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Impact of Fruit and Seed Maturity on Germinability

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Abstract

Seed growers harvest their crops when they have reached commercial maturity, a stage that does not necessary guarantee good seed quality; therefore, the appropriate harvest time for optimal seed quality has to be determinate for each particular crop. Physiological seed maturity is defined as the stage at which maximum dry matter accumulation is reached, and it has been associated to high physiological seed quality. Several parameters have been proposed to identify this crop stage. In experiments conducted at Chapingo Autonomous University it was defined that the best seed quality for tomato is obtained when pink and red fruits are harvested, while for husk tomato, high seed germination percentage is achieved when seeds are extracted from yellow fruits. In the 'Bayomecentral' bean variety, high germination is observed for seeds with 47 % moisture content. For 'Early perfection' pea variety, seed germination above 84 % was obtained when fruits were harvested 35 days after anthesis; however, high seed vigour was registered when fruits were harvested 35 days later. Maize single cross hybrid 'H-28' showed seed germination above 50 % when seeds were harvested 42 days after anthesis, and the highest germination and seedling vigour were observed when harvest was delayed until 56 to 63 days after the anthesis.

Keywords: Bean, husk tomato, maize, pea, seed quality, tomato

Introduction

Modern agriculture success depends on ecological, economic and technological factors interaction, where the use of improved varieties has been crucial since they have resistance to adverse factors, good fruit quality and high yields. Good quality seeds, besides of having genetic pureness and sanity, should also have good germination and vigour; and those attributes greatly depend on opportune seed harvesting (Álvarez-Medina et al., 2011). Because timely seed harvest is essential to reach high seed quality, various quantitative and qualitative indexes in fruits, plants and seeds have been proposed in order to identify the appropriate harvest time (Borisjuk et al., 2004).

Several studies have shown that when harvest is conducted close to the maximum dry matter accumulation stage, known as the physiological maturity phase, it assures good seed quality (Borisjuk et al., 2004); however, distinct studies also have shown that this situation cannot be applied to all plant species (Hamdollah et al., 2012). Therefore, fruit color could be a good indicator in tomato (Dias et al., 2006), and husk tomato (Martínez et al., 2004); in this last case, change in the calyx color and also in the seed color from white to beige can be associated to good seed germination and vigour (Criollo and Upegui, 2005).

For maize, in 1969 Daynard and Duncan proposed to use the presence of the "milk line", in addition to the formation of the black layer in the base of the grain, as good indicators that physiological maturity has been reached (Borisjuk et al., 2004). An additional criterion that has been established is grain moisture content, since it has been accepted that maturity is obtained at 35 to 40 % (Bennett, 1988); so, this is the main criterion for seed harvest among the maize hybrids industries.

In legumes, pod color has been considered a good indicator. For peanuts, it has been found that seed harvested at optimum maturity (> 75 % of pod surface brown) and over raped (> 80 % of pod surface black) showed similar percentages of germination and vigour, due to a higher calcium accumulation compared to previous stages. Therefore, it could be useful to initiate breeding programs that consider the maintenance of seed vigor with higher seed Ca content in cultivars (Nautiyal et al., 2010). In the case of the soybean, the best seed quality is obtained if harvest is performed when 80 % of the pods show brown color (Borisjuk et al., 2004). While for pee, is also necessary that seeds reach appropriate weight because immature seeds could present low germination due to low gibberellic contents (Swain et al., 1977). Thus, the aim of this study was to define indicators that allow the identification of the opportune harvest time for five crop species in order to obtain high quality seeds.

Materials and Methods

Five field experiments were carried out to evaluate the impact of fruit and seed maturity on germinability of tomato, husk tomato, maize, pea and bean seeds. The experiments were established at the field experimental station and at the seeds laboratory in Chapingo University, México.

