

INFLUENCE OF TEMPERATURE AND RELATIVE HUMIDITY ON GRAIN MOISTURE, GERMINATION AND VIGOUR OF THREE WHEAT CULTIVARS DURING ONE YEAR STORAGE

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SUMMARY

Changes in grain moisture, germination and vigour of three wheat cultivars packed in paper bags and stored for one year under four different conditions of environmental temperature and relative humidity (RH) were investigated. During the first ninety days of storage significant reduction in grain moisture content of 4, 2.5 and 0.9 %, respectively, under 40 °C, 25 °C and 4 °C and RH of 45 % occurred. Subsequently grain moisture remained constant until the end of storage. Seeds of examined cultivars lost their germination ability and vigour only under elevated storage temperatures. Germination and vigour loss after one year of storage differed between cultivars being higher for seeds kept under 40°C, RH = 45 % (35-85 % and 55-94 %, respectively), than under 25°C, RH = 45 % (10-20 % and 15-22 %, respectively). Obtained data indicate significant influence of storage conditions on moisture content, germination and vigour changes during storage of wheat seeds, as well as varietal dependence of seed viability.

Key-words: grain moisture, germination, relative humidity, temperature, vigour, wheat

INTRODUCTION

Environmental temperature and relative humidity are two most important factors influencing seed viability and longevity during the storage. Interdependence of these two factors during seed storage and their subsequent effect on grain moisture has been recognized by Harrington who suggested the three "rules of thumbs" regarding optimal seed storage. The first one which can be applied to seeds with grain moisture from 5 to 14 % states that each 1 % reduction of seed moisture doubles the storage life of the seeds; the second one states that for each 10 °F (5.6 °C) decrease in seed storage temperature storage life of seed is doubled; and the third one states that arithmetic sum of relative humidity and storage temperature should not exceed 100 for safe seed storage, or 120 as later reported (Bewley and Black, 1985; Copeland and McDonald, 1999; Harrington, 1973).

Temperatures below 21 °C and relative humidity values no higher than 60 % or 70 % for seeds kept at 4 °C should be used in implementation of these rules for long-term storage of crops, including wheat seeds, from 3 to 10 years. However, if the purpose of seed storage is to preserve planting stocks from one season to the next, implementations of suggested temperatures and humidity values for seed producers are impractical due to substantial costs regarding installation and maintenance of refrigeration and dehumidification equipment. Therefore, crop seeds and among them wheat, are in most cases stored under

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normal warehouse conditions. Since normal warehouse conditions fluctuate dependent on the season of the year, seeds in storage are exposed to low temperatures and humidity during winter, moderate temperatures and humidity during spring and autumn, and elevated during summer. Under such conditions seeds kept in cloths or paper bags temperate and easily exchange moisture with environmental air of defined relative humidity and temperature depending on species (Copeland and McDonald, 1999; Volenik et al., 2006). If moisture equilibration between seeds and environmental air result in an increase in seed moisture, deteriorative process increases with concomitant temperature within seeds speeds up, consequently leading to germination and vigour decrease.

Seed deterioration physiology and dynamics of seed mortality during storage have been reviewed by a number of authors (Bernal-Lugo and Leopold, 1998; Bewley and Black, 1985; Copeland and McDonald, 1999; McDonald, 1999; Walters, 1998). However, much less is known influence of storage temperature and relative humidity on possible differences in germination and vigour between wheat cultivars. Therefore, the aim of this study was to monitor changes in grain moisture, germination and vigour of three wheat cultivar seeds packed in paper bags and stored at four different storage conditions.

