Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi 7 (1):51-57, 2012
ISSN 1304-9984, *Araştırma Makalesi*

Effects of Seed Moisture Content and Threshing Methods on Bean (*Phaseolus vulgaris* L.) Seed Quality

Süleyman KAVAK[1*] Hülya İLBİ[2] Benian ESER[2]
Alison A. POWELL[3] Stanley MATTHEWS[3]

[1]Süleyman Demirel University, Faculty of Agriculture, Department of Horticulture, Isparta, Turkey
[2]Ege University, Faculty of Agriculture, Department of Horticulture, Bornova, İzmir, Turkey
[3]University of Aberdeen, School of Biological Sciences, Aberdeen, United Kingdom
*Yazışma yazarı: suleymankavak@sdu.edu.tr

Geliş tarihi: 13.10.2011, Yayına kabul tarihi: 13.04.2012

Abstract: The low seed quality of white-seeded cultivars of *Phaseolus vulgaris* L. can cause problems at field emergence. Bean seeds in Turkey are produced mainly in the hot dry summer season in the Konya plain. Bean seeds were harvested by hand from different commercial fields and the seeds were removed by hand or by mechanical threshing at different seed moisture contents (SMC) from 20% down to 11%. The lowest percentage of normal seedlings and significantly higher abnormal seedlings, as well as a higher incidence of cracked seed coats were found for machine threshed seeds at below 14% SMC. The field emergence at two sites showed evidence of reduced emergence in seeds that had been machine threshed at 11% SMC. These findings showed that bean seeds should not be harvested and threshed by machine at below 14% SMC if seed quality is to be maintained.

Key words: *Phaseolus vulgaris* L., seed moisture content, threshing methods, seed quality

Tohum Nemi ve Ayrım Yöntemlerinin Fasulye (*Phaseolus vulgaris* L.) Tohum Kalitesi Üzerine Etkileri

Özet: Beyaz tohum kabuğuna sahip fasulye (*Phaseolus vulgaris* L.) çeşitlerinde düşük tohum kalitesi tarla çıkışında problemlere neden olabilmektedir. Türkiye'de fasulye tohumluk üretiminin büyük bir kısmı, kuru ve sıcak yaz sezonuna sahip olan Konya düzlüklerinde üretilmektedir. Fasulye tohumları, farklı ticari tohumluk üretim tarlalarından elle hasat edilen bitkilerden, %11 ile %20 arasında değişen tohum nem içeriklerinde elle veya mekanik olarak ayrılmışlardır. %14 tohum neminin altında makineli ayrımlarda, normal çim oranında azalma, anormal çim oranınında önemli ölçüde artışın yanısıra kırık tohum kabuğunun görülme sıklığının arttığı belirlenmiştir. İki farklı lokasyonda yapılan tarla çıkış testi, %11 tohum neminde makine ile ayrılan tohumlarda çıkıştaki azalmanın bir kanıtı olmuştur. Bu bulgular, fasulyede tohum kalitesinin korunumu isteniyorsa, %14'ün altındaki tohum neminde makineli hasat ve ayrımın yapılmaması gerektiğini göstermektedir.

Anahtar kelimeler: *Phaseolus vulgaris* L., tohum nemi, ayrım yöntemleri, tohum kalitesi

Introduction

The quality of bean seeds depends on many pre and post-harvest factors, such as area of production, cultivation techniques, seed maturity, harvest, threshing, processing and storage conditions. Greven et al. (2004) reported that timing of harvest is an important factor since both seed immaturity and weathering reduce seed quality. During the growth of field crops maximum seed quality is gained at physiological maturity (PM) at the end of seed filling (Egli, 1998), and the seeds are harvested at harvest maturity (HM) when seeds dried to desired seed moisture content (SMC) that allows harvesting without considerable damage (Muasya et al., 2006). When bean seeds harvested between PM and HM, they showed the highest seed vigour and storability (Herat, 1992). After harvesting but not threshing of bean seeds before maximum seed weight had been reached leaving seeds in the pod had a significant influence on final seed size and viability (Greven et al., 2004). In pea, faba bean and soybean substantial decline in viability and increasing rate of seedling abnormalities were observed when harvest was delayed beyond the optimal SMC for harvest (Ellis et al., 1987). Sowing date and harvest method are important to maintain seed quality in soybean (Adam et al., 1989). Delaying pea harvest could also cause the seed to become too dry and therefore be more easily damaged (Padrit et al., 1996).

