31 Effect of Long-Term Storage on Wheat Nutritional and Processing Quality

Nitin Kumar Garg, Chirag Maheshwari, Muzaffar Hasan, Gajra Garg, Vedprakash, and Aruna Tyagi

Abstract

Wheat seeds constitute a key crop and food industry feedstock. A large number of wheat seed storage facilities are designed to mitigate the conflict between continuous food/feed consumption and seasonal wheat production. However, the degradation of grain caused by fluctuation of temperature, insect activity, air humidity, fungal growth, and many other factors is a negative consequence of large-scale grain storage which ultimately affects the grain processing quality. The deterioration of grain nutritional quality under various conditions should be thoroughly understood to minimize the economic and quality loss during storage. Several factors have been involved in the degradation of grains during storage. Temperature rise caused by grain cell respiration and solar radiation creates a conducive environment for insect growth which ultimately affects grain seed structure and accelerates deterioration. Along with this, humidity rise during storage helps in fungus growth which harms and depletes the nutritive value of grains. The chapter thoroughly addresses the effects of long-term storage and its impact on grain nutritional and processing quality.

N. K. Garg (✉) · Vedprakash
Sri Karan Narendra Agriculture University, Jobner, India

C. Maheshwari · M. Hasan
ICAR-Central Institute of Agricultural Engineering, Bhopal, India

G. Garg
Mahatma Jyoti Rao Phoole University, Jaipur, India

A. Tyagi
ICAR-Indian Agricultural Research Institute, New Delhi, India

P. L. Kashyap et al. (eds.), *New Horizons in Wheat and Barley Research*,
https://doi.org/10.1007/978-981-16-4449-8_31

Keywords

Wheat · Protein · Sedimentation · Vitamins · Tocopherol · Gluten · Hectoliter weight

31.1 Introduction

Cereals are cultivated as a staple food around the world. The world's leading cereal grains are wheat, maize, rice, barley, and oats. Wheat accounts for more than 50% of total cereals production worldwide and is one of the major crop from the point of economy, due to its increased use. The production of wheat is projected 100 million metric tonnes (MMT) in the 2019 MY (marketing year), according to USD Agricultural Science (Singh and Mark 2019). Because of its various applications in processed food products, wheat is the main cereal grain. Aspects such as gluten content, rheological factors, etc. are responsible for its extensive consumption.

Due to the new agricultural inputs and technology, the wheat production is constantly expanding. The safety of stored grain throughout the year is a genuine concern in the world in order to acquire and maintain high-quality grains supply. The explanation for this is a deterioration of nutrients because of prolonged and unsuitable storage from the field until the last use (Manandhar et al. 2018). The annual deterioration in the developing countries is almost 65% after total production in the handling and post-crop process due to budgetary, administrative, and advanced technical constraints. Thus, looking into the losses over the year due to bad agricultural and storage practices, it is mandatory to identify the potential storage problems and to minimize the nutritional losses of wheat. The central point of interest is to safeguard the wheat stock after harvest as it can easily get attacked by various contaminants under certain conditions. The quality wheat that is desirable for consumption must be rich in nutrients like minerals, vitamins, and dietary fibres and also free from microbes and various other contaminants. Importantly, the principal factors influencing the quality of wheat during storage are humidity, moisture, and temperature. It should be emphasized that other health-promoting factors, viz. proteins, carbohydrates, vitamins, and minerals, of wheat grain are also affected due to poor storage condition. Numerous reports have reported the considerable nutrient loss in wheat during storage (Malaker et al. 2008; Hasan Ahmed 2015; Badawi et al. 2017; El-Sisy et al. 2019). It has been confirmed by the chemical investigation that undesirable taste and off smells which makes the grain unsuitable for use are the result of those insects, pest, and other storage factors.