MATERIAL AND METHODS

Seeds of wheat cultivars Žitarka and Srpanjka harvested in 2005 were generously supplied by Agricultural Institute in Osijek, and Divana cultivar by Visoko gospodarsko učilište, Križevci. Seeds of examined cultivars containing 13.7 % of moisture, were divided in batches (4 ageing conditions x 12 months; 1 kg of seed per batch), packed in paper bags, bags sealed, and storage of wheat seeds was done at four different conditions of environmental temperature and relative humidity (% RH): (1) 40 °C, RH = 45 %; (2) 25 °C, RH = 45 %; (3) 4 °C, RH = 45 %; (4) the range of warehouse conditions on the basis of local environmental conditions, varying from 2 to 25 °C and RH = 40-74 %. Storage was carried out in thermostatic incubator Heraeus (Heraeus, Germany) (1), in a storage box placed in conditioned warehouse (2), in a refrigerator (3), and on a shelf positioned 20 cm from the floor of unconditioned warehouse (4). Relative humidity of 45 % during storage was adjusted using saturated solutions of calcium chloride or potassium nitrite (Copeland and McDonald, 1999). Samples were taken monthly over a period of 12 months and moisture content, germination and seed vigour were examined.

Grain moisture was measured in whole grains by Near Infrared Transmission (NIT) using Foss Tecator 1241 Grain Analyzer.

Seed vigour and germination of examined cultivars were determined by the standard method of examination according to The Ministry of Agriculture, Forestry and

Water Management of the Republic of Croatia (Narodne Novine, 04/2005). Filter paper was used as a sprouting base. Seed vigour was determined 4, and germination 7 days after germination test has been done.

Temporal changes in grain moisture content, seed vigour and germination at various conditions of temperature and relative humidity were analysed by Friedman ANOVA and Kendall coefficient of concordance, while differences among cultivars in viability curves at the same storage conditions were examined by Wilcoxon t-test ($p < 0.05$) using statistical software Statistica (Stat Soft Inc., USA).

RESULTS AND DISCUSSION

Hygroscopic nature of seeds allows them to maintain equilibrium moisture content with any given relative humidity of storage air, which may lead to decrease or increase in initial seed moisture content during seed storage until equilibrium has been reached. During the first 90 days of wheat seeds storage moisture equilibration between grains and storage air occurred as shown in Figure 1.

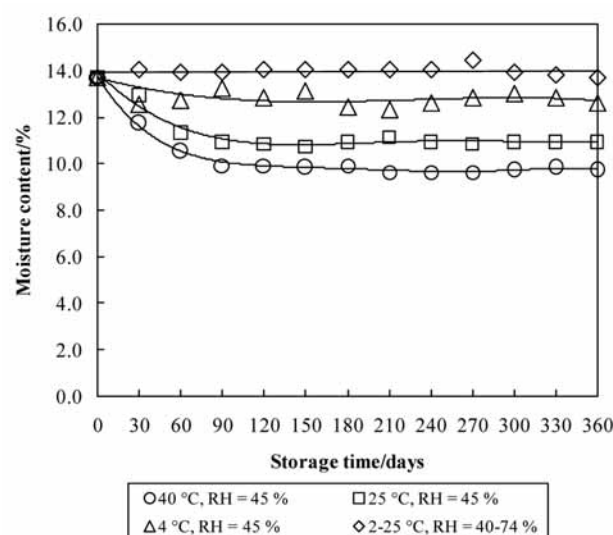


Figure 1. Grain moisture change of Divana wheat cultivar during storage at different temperatures and relative humidity values

Slika 1. Promjene vlažnosti zrna sorte Divana tijekom skladištenja pri različitim uvjetima temperature i relativne vlažnosti zraka

Grain moisture of examined cultivars decreased: (i) from 3.7 to 4 % for seeds kept at 40 °C, RH = 45 %, (ii) for 2.6 % at 25 °C, RH = 45 %, and (iii) from 0.6 to 0.9 % at 4 °C, RH = 45 %, while increase in grain moisture between 0.2 to 0.4 % was detected for seeds kept in warehouse under uncontrolled storage conditions (2-25 °C, RH = 40-74 %). After equilibration, grain moisture of

Table 1. Average grain moisture content of different wheat cultivars equilibrated with air after 90 days of storage

Tablica 1. Prosječne uravnotežene vlažnosti zrna sorti pšenica koje zrna poprimaju nakon 90 dana skladištenja

