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Influence of stages of harvesting and threshing methods on soybean [*Glycine max* (L.) Merrill]

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Abstract
Major constraint in soybean seed production is the rapid loss of seed viability during storage. The seed quality in soybean is affected by harvesting stages, threshing methods, storage conditions and mechanical damage *etc.* Among harvesting stages, soybean harvested at 90 DAS (days after sowing) recorded highest germination and moisture, vigour and lower mechanical damage, EC as compared to other harvesting stages. Delaying harvesting *viz*., 100 DAS and 110 DAS results in increased seed leachates and mechanical damage. Among threshing methods, beating with sticks recorded less mechanical damage and maximum germination, vigour and tractor trampling resulted in higher mechanical damage, EC and minimum germination and vigour. Study indicates that for good seed quality, soybean pods should be harvested at 90 DAS *viz.*, at physiological maturity and threshed by beating with sticks.

Keywords: Stages of harvesting, threshing methods, mechanical damage, seed quality of soybean

1. Introduction

The maintenance of seed quality after harvest and during storage, is a major problem in soybean seed because the seed is poor storer as it is more vulnerable to mechanical damage from harvesting to next sowing season (Paulsen *et al.* 1981) [53]. Greven *et al.* (2004) [23] reported that stages of harvest are an important factor since seed immaturity reduces seed quality. The seed quality in general did not change significantly between physiological maturity (PM) and harvest maturity (HM) but in some cases, the proportion of viable seeds increased between PM and HM especially when ambient temperatures were relatively low (Muasya *et al*., 2008) [46]. Kumar *et al.* (2002) [36] stated that seed yield and quality largely depend upon the stage of maturity of crop. Therefore, harvesting of seeds at the optimum stage of maturity is an important factor as harvesting either at early or late stage results in lower yields with poor quality seeds.

Physiological maturity is a stage where in quality of seed is at its best. Harrington (1972) [26] and Robortson *et al*. (1978) [61] defined the physiological maturity as the stage at which seed has attained the maximum dry weight. Eastin *et al*. (1973) [12] stated that the maximum viability and vigour can be obtained at physiological maturity. Unless seed dormancy becomes an impediment, the best results can be expected if seed is harvested at stage of physiological maturity, without waiting for field maturity. Seed development is the period between fertilization and maximization of fresh weight accumulation and seed maturation begins at the end of seed development and continues till harvest (Mehta *et al*. 1993) [43].

The seed reaches its maximum dry weight at physiological maturity and seeds should be harvested at this time to ensure their quality in terms of germinability and vigour. If the seeds are retained on mother plant after physiological maturity and physiological changes in seed may lead to formation of hard seeds or off coloured seeds in pulse crops. Attainment of physiological maturity is a genotypic character which is influenced by environmental factors (Mahesha *et al*. 2001) [41].

Soon after harvest, soybean seed is subjected to several post-harvest operations like threshing, drying, grading, transportation and other handling operations. During this loss of soybean seed quality is mainly due to mechanical damage, it is because of its very thin seed coat and low lignin content leads to little protection to the fragile radical which lies in a vulnerable position directly beneath the seed coat so soybean seed is regarded as a poor store and it loses its viability and vigour at a faster rate due to loss of membrane permeability of seed (Alvarez *et al.* 1997, Prakobbon, N., 1982, Puteh *et al.* 1997) [3, 55, 58]. Threshing is an important post-harvest operation. In India threshing of soybean seed is generally done by hand beating of pods with sticks and trampling the pods under the feet of bullocks or using a stone roller yoked to a pair of bullocks or other common practice is the use of tractors and mechanical thresher. These methods involve the rubbing action for separating the seed and threshing (Seema *et al*., 2020) [64, 65].

Presence of high lipid content and high level of polyunsaturated oleic acid, linolenic and linoleic acid is the main reason for short shelf life of soybean seed (Sung. 1996, Trawartha *et al*, 1995) [76]. Storability of seed is mainly a genetic character and it is influenced by pre storage history of seeds, seed maturation and environmental factors during pre and post-harvest stages. (Srivastava *et al.* 1975, Seneratna *et al.* 1988, Mahesha *et al*, 2001) [41, 66, 73].

Quality seed production is an important pre requisite for the agricultural production. The seed producers harvest seed as per their need and convenience, *i.e*., may be later or earlier or at physiological maturity or at harvest maturity. This, leads to variation in quality and yield of seeds and finally effect storage (Arulnandhy *et al*. 1987) [5]. The storage becomes successful depending upon quality of seeds to be stored. It is universal that when plant attains physiological maturity, on that day only the storage of seeds starts on plant itself. Initial moisture content reflects further germination and vigour of seed under storage (Seema *et al*., 2020) [64, 65].

Despite of its economic importance very little scientific information is available on optimum stage of harvesting in this crop and proper method of threshing to get high quality seed for long term storage. Keeping this in view the present review on seed quality in *Glycine max* L. as influenced by stage of harvesting and threshing methods on storability is presented.