Unsatisfactory storage system leads to the high moisture content in wheat stock and hence promoting the fungal attack that directly deteriorate the quality of grain (Chattha et al. 2015). Contamination of wheat stock by fungal strains during storage could also be the potential cause for great losses in grain quality and further hazard to human health (Schmidt et al. 2016). During storage, wheat grain quality is affected by biological (vertebrate, arthropod, and micro-flora), physical (temperature and humidity) and storage conditions, methods, and duration leading to substantial qualitative and quantitative losses in physicochemical and organoleptic changes. These facts obliged us to look into the parameters affected by long wheat storage. In addition, potential storage solutions need to be established to avoid losses both in quality and in quantity. This chapter will involve the overall compilation of data or profiling of several parameters that affect the wheat quality during the storage.

31.2 Nutritional Facts of Wheat

Wheat grain has nutritional importance in terms of its use in food consumption. Concerning to the nourishing part, it has almost all kind of bioactive compounds. According to Kumar et al. (2011) wheat is considered as health-building food due to rich source of protein, vitamins, minerals, and dietary fibres (Table 31.1). The recent study conducted by MH Mughal (2019) described the nutritional content of wheat. On the basis of dry weight basis, wheat contains about 10.8% of water and 20% of calories. It contains crude protein (26.50%), proteins (26–35%), crude fat (8.56%), lipids (10–15%), dietary fibres (1.5–4.5%), sugars (17%), minerals (4%), and ash content (4.18%). Additionally, it contains tocopherols, phytosterols, carotenoids, riboflavin and thiamine. Wheat grains are profoundly rich in essential amino acids, viz. lysine, leucine, isoleucine, valine, methionine, threonine, and aromatic amino acids like phenyl alanine and tryptophan.

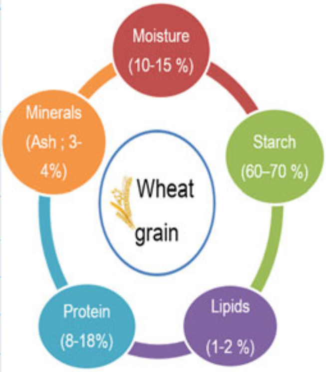
31.3 Effect of Storage on Nutritional Quality

Storage of foods are used as a precondition for ensuring food supply availability by man since the beginning of history. Storage conditions contribute to chemical changes influencing food's nutritional value. Vitamins are more susceptible than minerals and somewhere in them are amino acids. However, the correct storage conditions have a beneficial impact on the preservation of the original food nutrient content and also increase the supply of some nutrients and overall product quality. Figure 31.1 highlighted the effect of long-term storage on nutritional and processing quality of wheat grains.

Table 31.1 Nutrient content of wheat grains

Biomolecules	Content (%)
Protein	14.4
Fat	2.3
Crude fibre	2.9
Ash	1.9
Starch	64
Total dietary fibre	12.1
Total phenol (mg/100 g)	20.5

Nutritional quality	Effects
Protein	↓ crude protein ↓ functionality of protein ↓ lysine
Gluten Index	↓
Wet gluten	↓
Dry gluten	↓
Carbohydrate	↓
Fatty acids	↑↓
Vitamins	↓
Enzymatic activity	↓ (10°C), ↑ (45°C)



Processing quality	Effects
Hectoliter weight	↓
Thousands grain weight	↓
Sedimentation values	↓
Falling Number	↓
Flour Colour	↓
Ash content	↓
Hardness (%)	↓

Fig. 31.1 Effect of long-term storage on nutritional and processing quality (up arrow shows increase, and down arrow shows decrease in various parameters)