Seed processing is a fundamental component in any planned seed production programme, which aims at improving the seed characteristics (Araujo et al., 2008). Mechanical damage of bean seeds is of great importance for seed producers, farmers and food processors (Bay et al., 1995) and is considered the most common reason for poor seed quality in large seeded legumes and this occurs when seeds are threshed at unsuitable SMC and at high drum speed (Greven et al., 2001). Mechanical damage is a seed quality factor that may affect the worth of soybean seed lots (Luedders and Burris, 1979). The best seed germination, vigour and purity of bean seeds and also lowest seed damage were obtained with 14.1% SMC and a threshing cylinder velocity of 420 rpm (Souza et al., 2002).

Although, several studies had been done for improving the harvesting and handling of bean seeds (Hoki and Picket, 1973; Pickett, 1973) and soybean seeds (Shreekant et al., 2002) to reduce seed damage and maintain seed quality; seed size, colour and thickness of seed coat are changed in bean varieties. Especially white-seeded beans are more sensitive to processing than dark coloured-seeded beans. Also production area of bean seed is very important for seed quality. Dark coloured bean seeds developed and matured under cooler conditions produced higher seed yields and had larger size, better colour and higher vigour and toleration to field weathering changed according to variety (Herat, 1992). For this reason, harvest, drying period after harvest and threshing methods are important factors to obtain desired yield and quality in bean seed production and these factors should be optimized for different varieties and production areas.

The objective of this study was to investigate the effect of SMC and threshing methods (TM) on seed quality of white-seeded bean cultivar (*Phaseolus vulgaris* L.) which is mainly produced in the hot dry summer season in the Konya plain of Turkey.

Materials and Methods

Seed lots

In 2007, twelve different seed lots of bean cultivar “Gina” were collected according to SMC and TM from different commercial fields in the Konya plain of Turkey. Plants were harvested by hand between 25 and 30% SMC (data not shown) and the plants were left in windrows for drying. Seed samples were taken during mechanical (cylinder velocity of 450 rpm) threshing (MT) and hand threshing (HT) and put into sealed hermetic glass jars. SMC was determined at these samples according to ISTA (2007) rules. All seed lots were kept in a refrigerator in hermetic glass jars during the experiment.

Seed treatment

The seeds were surface sterilized with 1% (v/v) NaOCl for 10 min before standard germination (SG) and accelerated ageing tests (AA) with 1% (v/v) NaOCl for 10 min (ISTA, 2007). After sterilization, seeds were washed twice in tap water and rinsed with distilled water and dried to original seed weight in under laboratory conditions.

Standard germination (SG)

Germination tests were carried out using 4x50 seeds for each seed lot sown in peat in plastic boxes. Then boxes were kept in a growth chamber running at 25^{o}C for nine days (ISTA, 2007). At the end of germination tests the numbers of normal and abnormal seedlings were evaluated. Also mean germination time (MGT) was calculated using daily germination data (Pedersen et al., 1993).

Field emergence test (FE)

The field emergence tests of the seed lots were assessed for 4 x 50 seeds which were hand sown in two different regions. Seeds were sown on 5th of May 2008 in Izmir, 7th of May 2008 in Bursa. The lots were distributed completely at random within each experimental block. Emerged seedlings on the 18th day after sowing were evaluated as a percentage.

Seed vigour

To determine the effects of SMC during threshing and TM on seed vigour; electrical conductivity (EC) and accelerated ageing (AA) tests, which are recommended by International Seed Testing Association (ISTA), were used. Before the vigour tests SMC of all seed lots were adjusted 12% (±0.5%) as a weight basis (Sivritepe, 1992).

An EC test was conducted using three replicates of 50 seeds in all seed lots. Samples were prepared as described by ISTA (1995) for pea seeds. After 24 h (±15 min), the conductivity measurements of each flasks was measured using a conductivity meter (WTW, LF 538, Germany).

For AA from each seed lot 2x100 seeds were used. Seeds were placed in a single layer on wire inert chamber which contains 40 ml distilled water. These chambers were kept at a constant 41^{o}C (±0.3^{o}C) water jacketed incubator for 72 h (ISTA, 1995). If the SMC was between 30 and 32% (as weight basis) after AA test, germination test was carried out the same protocol as for standard germination test.

Physical quality of seed lots

Physical quality parameters of seed coat, percentage of yellowish seed coat (YSC), greenish seed coat (GSC), cracked seed coat (CSC) and total percentage of YSC, GSC and CSC were determined in seed lots with the help of magnifying lens.

