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Influence of drying conditions and storage period, in the physical integrity and cooking time of beans

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Abstract

The drying of grains allows a safe storage until consumption, however inadequate drying operations with hot air turn the grains more susceptible to mechanical damages, The susceptibility to damages with immediate and latent effects caused by drying conditions, varies according to species, cultivar, air drying temperature, drying air flow, moisture content and drying rate. The objective of this work was to evaluate immediate and latent effects in the different drying conditions on physical integrity and cooking characteristics, of common bean grains (*Phaseolus vulgaris*), storage during 225 days in a conventional system. The work was accomplished in a pilot stationary dryer, with a perforated central cylinder and air axial flow, with nominal capacity for 120 kg. Nine operational conditions of stationary drying were used, with 3 air flow and 3 temperature levels, distributed as: a) air flow 2 m^{-3} min^{-1} m^{-2}, at 30 ºC; b) air flow 2 m^{-3} min^{-1} m^{-2}, at 45 ºC; c) air flow 2 m^{-3} min^{-1} m^{-2}, at 60ºC; d) air flow 6 m^{-3} min^{-1} m^{-2}, at 30ºC; e) air flow 6 m^{-3} min^{-1} m^{-2}, at 45 ºC; f) air flow 6 m^{-3} min^{-1} m^{-2}, at 60 ºC; g) air flow 12 m^{-3} min^{-1} m^{-2}, at 30 ºC; h) air flow 12 m^{-3} min^{-1} m^{-2}, at 45ºC; i) air flow 12 m^{-3} min^{-1} m^{-2}, at 60 ºC. The results obtained show that drying temperatures above 45 ºC provoked more effects in the physical integrity of grains, in cooking time; the rupture of the bean tegument (band) it is more dependent of the drying drasticity than to wrinkle; cooking time increases with the time of storage, independent of the drying conditions used.

Key words: drying conditions, physical integrity, cooking time, beans.

Introduction

The common beans culture is one of the most important for Brazil, because it constitutes, together with rice, maize and cassava, the alimentary base of great population parcel. Brazil has characterized as world-wide greater producing of beans, with total production estimate 3.4 million tons for 2004/2005 crop destined to supplying the domestic market.

The grains in general are susceptible to adverse environment factors, that can provoke reduction in its quality, with consequences in the storage, industrialization and consumption. As advances the time after-maturation, it diminishes the grains resistance to pests attack and microorganism. The harvest must be carried through the appropriate moment and of adequate form. The harvest carried through in the range of recommended moisture content minimizes the losses, but it requires the use artificial drying. However, it is important to carry

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through the harvest as soon as it has conditions, therefore the longer the grains remain exposed to adversity, in the field, the higher will be the losses, by birds attack, rodents, insects and fungi (Proctor, 1994; Elias, 2002; Lorini et al., 2002).

The grains must be dried and stored in appropriate environment for quality maintenance, that depends on the species and variety, ambient conditions in the field, time and harvest method, drying and storage process (Peres, 2001; Elias, 2002). The drying has as main objective is the conservation of the nutritional and sensorial qualities developed during the field phase for long periods (Biagi and Bertol, 2002).

Among the stationary drying system methods, where the grains remain static and only air is put in movement during drying. In this system, in function of the air flow direction, the methods are classified in drying with air in axial flow and radial flow. Fastness and irregularity are the most undesirable system characteristics, but have little mechanic damage and the necessity of low investments in operational structure as positive characteristics (Peres, 2001; Barbosa et al., 2001; Elias, 2002).

High temperatures and air flows provides a fast drying, resulting in moisture gradient content very accented between the grain surface and interior, generating internal tensions. These tensions cause crackers and posterior breakers in the products, with consequences on the grains quality and problems during the storage. The drying speed is a factor of very important economic order, because is inversely proportional the drying spend.