Storage conditions	Divana	Žitarka	Srpanjka
	Grain moisture content/%		
40 °C, RH = 45 %	10.0 ± 0.3	9.8 ± 0.3	9.7 ± 0.4
25 °C, RH = 45 %	11.1 ± 0.3	11.1 ± 0.2	11.0 ± 0.3
4 °C, RH = 45 %	12.9 ± 0.2	12.8 ± 0.1	13.1 ± 0.2
2-25°C, RH = 40-74 %	13.9 ± 0.3	13.8 ± 0.4	14.1 ± 0.3

examined cultivars remained at a constant level (Table 1) until the end of storage period.

Analysis of differences in equilibrium grain moisture content (g.m.c.) by Wilcoxon t-test showed that significant differences in equilibrated g.m.c. exists between all applied storage conditions for each cultivar, while there were no significant differences in grain moisture content between cultivars kept at the same storage conditions. Decrease or increase in grain moisture in relation to relative humidity and temperature of storage air has been well documented (Bewley and Black, 1985; Brown, 2009; Chrastil, 1990; Copeland and McDonald, 1999; McDonald, 1999; Rehman and Shah, 1999; Volenik, 2006; Walters, 1998). The g.m.c. changes of examined wheat cultivars during moisture equilibration, observed in this work, as well as length of moisture equilibration period, and equilibrated g.m.c. are consistent with literature data (Brown, 2009; Copeland and McDonald, 1999). The decrease in wheat seed moisture content during the first 90 days of storage of approximately 4, 2.5 and 1 % at 40, 25 and 4 °C, respectively, and relative humidity of 45 % should lead to 8, 5 or 2-fold prolonged seed viability, since

each 1% decrease in grain moisture content doubles the viability of seeds (Copeland and McDonald, 1999). However, viability of seeds is not only influenced by relative humidity and consequently grain moisture content, but also with seed temperature. According to the second Harrington's "rule of thumb" each 5.6 °C reduction in seed temperature doubles the viability of the seed (Copeland and McDonald, 1999; Harrington, 1973), implying that seeds kept at 25 °C should have viability prolonged by factor 6 compared to seeds at 40 °C. When these factors of prolonged viability due to decrease in seed moisture content and temperature reduction are multiplied and compared, it becomes obvious that seeds kept at 25 °C should have 1.5-fold prolonged viability than seeds kept at 40 °C. This has been partially confirmed by observed changes in seed vigour and germination of examined wheat seeds.

During one year of storage at 40 °C, RH = 45 % and 25 °C, RH = 45 % there was significant loss of germination and vigour in all examined cultivars. On the other hand, seeds kept at 4 °C, RH = 45 % and in warehouse with fluctuating environmental conditions