31.3.1 Effect on Protein Quality

Gluten (about 85%) is the principal protein ingredient for wheat, offering excellent elasticity and extensibility in dough. This feature makes wheat special amongst other grain crops. Gluten mainly composed of gliadin and glutenin. Both composition of gluten influnces the viscoelastic property of gluten which is used in various baking products. Storage of wheat on high temperature, i.e. more than 30 °C, leads to the degradation of protein content and therefore restraining the functionality of gluten. During wheat grain storage, the decrease in wheat gluten proteins can be explained by lower levels of wet gluten, sedimentation (Sisman and Ergin 2011; Kibar 2015), and decreased stability of farinographs (Lukow et al. 1995). However, the initial 2-month storage period indicates increased sedimentation and gluten content while subsequent decreases in over 6-month storage. Mhiko (2012) reported that the protein contents decreased to 10.8% after long storage, whereas initial protein content was 12.6% before storage. After prolonged storage, lysine which is central to human diets and fall in category of essential amino acid was significantly reduced. Mughal (2019) reported the lysine content in around 10.26 g/100 g, which started to decrease in relation to fresh stock after inappropriate storage and tends to decrease with more annual storage. In addition to long storage and high temperatures, insect infestation also played a negative role in protein content aspects (Jood et al. 1996). During storage raw protein is the highly sensitive parameter to storage duration. Crude protein content dropped to 11.37% during storage from the initial value of 13.48% (Polat 2013).

31.3.2 Effect on Gluten Index

Gluten index is defined by gluten elasticity test (Raugel et al. 1999), and it is influenced by the length and the temperature of the wheat flour storage. It is necessary to determine the gluten content for the evaluation of the quality of the wheat flour. The gluten content also plays an important role to deciding the purpose of baking because low-, medium-, and high-gluten content are intended for cookies and biscuits, cakes, and bread, respectively. If the gluten index is high, the gluten percentage released by the sieve is low, which is a strong indicator of gluten quality. The ageing of the flour induced a gradual decrease in the gluten index so that the gluten content remained intact for 8 weeks, while the flour was refrigerated. A high gluten index above 95% indicates strong gluten, while indices below 60% indicate that meal is too weak for production of bread (Violeta and Georgeta 2010).

31.3.3 Effect on Wet Gluten Content

Intensity of the gluten is one of the main characteristics defining between the quality parameters of wheat flour and commercial use of flour for bread, cookies, and pasta. The wet gluten content was influenced by relative humidity and storage temperature. The wet gluten content is decreased after long-term storage. After 8 weeks of storage, Jennifer (2013) reported that the amount of wet gluten decreased from 39.5% to 38.1%. Gluten protein becomes less elastic and brittle for more than 2 weeks in storage at higher temperatures, thereby reducing gluten consistence with a high temperature (>35 °C). Another similar study reported the reduction in wet gluten from 30.22% to 25.45% after 180 days of storage (Karaoglu et al. 2010).

31.3.4 Effect on Dry Gluten Content

For all storage conditions, the improvement of dry gluten was the same as for wet gluten. Wet gluten is colloidal and contains 60–70% water and 75–90% dry protein (gliadins and glutenins), and with high inflammatory properties, the ability to bind water is the difference between moist and dry gluten (Karaoglu et al. 2010). Over the maximum storage period, dry gluten decreased from 11.40% in the beginning to 9.73% after 6 months of storage at the end (Karaoglu et al. 2010).

31.3.5 Effect on Carbohydrates

Carbohydrate is the essential macromolecule that gives the grain membrane integrity during dehydration. In general, wheat grains are stored at a temperature of 25 °C which increases the concentration of soluble sugar. The decrease of soluble sugars was observed when stored at higher temperature because of non-enzymatic browning response (Maillard reaction). In endosperm or the meal part of the kernel, the main carbohydrate is starch. If the seed is stored for a long time, the content of starch is reduced by 67.59% after 180 days of storage. Previous studies also reported decreases in carbohydrates during the extended wheat storage (Rehman et al. 2011; Chattha et al. 2015). After 8-year of storage (Pixton and Hill 1967), the total sugars have been significantly decreased, but very less change was observed in the value of maltose and sucrose.

