detect significant effects of storage strategies within each period of storage. The same method was applied to detect significant effects of storage periods within each storage strategy. Bartlett's test was employed to test the homogeneity of variances among different storage strategies or periods. Tukey's HSD test was used to separate the means when there were significant differences at $P < 0.05$. A two-sample t-test was applied to compare the trend of change in the mean values of parameters between the baseline and those after six months. R software Version 3.5.0 was used for data analysis. SigmaPlot software Version 12.5 was used to plot graphs [22].

3. Results

3.1. Water activity

The water activity of wheat at the onset of storage was 0.428 ± 0.003, and it was significantly influenced by storage strategy across all storage periods (Table 1). After two months, it ranged from 0.434 in PICS bag to 0.493 in filter-cake treated wheat stored in a polypropylene bag. At four months of storage, hermetic bags and the airtight metal silo had water activity values significantly lower than the control (polypropylene bag) while that of triplex and filter-cake treated wheat were not significantly different from the control (Table 1).

The influence of storage period on water activity of wheat stored in different strategies is depicted in Figure 1. Storage period had significantly influenced water activity of wheat grains in the control (polypropylene bag) ($F_{2,4} = 633.4$; $P < 0.001$), triplex treated wheat in polypropylene bag ($F_{2,4} = 49.2$; $P < 0.01$), and filter-cake treated wheat in polypropylene bag ($F_{2,4} = 122.9$; $P < 0.001$). The water activity of wheat in the metal silo, Super GrainPro bag, and PICS bag was not significantly affected by the storage period at $\alpha = 0.05$ (Figure 1).

3.2. Protein

The protein content of wheat at the onset of the experiment was 11.37 ± 0.15%. It was not significantly affected by storage strategy until the fourth month. After six months, significant differences were detected among storage strategies in protein level (Table 1). After six months, wheat stored in the control exhibited significantly lower protein content than other storage strategies (Table 1). Moreover, storage period had a significant effect on the protein content of wheat stored in the polypropylene bag (control) ($F_{2,4} = 9.2$; $P < 0.05$).

Table 1. Mean (±SD) water activity, protein, ash, wet gluten and sedimentation values of wheat grain stored under different strategies[1,2].