The grains quality can be judged in three ways, under the technological aspect: the commercial, culinary and nutritional. For commercial quality it understands the grain type and appearance, color, brightness, form and size. Among the desirable culinary characteristics for the consumers are: fast hydrate, low cooking time, production of a thick broth, good flavor and texture, grains moderately cracked, thin tegument and good color stability, while the nutritional quality is in the dependence of the chemical composition and of its constituent ratio (Skowronski et al., 2003).

Beans storage in high temperature conditions also can result in increases in cooking time, in loss quality and the water absorption is reduced during cooking (Kato et al., 2000; Yousif and Deeth, 2003). This results in a reduction of the commercial value of the stored grains beans.

Material and methods

The activities were developed in Post-Harvest and Grain Industrialization Laboratory, Agronomy Faculty “Eliseu Maciel”, Federal University of Pelotas, during the period of January to October, 2005. Were used grains of variety Guapo Brilhante (black group), produced in the Canguçu city - RS. The dryings were carried out in stationary drier pilot, with central cylinder perforated and axial air distribution, with nominal capacity for 120 kg. The supply of the heat was carried through electric energy. Nine operational conditions of stationary drying were used, with 3 air flows entrance and 3 levels temperature, distributed: a) the air flow 2 $m^3 \cdot min^{-1}.m^{-2}$ at 30 ºC; b) air flow 2 $m^3\,min^{-1}\,m^{-2}$ at 45 ºC; c) air flow 2 $m^3\,min^{-1}\,m^{-2}$at 60 ºC; d) air flow 6 $m^3\,min^{-1}\,m^{-2}$ at 30 ºC; e) air flow 6 $m^3\,min^{-1}\,m^{-2}$ at 45 ºC; f) air flow 6 $m^3\,min^{-1}\,m^{-2}$ at 60 ºC; g) air flow 12 $m^3\,min^{-1}\,m^{-2}$ at 30 ºC; h) air flow 12 $m^3\,min^{-1}\,m^{-2}$ at 45 ºC; i) air flow 12 $m^3\,min^{-1}\,m^{-2}$ at 60 ºC. After the drying, the grains were placed in rafia bags and stored by conventional storage system, where remained for 225 days, with operational monitor that consisted of ambient conditions control and the pests attack. The determination grains water content was carried in the ending of the drying and to each 75 days of storage, in stove at 105 ± 3 ºC for 24 hours. The identification and quantification of the broken grains (“bandinha”) and wrinkled were carried through in accordance with the norms for qualification and commercialization beans grain in Decree n º 262, of 23 of November of 1983 of the Ministry of Agriculture. The cooking time was determined following the method considered for Sartori (1982), with adaptations. Samples were selected, in three repetitions, 25 uniforms and whole grains, previously absorbed in distilled water, for 12 hours, at 25 ºC ± 2, and placed in the Mattson equipment, constructed with modifications. The equipment with the grains was placed in Becker of 2000 mL, contends 400 mL of distilled water in boiling on electric plate. The samples cooking time were chronometer in minutes after the water reach 90 ºC and finished at the moment the 13ª rod fall, perforating, in this way more than 50 % of the grains. The experimental results were submitted to variance analysis and the averages compared between itself for the test Tukey, 5 % of probability ($p \leq 0,05$). Software was the SAS Institute.

Results and discussion

The results of the moisture content, physical integrity and wrinkle of the beans grains submitted to different drying conditions and times of storage are presented in Tables 1 to 5.

Table 1. Water content in the beans grains submitted the stationary drying and conventional storage.

	Days of storage			
Drying condition	1	75	150	225
F-2.T-30 ºC	11.3 a D	12.5 a C	13.5 a B	14.3 a A
F-2.T-45 ºC	11.7 a C	11.9 a C	13.4 a B	14.5 a A
F-2.T-60 ºC	11.6 a C	12.3 a BC	13.0 a B	14.5 a A
F-6.T-30 ºC	11.4 a C	12.1 a C	13.7 a B	14.7 a A
F-6.T-45 ºC	11.6 a B	12.0 a B	13.2 a A	14.2 a A
F-6.T-60 ºC	11.7 a C	12.3 a BC	13.4 a AB	14.5 a A
F-12. T-30 ºC	11.5 a B	11.9 a B	13.2 a A	14.1 a A
F-12. T-45 ºC	11.6 a C	12.3 a C	13.4 a B	14.4 a A
F-12.T-60 ºC	11.5 a D	12.4 a C	13.2 a B	13.9 a A
Average	11.5	12.2	13.3	14.3