31.3.6 Effect on Fatty Acid

Fatty acids (FA) are closely correlated with nature of the grain. Fatty acid content varies with seed variety and storage time. Tian et al. (2019a, b) stated that the FA content gradually increased in early storage of wheat and then rapidly increased during the 240–270 days of storage. Fatty acid content and titrant grain acidity during storage are most likely to increase due to lipase hydrolysis (Karaoglu et al. 2010; Pixton et al. 1975). Pomeranz (1992) reported that in wheat grains, biological order protects lipids against lipases and other enzymes, which reduce oxidation and hydrolysis while being stored. However, a linear increase in grain fatty acidity during storage of 15 months was found by Lukow et al. (1995). The total titrable acidity of wheat grains during storage were also substantially increased over 9 months and 16 years (Pixton et al. 1975). Rehman and Shah (1999) reported the titrable acidity of the wheat grain during storage at two different temperatures (25° and 45 °C) increased substantially over a period of 6 months but not 10 °C. It is presumed that hydrolysis of lipids by lipase enzyme responsible for substantial rise in fatty acids content mainly occurs in germ and aleurone layers.

31.3.7 Effect on Vitamins

Naturally, wheat grain is a superior source of vitamins. Extensive temperatures, improper handling, and undesired storage conditions cause loss of thiamine to various extents. Several researchers found thiamine as an important factor of health-promoting activities (Shewry and Hey 2015). Effect of long storage on the quality of wheat and its flour was detected by El-Sisy et al. (2019) and reported that the content of vitamin varied significantly with the source of wheat. Rehman (2006) reported that in 6 months of storage of wheat grain, the content of thiamine decreased by 21.4 and 29.5% at 25 and 45°, respectively. No major nutritional quality changes were observed when cereal grains were being stored at 10 °C.

31.3.8 Effect on Enzymatic Activity

Amylase is the lead enzyme that quick hydrolyses starch, i.e. the grain food storage reserves in the endosperm of the wheat seeds during seed germination. It forms glucose fragments known as maltodextrins (Shewry 2009). Long storage and varying temperatures minimise the activity of the enzyme to different degrees. However, a slow decrease in activity was observed at 10 °C, while a higher decrease was observed at 45 °C (Rehman 2006).

31.4 Effect of Storage on Processing Quality

After harvest, wheat grain is slowly but constantly changing its composition and its physical and biochemical characteristics, its durability, and its nutritional and processing consistency, during storage. The storage of wheat grain after harvest affects various parameters of processed quality such as flour milling, hectolitre weight, sedimentation, falling numbers, flour colour, and taste.

31.4.1 Effect on Flour Milling

Wheat grain storage had little effect on experimental milling properties and flour attributes. Baik and Donelson (2018) reported that flour milling yield potential of wheat grain for the first 4 weeks of storage showed evident fluctuations while remained constant for 26 weeks. Wheat grains storage at 50 °C for 5 months affected the milling yield (Srivastava and Rao 1994). Another at 25 °C for 15 months, flour production analysis showed a slight reduction in flour yield of stored grain (Lukow et al. 1995).

31.4.2 Effect on Hectoliter Weight

A quality metric and an estimated measure of the flour yield is hectoliter weight. If the hectoliter weight of wheat seeds is higher, the yield and quality of flour will be increased (Karaoglu et al. 2010). For wheat during storage, hectoliter weight decreased. This decrease attributed to difference in moisture during storage (gain or loss). Karaoglu et al. (2010) reported that during storage, hectoliter weight variations were mainly linked to the grain moisture content. Decrease in grain density during the storage period is major reason for the reduction in the hectoliter weight. Strelec et al. (2010) also reported that the hectoliter weight was decreased after 360 days of storage. In case of 180 days storage period, hectoliter weight reduced by 80.86 to 75.51 kg hL^{-1}.

31.4.3 Effect on Thousand Grain Weight

The milling industry uses the 1000-grain weight to determine the possible yield of flour for stored wheat grain (Boz et al. 2012). The weight of 1000 kernels of wheat steadily declined as the storage time increased. Thakor et al. (2012) also reported a decrease in 1000 grain weight with storage time for paddy. A decrease in the 1000 grain weight of harvested barley grains during storage in different moisture conditions was reported by De Tunes et al. (2010). With increase in the storage duration 0 to 180 days, difference of 1000 grains with storage time decreased from 35.74 g to 28.97 g. There is a significant difference in the 1000 grains weight with increasing storage duration.