Storage strategy by month	Water activity	Protein (12% wb)[3]	Ash (% db[4])	Wet gluten (14% wb)	Sedimentation value (mL 14% wb)
Two months					
Polypropylene bag (control)	0.484 ±0.006^{ab}	11.13 ±0.12	1.59 ±0.03^{b}	26.7 ±0.5	31.8 ±0.2
Triplex in a polypropylene bag	0.481 ±0.014^{abc}	11.17 ±0.06	1.66 ±0.02^{a}	26.4 ±0.8	31.5 ±0.4
Metal silo of 100 kg size	0.451 ±0.006^{bcd}	11.13 ±0.12	1.57 ±0.02^{b}	27.4 ±0.3	32.0 ±0.3
Filter-cake in a polypropylene bag	0.493 ±0.016^{a}	11.23 ±0.06	1.67 ±0.03^{a}	26.3 ±0.2	31.1 ±0.6
Super GrainPro bag	0.443 ±0.022^{cd}	11.12 ±0.12	1.57 ±0.02^{b}	26.9 ±0.7	32.1 ±0.1
PICS bag	0.434 ±0.009^{d}	11.03 ±0.25	1.58 ±0.02^{b}	26.5 ±0.6	32.0 ±0.1
$F_{5,10}$	10.3	1.8	13.1	1.5	3.4
P-Value	<0.01	0.22	<0.01	0.27	0.05
Four months					
Polypropylene bag (control)	0.572 ±0.005^{a}	11.03 ±0.21	1.61 ±0.02^{b}	26.9 ±0.7	31.0 ±0.5^{ab}
Triplex in a polypropylene bag	0.576 ±0.01^{7a}	10.97 ±0.31	1.68 ±0.02^{a}	26.8 ±1.4	31.4 ±0.5^{ab}
Metal silo of 100 kg size	0.443 ±0.015^{b}	11.15 ±0.21	1.58 ±0.04^{b}	27.6 ±0.4	32.1 ±0.4^{a}
Filter-cake in a polypropylene bag	0.576 ±0.008^{a}	11.20 ±0.20	1.69 ±0.02^{a}	25.6 ±1.0	30.1 ±0.9^{b}
Super GrainPro bag	0.446 ±0.009^{b}	11.07 ±0.21	1.59 ±0.02^{b}	27.1 ±0.4	31.8 ±0.5^{a}
PICS bag	0.446 ±0.005^{b}	11.13 ±0.21	1.59 ±0.03^{b}	27.2 ±0.9	31.9 ±0.3^{a}
$F_{5,10}$	124.6	0.45	13.3	1.9	5.0
P-Value	<0.01	0.81	<0.01	0.2	0.02
Six months					
Polypropylene bag (control)	0.571 ±0.002^{a}	10.50 ± 0.20^{b}	1.79 ±0.03^{a}	24.7 ±0.6^{b}	30.2 ±0.7^{b}
Triplex in a polypropylene bag	0.514 ±0.008^{b}	11.27 ±0.25^{a}	1.71 ±0.02^{b}	26.0 ± 0.7^{ab}	30.5 ±0.8^{ab}
Metal silo of 100 kg size	0.445 ±0.005^{c}	11.20 ±0.10^{a}	1.61 ±0.03^{c}	27.0 ±1.1^{a}	31.6 ±0.4^{ab}
Filter-cake in a polypropylene bag	0.525 ±0.005^{b}	11.13 ±0.06^{a}	1.71 ±0.02^{b}	26.2 ± 0.6^{ab}	30.4 ±0.8^{ab}
Super GrainPro bag	0.434 ±0.012^{c}	11.23 ±0.06^{a}	1.58 ±0.02^{c}	27.8 ±0.8^{a}	32.0 ±0.2^{a}
PICS bag	0.433 ±0.008^{c}	11.13 ±0.12^{a}	1.60 ±0.02^{c}	27.0 ±0.4^{a}	31.8 ±0.6^{ab}
$F_{5,10}$	228.3	10.0	47.3	6.0	5.1
P-Value	<0.01	<0.01	<0.01	<0.01	0.01

Note: [1]Data are based on three replications; [2]Means followed by the same letter are not significantly different at Tukey's 5% level of significance; [3]wb = wet basis; [4]db = dry basis.