Simple arithmetic average of three repetitions, followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test from Tukey 5 % from probability. F-2, F-6, F-12 = Flow of the drying air 2, 6 and 12 $m^3 \cdot min^{-1} \cdot m^{-2}$, respectively. T-30 ºC, T-45 ºC, T-60 ºC = Temperature of the air drying at 30, 45 and 60 ºC respectively.

Table 2. Effect of the air temperature and the time of storage on the physical integrity. express in % beans grains broken dry for the stationary system and stored by the conventional system, in three air flows rates.

	Days of storage			
Drying condition	1	75	150	225
F-2. T-30 ºC	0.18 c A	0.20 c A	0.17 c A	0.17 c A
F-2. T-45 ºC	0.35 b A	0.36 b A	0.37 b A	0.37 b A
F-2. T-60 ºC	0.59 a A	0.60 a A	0.63 a A	0.64 a A
Average	0.37	0.39	0.39	0.39
F-6. T-30 ºC	0.19 b B	0.19 b B	0.21 b B	0.25 b A
F-6. T-45 ºC	0.24 b A	0.23 b A	0.21 b A	0.28 c A
F-6. T-60 ºC	0.48 a A	0.47 a A	0.50 a A	0.51 a A
Average	0.30	0.30	0.31	0.34
F-12 T-30 ºC	0.20 c AB	0.22 c AB	0.23 c A	0.24 c A
F-12. T-45 ºC	0.31b A	0.30 b A	0.32 b A	0.33 b A
F-12. T-60 ºC	0.53 a A	0.50 a A	0.53 a A	0.52 a A
Average	0.35	0.34	0.36	0.36

Simple arithmetic average of three repetitions, followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test from Tukey 5 % from probability. F-2, F-6, F-12 = Flow of the drying air 2, 6 and 12 $m^3 \cdot min^{-1} \cdot m^{-2}$, are cubical meters of air, per minute, for square meter, respectively.

Table 3. Effect of the air flow and the storage time on the physical integrity express in % of beans grains broken (bandinha) dry for the stationary system and stored by the conventional system, in three air temperature conditions.

	Days of storage			
Drying condition	1	75	150	225
F-2. T-30 ºC	0.18 a A	0.20 a A	0.17 b A	0.17 b A
F-6. T-30 ºC	0.19 a B	0.19 a B	0.21 b B	0.25 a A
F-12. T-30 ºC	0.20 a AB	0.22 a AB	0.23 a A	0.24 b A
Average	0.19	0.20	0.20	0.22
F-2. T-45 ºC	0.35 a A	0.36 a A	0.37 a A	0.37 a A
F-6. T-45 ºC	0.24 b A	0.23 b A	0.21 b A	0.28 a A
F-12. T-45 ºC	0.31ab A	0.30 ab A	0.32 a A	0.33 a A
Average	0.30	0.30	0.30	0.33
F-2.T-60 ºC	0.59 a A	0.60 a A	0.63 a A	0.64 a A
F-6.T-60 ºC	0.48 b A	0.47 b A	0.50 b A	0.51 b A
F-12.T-60 ºC	0.53 ba A	0.50 b A	0.53 b A	0.52 b A
Average	0.53	0.52	0.55	0.56

Simple arithmetic average of three repetitions, followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test from Tukey 5 % from probability. F-2, F-6, F-12 = Flow of the air of drying. The 2, 6 and 12 $m^3 \cdot min^{-1}.m^{-2}$ are cubical meters of air, per minute, for square meter, respectively.

Table 4. Effect of the air temperature and the storage time on the beans grain wrinkle dry for the stationary system and stored by the conventional system, in three air flows rates.