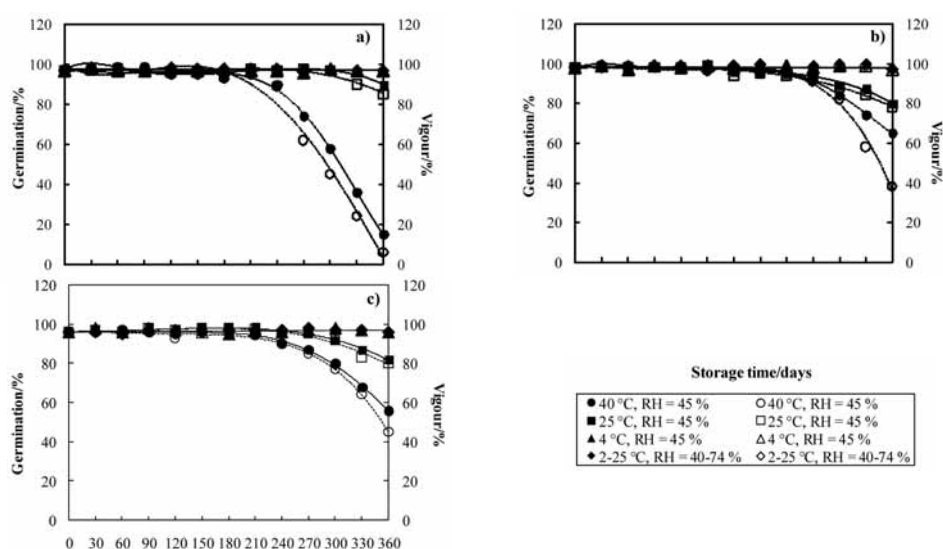


Figure 2. Changes of germination and vigour of different wheat cultivars during storage at different environmental temperatures and relative humidity values. Wheat cultivars: (a) Divana, (b) Žitarka, and (c) Srpanjka; Full markers and lines represent germination, and empty markers and dotted lines vigour changes

Slika 2. Promjena klijavosti i energije klijanja sorti pšenica tijekom skladištenja pri različitim uvjetima temperature i relativne vlažnosti zraka. Sorte: (a) Divana, (b) Žitarka i (c) Srpanjka; Punim markerima i linijama označena je klijavost, a praznim markerima i isprekidanim linijama energija klijanja

(2-25 °C and RH = 40-74 %) did not show significant changes in either germination or vigour (Figure 2).

Decrease in germination and vigour was much greater for seeds kept at 40 °C than at 25 °C (Figure 2). Significant decrease in germination has been observed for Divana and Srpanjka at 240 days, and at 270 days of storage at 40 °C, RH = 45 % for Žitarka cultivar. For wheat seeds kept at 25 °C, RH = 45 % significant decrease started at 300 days of storage for Žitarka, at 330 days for Srpanjka, and at 360 days for Divana cultivar. At the end of storage period at 40 °C, RH = 45 % germination percentage of cultivar Divana was the lowest, only 15 %, compared to cultivars Žitarka and Srpanjka which had significantly higher germination percentage of 65 and 56 %, respectively. On the contrary, germination percentage of Žitarka and Srpanjka stored at 25 °C, RH = 45 % was lower, 80 and 82 %, compared to Divana (90 %). Similar decrease was observed for the seed vigour, which only in the case of Divana started to decrease 30-60 days earlier than germination. All cultivars had lower vigour than germination percentage (Figure 2). Cultivar Divana had vigour of 6 and 85 %, Žitarka 38 and 78 %, while Srpanjka cultivar 45 and 80 % at the end of storage period at 40 °C and 25 °C, respectively (RH = 45 %). Due to lower values of vigour compared to germination percentage, seed viability curves of vigour changes during storage at 40 °C and 25 °C, always preceded the ones representing germination changes (Figure 2). Such differences in viability curves were expected since vigour was being determined fourth and germination percentage seventh day of the germination test. Therefore, incompletely developed seeds fourth day of germination, unaccounted to vigour, had additional three days for development, and if developed properly they are accounted for germination percentage. This implies vigour as better indicator of seed deterioration. Viability curves of germination or vigour changes during storage of seeds at 40 °C, RH = 45 % as well as at 25 °C, RH = 45 % slightly differed between the examined cultivars. Analysis of differences among cultivars in viability curves at the same storage condition by Wilcoxon t-test showed that there was significant difference in viability curves of germination changes during storage at 40 °C, RH = 45 % between all cultivars, while no significant differences between cultivars could be found for seeds kept at 25 °C, RH = 45 %. Similarly, for viability curves of vigour changes during storage there were no significant differences for seeds kept at 25 °C, RH = 45 % while for seeds kept at 40 °C, RH = 45 % only cultivar Divana significantly differed from Žitarka and Srpanjka ($p < 0.05$). Differences in viability curves between the wheat cultivars point to that seed viability during storage was not only influenced by storage temperature, relative humidity and grain moisture content, but also by varietal characteristics. Seed viability differences between cultivars of the same species have been reported for maize, barley, soybeans and rice (Ali et al., 2003; Bewley and Black, 1985; Copeland and McDonald, 1999; Moller and Munck,