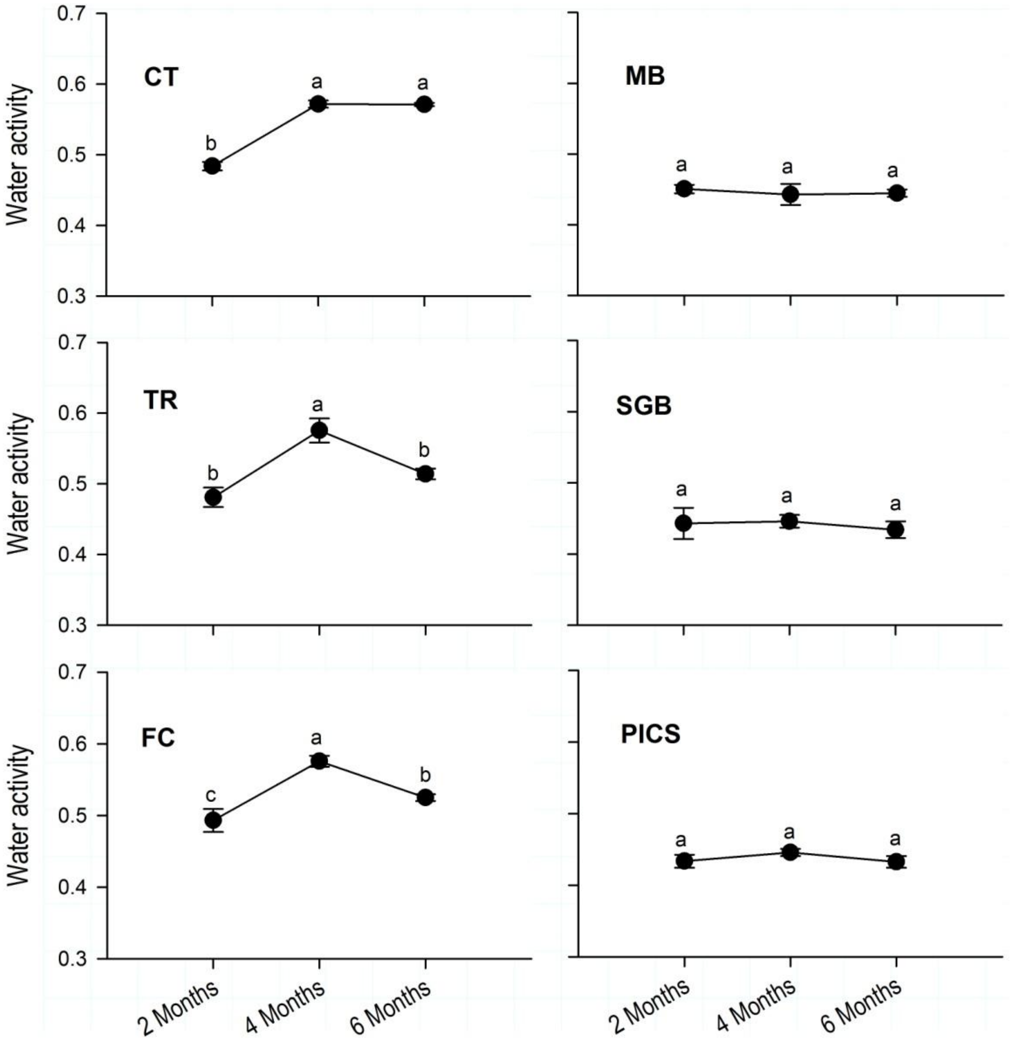

Figure 1. Mean (±SD) of water activity of wheat grain stored for six months under different strategies. CT = Polypropylene bag (control), TR = Triplex in polypropylene bag, FC = Filter-cake in polypropylene bag, MB = Metal silo, SGB = Super GrainPro bag, PICS = Purdue Improved Crop Storage bag, Data are based on three replications. Means followed by the same letter are not significantly different at Tukey's 5% level of significance.

3.3. Ash

The ash content of wheat at the baseline was 1.56 ± 0.01%. Storage strategies posed significant effect on ash content of wheat across all storage periods (Table 1). A significantly higher ($P < 0.05$) ash contents were observed in wheat treated with filter-cake and triplex at both two and four months of storage periods. After six months, ash contents of wheat treated with filter-cake and triplex were significantly lower than the control, but they remained higher than those in Super GrainPro bag, PICS bag, and metal silo (Table 1). Figure 2 depicts that ash content of wheat stored in each storage strategy was not significantly influenced by storage period except for the control ($F_{2,4} = 47.5$; $P < 0.01$).