1.1 Effect of stages of harvesting on seed quality of soybean

Seed yield and quality largely depend upon the stage of maturity of crop. Therefore, harvesting of seeds at the optimum stage of maturity is an important factor as harvesting either at early or late stage results in lower yields with poor quality seeds (Tutu, I. O., 2014) [77]**.** Lopes *et al.* (2000) [38] studied the physiological seed quality in ten soybean genotypes and found that seed quality was highest at physiological maturity stage in genotypes *viz.*, Doko and CAC-I.

The test weight, germination percentage, oil content and dry matter content of seeds were gradually increased up to physiological maturity stage and then decreased afterwards in soybean cultivar JS-335 during *kharif* season in Maharashtra region (Jadhav *et al.* 2001) [29]. Ojo *et al.* (2001) [48] observed the effect of time of harvest of germination and seedling emergence in soybean under rainfed conditions. Result indicated that the late harvesting reduces germination and field emergence capacity of seed. The study also indicated that the production site and weather conditions at harvest time also affect seed quality.

Adu-Dapaah *et al.* (2005) [2] stated that soybean can be harvested either manually (by hand) or mechanically (by machine e.g. combine harvesters). In Ghana, most farmers harvest soybean manually because their farms are usually small (0.25 to 2 ha). In manual harvesting, soybean plants are cut at soil level or uproot and heap at various points. For high quality seed, harvesting should be done, when leaves, pods and seeds change their colour. Demir *et al.* (2008) [10] also indicated that the stage of maturity at harvest is one of the most important factors that can influence the quality of seeds. Harvesting too early may result in low yield and quality, because of the partial development of essential structures of seeds (Keller and Kollmann, 1999, Wang *et al.* 2008) [34, 87]. Whereas, harvesting too late may enhance the risk of shattering and reduce the quality of seeds due to ageing. Adverse environmental conditions such as rainfall or precipitation may also result in sprouting of seeds on mother plants (Ellis and Pieta Filho, 1992) [14]. Physiological maturity is a genotypic character which is influenced by environmental factors (Mahesha *et al.* 2001) [41].

The seed yield and quality parameters in any crop are associated with stage at which the seed crop is harvested. In early harvested crop seed, the seed quality will be very poor due to more number of immature and undeveloped seeds, while in delayed harvesting, seed quality are affected on account of field weathering. Hence harvesting of the seed crop at physiological maturity is better as seeds will be having maximum dry weight, higher viability and vigour, besides higher seed yield and yield attributing parameters. (Vasudevan *et al.* 2008) [80].

Kandel, (2010) [31] observed that pre-harvest losses are influenced by the time of harvest and can be reduced by harvesting at physiological maturity. Pre-harvest losses are due to beans that have dropped on the ground prior to harvest. Soybeans usually are treaded on a 13% moisture basis, so harvesting, storing and selling soybean as close to 13% moisture (wet basis) as possible is to the farmer‘s advantage. Soybeans that have moisture content above 13% are likely to mold under warm conditions. On the other hand, soybeans are more likely to split during handling when the moisture content is below 13%. Divsalar Maryam and Bita oskouie (2011) [11] conducted research to evaluate the effect of mechanical damage on soybean seeds germination and vigor after processing. The treatments were, cultivar at three levels (Sahar, Williams and D.P.X) and the moisture percentage at three levels (12-14, 14-16 and 16-18 percent) and the measured characters were mechanical damage percentage and germination percentage. Also the electrical conductivity test and accelerated aging test were conducted to evaluate seed vigour. The variance analysis results showed there was a significant difference in mechanical damage and germination percentage between cultivars in a way that the cultivar of Sahar had the maximum mechanical damage and the highest amount of electrical conductivity and minimum germination percentage. Also there was a significant difference between three moisture levels in measured characters. The moisture of 12-14 percent had the lowest amount of mechanical damage and maximum germination percentage and 16-18 percent had the highest mechanical damage and the lowest germination ability.

Soybean maturity depends on the variety and requires timely harvesting to reduce excessive yield losses. At maturity, the pod is straw-coloured. Soybean should be harvested at physiological maturity, that is when about 90% of the pods have turned brown for a non-shattering variety (e.g. Jenguma) but 80% for shattering varieties (e.g. *Salintuya* I and *Salintuya* II). Some newly released varieties such as Jenguma are low shattering but losses in yield may occur from other causes if harvesting is delayed. If left on the fields after pods are dry, the seeds begin to deteriorate, especially if it is still raining. (SARI, 2012) [63]. The maximum seed quality or physiological maturity may occur at the end of seed filling period or slightly after this phase (Eskandari, 2012) [15].