31.4.4 Effect on the Sedimentation Values

The sedimentation test is used as an easy way to estimate the baking consistency of the wheat flour. Sedimentation test is based on the interaction between the intensity of flour baking and the ability of gluten hydration that depends on gluten quantity and quality (Karaoglu et al. 2010). The amount of sedimentation decreases during long-term storage (Srivastava and Rao 1994; Lukow et al. 1995; Hruskova et al. 2004).

Wheat grain storage for 26 weeks showed a slight decrease in the sedimentation volume of flour. The sedimentation of flour decreased, from 23.0 mL and 19.5 mL to 22.5 and 18.5 mL, respectively, immediately after the harvest (Baik and Donelson 2018). Wheat grains stored for 6 months was reported with gradual decreases in sedimentation volume (Sisman and Ergin 2011; Karaoglu et al. 2010). The sedimentation volume during storage for 15 months declined only marginally but steadily (Lukow et al. 1995). The sedimentation rates of wet gluten and dry wheat gluten content were increased during the storage of the first 2 months in galvanised steel silos, followed by decreases with prolonged storage up to 6 months (Kibar 2015). The decline in sedimentation values can partly be attributed to concomitant protein reduction due to increased proteolytic activity (Mhiko 2012; Kibar 2015) and increased soluble protein-protein interaction during storage.

31.4.5 Effect on Falling Number

The falling number (FN) reflects a measure of α-amylase activity and the degree to which enzyme activity in the kernel has led the starch breakdown (Karaoglu et al. 2010). During the storage period, the quality parameter that is strongly affected is the falling number. Falling number increased between each assessment period, but the magnitude of the increase depended on the storage conditions. An additional substantial change occurring during storage is recorded in FN increases, a measure of the pre-harvest sprouting, and largely influenced by α-amylase activity (Karaoglu et al. 2010; Kibar 2015). The falling number was clearly affected by the temperature. This is in line with previous studies showing a rise in the falling number of storage periods (Srivastava and Rao 1994; Karaoglu et al. 2010; Gonzalez-Torralba et al. 2013).

At elevated temperatures after several months of storage, the activity of α-amylase decreases considerably. This can have a negative impact on the bread making process, because low amylase activities may make the fermentation process slow. Baik and Donelson (2018) recorded a substantial increase in falling number during wheat grain storage. After 2 weeks of storage, the FNs were 262 and 258, increased to 335 and 303 in 21 weeks and then to 334 and 307, respectively, at 26 weeks in Milton and Terral TV 8861, respectively, indicating substantial increases in the first 21 weeks of storage. Karaoglu et al. (2010) also documented the influences of storage temperature and time on increases in FN of wheat grain. Lukow et al. (1995) reported a steady rise for 15 months during storage in atmospheric conditions in the grain FN of two hard red spring wheat varieties. The increase in FN of bread-wheat grains in storage from 350 to more than 400 was recorded with a substantial increase at 30° over 15 °C. It is expected that during storage of wheat grains, the FN rises because of α-amylase activity reduces (Ji and Baik 2016; Rehman and Shah 1999) and starch gelatinization characteristics changes (Lukow et al. 1995). Brandolini et al. (2010) observed negative correlation between α-amylase and the falling number of meals of both einkorn and bread wheat during storage for 374 days, at 30 ° C and 38 ° C. Srivastava and Rao (1994) also reported a negative correlation between α-amylase activity and falling number and amylograph peak viscosity. It is apparent that postharvest storage time needs to be considered to produce consistent test results for wheat grain FN.

31.4.6 Effect on Flour Colour

The colour of the flour has been heavily affected by storage times. The degradation of the colour is the result of the flour oxidation and the presence of environmental oxygen and enzymes due to the high temperature and time of storage. If the endosperm was easier to extract from the bran during milling, a small colour number obtained a higher yield.