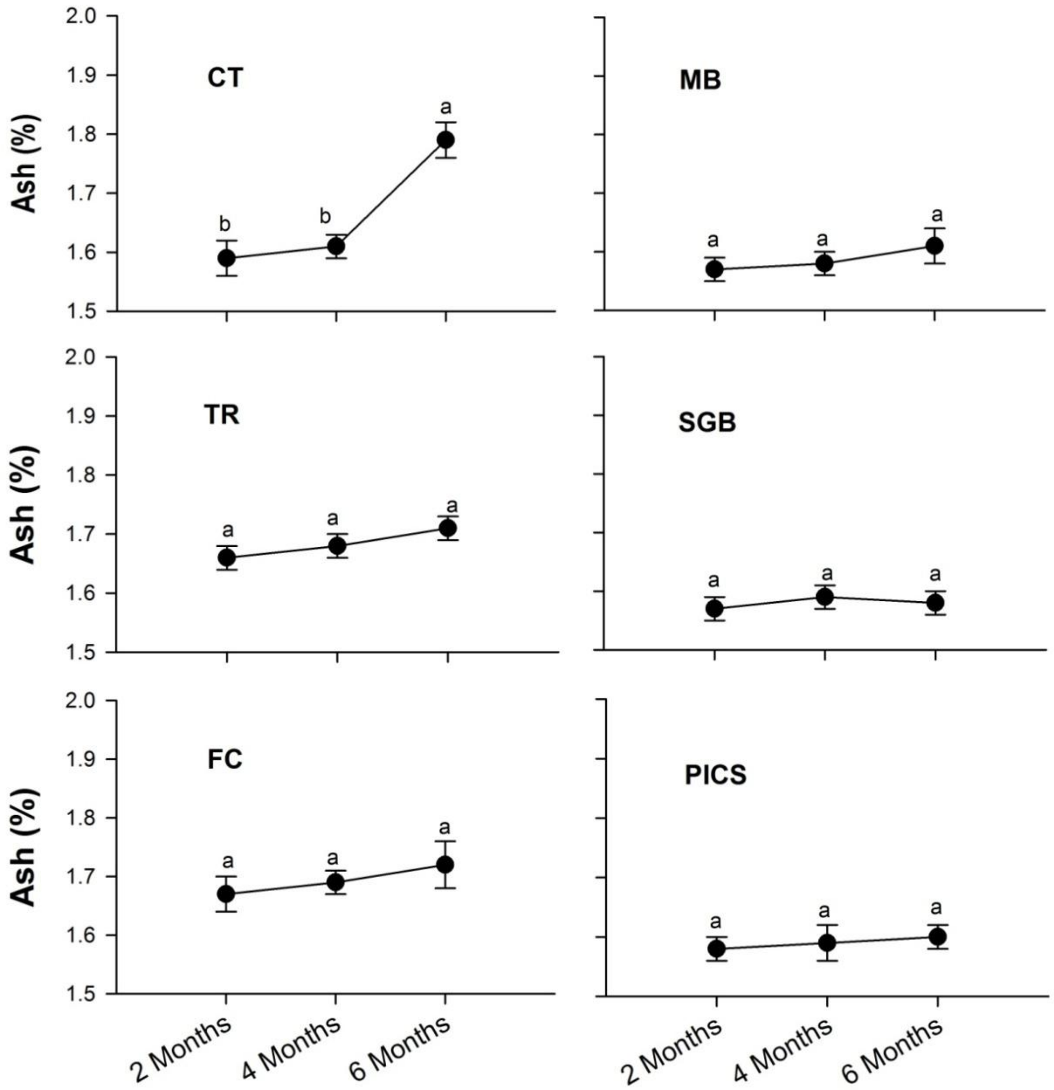

Figure 2. Mean (±SD) ash content (% dry base) of wheat grain stored for six months under different strategies. CT = Polypropylene bag (control), TR = Triplex in polypropylene bag, FC = Filter-cake in polypropylene bag, MB = Metal silo, SGB = Super GrainPro bag, PICS = Purdue Improved Crop Storage bag, Data are based on three replications. Means followed by the same letter are not significantly different at Tukey's 5% level of significance.

3.4. Wet gluten and sedimentation values

Wet gluten and sedimentation values at the onset of the experiment were 27.5 ±0.4% and 32.1 ±0.2 mL, respectively. Wet gluten was significantly affected by storage strategy after six months while sedimentation was after four and six months (Table 1). Wet gluten content ranged between 24.7% (in the control) and 27.8% in Super GrainPro bag after six months while sedimentation value ranged between 30.2 mL (control) and 32.0 mL (Super GrainPro bag) (Table 1). Both wet gluten and sedimentation values were not significantly affected by the storage period ($\alpha = 0.05$) except for the control (polypropylene bag). Wheat stored in the control was significantly affected by storage period regarding wet gluten ($F_{2,4} = 9.7$; $P = 0.05$) and sedimentation ($F_{2,4} = 10.3$; $P < 0.05$). Wet gluten and sedimentation values of flour from wheat in the control were significantly reduced after six months to 24.7% and 30.2 mL, respectively. Differences in wet gluten contents between wheat at baseline (27.5%) and that from each storage strategy after six months was not significant ($P > 0.05$) in PICS, Super GrainPro Bags, and metal silo. However, significant differences were observed between wet gluten content at baseline and that from filter-cake treated wheat ($t = 3.1$; $df = 4$; $P < 0.05$) or wheat in the control (Polypropylene bag) ($t = 7.1$; $df = 4$; $P < 0.01$) after six months of storage. Similarly, sedimentation of flour from filter-cake treated wheat in polypropylene bag ($t = 3.7$; $df = 4$; $P < 0.05$) and wheat in the control after six months ($t = 4.7$; $df = 4$; $P < 0.01$) were significantly reduced compared to the baseline value.