Osei Tutu, *et al.* (2016) [77] conducted study to determine the most appropriate stage of harvesting in soybean, with minimal effects on seed quality characteristics. The field experiment was conducted at the Research fields of CSIR-Crops Research Institute at Fumesua, Kumasi Ghana (01°36'W; 06°43'N) with the treatment of harvesting soybean pods at physiological maturity, one and two weeks after physiological maturity. Physiological maturity was determined when 90% of the pods on the plant turned brown. The study revealed that soybean varieties harvested at physiological maturity recorded the highest seed yield as compared to other harvesting stages. Delaying harvesting by one and two weeks after physiological maturity resulted in seed yield loss of 49.4% and 63.2% respectively. Varieties harvested at physiological maturity registered high germination percentage, vigour and fat content while those harvested two weeks after physiological maturity had the lowest. Moreover, none of the varieties harvested at physiological maturity stage encountered shattering loss. However, varieties harvested one and two weeks after physiological maturity resulted in 20 and 31.22% shattering loss, respectively, of the total seed weight. The results obtained indicated that for good yield and seed quality, soybean pods should be harvested at physiological maturity.

Raquel, *et al*. (2016) [60] conducted study to characterize the harvest phenological stages of soybean cultivars intended for silage. Cultivars were evaluated for dry weight of the composite sample, branches, leaves and pods; wet mass of branches, leaves, pods and ground natural matter. The first factor corresponds to the harvest stage: R4, R5 and R6; and the second factor refer to two soybean maturity groups (8.0 and 8.1). A significant interaction was detected only for ground natural matter. Higher values of most traits evaluated were observed for the R6 harvest phenological stage. The cultivar with maturity group 8.0 showed higher values for ground natural matter. Gaikwad and Bharud. (2017) [21] studied on four varieties of soybean *viz.*, KDS-837, KDS-798, JS-335 and DS-9712 were grown to determine the effect of time of harvesting on its physical and chemical properties. The hundred seed weight of soybean significantly decreased after physiological maturity. The electrical conductivity of seed was significantly increased after physiological maturity. The protein, oil and reducing sugar of soybean seeds also increased after physiological maturity.

1.2 Effect of threshing methods on seed quality of soybean

Soybean seed is subjected to several post-harvest operations like threshing, drying, grading, transportation and other handling operations. Threshing involve the rubbing action for separating the seed, during this loss of soybean seed quality is mainly due to mechanical damage, it is because of its very thin seed coat and low lignin content leading to little protection to the fragile radical which lies in a vulnerable position directly beneath the seed coat.

The percentage of mechanical damage were non-significant for varieties of soybean. Significant differences in mechanical damage were caused by different threshing methods Jha *et al*. (1996) [30]. Hahalis and Smith (1997) [25] observed that root growth was more sensitive to ageing than shoot growth in soybean. These findings suggest that seed deterioration is generally initiated in meristematic areas of the seed and that the radical tip may be most prone to deterioration. The plumule or embryonic stem is fairly well developed in the resting seed and lies between two cotyledons or seed leaves. Also the radical or embryonic root has practically no protection except that provided by the seed coat and thus it is unusually vulnerable to breakage especially when dry and roughly treated. The radical and plumule or cotyledon can be damaged. Moreover, the resistance is a genetic characteristic that varies among soybean cultivars (Carbonell and Krzyzonowski, 1995) [6].

Ujjinaiah and Shreedhara (1998) [78] reported significant difference for mechanical damage, seed quality aspects and period of storage among threshing methods. Significantly higher mechanical damage of 6.55 per cent was recorded in multicrop thresher as compared to beating with stick (2.33%). The longevity of seed threshed by beating with stick was prolonged up to 15 months, whereas multicrop thresher used seeds could retained only for eight months. Non-significant differences were observed for different moisture levels tried for threshing.

The lower mechanical damage (15.92%) and seed infection (28.37%) was observed in soybean with hand shelling as compared to threshing by beating with sticks on cement floor (33.93 and 28.80 per cent respectively) (Pavankumar, 2000) [54]. Utrecht *et al*. (2000) [79] remarked that, as the embryonic axis in soybean seed is placed at surface of seed, it is prone to the injuries of impacts due to brusing. The moisture content less than 10 per cent prone seeds to split however high moistures may result in seed crushing and brusing that reduce seed germination by accelerating deterioration.

Yadav and Sharma (2000) [68] stated the effects of delayed sowing (22 days later) and delayed threshing (3, 10 and 20 days after harvesting) on seed yield and seed quality in soybean cv. Punjab 1, PK 416 and PK 472 and found that, late sowing reduced seed yield by 28-52%, depending on cultivar. However, there was no decline in 100-seed weight. The germination of the seeds remained above the minimum prescribed level (70%) for 8 months in ambient conditions when the seeds were stored at 8-9 per cent moisture content. Germination was not affected by late sowing or threshing. Lori *et al.* (2001) [39] reported the effect of different damage factors on soybean seed quality and found that, poor quality in soybean (*Glycine max*) seed can be due to physiological, pathological, morphological, anatomical and mechanical causes. They studied soybean seed samples from 7 pre-trading lines, obtained in two consecutive crops. Assessments were performed on day 40 and day 160 after harvesting for the first trial and on day 50 and day 150 after harvest in the second. The method employed was the blotter test. They evaluated different parameters, damaged cotyledons, rotten seed, fungal contamination and germination capacity. Rotten seeds and damaged cotyledons caused by moisture had a striking influence on seed quality and preservation during storage.