31.4.7 Effect on the Oil Tocopherol Concentration

The wheat germ accounts for 2–3% of all wheat, and it contains 8–14% of the oil (Sonntag 1979; Pomeranz 1988). It is an industrial wheat milling sub-product which is broken off from endosperm and used primarily as a forage and as a source of oil. It is a valuable commodity for its medicinal and nutritive properties (Zacchi et al. 2006; Eisenmenger and Dunford 2008). Wheat germ oil has been well-known to have positive health impacts and mainly contains linoleic acid (omega 6 between 44 and 65%) and linolenic (omega 3, 4–11%) because of its high vitamin E and polyunsaturated fatty acids (omega3) (Wang and Johnson 2001; Megahad and El Kinawy 2002). Tocopherols protect vegetable oils against oxidation and carry out essential biological activities such as vitamin E. The high level of polyunsaturated fatty acids however makes the oil extremely oxidised. Therefore, it can be transformed, which can influence both its nutritional and organoleptic properties. The optimum retention of tocopherols during germ processing and storage would minimise oxidation processes in oil that are rich in polyunsaturated fatty acids (Wang and Johnson 2001).

Capitani et al. (2011) observed low concentration of total tocopherol in oil accompanying with rise in storage temperature of the wheat germ and as the storage time elapsed, the total concentration of tocopherol decreased. In perspective to biological property, the concentration of α-tocopherol which exhibits highest vitamin E activity and the concentration of γ-tocopherol which exhibits strong antioxidant activity primarily affect the oil quality and stability, respectively (Burton and Ingold 1981). In addition, β-tocopherol concentration in wheat germ oil was affected by both the storage temperature and time. The concentration of total tocopherols in oil significantly decreased during the storage of the wheat germ.

31.4.8 Effect on Ash Content

The ash content of the flour sample stored at room temperature decreased compared to the ash content stored at room temperature under air conditioning. That means that under room temperature, due to oxidation of lipids, flour storage is bleached by the high temperature. The ash content is therefore lower in value.

31.4.9 Effect on Hardness (%)

The hardness percentage decreased with increase in storage time. It was observed that wheat hardness (percentage) was significantly affected by storage periods ($P < 0.05$). Nizamani et al. (2019) reported that maximum hardness was observed in seeds stored for 3 months (10.55%). Minimum hardness (10.28%) was, however, noted in seeds preserved for 6 months.

31.5 Summary

Wheat (*Triticum aestivum L.*) is one of the world's most popular crops for agriculture and plays an important role in the diet of humans. Significant amounts of postharvest wheat are preserved for 3 to 5 years in granaries, but wheat seeds are aged and destroyed, like other species (Kirkwood and Melov 2011). The quality of wheat seeds naturally deteriorates during storage, which adversely impacts the quality of processing and the taste of flour (Varzakas 2016). In recent years, therefore the quality degradation of wheat during storage has received increased attention. There are declines in both nutritional and processing efficiency during long-term storage. The storage conditions therefore need to be improved to ensure the availability of grains with most of their nutrients intact after storage with enhanced nutrients.

References

Ahmed MSH (2015) Effect of storage temperature and periods on some characteristics of wheat flour quality. Food Sci Nutr 6:1148–1159

Badawi MA, Seadh SE, Abido WAE, Hasan RM (2017) Effect of storage treatments on wheat storage. Int J Adv Res Biol Sci 4(1):78–91

Baik BK, Donelson T (2018) Postharvest and postmilling changes in wheat grain and flour quality characteristics. Cereal Chem 95(1):141–148

Boz H, Gerçelaslan KE, Karaoglu MM, Kotancilar HG (2012) Differences in some physical and chemical properties of wheat grains from different parts within the spike. Turk J Agric For 36: 309–316

Brandolini A, Hidalgo A, Plizzari L (2010) Storage-induced changes in einkorn (*Triticum monococcum* L.) and bread wheat (Triticum aestivum L. ssp. aestivum) flours. J Cereal Sci 51:205–212