Statistical analysis

All data were statistically analyzed using ANOVA in SPPS version 13.0 for windows. Duncan's test was used to compare means at the 0.05 significance level.

Results and Discussion

Standard germination

Normal seedling percentage of the seed lots ranged from 89,5% to 99%, while abnormal seedling percentage ranged from 0,5% to 10,5% (Table 1). Generally, in seed lots, while normal seedling percentage decreased, MGT of seed lots increased with decreasing SMC during threshing regardless of threshing methods. Threshing the seeds when SMC between 17 and 20% increased germination but threshing seed more than or equal to 30% SMC reduced germination and vigour (Greven et al., 2001). TM and SMC during threshing were statistically affected normal and abnormal seedling percentage (Table 2). HT and above 14% SMC seed lots increased normal seedling percentage and decreased abnormal seedling percentage compared to MT and below 14% SMC seed lots. Ellis et al. (1987) reported substantial decline in viability and increase in seedling abnormalities when harvest was delayed beyond the optimal moisture content for harvest in pea, faba bean and soybean.

Field emergence

FE test results of seed lots were changed due to locations where the tests were conducted (Table 1). FE emergence of seed lots varied from %80 to %92 in Izmir and from %79 to %93 in Bursa. In Izmir location, the highest FE was determined as 92% from K-6 (HT and 11% SMC) and the lowest FE was determined as 80% from K-12 (MT and 11% SMC), in Bursa location the highest FE was determined as 93% from K-3 (HT and 16% SMC) and the lowest FE was determined as 79% from K-11 (MT and 11% SMC). TM and SMC during threshing did not statistically affected FE of seed lots in Izmir. (Table 2). Like as normal seedling percentage HT and above 14% SMC seed lots gave better FE emergence than MT and below 14% SMC seeds lots in Bursa location. It could be concluded that according to FE results in Izmir and Bursa if SMC content is below 12% seeds must be threshed by hand not by machine.

Seed vigour

EC values of seed lots were between 20,9 µS/cm/g and 25,3 µS/cm/g (Table 1). The highest EC values were measured in both threshing methods as 25,3 µS/cm/g and 24,7 µS/cm/g (HT seed lot K-5 and MT seed lot K-12, respectively). Highest EC values of HT seed lots K-5, K-4 and K-6 could be explained highest GSC of these lots (7,1%, 6,9% and 6,3% respectively). This could be explained that these lots harvested early and immature stage. When bean seeds harvested early and immature, small, of low vigour and had a high EC value per gram seed (Siddique and Goodwin, 1985). In both threshing methods, EC values of seed lots increased with decreasing SMC. The lowest EC values were determined in both threshing methods from highest SMC seed lots (HT seed lot K-1, 20,9 µS/cm/g and MT seed lot K-7, 21,0 µS/cm/g, respectively). Prusinski and Borowska (1993) stated that increasing SMC of pulse crop seeds up to 20%, increased resistance of seeds against mechanical effects and percentage germination and decreased EC values.

When we look at the normal and abnormal seedlings percentage of seed lots after AA test, both of the HT and MT seed lots were divided into two different groups according to their SMC (Table 1). K-1, K-2 and K-3 seed lots were collected in the first group, their SMC were changed from 20% to 16% and K-4, K-5 and K-6 were collected in the second group with their SMC ranging from 15% to 11% in HT seed lots. Also the same differentiation occurred in MT seed lots. Although normal seedling percentage of HT seed lots after AA test was increased with decreasing SMC, normal seedling percentage of MT seed lots after AA test was decreased with decreasing SMC. This result could be explained by the importance of maximum seed weight that when maximum seed weight is reached, leaving the seeds in the pod has a significant influence on final seed size and viability (Greven et al., 2004).

Neither TM nor SMC during threshing affected EC and AA test results statistically (Table 2). Although there was no significant effect of TM and SMC on seed vigour, EC values of seed lots below 14% SMC was higher than seed lots above 14% SMC.