Patil and Suryawanshi (2001) [33] remarked that higher resistance to mechanical damage in variety JS-335 due to high lignin content in seed coat as compared to MACS- 124. However, they found negative correlation of seed coat thickness and resistance to mechanical damage and stated that in spite of thin seed coat but maximum lignin content in variety JS-335 it was more resistant to mechanical damage as compared to variety MACS-124. Sharma *et al.* (2001) [68] conducted experiment on seed deterioration during harvesting, threshing and processing of soybean cultivars (PK-472, MACS-13, MACS-58, JS-75-46 and Pusa-16) in field experiments were made in Rajasthan, India, and a comparison of seed quality was made between mechanical and manual post-harvest handling operations during 1995-96 and 1996-97. The mechanical damage of seed ranged from 14 to 36% during 1995-96 and from 11 to 24% during 1996-97 compared to hand-collected seeds where insignificant damage was observed in all the cultivars. The damage was less in all the cultivars during 1996-1997 and was associated with higher seed moisture (11 to 12%) at the time of processing. (Kashaninejad *et al.* 2008) [32].

Vearasilpa *et al.* (2001) [81] reported the significant difference in mechanical damage and broken seeds, after processing and handling between two cultivars. They concluded that the cultivar which had larger seed size and thinner seed coat prone to mechanical damage in comparison with other cultivar. Arango *et al.* (2002) [4] studied the effect of the intensity of mechanical cut damage in the hypocotyls radical axis on the capacity of soybean seeds to produce seedlings with secondary and/or adventitious roots for that purpose seeds of different soybean genotypes, classified into three quality levels (high, medium or low germination capacity) were used. Cuts of 1/3, 1/2, and 2/3 were made using a scalpel on the hypocotyl-radicle axis of non-imbibed seeds. Results indicated that, hypocotyl length was reduced in all three cut intensities. The number of secondary and/or adventitious roots decreased with increasing cut intensity in seeds with high quality level. The cut increased the number of seedlings with negative geotropism in seeds of all quality levels. A cut of 1/2 on the hypocotyl-radicle axis recorded the highest number of seedlings with negative tropism (Wilson, R. F., 2004) [88].

Parde *et al.* (2002) [51] noticed the effect of seed cleaning and handling on soybean seed germination and physical integrity with changing seed moisture content. They also studied the damage resulting from free fall of soybean seed from different height. The vertical bucket elevator significantly decreased germination and increased splits and seed coat damage. The seed lots at 12% M.C. (dry basis), suffered less loss in seed quality than the lots at 10% or 11% M.C. A free fall of soybean seed from varying heights on to the cement floor resulted in immense loss in quality than when dropped on to galvanized iron floor. Rame gowda *et al.* (2002) [59] did the field experiment to determine the effects of different threshing methods (hand shelling, beating with stick on gunny bags, beating with stick on cement floor, mechanical threshing and tractor threshing) on seed quality parameters of soybean cultivars KB-79 and MACS-124 reported that, the highest germination percentage, field emergence percentage and seedling vigour, and lowest seed damage and decrease in germination percentage was recorded in hand shelled KB-79 compared to the control. Mechanically threshed KB-79 showed the lowest seedling infection percentage. Hand shelled MACS-124 had the highest seed moisture content percentage before and after threshing, threshing recovery percentage.

Irrespective of varieties the vigour index of soybean seed threshed by stick beating and processed manually was significantly higher than that of seeds threshed and processed by machine. The different threshing methods produces breaks, cracks, bruises and abrasions in seeds which in turn results in abnormal seedlings of questionable planting value. It is obvious from the available information that mechanical injury to seed not only diminishes production of normal seedlings but also decreases the storage potential of damaged seed that apparently would have produced normal seedlings prior to storage. The obvious manifestation of physical seed damage includes fractures of the radical or bruising of the cotyledons which are difficult to detect under the seed coat. In extreme instances damage to the radical can result in abnormal seedlings which fail to germinate. Any damage to the cotyledons is also concerns because it retards translocation of essential nutrients to growing embryonic axis which culminates in delayed seedling growth (Hartwig *et al*. 1987, Shelar, 2002) [27, 70].

Addo *et al.* (2004) [1] identified the effects of spike-tooth and rasp-bar threshing cylinders on soybean quality. They showed lowest seed-coat damage of 5.36 per cent was obtained with the spike- tooth cylinder at 316 rpm as against 7.17 per cent at the same speed for the rasp-bar cylinder. They concluded that the germination loss was lowest at rasp-bar threshing cylinder speed of 316 rpm and better results were achieved at the lowest cylinder speed in both cases. In general, in soybean threshing at 10 per cent moisture content, spike-tooth cylinder gave better results compared to the rasp-bar cylinder. Fernando *et al.* (2004) [18] reported that, the threshing efficiencies of the threshing mechanism, operating at 1000, 1800, and 2600 rpm, were <50%, 87.3%, and 93.7%, respectively. Seed breakages of 0.35% to 1.11% and seed coat damages of 11.8% to 16.6% were observed.