Tomato

Five commercial hybrids: 'Loreto', 'Reserva', 'Charanda', 'Marcia' and 'Sahel', with indeterminate growth habits and saladette fruit types were grown hydroponically in greenhouse conditions, under a randomized complete block design, with four repetitions. Twenty fruits were collected at five distinct maturation stages: a) green: fruits completely developed but with green color, b) mottled: green color had disappeared from at least 90 % of the fruit surface and presented in a pink color, c) red: fruits showed a strong red coloration and firmness, d) 20 days after maturity (20 DAM): fruits were harvested at the red stage and left at room conditions in the lab for 20 days, e) 40 days after maturity (40 DAM): fruits were harvested at red stage and left at lab conditions for 40 days.

Dried seeds from the twenty five treatments were sown in lab conditions using a completely randomized design, where each experimental unit was formed by one 3.5“ diameter Petri dish containing 50 seeds and filter paper as substrate. Petri dishes were put into a Seedburo® germination chamber at 25^{o}C and 98 % relative humidity for 21 days (ISTA, 2005).

Husk Tomato

A field plot of husk tomato (*Physalis ixocarpa* Brot.) 'Rendidora' variety was established, and samples of one hundred fruits were obtained at commercial maturity, 77 days after transplant. Seeds were extracted at 15, 60 and 75 days after harvest.

Physiological seed quality was evaluated using a completely randomized design with eight repetitions, where each experimental unit was formed by one 3.5“ diameter Petri dish containing 50 seeds and filter paper as substrate. Petri dishes were put into a Seedburo® germination chamber at 30^{o}C and 98 % relative humidity for 21 days (Martínez et al., 2004).

Bean

A field plot of bean commercial variety 'Bayomecentral' was established under a randomized complete block design with four repetitions, where the experimental unit was integrated by 20 rows of 10 m long and 0.70 m width (140 m^2). Eighty days after sowing, seed samples were harvested every week for 15 weeks, including different maturation and post maturation stages.

Dried seeds were used to conduct rolled up wet paper towels standard germination tests under lab conditions. A completely randomized design with four repetitions of one hundred seeds each was used. “Rolls” were put into plastic bags and collocated in a Seedburo® germination chamber at 25^{o}C and 98 % relative humidity for 8 days (ISTA, 2005).

Pea

A field plot of 'Early perfection' commercial pea (*Pisum sativum* L.) variety was established under a randomized complete block design with four repetitions, where the experimental unit was integrated by 20 rows of 10 m long and 0.70 m width (140 m^2). Twenty two days after flowering, seed samples were obtained every week for 16 weeks, covering different maturation stages.

After the seeds were dried, germination tests in 30 x 24 x 7 cm plastic trays filled with agrolite were conducted at greenhouse conditions, at 25^{o}C. Tests were established under a completely randomized design with four repetitions of 25 seeds each during 21 days. Seeds were sowed 4 cm depth.

Maize

H-30 maize hybrid's parents were planted at field conditions under a randomized complete block design with two repetitions, where experimental units consisted of 30 rows of 10 m long, 0.80 m width and plants 25 cm apart. Thirty five days after the anthesis of H-30 maize hybrid male parent, samples of six ears were harvested to obtain seeds every week for 9 weeks. Ears were dried at room temperature and afterwards dried seeds were used to conduct rolled up wet paper towels standard germination tests under lab conditions. A completely randomized design with three repetitions of one hundred seeds each was used. "Rolls" were put into plastic bags and collocated in a Seedburo® germination chamber at 25^{o}C and 98 % relative humidity for 8 days (ISTA, 2005). The percentage of germination and the speed of the germination index were estimated. In addition, accelerated aging tests and cool test were conducted under a completely randomized design with four repetitions of one hundred seeds each, according to suggestions from the vigor test manual (Hampton and Tekrony, 1995).

Physiological Seed Quality

Twenty one (tomato, husk tomato and pea) and eight (bean and maize) days after sowing at laboratory conditions, the following traits were evaluated: percentage of germination (PG), and speed of germination (SG) according to Maguire (1962). In addition, a 10 seedlings sample per variety was used to measure root length (RSL) considering from the root tip to seedling neck, and aerial seedling length (ASL) from seedling neck to last leave tip.