Table 1. Standard germination, field emergence and vigour parameters of 12 bean seed lots

			Standard germination test					**AA**		
Lots	**TM**	**SMC (%)**	**Normal seedlings (%)**	**Abnormal seedlings (%)**	**MGT (day)**	**FE Izmir (%)**	**FE Bursa (%)**	**Normal seedlings (%)**	**Abnormal seedlings (%)**	**EC (µS/cm/g)**
K-1	HT	20	98,5 a	1,5 d-f	4,4 a-c	89 ab	92 ab	67,0 de	32,0 ab	20,9 f
K-2	HT	17	96,5 ab	3,5 c-f	4,3 b-d	87 ab	88 a-d	69,0 c-e	30,5 ab	22,6 de
K-3	HT	16	98,5 a	1,0 ef	4,2 d	88 ab	93 a	62,5 e	37,5 a	23,3 cd
K-4	HT	15	96,0 ab	4,0 b-e	4,4 a-c	90 ab	85 a-d	91,0 a	8,5 e	25,2 ab
K-5	HT	14	98,0 a	2,0 d-f	4,5 ab	88 ab	91 a-c	87,5 a	12,5 de	25,3 a
K-6	HT	11	98,0 a	2,0 d-f	4,5 ab	92 a	88 a-d	82,0 a-c	18,0 b-e	23,8 b-d
K-7	MT	16	99,0 a	0,5 f	4,3 b-d	85 ab	81 bc	72,0 b-e	27,0 a-c	21,0 f
K-8	MT	15	95,5 ab	4,5 b-d	4,4 a-c	89 ab	88 a-d	71,5 b-e	28,0 a-c	21,4 ef
K-9	MT	15	96,5 ab	3,0 d-f	4,2 d	85 ab	91 a-c	72,5 b-e	27,0 a-c	21,1 f
K-10	MT	12	89,5 d	10,5 a	4,6 a	86 ab	82 b-d	74,0 b-e	24,5 a-d	23,5 cd
K-11	MT	11	93,5 bc	6,5 bc	4,5 ab	84 ab	79 d	84,0 ab	15,5 c-e	22,9 d
K-12	MT	11	92,0 cd	7,0 b	4,5 ab	80 b	83 a-d	78,5 a-d	19,5 b-e	24,7 a-c
Mean			**96,0**	**3,8**	**4,4**	**86,95**	**86,93**	**76,0**	**23,4**	**23,0**
p<0,05										

* ns: non significant, TM: threshing method, HT: hand threshing, MT: machine threshing, MGT: mean germination time.

Physical quality of seed lots

MT increased YSC and CSC percentage when compared with HT (Table 3). The seed lot K-12 had lowest SMC in MT seed lots and gave highest CSC percentage as 4%. While CSC and YSC percentages were higher in MT seed lots than HT seed lots, GSC percentage were higher in HT seed lots

Table 2. Effects of seed moisture content during threshing and threshing methods on germination, vigour and field emergence.

			Standard germination			**Accelerated ageing**			
		EC (µS/cm/g)	**Normal seedlings (%)**	**Abnormal seedlings (%)**	**MGT (Day)**	**Normal Seedlings (%)**	**Abnormal Seedlings (%)**	**FE Izmir (%)**	**FE Bursa (%)**
TM	HT	23,5	97,6	2,3	4,4	76,5	23,2	89,0	89,6
	MT	22,4	94,3	5,3	4,4	75,4	23,6	84,9	83,8
	Mean	**23,0**	**96,0**	**3,8**	**4,4**	**76,0**	**23,4**	**86,9**	**86,7**
	p<0,05	**ns***			**ns**	**ns**	**ns**		
SMC (%)	>14%	22,6	97,3	2,5	4,3	74,1	25,4	87,6	88,0
	<14 %	23,8	93,3	6,5	4,5	79,6	19,4	85,6	83,1
	Mean	**23,2**	**95,3**	**4,5**	**4,4**	**76,9**	**22,4**	**86,6**	**85,6**
	p<0,05	**ns**				**ns**	**ns**	**ns**	

* ns: non significant, SMC: seed moisture content, TM: threshing method, HT: hand threshing, MT: machine threshing, and MGT: mean germination time.

Table 3. Yellow, green and cracked seed coat percentage of 12 seed lots after threshing

Lots	**TM***	**SMC (%)**	**YSC (%)**	**CSC (%)**	**GSC (%)**	**Total YSC, CSC and GSC (%)**
K-1	HT	20	1,8 c-e	0,8 d	3,4 c	6,1 ab
K-2	HT	17	1,8 c-e	1,0 cd	2,0 c	4,7 b
K-3	HT	16	1,0 d-f	0,8 d	2,0 c	3,8 b
K-4	HT	15	0,4 ef	0,0 d	6,9 a	7,3 ab
K-5	HT	14	0,0 f	0,3 d	7,1 a	7,4 ab
K-6	HT	11	2,9 a-c	0,9 cd	6,3 ab	10,2 a
K-7	MT	16	1,7 c-e	2,2 b	2,8 c	6,7 ab
K-8	MT	15	3,3 ab	2,0 b	2,8 c	8,1 ab
K-9	MT	15	4,3 a	2,5 b	2,4 c	9,2 ab
K-10	MT	12	2,2 b-d	1,9 bc	3,2 c	7,2 ab
K-11	MT	11	2,2 b-d	2,1 b	3,6 bc	7,9 ab
K-12	MT	11	1,5 c-e	4,0 a	2,1 c	7,7 ab
Mean **p<0,05**			**1,9**	**1,5**	**3,7**	**7,2**