Padule *et al.* (2004) [50] conducted study on effects of different seed grades (healthy, discoloured, damaged and shrivelled) and threshing methods (tractor and machine threshing) on association of seed borne fungi, seed germination and seedling vigour in the soybean cultivars JS-335 and PK-1029 and found that, healthy seeds showed *Alternaria alternata* and *Fusarium oxysporum* incidence ranging from 4 to 9% with germination from 77 to 83% and seedling vigour index from 2135 to 2181. Discoloured seeds showed *F. oxysporum*, *Cercospora kikuchii* and *Macrophomina phaseolina* incidence ranging from 60 to 68% with germination from 32 to 40% and seedling vigour index from 421 to 467. Damaged seeds showed *Penicillium citrinum* and *Aspergillus niger* incidence ranging from 26 to 37% with germination from 56 to 63% and seedling vigour index from 1053 to 1099. Shrivelled seeds showed *F. oxysporum* and *C. kikuchii* incidence ranging from 41 to 56% with germination from 43 to 52% and seedling vigour index from 712 to 758. Vejasit and Salokhe (2004) [82] studied on machine crop parameters of an axial flow thresher for threshing soybean and found that, the grain damage and grain loss were less than 1 and 1.5% respectively at drum speeds of 600 to 700 rpm and 540 to 720 kg (plant)/h feed rates and at 14.34 to 22.77% (w.b.) seed moisture contents. The maximum power requirement was 2.29 kW at grain moisture content of 32.88% (w.b.) at a drum speed of 700 rpm. The best combination of feed rate, drum speed at 14.34% (w.b.) seed moisture content to obtain higher output capacity, threshing efficiency, lower grain damage and grain losses was 600 to 700 rpm drum speed (13.2 to 15.4 m s-1) at a feed rate of 720 kg (plant ha-1).

Marcondes *et al.* (2005) [42] noticed that there were variations in the soybean seed moisture content during the day that could be lesser by up to three percentage points at the end of the afternoon (6 p.m.) than at the start of harvesting (10 a.m.). Neither the conventional nor the axial flow combine harvesters, when used with specific adjustments, caused differences in soybean seed physiological quality. Mesquita *et al.* (2005) [18] conducted experiment on mechanical harvesting of soybean in Brazil according to different brands and ages of the harvesters, harvesting ground speed, threshing cylinder rotation and grain moisture content and found that, the only brand that carries the axial threshing system showed significantly low levels of mechanical damage and broken grains. Combines which are >15 years old lost significantly more grain than < = 5 years old harvesters. With ground speeds over 7 km h-1, grain losses were 34 and 15.8%

superior than the other ground speeds.. Mechanical damage on grain with >15% moisture content were significantly higher than the damage on the grains with lower level of moisture content.

Mundhe (2005) [47] notified the effect of moisture content (MC) and mechanical processing on seed quality (mechanical damage, germination percent, vigour index, seed coat cracking, recovery and physical purity) of processed soybean (cv. JS-335) seeds and noticed that, seed MC (initially 14.0%) was reduced to 11.7, 9.7 and 8.2% by drying. With increase in MC, mechanical damage decreased at all the stages. For all moisture levels, mechanical damage was higher in elevator than in seed cleaner cum grader and specific gravity separator. When compared to unprocessed seeds for all moisture levels, germination percentage was lower for seeds processed through elevator. Superior germination percentage was observed for seeds processed by seed cleaner cum grader and specific gravity separator compared to raw seeds for all moisture levels. Maximum vigour index was observed as 1390.5 at 11.7% MC for seeds separated by specific gravity separator. With increase in MC at all processing stages seed coat cracking was decreased. The recovery per cent was lowest (84.0%) at 11.7% MC for the seeds processed by specific gravity separator. Highest physical purity of 99.3% was found at 11.7% MC for samples at the outlet of specific gravity separator, i.e. above seed certification standard (98.0%). Henning *et al.* (2006) [28] reported that the seed quality of soybean is reduced due to mechanical damage. The seed injuries are caused from weathering, fungi, artificial drying and mechanical damage during harvest, handling, threshing and storage.

Kausal *et al.* (2006) [33] made experiment on management of mechanical damage to soybean seeds during threshing at Seed Technology Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (M.S.), India and reported that, soybean threshed by tractor treading or by multicrop thresher at 500 rpm showed the least mechanical damage along with the maximum germination percentage and seed vigour index. The use of thresher at 720 rpm lead to reduced seed quality associated with mechanically damaged seeds. The produce from the multicrop thresher at 720 rpm contained 6.5% splits and 31% seed coat-damaged seeds. Removal of all teeth from the concave drum resulted to an acceptable quality containing considerable quantity of chaff with seed. At a speed below 500 rpm, the cleaning system does not work, and recurrent clogging of feed material was also observed which leads to a decrease in the threshing efficiency. Miah *et al.* (2006) [45] identified the effect of storage relative humidity (RH) on germination and vigour of soybean seed and reported that, storage relative humidity, variety and their interaction significantly influenced the seed moisture content, germination percentage and vigour index. The moisture content of soybean seed during storage were found between 7.9-8.5, 9.6-9.8, 12.0-12.3 and 15.3-16.1% for 50, 60, 70 and 80% storage RH, respectively against their initial moisture content of 8.4-9.5% just before storage. With increasing storage RH, the germination and vigour of all the varieties decreased. For each of the soybean variety, the maximum germination percentage was obtained from 50% storage RH and no seed germination was occurred in any of the variety stored under 80% storage RH after two months of storage. More than 92% seed germination was maintained for all the varieties after 6 months of storage. The seed stored under 70% RH showed 83% germination in July that reduced to 74% in November, 2004.