Statistical Analysis

Results were subjected to the analysis of variance, and multiple means Tukey's test using SAS 9.1 ver. software.

Results and Discussion

Tomato

All physiological seed quality evaluated traits showed significant differences among maturation stages (Table 1). Seeds obtained from green fruits showed low values for the percentage of germination (PG), speed of germination (SG), aerial seedling length (ASL), and root seedling length (RSL). These results could be attributed to the fact that at the green stage embryo development has not been completed and dry matter accumulation in the seed is still low (Borisjuk et al., 2004).

High PG values were observed for seeds extracted from pink and red fruits storage for 20 days (20 DS); therefore, it can be considered that during this period seeds could have reached their physiological maturity (Dias et al., 2006), since at 40 days of storage (40DS) seed germination declined due to deterioration.

Table 1. *Physiological Seed Quality Traits in Tomato Seeds Extracted from Fruits at Different Ripening Stage*

Ripening stage	PG (%)	SG	ASL (cm)	RSL (cm)
Green	18.85 c[z]	1.68 d	1.59 b	2.72 c
Pink	92.61 a	11.61 c	3.42 a	10.87 a
Red	90.58 ab	12.28 c	3.78 a	10.68 ab
20 SD	94.00 a	15.47 a	3.76 a	9.91 b
40 SD	87.26 b	13.36 b	3.61 a	11.02 a
HSD	4.0334	0.6825	0.4325	0.8775

[z]Values with different letters in columns are statistically different (Tukey, $p \leq 0.05$); DS: Days of storage; PG: percentage of germination; SG: speed of germination; ASL: Aerial seedling length; RSL: Root seedling length; HSD: Honestly significant difference.

High SG was observed at 20 SD, while vigour traits such as ASL and RSL presented good performance at all ripening stages with the exception of green stage; therefore it could be considered that starting at the stage when fruit becomes pink, seed weight and physiological quality achieved optimal conditions (Dias et al., 2006).

In conclusion, the tomato best seed quality is obtained when seeds are extracted from pink and red fruits storage for 20 days (20 SD), since apart of showing a high percentage of germination, also presented high vigour (SG, ASL, RSL). However, it is important to establish that distinct tomato genotypes could behave differently for fruit ripening.

Husk Tomato

Seeds extracted 60 days after commercial maturity showed the highest percentage of germination (93.2 %), exceeding in 79 % samples extracted from fruits storage for 15 days, due to the immature stage of the seeds in early stages (Borisjuk et al., 2006), which is also reflected in low speed of germination (SG) (Table 2). Seeds obtained from fruits storage for 75 days were 15 % lower than the highest value, probably due to slight deterioration (Martínez et al., 2004); however SG was similar to the best treatment. These results indicate that seeds storage for 60 and 75 days have completed their metabolic processes (Borisjuk et al., 2006) and therefore allowed a good expression of SG.

Aerial seedling length (ASL) and root seedling length (RPL) exhibited the same behavior for the three evaluated treatments, which suggest that at the harvest time the maximum accumulation of dry matter has already occurred, since both variables depend mainly on seed dry weight (Bennett et al., 1988; Hamdollah et al., 2012). Then, differences between PG and SG could be explained because metabolic and hormonal processes were different for each storage period.

Table 2. *Physiological Seed Quality Traits in Husk Tomato Seeds Extracted from \Commercial Ripe Fruits after Three Storage Periods*

Storage period	PG (%)	SG	ASL (cm)	RSL (cm)
15 days	19.6 c[z]	3.4 b	1.3 a	0.22 a
60 days	93.2 a	24.9 a	1.8 a	0.20 a
75 days	79.2 b	27.1 a	1.9 a	0.25 a
HSD	9.83	4.58	0.75	0.28

[z]Values with different letters in columns are statistically different (Tukey, $p \leq 0.05$); SD: Storage days; PG: germination percentage; SG: Speed of germination; ASL: Aerial seedling length; RSL: Root seedling length; HSD: Honestly significant difference.