	Days of storage			
Drying condition	1	75	150	225
F-2. T-30 ºC	10.54 b A	10.07 b A	10.36 a A	10.61 a A
F-2. T-45 ºC	12.05 ab A	11.58 ab A	11.64 a A	12.05 a A
F-2. T-60 ºC	13.06 a A	13.05 a A	13.0 a A	12.71 a A
Average	11.8	11.57	11.67	11.79
F-6. T-30 ºC	9.92 c A	8.98 b A	9.77 a A	10.23 a A
F-6. T-45 ºC	10.56 bc A	10.93 ab A	11.01 a A	10.99 a A
F-6. T-60 ºC	11.88 a A	11.88 a A	12.13 a A	12.03 a A
Average	10.79	10.60	10.37	11.08
F-12 T-30 ºC	9.69 b A	9.74 b A	9.79 a A	9.90 a A
F-12. T-45 ºC	9.77 b A	9.81 b A	9.81 a A	9.91 a A
F-12. T-60 ºC	12.89 a A	12.81 a A	12.11 a A	12.14 a A
Average	10.78	10.79	10.57	10.65

Simple arithmetic average of three repetitions, followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test from Tukey 5 % from probability. F-2, F-6, F-12 = Flow of the air of drying. The 2, 6 and 12 $m^3 \cdot min^{-1}.m^{-2}$ are cubical meters of air, per minute, for square meter, respectively.

Table 5. Effect of the air flows and the storage time on the beans grains wrinkle dry for the stationary system and stored by the conventional system, in three air temperature conditions.

	Days of storage			
Drying condition	1	75	150	225
F-2. T-30 ºC	10.54 a A	10.07 a A	10.36 a A	10.61 a A
F-6. T-30 ºC	9.92 a A	8.98 a A	9.77 a A	10.23 a A
F-12 T-30 ºC	9.69 a A	9.74 a A	9.79 a A	9.90 a A
Average	10.05	9.60	9.97	10.25
F-2. T-45 ºC	12.05 a A	11.58 a A	11.64 a A	12.05 a A
F-6- T-45 ºC	10.56 a A	10.93 a A	11.01 a A	10.99 a A
F-12- T-45 ºC	9.77 a A	9.81 a A	9.81 a A	9.91 a A
Average	10.79	10.77	10.82	10.98
F-2. T-60 ºC	13.06 a A	13.05 a A	13.0 a A	12.71 a A
F-6. T-60 ºC	11.88 a A	11.88 a A	12.13 a A	12.03 a A
F-12. T-60 ºC	12.89 a A	12.81 a A	12.11 a A	12.14 a A
Average	12.61	12.58	12.41	12.29

Simple arithmetic average of three repetitions followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test from Tukey 5 % from probability. F-2, F-6, F-12 = Flow of the air of drying. The 2, 6 and 12 $m^3 \cdot min^{-1}.m^{-2}$ are cubical meters of air, per minute, for square meter, respectively.

Table 1 show that the moisture content of the grains increased during storage for all the drying conditions. This demonstrates that the grains moisture equilibrium approaches to 14 %, and it is dependent on the air temperature conditions and moisture content in the storage place.

In the drying conditions where high air flow was used combined with high temperature, or small air flow with high temperature, were observed the highest percentages of broken grains "bandinha" (Tables 2 and 3) and with wrinkle tegument (Tables 4 and 5). However, these defects had presented minor intensity for the smaller air drying temperature (Junior and Correa, 2000).

The grains quality is affected by the temperature and air moisture content of the drying and consequently, by the drying speed (Andrade et al., 1999). Radajewski et al. (1992), studying the bean drying, conclude that the air temperature of bean drying and the drying rate has great effect on the final product quality.

In bean commercialization, the presence of broken grains (bandinha) is undesirable, causing loss of the product commercial value, and broken grains are more susceptible to pests and microorganism attack, which speed up the degradation and intensify the grains metabolism, increase consumption nutritional substances of the product reserve. The consumers associate this to "aged beans".