The cumulative soybean seed losses were least for stick beating (1.35%), followed by mechanical threshing (2.70%) and tractor trading (3.84%) in hill areas. A similar pattern was observed for mechanical damage to seeds (7.3, 9.9 and 10.9%, respectively). PK 472 cultivar showed slighter seed damage due to threshing (2.3%) than PK 416 (9.9%) and Soya Harit (10.9%). Stick beating resulted in a high germination percentage. Due to differences in seed moisture contents and climatic conditions the variation in 100-seed weight among the cultivars were observed. Seedling vigour was maximum for seeds of PK 472 and PK 416 obtained through stick beating Sharma and Swaran (2006) [67].

Vieira *et al.* (2006) [84] reported that the combination of speed operations and rotation of threshing cylinder evaluated, did not affect the seed vigor, impurity, bands, sand emergence and germination speed index and that increasing the rotation of the 400 to 500 rpm broken seeds were bigger. Cunha *et al.* (2008) [9] studied effect of the threshing system on the quality of mechanically harvested soybean seeds. Treatment consist of three dissimilar harvesters (conventional cylinder, axial rotor and twin axial rotor), at two ground speeds (6.0 and 7.0 km h-1) and two rotations of the threshing cylinder. The harvester of conventional cylinder worked with a cylinder rotation of 500 and 600 rpm, the axial rotor harvester, with 450 and 500 rpm, and the harvester with twin axial rotor, with 800 and 900 rpm. The results showed that the conventional threshing harvester, as much as the axial ones, conveniently regulated, did not influence the germination and the vigor of the soybean seeds. As to the mechanical injury, the machines of axial flow were better than the conventional one, resulting in a smaller percentage of injury. The twin rotor harvester showed alike performance to the simple rotor.

In the soybean seed production mechanized harvesting losses are one of the main problems. The test was carried out using a randomized design in a factorial scheme 2x2, being treatments composed by two harvesting operating in two speeds, 4,0 a 4,5 km h-1 and 6,0 a 7,0 km h-1,with five replications for each treatment. The results showed the losses of systems of separation was influenced by harvesting, and the others variables are not significative alterations and the losses in the systems of cleaning showed more contribution for the total losses Magalhaes (2009) [40]. Gao Lian Xing *et al.* (2010) [22] evaluated on characteristics and ratio of soybean kernel mechanical damage, results showed that the damaged soybean ratio was notable when soybean kernels compressed in different ways. Strain and load of smashing were also dissimilar when load-speed altered.

Suleyman *et al.* (2011) [74] made study on effects of seed moisture content and threshing methods on bean (*Phaseolus vulgaris* L.) seed quality and reported that 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 occurrence 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 results showed that bean seeds should not be harvested and threshed by machine at below 14% smc if seed quality is to be retained.

Gagre *et al.* (2014) [20] made experiment on study of mechanical damage of soybean due to different threshing and processing methods by using sodium hypochlorite test and reported that the soybean seed coat is very thin and due to this the mechanical damage occurs which is one of the causes of great loss in soybean seed quality during harvest and processing. The mechanical damage to the soybean seed due to threshing & processing methods detected by sodium hypochlorite test shows the lowest damage (10.28%) in variety JS -9305 (V2) followed by JS -335 (V1). The highest mechanical damage was recorded in variety JS - 9560 (V3). Among the threshing methods, the lowest mechanical damage (8.62%) was recorded due to threshing with stick beating (T-1) followed by multicrop thresher (T2). The highest mechanical damage (15.87%) recorded in combine harvester threshing (T3). The seed sample collected before processing (control - P1) showed minimum damage (10.22%) which was at par with mechanical damage of soybean seed drawn at inclined flight belt conveyor -I (P5). The highest mechanical damage was recorded in soybean seed collected at specific gravity separator (P8) (14.44%) from second processing plant sequence. The interaction effect between varieties and threshing methods shows the variety JS 9305 (V2) recorded the lowest mechanical damage (7.04%) when seed threshed with steak beating method and the interaction effect of varieties and processing locations shows that the variety JS 9305 (V2) recorded the lowest mechanical damage (8.67%) when seed sample collected at inclined flight belt conveyor- I in second processing plant sequence. The interaction effect between threshing methods and processing locations shows that threshing with stick beating recorded the lowest mechanical damage (7.00%) when collected before processing. Mechanical damage due to interaction effect between varieties, threshing methods and processing locations was detected by sodium hypochlorite test of soybean seeds shows the variety JS 9305 threshed with stick beating collected before processing recorded the lowest mechanical damage (5.67%).