* TM: threshing method, HT: hand threshing, MT: machine threshing, YSC: yellow seed coat, CSC: cracked seed coat and GSC: green seed coat.

Table 4. Effects of seed moisture content during threshing and threshing method on yellow, green and cracked seed coat percentage.

		YSC (%)	**CSC (%)**	**GSC (%)**	**Total YSC, CSC and GSC (%)**
TM	HT	1,3	0,6	4,6	6,6
	MT	2,5	2,4	2,8	7,8
	Mean	**1,9**	**1,5**	**3,7**	**7,2**
	p<0,05				**ns**
SMC (%)	>14%	1,8	1,2	3,7	6,7
	<14 %	2,2	2,2	3,8	8,3
	Mean	**2,0**	**1,7**	**3,7**	**7,5**
	p<0,05	**ns***		**ns**	**ns**

* ns: non significant, SMC: seed moisture content, TM: threshing method, HT: hand threshing, MT: machine threshing, YSC: yellow seed coat, CSC: cracked seed coat and GSC: green seed coat.

than MT seed lots. It might be explained by the fact that during MT, the threshing machine did not threshed green pods and throw them out of machine. Off-coloured seeds in white-seeded crops not only affect general appearance of seed lots, but also may be indicative of decreased seed quality. Seeds in the coloured fractions (brown, tan and green) were of poorer quality in comparison with white seeds (Lee et al., 1998). Black, brown and gray seeds had poor quality and must be discarded in mung bean seed lots (Araujo et al., 2008).

Although TM significantly affected all physical quality determinations of seed lots, SMC during threshing only affected CSC percentage as statistically (Table 4). MT threshing increased CSC percentage by four times compared with HT (2,4% and 0,6%, respectively), and also SMC below 14% almost doubled CSC percentage compared with SMC above 14% (2.2% and 1,2%, respectively). Bay et al. (1995) stated that the amount of splitting damage in navy beans increased at SMC below 11% and also Parde et al. (2002) reported that the seed lots at 12% SMC (dry basis), suffered less mechanical damage than the lots at 10% or 11% SMC in soybean during processing. Percentage of broken seed coats and abnormal seedlings were negatively correlated with germination and emergence and positively correlated with each other in soybeans (Luedders and Burris, 1979). Their results confirm that MT seed lots K-10, K-11 and K-12 which had SMC below or equal to 12%, gave lower normal seedling percentage and field emergence values in all seed lots (Table 1).

Conclusion

In order to decrease mechanical damage during threshing and maintain seed quality along with processing and storage in white-seeded bean following factors should be considered during threshing.

- Seed moisture content is an important factor to determine threshing of seeds by hand or by machine. Below 14% SMC, mechanical threshing should not be used for bean seeds to maintain seed quality and less damage.
- Early and late harvests not only decrease physical quality of seed lots but also decrease seed quality. Harvesting immature seeds increases green and yellow seed coat ratio in seed lots, while late harvest and machine threshing increase cracked seed coat ratio in seed lots.
- Hand harvesting and threshing should be used for mechanical damage sensitive white-seeded bean varieties. If this is not possible, seed moisture content, feeding rate and cylinder velocity of threshing machine must be determined for each variety.
- Additionally harvest maturity and drying time at windrow should be determined for each seed production area.

Acknowledgements

We would like to thank to The Scientific and Technological Research Council of Turkey (TUBITAK) for financial support and May Seed Company, Bursa, Turkey, for supplying bean seeds.

References

Adam, N.M., McDonald Jr, M.B. and Henderlong, P.R. 1989. The influence of seed position, planting and harvesting dates on soybean seed quality. Seed Science and Technology, 17, 143-152.

Araujo, R.F., Araujo, E.F., Vieira, R.F., Sofiatti, V., Zonta, J.B. and Souza, LT. 2008. Physiological and sanitary quality of mung beans subjected to post-harvest mechanical processing. Revista Brasileira de Armazenamento, 33(1): 43-51.