Pea

The means comparison test shows that the percentage of germination was the same from 35 days after anthesis (DAA); however, 100 % of PG was observed at 49 DAA (Table 3), possibly because at this stage the seeds had their maturity characteristics more defined since as seeds mature, their ability to germinate rapidly and vigorously also increases (Hamdollah et al., 2012).

By the contrary, seeds from early stages presented germination percentages from 26 to 33 %, which could be attributed to the fact that they still did not have adequate conditions to reach a better physiological quality (Swain et al., 1997).

Tukey's test indicates that between 22 and 35 DAA low SG values were obtained, probably because the seeds were not completely developed and consequently their physiological processes were at an unsatisfactory stage (Nautiyal et al., 2010); nevertheless, from 42 DAA values increased reaching 5.4 of SG at 63 DAA, showing a light tendency to decrease in the last samples due to deterioration.

The largest aerial seedling length (ASL) was observed between 49 to 85 DAA, possibly due to the fact that during this period the seeds reached their highest dry weight from which seedling length majorly depends (Hamdollah et al., 2012). Low ASL both in early and late samples responded to low dry weight accumulation and deterioration, respectively.

Table 3. *Physiological Seed Quality Traits in 'Early Perfection' Pea Variety Extracted from Pods at Different Ripening Stage*

DAA	PG (%)	SG	ASL (cm)
22	33.0 b[z]	0.7 d	3.8 f
28	26.5 b	0.5 d	4.9 bcde
35	84.0 a	2.7 d	4.3 ef
42	84.0 a	3.7 ab	5.1 bcd
49	100.0 a	4.3 ab	5.4 abc
56	99.0 a	4.1 ab	5.1 bcde
63	96.0 a	4.5 a	5.2 abcd
70	98.0 a	4.4 ab	5.9 a
77	96.0 a	4.3 ab	5.2 abcd
85	91.0 a	3.6 b	5.5 ab
92	97.0 a	3.7 ab	4.8 bcde
97	92.0 a	2.5 bc	5.0 bcde
104	95.0 a	3.7 ab	4.6 cdef
111	97.0 a	3.9 ab	4.5 def
118	97.0 a	3.7 ab	4.6 cdef
126	95.0 a	4.0 ab	4.8 bcde
HSD	2.61	0.879	0.7951

[z]Values with different letters in columns are statistically different (Tukey, $p \leq 0.05$); DAA: days after anthesis; PG: germination percentage; SG: Speed of germination; ASL: Aerial seedling length; HSD: Honestly significant difference.

Bean

Analysis of variance indicates highly significant differences among the 15 samples. From 80 to 121 days after planting (DAP) moisture content diminished to 69 %, concurring with dry matter accumulation, meaning that seeds went through different development stages (Borisjuk et al., 2004). From 121 to 176 DAP moisture content equilibrated to the environment (Table 4).

During the first three harvest dates, seed germination (PG), speed of germination (SG), and seedling length (SL) were low; however, from 107 DAP these values increased, showing 88 % of PG at 128 DAP and 2.38 and 6.82 values for SG and SL, respectively, at 150 DAP. These results indicate that the harvest of immature seeds results in low germination, while late harvest also decreased it slightly due to deterioration (Bhering et al., 2006).