These defects were not intensified with the storage period (Table 2 and 3), in consequence of the fact that grains submitted to movement could increase the damage from impact, therefore the drying system chosen was the stationary.

Table 2 show at the same air flow, the air temperature influences directly the incidence of grains broken, called of "bandinha".

Drying with air in constant temperature provokes great initial disequilibrium in the water distribution molecules and heat between the diverse grains layers. As the beans are rich in proteins (around 23 %), and these molecules are more hygroscopic of the others, the proteic part of cotyledons is the first to suffers alteration in its water content during the drying operation. Thus, it has a great volume reduction by cotyledons dehydration, differently of the epidermis film (tegument), whose minerals and fibers contents, that have low hygroscopicity, are higher.

As it does not have the same proportionality between the tegument and cotyledons in the drying, wrinkling of the cotyledon occurs. This wrinkling results in mechanics resistance reduction of the tegument, disruption and separation of cotyledons, provoking the defect called bandinha. In the same air flow, the increase the drying temperature provokes increases in the physical grain damages, what it can be verified by the increase of broken grains percentages (Table 2) and wrinkled (Table 4). These effects there are not clear in relation to the increase of the air flows in the same temperatures (Tables 3 and 5). However, in high temperature (60 ºC), the use of smaller flows (2 m^3 ar.$min^{-1}m^{-2}$) provokes greater physical damages of the grains than at the higher flow.

The effect of the temperature (Tables 2 and 4) and air flow (Table 3 and 5) showed to have more immediate damages than latent, and it did not have alterations in the broken grains percentages (Table 2 and 3) neither wrinkled (Table 4 and 5) during storage.

The variations presented in the grains wrinkle are more dependent to the variations of the moisture equilibrium (Table 1) than to the effects of the air drying (Table 2 and 4).

Increase of temperature from 45 to 60 ºC provoked more intense effect in the grains physical integrity than an increase of temperature from 30 to 45 ºC, independently of the air flow used although the percentages of broken grains (Tables 2 and 3) at temperature of 30 and 45 ºC is well below of the average of each flow, being only above the average of the grains dried with air at 60 ºC. For wrinkled grains (Tables 4 and 5), however, this fact alone is verified in the highest air flow (12 $m^3 min^{-1} m^{-2}$), indicating that the rupture of the bean grains tegument is more dependent to the drying drasticy than wrinkling. The percentages of broken (Table 2) and wrinkled grains (Table 4) do not showed to be affected by the storage period, independently of the temperature (Table 2 and 4) or of the air flow (Table 3 and 5) in the drying.

Tables 6 and 7 show the results of the beans grains cooking time submitted to different conditions of stationary drying and stored by the conventional system for 225 days.

The effect of the air temperature (Table 6) showed that after 75 days of storage with drying air flow of 2 $m^3 min^{-1} m^{-2}$ at 60 ºC, the cooking time was longer than necessary for the grains dried with air at 30 to 45 ºC. The same tendency was verified for the flows to 6 and 12 $m^3 min^{-1} m^{-2}$. The effect of the air drying flows are presented in Table 7, where it was observed that air drying temperature at 30 ºC, with air flow of 2 $m^3.min^{-1}.m^{-2}$ presented longer cooking time in relation to air flows at 6 and 12 $m^3 min^{-1} m^{-2}$. The same was observed for the air drying temperature levels of 45 and 60 ºC. The drying when processed of very fast form, with high temperature, does not allow enough time for moisture content in the grain migrate until the external layer, causing damages and accelerating the grains deterioration. Low air flow rates for drying promote slower drying, what make the grains remain longer periods at gh moisture content and consequently with higher metabolic activity, and this also accelerates the grains deterioration. Low flows combined with high air temperature in the drying also cause damages to the grains, because these are much time exposit to the high temperature. There is an increase of cooking time during the grain storage for all the drying conditions, reaching an increase of 2 times the cooking time in relation the initial evaluation. These cooking times are inside an acceptable range for commercialization. Similar results to the gotten ones in this study were evidenced by Canniatti-Brazaca et al. (1998). that worked with guandu bean and concluded that the amount of absorbed water was diminishing along the storage period, while the cooking time increased. In a similar way, Ribeiro et al. (2005) observed that the bean storage in high temperature and relative moisture content induced the hardening of the grains, causing an increase from 2.3 and 6.4 times the cooking time of the beans stored for 30 and 60 days. Also Donadell and Prudencio-Ferreira (1999) verified an increase between 5.61 and 6.25 times the cooking time when beans grains, Carioca, had been stored for 30 and 40 days at 41 ºC, without control of the relative humidity.