3.5. *Farinograph data*

Farinograph water absorption of wheat flour at the baseline was 65.1%. It showed a declining trend regardless of the storage period and strategy. No significant difference was observed among storage strategies at two months of storage. After four months, water absorption ranged from 62.6% in filter-cake treated wheat to 60.5% in Super GrainPro bag. After six months, the water absorptions of flours ranked in ascending order as PICS and Super GrainPro bags < metal silo, triplex and filter-cake treated wheat < polypropylene bag (control) (Table 2).

Significant effect was posed on flour water absorption by storage period for all storage strategies (Figure 3): Polypropylene (control) ($F_{2,4} = 12.2$; $P < 0.05$), triplex treated wheat in polypropylene bag ($F_{2,4} = 52.1$; $P < 0.01$), metal silo ($F_{2,4} = 116.2$; $P < 0.01$), filter-cake treated wheat in polypropylene bag ($F_{2,4} = 329.7$; $P < 0.01$), Super GrainPro bag ($F_{2,4} = 245.9$; $P < 0.01$), and PICS bag ($F_{2,4} = 303.7$; $P < 0.01$).

Dough development time of wheat flour (baseline = 6.3 min) was not significantly influenced by storage strategy until four months of storage. After six months, it was significantly affected by storage strategies, and it ranged from 4.0 min in the control to 6.1 min in Super GrainPro bag (Table 2). Storage period did not show a significant effect on dough development time in all storage strategies except the control ($F_{2,4} = 16.1$; $P < 0.01$).

The baseline values for dough stability and degree of softening were 6.3 $\pm$ 0.3 min and 63.3 $\pm$ 1.5 Farinogram unit (FU), respectively. No significant effect was observed on both dough stability and degree of softening by storage strategy for the first four months. A significant effect was posed by storage strategy on dough stability and degree of softening after six months of storage (Table 2). Flour from wheat stored in polypropylene bag (control) exhibited significantly lower dough stability and a higher degree of softening after six months compared with the other strategies (Table 2).

Storage period did not pose a significant effect on both dough stability and degree of softening except in the control. Flour from wheat stored in the control was affected by storage period regarding dough stability ($F_{2,4} = 17.2$; $P < 0.01$) and degree of softening ($F_{2,4} = 88.8$; $P < 0.01$).