Table 4. *Physiological Seed Quality Traits in 'Bayomecentral' Bean Variety Extracted from Pods at Different Ripening Stage*

Sample	DAP	MP (%)		PG (%)		SG		SL (cm)	
1	80	84.0	a[z]	1	d	0.93	e	1.58	cd
2	86	80.5	a	9	d	0.27	de	3.70	bc
3	93	72.3	b	2	d	0.06	e	0.69	d
4	100	64.8	c	51	bc	0.66	d	3.74	bc
5	107	47.3	d	74	abc	2.20	abc	4.92	ab
6	114	42.0	d	64	abc	2.20	abc	5.48	ab
7	121	31.8	e	78	abc	2.06	abc	5.66	ab
8	218	15.0	f	88	a	2.33	ab	6.48	a
9	135	10.0	g	81	ab	1.81	c	5.52	ab
10	143	15.5	f	45	c	2.11	abc	6.17	ab
11	150	15.0	f	49	bc	2.38	a	6.82	a
12	155	10.3	fg	60	abc	1.98	abc	6.28	a
13	162	10.5	fg	81	ab	1.85	bc	6.47	a
14	169	9.3	g	63	abc	1.82	c	5.28	ab
15	176	8.8	g	53	bc	1.75	c	5.39	ab

[z]Values with different letters in columns are statistically different (Tukey, $p \leq 0.05$); DAP: days after planting; MP: Moisture percentage; PG: germination percentage; SG: Speed of germination; SL: Seedling length.

Maize

High percentages of germination (PG) were obtained by samples between 56 and 84 days after anthesis (DAA), period of time in which physiological maturity probably occurred; for early stages, seed germination in the first sample (35 DAA) was 36 % lower than the best treatment; these results suggest that immature embryo (Borowskil et al., 1991), low hormone content (Swain *et al.*, 1997), and unfinished metabolic processes (Borisjuk et al., 2006) in the seeds caused low expression of germination (Table 5). Germination did not reached values greater than 88.6 % as a result of the selection of seeds at random coming from the same ear but with distinct degrees of maturity.

The highest speed of germination (SG) was observed at 63 DDA, while lower values were obtained both in early and late harvest, as a result of immaturity and deterioration, respectively. These explanations also apply to results obtained for vigour tests, since in samples 1, 2, 3, 4, and 9 vigour was low. Accelerated ageing test (AA) and cool test (CT) found the highest vigour at 77 DDA and from 63 to 84 DDA, respectively. If it is considered that the germination test and cold test were developed to evaluate vigour in maize (Bhering *et al*., 2006), it can be concluded that the best physiological seed quality is obtained between 63 and 84 DDA.

Table 5. *Physiological Seed Quality of Maize Harvested at Different Maturity*

Sample	DAA	PG (%)		SG		AA (%)		CT (%)	
1	35	56.7	g[z]	2.81	g	19.7	i	49.6	d
2	42	62.5	e	3.16	f	31.2	h	73.6	c
3	49	82.3	d	3.67	d	50.3	g	82.0	b
4	56	86.9	abc	3.79	b	57.2	f	83.7	b
5	63	88.6	a	3.94	a	68.7	d	88.2	a
6	70	84.5	cd	3.77	bc	73.1	b	87.2	a
7	77	87.9	ab	3.69	cd	75.6	a	86.0	a
8	84	87.2	abc	3.61	d	71.1	c	86.0	a
9	91	85.1	cb	3.34	e	62.6	e	83.0	b
HSD		2.21		0.09		1.55		2.81	

[z]Values with different letters in columns are statistically different (Tukey, $p \leq 0.05$); DAA: days after anthesis; PG: germination percentage; SG: Speed of germination; AA: Accelerated ageing test; CT: Cold test: HSD: Honestly significant difference.

Conclusions

Early and late harvest affected the physiological seed quality negatively, in all the crops evaluated.

Tomato seeds extracted from pink and red fruits as well as from red fruits storage for 20 days reached the highest germination.

Husk tomato seeds extracted 60 days after commercial maturity showed the highest percentage of germination.

Even though high germination in pea seeds was obtained from 35 days after anthesis (DDA), 100 % germination was only observed at 49 DAA.

The highest seed germination of bean was obtained between 107 and 169 days after planting (DAP), meanwhile the highest speed of germination was reported between 107 and 155 DAP.

High percentages of germination were obtained on maize kernels harvested between 56 and 84 days after the anthesis, period in which physiological maturity probably occurred.

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