Burton GH, Ingold KU (1981) Autoxidation of biological molecules. 1. The antioxidant activity of vitamin E and related chain reaction of unsaturated lipids. Food Chem 9:21–25

Capitani M, Mateo CM, Nolasco SM (2011) Effect of temperature and storage time of wheat germ on the oil tocopherol concentration. Braz J Chem Engi 28(2):243–250

Chattha SH, Hasfalina CM, Mahadi MR, Mirani BN, Lee TS (2015) Quality change of wheat grain during storage in a ferrocement bin. ARPN J Agric Biol Sci 10(8)

De Tunes LM, Barros ACSA, Badinelli PG, Garcia DC (2010) Storability of seeds of barley harvested in different periods. Biosci J 26:403–412

Eisenmenger M, Dunford NT (2008) Bioactive components of commercial and supercritical carbon dioxide processed wheat germ oil. J Am Oil Chemists Soc 85(1):55–61

El-Sisy TT, Abd El Fadel MG, Gad SS, El-Shibiny AA, Emara MF (2019) Effect of handling, milling process and storage on the quality of wheat and flour in Egypt: rheological properties of wheat kernals and their flours. Acta Scienti Microbiol 2(10)

Gonzalez-Torralba J, Arazuri S, Jaren C, Arregui LM (2013) Influence of temperature and r.h. during storage on wheat bread making quality. J Stored Products Res 55:134–144

Hruskova M, Skodova V, Blazek J (2004) Wheat sedimentation values and falling number. Czech J Food Sci 22:51–57

Jennifer SJ (2013) Changes in physico-chemical characteristics of wheat flour during storage and the effects on baking quality. J Sci Food Agric 210(2):412–420

Ji T, Baik BK (2016) Storage conditions affecting increase in falling number of soft red winter wheat grain and the impact on a-amylase activity. Cereal Chem 93:263–267

Jood S, Kapoor AC, Singh R (1996) Chemical composition of cereal grains as affected by storage and insect infestation. Trop Agric 73:161–164

Karaoglu MM, Aydeniz M, Kotancilar HG, Gerçelaslan KE (2010) A comparison of the functional characteristics of wheat stored as grain with wheat stored in spike form. Int J Food Sci Technol 45:38–47

Kibar H (2015) Influence of storage conditions on the quality properties of wheat varieties. J Stored Products Res 62:8–15

Kirkwood TB, Melov S (2011) On the programmed/non-programmed nature of ageing within the life history. Curr Biol 21:701–707

Kumar P, Yadav RK, Gollen B, Kumar S, Verma RK, Yadav S (2011) Nutritional contents and medicinal properties of wheat: a review. Life Sci and Medicine Res 22

Lukow OM, White NDG, Sinha RN (1995) Influence of ambient storage conditions on the breadmaking quality of two hard red spring wheats. J Stored Products Res 31:279–289

Malaker PK, Mian IH, Bhuiyan KA, Akanda AM, Reza MMA (2008) Effect of storage containers and time on seed quality of wheat. Bangladesh J Agril Res 33(3):469–477

Manandhar A, Milindi P, Shah A (2018) An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. Agriculture 8:57

Megahad OA, El Kinawy OS (2002) Studies on the extraction of wheat germ oil by commercial hexane. Grasas Aceites 53(4):414–418

Mhiko TA (2012) Determination of the causes and the effects of storage conditions on the quality of silo stored wheat (Triticum aestivum) in Zimbabwe. Nat Prod Bioprospect 2:21–28

Mughal MH (2019) Wheat compounds—a comprehensive review. Integr Food Nutr Metab 6:1–6

Nizamani MM, Nizamani FG, Rind RA, Khokhar AA (2019) Assessment of genetic variability and heritability estimates in F2 populations of bread wheat (Triticum aestivum L.). Discov Agri 5:177–188