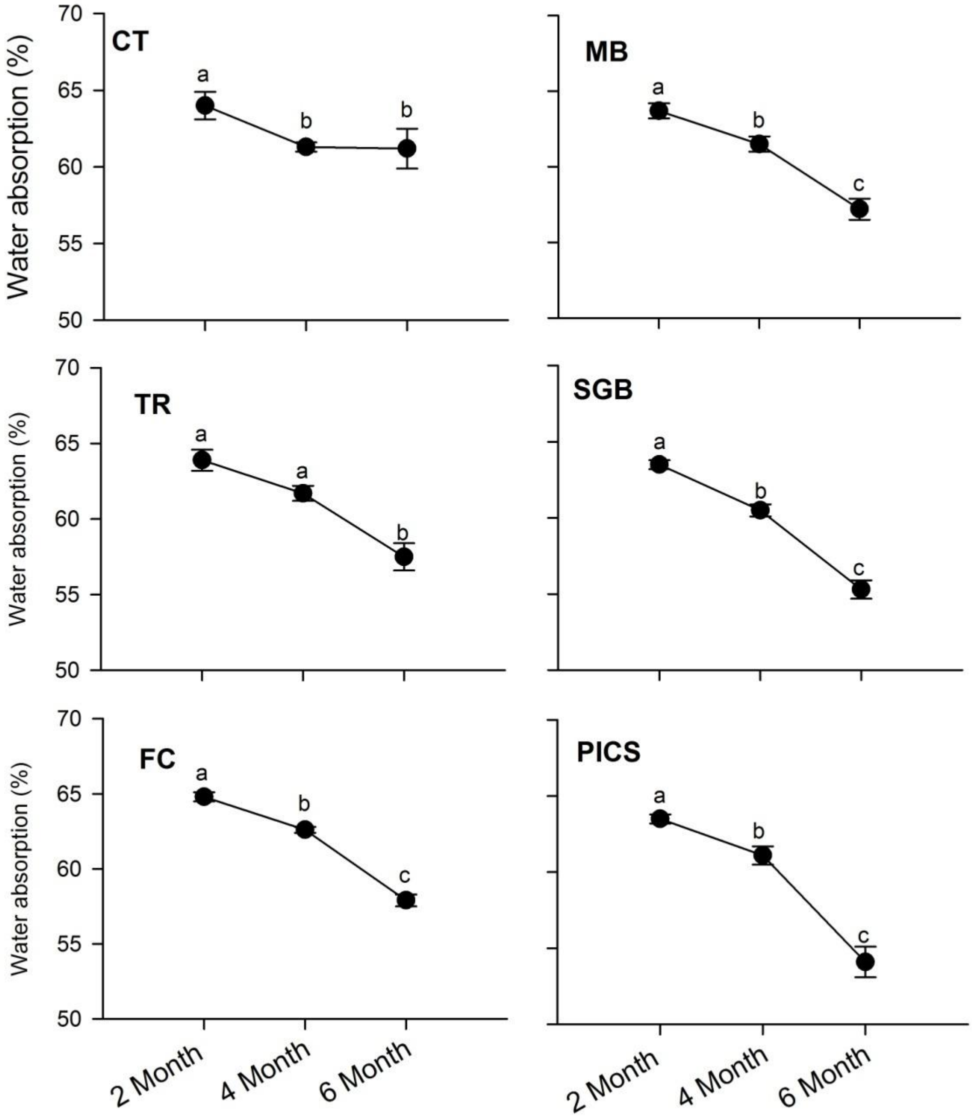

Figure 3. Mean (±SD) of Farinograph water absorption (14% moisture basis) of wheat flour stored for six months under different strategies. CT = Polypropylene bag (control), TR = Triplex in polypropylene bag, FC = Filter-cake in polypropylene bag, MB = Metal silo, SGB = Super GrainPro bag, PICS = Purdue Improved Crop Storage bag, Data are based on three replications. Means followed by the same letter are not significantly different at Tukey's 5% level of significance.

Table 2. Mean (±SD) water absorption, dough development time, dough stability, and degree of softening of flours from wheat grain stored under different strategies[1,2].