Bay, A.P.M., Taylor, A.G. and Paine, D.H. 1995. Mechanical damage resistance of snap bean (*Phaseolus vulgaris* L.) seeds: protection of embryonic axis by the cotyledons. Plant Varieties and Seeds, 8: 151-159.

Egli, D.B. 1998. Seed biology and the yield of grain crops. CAB International, Wallingford, 178 pp.

Ellis, R.H., Hong, T.D. and Roberts, E.H. 1987. The development of desiccation tolerance and maximum seed quality during seed maturation in six grain legumes. Annals of Botany, 59: 23-29.

Greven, M.M., McKenzie, B.A., Hampton, J.G., Hill, M.J. and Hill, G.D. 2001. Some factors affecting seed quality during the mechanical threshing of dwarf French bean (*Phaseolus vulgaris* L.). Agronomy New Zealand, 31: 121-126.

Greven, M.M., McKenzie, B.A., Hampton ,J.G., Hill, M.J., Sedcole, J.R. and Hill, G.D. 2004. Factors affecting seed quality in dwarf French bean (*Phaseolus vulgaris* L.) before harvest maturity. Seed Science and Technology, 32: 797-811.

Herat, L.G. 1992. Effects of maturity and seed size on seed vigour and plant growth in snap bean (*Phaseoulus vulgaris* L.). Ph.D. Thesis, Virginia Polytechnic Institute and State University, pp.117

Hoki, M. and Picket, L.K. 1973. Factors effecting mechanical damage of Navy beans. Transaction of the American Society of Agricultural Engineers, 16: 1054-1057.

ISTA, 1995. Handbook of Vigour Test Methods. 3rd Edition, Edited by J.G. Hampton and D.M. TeKrony, Zurih, Switzerland.

ISTA, 2007. Internatioanal Rules for Seed Testing. International Seed Testing Association, Bussesdorf, Switzerland.

Lee, P.C., Paine, D.H. and Taylor, A.G. 1998. Dedection and removal of off-colored bean seeds by color sorting. Seed Technology, 2(1): 43-55.

Luedders, V.D. and Burris, J.S. 1979. Effects of broken seed coats on field emergence of soybeans. Agronomy Journal, 71: 877-879.

Muasya, R.M, Lommen, W.J.M., Auma, A.U. and Struik, P.C. 2006. Relationship between variation in quality of individual seeds and bulk seed quality in bean (*Phaseolus vulgaris* L.) seed lots. NJAS, 54(1): 5-16.

Padrit, J., Hampton, J.G., Hill, M.J. and Watkin, B.R 1996. The effects of nitrogen and phosphorus to the mother plant on seed vigour in garden pea (*Pisum sativum* L.) cv. Pania. Journal of Applied Seed Production, 14: 41-45.

Parde, S.R., Rameshwar, T.K., Digvir, S.J. and Noel, D.G.W. 2002. Mechanical damage to soybean seed during processing. Journal of Stored Products Research, 38, 385-394.

Pedersen, L.H., Jorgensen, P.E. and Pulsen, I. 1993. Effects of seed vigour and dormancy on field emergence, development and grain yield of winter wheat (*Triticum aestivum* L.) and winter barley (*Hordeum vulgare* L.). Seed Science and Technology, 21: 159-178.

Pickett, L.K. 1973. Mechanical damage and processing loss during navy bean harvesting. Transaction of the American Society of Agricultural Engineers, 16: 1047-1050.

Prusinski, J. and Borowska, M. 1993. The application of the electroconductivity test in vigour evaluation of mechanically damaged pulse crop seeds. Biuletyn Instytutu Hodowlii Aklimatyzacji Roslin, No. 186: 133-144.

Shreekant, P.R., Rameshwar, T.K., Digvir, S.J. and Noel, D.G.W. 2002. Mechanical damage to soybean seed during processing. Journal of Stored Products Research, 38: 385-394.

Siddique, M.A. and Goodwin, P.B. 1985. Conductivity measurements on single seeds to predict the germinability of French beans. Seed Science and Technology, 13: 643-652.

Sivritepe, H.Ö. 1992. Genetic deterioration and repair in pea (*Pisum sativum* L.) seeds during storage. PhD Thesis, University of Bath, pp. 227.

Souza, C.M.A., Queiroz, D.M., Mantovani, E.C. and Cecon, P.R. 2002. Effect of mechanical harvesting on the quality of seeds of bean (*Phaseolus vulgaris* L.). Revista Brasileira de Armazenamento, 27(1): 21-29.