1.3 Effect of stage of harvesting and threshing method on storability of soybean seed

Storability of seed is mainly a genetic character and it is influenced by pre storage history of seeds, seed maturation and environmental factors during pre and post-harvest stages and storage conditions. Vieira *et al.* (1999) [85] studied on soybean seed in terms of physiological quality and found that significant correlation between mechanical damage, standard germination, accelerated ageing, electrical conductivity and seedling field emergence.

Estevao (2002) [16] evaluated the physiological and pathological seed qualities of two cultivars of soybean (‘BRS 155’43 and ‘Embrapa 48’), treated or not with the fungicide carbendazim (30g a.i./100 kg of seed), stored in two ambient conditions: laboratory (open storage) and simulated tropical conditions during a period of 180 days. He noticed that there was no advantage of using the fungicide to avoid seed deterioration during storage. Seeds of both cultivars lost viability and vigor, after 120 days of storage under simulated tropical conditions. Even so, seeds stored under laboratory conditions (open storage) maintained their quality along the storage period.

Parde *et al*. (2002) [51] studied on mechanical damage to soybean seed during processing. With changing seed moisture content (M.C.) the effects of seed cleaning and handling on soybean seed germination and physical integrity were determined. In addition, storage behaviour of seed and loss of storability caused by damage resulting from free-fall from different heights were determined. Six lots of the variety "MACS-13" at three different M.C.'s were passed through a vertical bucket elevator, cleaner with grader, and gravity separator and assessed for mechanical damage, germination, and vigour index. The storage behaviour of the lots, at varying stages of processing, was studied by performing an accelerated aging test. The vertical bucket elevator significantly decreased germination and increased splits and seed coat damage. The seed lots at 12% M.C. (dry basis), suffered less loss in seed quality than the lots at 10% or 11% M.C. The storage quality of seed, as predicted by the accelerated aging test, at 12% M.C. was also improved than the lots at 10% or 11% M.C. A free-fall of soybean seed from different heights on to the cement floor resulted in greater loss in quality than when dropped on to the galvanized iron floor. Lazarani *et al.* (2001) studied the effect of sowing dates on seed quality of soybean during storage. They reported that with an increased storage period, the seed quality decreases.

The electrical conductivity and leaching of sugars enhanced with an increase in storage period Prasad (2002) [56]. Rupollo *et al.* (2004) [62] conducted experiment on soybean and reported that soybeans are subjected to qualitative and quantitative losses due to numerous factors such as lipid 46 degradation in soybean seeds due to biochemical processes, such as respiration or oxidation. There were significant differences ($P < 0.05$) in the germination percentage.

Venkatareddy *et al.* (2002) [83] reported that seed germination, vigour and storability in soybean were maximum in seeds harvested at. The quality level increased up to physiological maturity stage and then decreased gradually. Colete *et al.* (2004) [7] studied the relationship between the electrical conductivity test and the seedling emergence of soybean in field and laboratory. Germination and seedling emergence reduced as the substrate water potential was reduced, indicating a relationship among the germination, water potential and seed vigor. The electrical conductivity test may be efficient to evaluate soybean 18 seed vigor and, consequently, the performance potential in the field. However, further work is necessary to determine the values or the range of values that indicate the seed vigor level and the adequate use of a given seed lot.

The production of good quality soybean seed which could keep its viability through a storage season is a major challenge in most areas of the humid tropics and sub-tropics. The fast seed deterioration of soybean is thought to be due to lipid peroxidation. Subsequently, resulting in loss of seed viability and quality. The seed invigoration of soybean could be a tool in improving the quality of soybean seed during storage. Soybean seed reaches its maximum potential for germination and vigour at physiological maturity and starts deteriorating on plant itself if harvesting is delayed (field weathering). During post-harvest processing and storage, mechanical damage is another major factor responsible for deterioration in seed quality. Care must be taken during harvesting, threshing, processing, packing, transporting and storage to reduce the rate of deterioration in seed quality of soybean (Gupta, 1976, Shelar 2007) [24, 70].

Shelar *et al.* (2008) [72] found that soybean seed quality is affected during pre and post-harvest periods. At physiological maturity soybean seed reaches its highest potential for germination and vigour. The germination potential (viability) is very short lived in soybean as compared to other oilseed crops and is often decreased prior to planting time. This loss of germination is much more severe under tropical conditions like India. These environmental conditions make very difficult to keep its viability during storage. Such deteriorated seed is one of the basic reasons for low productivity in soybean. Further, the soybean seed is very much susceptible to mechanical injury and damage occurring during post-harvest handling, which affects the viability and vigour of soybean seed during storage. Besides these, large numbers of pathogens are also associated with soybean seed which lead to the decline in germination and storability of the seed. However, the seed quality and viability during storage depend upon the initial quality of seed and the manner in which it is stored. The rapid seed deterioration of soybean is thought to be due to lipid peroxidation, subsequently resulting in loss of seed viability.