Storage strategy by month	Water absorption (%)	Dough Development time (minutes)	Dough Stability (minutes)	Degree of Softening (FU)[3]
Two months				
Polypropylene bag (control)	64.0 ±1.0	6.2 ±0.3	10.2 ±1.0	38.0 ±2.0
Triplex in a polypropylene bag	63.9 ±0.7	5.9 ±0.1	9.2 ±0.4	38.7 ±3.1
Metal silo of 100 kg size	63.7 ±0.5	5.7 ±0.6	9.1 ±0.4	41.7 ±2.1
Filter-cake in a polypropylene bag	64.8 ±0.3	5.6 ±0.6	9.0 ±0.5	42.3 ±2.1
Super GrainPro bag	63.5 ±0.3	6.1 ±0.4	9.9 ±0.5	37.7 ±1.5
PICS bag	63.5 ±0.3	6.1 ±0.4	9.7 ±0.9	41.0 ±4.6
$F_{5,10}$	2.0	0.93	1.5	1.38
P-Value	0.16	0.50	0.28	0.31
Four months				
Polypropylene bag (control)	61.3 ±0.3[bc]	5.5 ±0.6	9.8 ±1.3	37.7 ±5.0
Triplex in a polypropylene bag	61.7 ±0.5[ab]	5.5 ±0.4	9.3 ±0.9	38.7 ±2.3
Metal silo of 100 kg size	61.5 ±0.1[abc]	5.3 ±0.1	10.6 ±0.8	34.0 ±1.4
Filter-cake in a polypropylene bag	62.6 ±0.2[a]	5.5 ±0.4	8.9 ±1.9	40.3 ±4.0
Super GrainPro bag	60.5 ±0.3[c]	5.2 ±0.2	9.2 ±0.5	40.0 ±1.7
PICS bag	61.1 ±0.6[bc]	5.5 ±1.0	9.9 ±2.3	37.7 ±1.5
$F_{5,10}$	8.6	0.22	0.69	1.03
P-Value	<0.01	0.95	0.64	0.45
Six months				
Polypropylene bag (control)	61.2 ±1.3[a]	4.0 ±0.3[b]	5.2 ±0.8[b]	75.7 ±5.5[b]
Triplex in a polypropylene bag	57.5 ±0.9[bc]	5.5 ±0.3[ab]	8.6 ±1.1[a]	41.3 ±2.1[a]
Metal silo of 100 kg size	57.2 ±0.7[bc]	5.7 ±0.8[a]	9.7 ±0.9[a]	45.7 ±6.4[a]
Filter-cake in a polypropylene bag	57.9 ±0.4[b]	5.6 ±0.2[a]	9.4 ±0.4[a]	43.7 ±3.5[a]
Super GrainPro bag	55.3 ±0.6[cd]	6.1 ±0.6[a]	9.1 ±0.6[a]	43.0 ±4.6[a]
PICS bag	54.1 ±1.0[d]	5.5 ±0.3[ab]	8.3 ±1.3[a]	41.3 ±1.5[a]
$F_{5,10}$	30.2	5.6	10.1	28.1
P-Value	<0.01	0.01	<0.01	<0.01

Note: [1]Data are based on three replications; [2]Means followed by the same letter are not significantly different at Tukey's 5 % level of significance; [3]FU = Farinogram Units.

4. Discussion

In smallholder grain production systems of developing countries, storage losses are considered highest among other postharvest steps [23]. Physical and biological factors are the major causes affecting the quality of grains during storage [23], moisture content (mc) or water activity being the primary one [24]. Maintaining dryness of grains that were sufficiently dried before storage is a recommended approach to preserve the initial quality of the product [24]. The initial mc/water activity of wheat grain used in the present study was within the safe range (mc = 10.4; water activity = 0.428), and the grain temperature at the time of loading was 28.5 °C [1].

Changes in water activity in the non-hermetic containers (polypropylene bag, triplex and filter-cake treated wheat) might be attributed to the change in the RH of the storage room, which was influenced by the weather condition. The experiment was carried out during a period of hot and dry weather at the onset (April and May) through the rainy season (June to September). Besides, the high insect activity in the control (polypropylene bag) previously reported by Kalsa et al. [1] might have contributed to the increased water activity of wheat stored in it. The lower water activity of wheat in the airtight containers (Metal silo, PICS, Super GrainPro bag) (Table 1), which was maintained throughout the storage period (Figure 1), was consistent with previous reports [25,26]. Hence the airtight containers satisfy the dry-chain concept introduced by Bradford et al. [24] to preserve the overall postharvest quality of stored grain.