Pixton SW, Hill ST (1967) Long-term storage of wheat-II. J Sci Fd Agric 18:94–98

Pixton SW, Warburton S, Hill ST (1975) Long-term storage of wheat—III: Some changes in the quality of wheat observed during 16 years of storage. J Stored Prod Res 11:177–185

Polat HE (2013) Integration the effects of different storage types on nutritional quality characteristics of some feedstuffs. J Food Agric Environ 11:897–903

Pomeranz Y (1988) Chemical composition of kernel structures. In: Wheat: chemistry and technology, vol I, 3rd edn, pp 97–158

Pomeranz Y (1992) Biochemical, functional, and nutritive changes during storage. In: Sauer DB (ed) Storage of cereal grains and their products, 4th edn. AACC International, St. Paul, MN, pp 55–141

Raugel PJ, Robertson PO, David CT (1999) Perten instruments. In: Rapid food analysis and hygiene monitoring. Springer, Berlin Heidelberg, pp 439–455

Rehman A, Sultana KN, Minhas M, Gulfraz G, Raja K, Anwar Z (2011) Study of most prevalent wheat seed-borne mycoflora and its effect on seed nutritional value. Afr J Microbiol Res 5: 4328–4337

Rehman ZU (2006) Storage effects on nutritional quality of commonly consumed cereals. Food Chem 95:53–57

Rehman ZU, Shah WH (1999) Biochemical changes in wheat during storage at three temperatures. Plant Foods Human Nutr 54:109–117

Schmidt M, Horstmann S, Colli LD, Danaher M, Speer K, Zannini E, Arendt EK (2016) Impact of fungal contamination of wheat on grain quality criteria. J Cereal Sci 69:95–103

Shewry PR (2009) Wheat. J Exp Bot 60(6):1537–1553

Shewry PR, Hey SJ (2015) The contribution of wheat to human diet and health. Food and Energy Security 4(3):178–202

Singh SK, Mark W (2019) USDA Foreign Agricultural service GAIN (Global Agricultural Information Network) report Grains and Feed Annual 2019. GAIN Report Number: IN9025

Sisman CB, Ergin AS (2011) The effects of different storage buildings on wheat quality. J Appl Sci 11:2613–2619

Sonntag NOV (1979) Composition and characteristics of individual fats and oils. In: Bailey's industrial oil and fat products, vol 1, pp 289–477

Srivastava AK, Rao PH (1994) Changes in the functional characteristics of wheat during high temperature storage. J Food Sci Technol 31:36–39

Strelec I, Popovic R, Ivanisic I, Jurkovic V, Jurkovic Z, Ugarcic-Hardi Z, Sabo M (2010) Influence of temperature and relative humidity on grain moisture, germination and vigour of three wheat cultivars during one year storage. Poljoprivreda 16:20–24

Thakor NJ, Patil SC, Sawant AA, Sawant SD (2012) Influence of storage period on physical properties and quality of paddy stored in GIC silo and bag storage under humid konkan climatic conditions. J Agric Eng 49:43–47

Tian PP, Lv YY, Yuan WJ, Zhang SB, Hu YS (2019a) Effect of artificial aging on wheat quality deterioration during storage. J Stored Prod Res 80:50–56

Tian S, Sun Y, Chen Z, Yang Y, Wang Y (2019b) Functional properties of polyphenols in grains and effects of physicochemical processing on polyphenols. J Food Qual:1–8

Varzakas T (2016) Quality and safety aspects of cereals (wheat) and their products. Crit Rev Food Sci Nutr 56:15

Violeta IC, Georgeta SP (2010) Comparative evaluation of wet gluten quantity and quality through different methods, The Annals of the University Dunarea de Jos of Galati, Fascicle. Food Technol 34(2):231–239

Wang T, Johnson LA (2001) Refining high-free fatty acid wheat germ oil. J Am Oil Chem Soc 78(1):71–76

Zacchi P, Daghero J, Jaeger P, Eggers R (2006) Extraction/fractionation and deacidification of wheat germ oil using supercritical carbon dioxide. Braz J Chem Engi 23(1):105–110