Vieira *et al.* (2008) [86] stored two soybean seed lots of different physiological potential in moisture proof containers either at constant temperatures of 10° C and 20° C or at the temperature of 20°C during the first seven months of storage followed by a change to 10°C for the rest of the storage time (9 months). They observed that the maximum amount of leakage was for potassium, followed by calcium and magnesium, iron and sodium regardless of storage period and temperature. As the electrical conductivity test measures the electrolytes that leach out of the seeds when they immersed in water and this leakage is a sign of seed vigour. Cunha *et al.* (2009) [8] conducted experiment on soybean seed quality after harvesting with two types of harvester and two storage times and found that, the use of axial flow and conventional harvesters did not affect the emergence seed index, vigor and germination of soybean seeds. However, the axial flow system provided least mechanical damage. The increase of displacement speed, within the ranges of the operating parameters recommended by the manufacturer, did not change seed quality. Seed vigor reduced during storage.

The soybean seed with good germination, 80% as a minimum and free of weed seed, trash, and damaged beans are recommended to be used for planting. In storage, soybean seed loses its viability rapidly (Pratt *et al*. 2009) [57]. Sharma *et al.* (2009) [69] observed germination percentage, seedling vigor, oil and protein content in germinating soybean seeds located at different node positions of stem axis and reported that per cent germination and vigor index of soybean seeds reduced with storage period of 180 days, also the dry matter content of cotyledons and embryonic axis also decreased during storage.

Fessel *et al.* (2010) [19] studied the effect of temperature and time of storage on electrical conductivity and chemical composition of the imbibing solution of soybean seeds and reported that the electrical conductivity test is not suitable to estimate vigor of soybean seeds stored at low temperature, and potassium is the major ion leakage regardless of the storage temperature. El Abady *et al.* (2012) [13] conducted field experiment on soybean seed quality as affected by cultivars, threshing methods and storage periods and found that, G-21 surpassed G-35 and G-111 cultivars on seed yield and related attributes, oil and protein%, germination, germination after accelerated aging%, seed and seedling vigor. Oil and protein percentages not significantly affected by threshing methods, but exhibited significant effect on seed yield and seed quality. Threshing by hand or by stick methods were reduced seed quality less than mechanical method. Seed viability of soybean cultivars decreased gradually with increasing storage period up to six months. G-111 showed lesser resistance to storage conditions, which might be classed as poor "storer" under the experimental conditions. Higher viability of G-21 seed (as indicated by germination score) than others (G-35 and G-111) might be classified as a good "storer".

The germination potential of soybean seeds declines more quickly during storage than it does in other grain crops (Khaliliaqdam *et al.* 2012) [35]. Fabio *et al.* (2015) [17] reported that mechanical harvesting causes injuries on seeds and may affect their quality. Diverse threshing mechanisms and their adjustments may also affect the intensity of impacts that machines cause on seeds. Study aimed at diagnosing and evaluating the effect of two combines: the first one with a threshing system of axial flow and the other one with a threshing system of tangential flow, under adjustments of concave opening (10 mm, 30 mm and 10 mm for a combine with axial flow and 3.0 mm, 15 mm and 3.0 mm for a combine with tangential flow) and three cylinder rotations on the quality of soybean seeds harvested at two moisture contents. Soybean seeds of cultivar 'ND 4910' were harvested at 16.6% moisture (mid-morning) and 13.7% moisture in the afternoon. The seeds quality was assessed by germination tests, germination speed index (GSI), germination rate, moisture content, percentage of purity and vigor by tetrazolium test. Despite the combine, the results showed that the mechanical injury has most reduced seeds quality, at 16.6% moisture content, concave opening of 30 mm (axial) and 10 mm (tangential) and cylinder rotation of 1100 rpm (axial) and 1000 (tangential), both with the maximum rotations used. The combine with tangential flow had the maximum degree of seeds purity. When seeds moisture content at harvest was close to 13.7%, there was the maximum seed injury, while, at 16.6%, there was maximum number of crushed soybeans, regardless the combine adjustment.

Among harvesting stages, soybean harvested at 90 DAS recorded highest germination and moisture, vigour and lower mechanical damage, EC as compared to other harvesting stages. Delaying harvesting *viz*., 100 DAS and 110 DAS results in increased seed leachates and mechanical damage. Among threshing methods, beating with sticks recorded less mechanical damage and maximum germination, vigour and tractor trampling resulted in higher mechanical damage, EC and minimum germination and vigour. Study indicates that for good seed quality, soybean pods should be harvested at 90 DAS ie at physiological maturity and threshed by beating with sticks (Seema *et al*., 2020) [64, 65].

2. Conclusions

Optimum stage of harvesting is a crucial factor as it directly impacts on seed quality. Soybean seed with a thin seed coat and embryo placed outwards is susceptible to mechanical damage during the threshing operations as the seeds are being rubbed. Thus, seeds should be harvested at physiological maturity *viz*., 90 days after sowing and threshed by beating with sticks to maintain better germination and vigour and seedling dry weight and reduced mechanical damage with minimum seed leachate content throughout storage period.

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