In the present study, the physicochemical properties of wheat stored under different storage strategies for six months were compared. There was a general trend of decline in farinograph water absorption of flour from wheat across storage period regardless of storage strategy. The observed higher water absorption of flour from wheat stored in the control after six months might be attributed to its high level of insect damage. A separate report of the same experiment showed that highest number (134.7 count/kg) of live adults of *Rhyzopertha dominica* and grain damage (14.3%) was observed in wheat from the control (polypropylene bag) after six months [1]. Sanchez-Marinez et al. [8] pointed out that flour from *Rhyzopertha dominica* infested wheat absorbs more water than that without infestation. This increase in water absorption might be attributed to either or both of increased fiber content and starch damage of flour from wheat infested with *Rhyzopertha dominica*. This species generally feeds on endosperm and hence reduces the ratio of the endosperm to bran [9]. Increased level of fiber content in wheat flour [27] and higher starch damage level [28] can be associated with increased farinograph water absorption.

Filter-cake and triplex treated wheat, although not infested with insect even after six months [1], exhibited higher water absorption than that stored in PICS and Super GrainPro bags. The increased water absorption is probably due to the residual filter-cake and triplex powders. Silicon dioxide is a significant component of filter-cake and triplex [29], similar to diatomaceous earth, which was reported to cause increased water absorption in flours treated with it [30].

Furthermore, the reduced dough development time observed in wheat from the control after six months (Table 2) might also be associated with the high insect damage incidence [8].

The farinogrph dough stability and degree of softening values of wheat in the different storage strategies were unchanged until six months of storage except in the control. The weakening of the dough of the wheat from the control (polypropylene bag) may also be attributed to the high infestation with *Rhyzopertha dominica* and the consequent grain damage level [8,9].

The reduction in wet gluten and sedimentation values after six months in wheat from the control can be explained by the high insect infestation level compared to the other strategies [9,31]. However, the reduction in wet gluten and sedimentation values of wheat treated with filter-cake and triplex powders might be associated with the residue of the powders in the wheat flour. This result is in line with the report of Freo et al. [15], who pointed out that wet gluten and gluten index values were diminished due to treatment with diatomaceous earth.

A marked increase in ash content of wheat in the control (polypropylene bag) after six months (Figure 2) might be due to the higher level of damage by *Rhyzopertha dominica* (internal feeder), which reduces the ratio of the endosperm to bran [9]. The increase in ash content of triplex and filter-cake treated wheat across all periods, however, may have resulted from the triplex and filter-cake powders adhered to the grain and hence made their way to the flour. This assumption is supported by the previous report of Freo et al. [15] who indicated that higher ash content was observed in diatomaceous earth treated wheat, which was composed mainly of amorphous silicon dioxide. The triplex and filter-cake powders used in the present study were composed mainly of silicon dioxide and other inorganic compounds [29].

5. Conclusion

The traditional method used in the country to store wheat (polypropylene bag), which had served here as an experimental control, showed the highest degree of deterioration in the physicochemical properties of the grain compared with the other strategies. The airtight storage strategies (metal silo, PICS, and Super GrainPro bags) provided better maintenance of initial physicochemical properties of wheat grains. The application of filter-cake and triplex powders resulted in increased water absorption and ash content apart from demonstrating diminished gluten content and sedimentation values. The use of these powders may pose a negative influence on the baking performance of flour from the treated wheat.

Bag storage of grains is becoming a widespread practice among smallholders because bags are portable, readily available in rural markets, and occupy less space in the house enabling regular monitoring [23]. Hence, the introduction of improved storage technologies should consider the preference of smallholder farmers. Besides, farmers should be convinced of the economic return of investing in such technologies. A study in Tanzania indicated that Super GrainPro and PICS bags are profitable for extended grain storage in areas where seasonal price fluctuation predominates [32]. However, the profitability of investing in a metal silo can depend on the volume of surplus grain to be stored. Metal silos with bigger storage capacity can increase the income of farmers who have bigger surplus grain to sale [32].

Finally, it is essential to investigate a method of removal of the filter-cake and triplex powders before local milling of the treated wheat grains. Removal of the residual powders is essential since the most substantial proportion of wheat grain in Ethiopia is ground using local whole grain mills for the most popular end-use: whole grain bread. Besides, it is necessary to investigate the extent of removal of these powders from treated wheat grains using existing cleaning and tempering operations of commercial mills.

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Conflicts of interest

The authors declare no conflict of interest.

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