Table 6. Effect of the air temperature and the storage time on bean grains cooking time (minutes) dried in a stationary system in three air flow rates and stored in a conventional system.

	Storage (days)			
Drying condition	1	75	150	225
F-2. T-30 ºC	21.06 a D	24.06 b C	34.36 a B	38.41 ab A
F-2. T-45 ºC	22.13 a D	24.30 b C	31.17 b B	36.17 b A
F-2. T-60 ºC	22.18 a D	26.51 a C	34.40 a B	41.40 a A
Average	21.79	24.96	33.31	38.66
F-6. T-30 ºC	20.42 a D	23.14 b C	33.00 ab B	38.00 ab A
F-6. T-45 ºC	21.07 a D	24.46 ab C	29.17 b B	35.17 b A
F-6. T-60 ºC	21.10 a D	25.12 a C	36.29 a B	41.29 a A
Average	20.86	24.24	32.82	38.15
F-12. T-30 ºC	20.36 a D	23.46 b C	30.25 a B	35.25b A
F-12. T-45 ºC	21.08 a D	24.23 b C	31.10 a B	36.10 b A
F-12. T-60 ºC	21.01 a D	26.03 a C	32.49 a B	39.49 a A
Average	20.86	24.24	32.82	38.15

Simple arithmetic average of three repetitions, followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test, from Tukey 5 % from probability. F-2, F-6, F-12 = air flow of drying; The 2, 6 and 12 $m^3.min^{-1}.m^{-2}$ are cubical meters of air, per minute, for square, respectively.

Table 7. Effect of the air flow and the storage period on the bean grains cooking time dried in a stationary system in three drying temperature levels stored in a conventional system.

	Storage (days)			
Drying condition	1	75	150	225
F-2. T-30 ºC	21.06 a D	24.06 a C	34.36 a B	38.41 a A
F-6. T-30 ºC	20.42 a D	23.14 a C	33.00 a B	38.00 a A
F-12. T-30 ºC	20.36 a D	23.46 a C	30.25 b B	35.25 b A
Average	20.61	23.55	32.54	37.22
F-2. T-45 ºC	22.13 a D	24.30 a C	31.17 a B	36.17 a A
F-6. T-45 ºC	21.07 a D	24.46 a C	29.17 a B	35.17 a A
F-12. T-45 ºC	21.08 a D	24.23 a C	31.10 a B	36.10 a A
Average	21.43	24.33	30.48	35.81
F-2. T-60 ºC	22.01 a D	26.51 a C	34.40 a B	41.40 a A
F-6. T-60 ºC	21.10 a D	25.12 a C	36.29 a B	41.29 a A
F-12. T-60 ºC	21.01 a D	26.03 a C	32.49 a B	39.49 a A
Average	20.11	25.89	34.39	40.73

Simple arithmetic average of three repetitions, followed by different lower case letters in the same column and capital letters in the same line, differ between itself for the test from Tukey 5 % from probability. F-2. F-6. F-12 = air flow of drying. The 2, 6 and 12 $m^3.min^{-1}.m^{-2}$ are cubical meters of air, per minute, for square meter respectively.

Conclusions

The results showed that: a) temperature of drying above 45 ºC provokes greater intense effect in the physical grains integrity and in the cooking time; b) the tegument rupture of the bean (bandinha) is more dependent to the drying intensity than to wrinkling; c) the cooking time increases with the storage period, independently of the flow and temperature of the drying air used.

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