2002; Ramanadane and Ponnuswamy, 2004). The most significant reasons for variety differences in seed viability as well as dynamics of seed mortality are: (a) amount of soluble sugars in seeds that influence glassy state of living parts of grains and prevents deterioration reaction within seeds during storage; (b) antioxidants potential of seeds dependent on the level of endogenous antioxidants such as carotenoids, tocoferols, reduced glutathione, ascorbic acid, polyphenols, flavonoids and free amino acids which prevent oxidation and non-enzymatic glycolysation of proteins, lipids and nucleic acids within seeds during storage, and (c) endogenous level of proteolytic and antioxidant enzymes that are capable to fix cellular impairments caused by storage at onset and during germination process (Bernal-Lugo and Leopold, 1998; Calucci et al., 2004; McDonald, 1999; Pinzino, 1999; Steadman et al., 1996; Strelec et al., 2008; Sun and Leopold, 1993). Lower levels of soluble sugars, antioxidants, or endogenous enzymes in Divana cultivar could be the reasons for diminished viability of Divana seeds compared to Žitarka and Srpanjka cultivars. Further research may reveal probable culprit and give insights into desirable compositional qualities of the wheat seeds.

CONCLUSION

Wheat seeds packed in paper bags and stored during one year at four different storage conditions change moisture content, germination and vigour dependent on applied temperature and relative humidity values of environmental air. Significant decrease in grain moisture content of 4 %, 2.5 and 1 % at relative humidity of 45 % and temperature of 40 °C, 25 °C and 4 °C, respectively, occurred during first ninety days of seed storage. Seed germination and vigour are significantly reduced during one year storage only at elevated temperatures. Storage of seeds at 40 °C, RH = 45 % caused 35-85 % decreased germination and 55-94 % reduced vigour; at 25 °C, RH = 45 %, 10-20 % decrease in germination and 15-22 % reduced vigour were detected. Significant differences between cultivars in viability curves of germination and vigour changes during storage at 40 °C, RH = 45 % indicate that wheat seeds viability may be highly dependent on cultivar probably due to variety differences in soluble sugar content, antioxidant potential, and endogenous oxido-reductive and proteolytic enzyme levels.

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UTJECAJ TEMPERATURE I RELATIVNE VLAŽNOSTI ZRAKA NA UDIO VLAGE U SJEMENU, KLIJAVOST I ENERGIJU KLIJANJA TRIJU SORTI PŠENICE TIJEKOM JEDNOGODIŠNJEGA SKLADIŠTENJA

SAŽETAK

Cilj ovoga rada bio je ispitati utjecaj četiri različita uvjeta temperature i relativne vlažnosti zraka (RH) na promjene vlažnosti sjemena, klijavost i energiju klijanja triju sorti pšenice pakirane u papirnate vrećice i skladištene godinu dana. Tijekom prvih 90 dana skladištenja nastupilo je značajno sniženje vlažnosti sjemena od 4, 2,5 i 0,9 %, pri uvjetima skladištenja od 40 °C, 25 °C i 4 °C pri 45 % RH, nakon čega je sjeme zadržalo vlažnost na istoj razini sve do kraja skladištenja. Gubitak klijavosti i energije klijanja nastupio je samo pri višim temperaturama skladištenja i razlikovao se među sortama. Nakon godinu dana skladištenja, gubitak klijavosti i energije klijanja bio je veći kod sjemena skladištenoga pri 40 °C (35-85 % i 55-94 %), nego pri 25 °C i 45 % RH (10-20 % i 15-22 %). Podaci istraživanja ukazuju na značajan utjecaj temperature i relativne vlažnosti zraka na promjene vlažnosti sjemena, klijavost i energiju klijanja ispitivanih sorti tijekom skladištenja, kao i na značajnu ovisnost promjena klijavosti i energije klijanja o sortnim karakteristikama.

Ključne riječi: *vlažnost zrna, klijavost, relativna vlaga zraka, temperatura, vigor, pšenica*

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