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Validity of the Mechanical Threshing of Onion Seeds from the Point of View of Seed Quality

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Abstract: Background: The production of seeds for horticultural crops has seen a steady growth since 2006. Onion is one of the most widespread crops that followed this trend until 2013, undergoing a slight decline in 2016. Even though these crops are characterized by high economic value, they present some important issues such as high costs and labor required by some operations such as threshing. The purpose of this study is the evaluation of a patented and dedicated system for mechanical threshing throughout the evaluation of seed quality parameters. Methods: The study was conducted comparing seed samples mechanically threshed obtained from 12 companies and samples of the same batches manually threshed to determine the maximum qualitative potential. The chosen terms for comparison are the most important qualitative parameters included within ISTA standards for seed evaluation. Results: The mechanically threshed seeds show lower values for all the considered quality parameters compared to those found in the control samples. In the same way, there is also greater variability. Conclusions: The introduction of the dedicated mechanical systems allows the reduction of seed processing time while maintaining the quality standards within the limits of merchantability, but for obtaining higher standards, further analysis is necessary.

Keywords: germination; germination energy; *Allium cepa*; threshing; survey; manual threshing; mechanical threshing; abnormal seeds; rotten seeds; rotten germs

1. Introduction

Seed crops are characterized by relatively low cultivation surface but high economic value. The total surface devoted to the production of seeds in Italy in 2016 was over 37,000 ha with an increase of more than 10,000 ha when compared to 2014 [1,2]. In 2014, onion was the first crop in terms of cultivated area, after coriander, with a consistent drop in 2016 from 1700 ha to 980 ha. Three regions hold the primacy: Emilia Romagna, Marche and Puglia with respectively 34%, 24%, 11% of the total cultivated surface [2]. Marche region is the second producer in Italy with an increased surface of about 9000 ha (from 7000 in 2014) [1]. As described by Gaikwad et al. [3] the most common method used to produce onion seeds is the "bulb to seed" method. According to this method, the production is divided into two steps, based on the biyearly physiological characteristics of onion. In the first year, onion mother-bulbs are produced in nurseries starting from seeds. Subsequently, mother-bulbs are sorted and transplanted in the following year to produce seeds [3]. Seed crops are highly specialized and the production requires many steps with high economic costs that are labor consuming. From a study of Centro di Ricerca Produzioni Vegetali (CPRV) of Cesena, it emerged that the total cost to cultivate one hectare of onion ranges from 4700 and 7300 euros.

As an overview, transplanting, pests and disease control, harvesting, cutting and threshing are the main expenditure items with percentages of 10–16%, 5–15%, 23–27%, 15–19% and 5–7% respectively [4]. For this reason, companies have pushed for an ever-greater mechanization of the main production phases in order to minimize time, labor and therefore costs. In recent years, many machines for harvesting have been developed and released in the market. Examples are Spapperi model RC443, onion harvester by Meneguzzo, and onion harvester by Montebelli. These machines have been designed to reduce collection time on large plots and their use is almost exclusively possible on flat ground. The onion seed crops of Marche region are typically cultivated in hilly terrain and on surfaces that hardly exceed two hectares. In these conditions, the aspects of greater economic impact are difficult to be minimize, so companies opted for phases in which environmental conditions have little importance such as threshing. In the past, the most common system employed for onion threshing was the manual one, in which the flower heads, after a drying period, are rubbed between the palm of the operator's hands to allow the seeds to be released from the capsule. Manual threshing is a long and laborious process which often discourages farmers from cultivating onion due to a lack of skilled labour or the excessive cost. Anyway, onion is still considered an important crop to be valorized [4]. To limit threshing costs, the practice has shifted to mechanical systems. The first generation of mechanical threshing machines, still widely used, consists of common wheat threshing machines appropriately set. These settings generate excessive variability in seed quality. The second generation of threshing machines is designed and constructed only for plants of horticultural interest of the Liliaceae family [5,6]. The principal aim of these machines is the increase of threshing yield without compromising seed quality. Considering that seed crops have the aim of producing breeding material for food crops, seed quality is a critical aspect [7], essential to ensuring crop success. As stated by the Italian government in the legislative decree number 212–001 [8], the minimum germination for marketing of onion cannot be less than 70% * (Value related to hybrid seed. For quality declared seed systems of FAO (Food and Agriculture Organization) the minimum percentage for open pollinating onion seeds is 60%), the same value was stated by FAO in quality declared seed system in 2006 [9]. The market demands a significantly higher germinability. From the point of view of the seed user, the high germination ensures greater propagation efficiency and lesser problems arising from the low plant emergence. Therefore, in the production of seeds, any innovation or variation in the production process should maximize economic convenience without affecting seed quality. Many authors already stated that mechanical damages to seeds can reduce their germination and storability for different species: Phaseolus and pulses [10–13]; rice [14], wheat [15] and other minor crops [16]. Despite the fact that the previous information is essential for a correct design of a threshing machine, only few studies analyzed onion. Some authors analyzed the mechanical and physical properties of onion seeds [17–20] as static coefficient of friction of seeds in relation to moisture, finalizing the results to thresher manufacture or setting up. Other authors evaluated the effects of operational variables on seed quality parameters, and developed a performance index [5], others, again, developed the machine and tested the qualitative parameters of the seeds [6].

The principal aim of the present study is the evaluation of mechanical threshing reliability of a machine employed in Italy through the assessment of standard quality parameters for seeds in comparison with manual threshing.

2. Materials and Methods

The cultivation system of the biennial onion seed production considered in this study follows the "bulb-to-seed" principles. So, the cultivation entails two phases:

1. Vivarium: consists in the production of bulb-seed used as transplanting material for seed production in the next cropping season.
2. Cultivation: is the core phase for seed production.

In this study, the subject is this last phase and the following surveys were conducted.

2.1. Geographical and Climatic Framing

Selected farms are all included within the Cesano river basin, between the districts of Ancona and Pesaro Urbino, as reported in Figure 1. The same basin is commonly divided into low valley and high valley. The companies under examination are all in the lower valley where annual climate is typically Meso-Mediterranean as evident in the thermo-pluviometric trend reported in Figure 2.

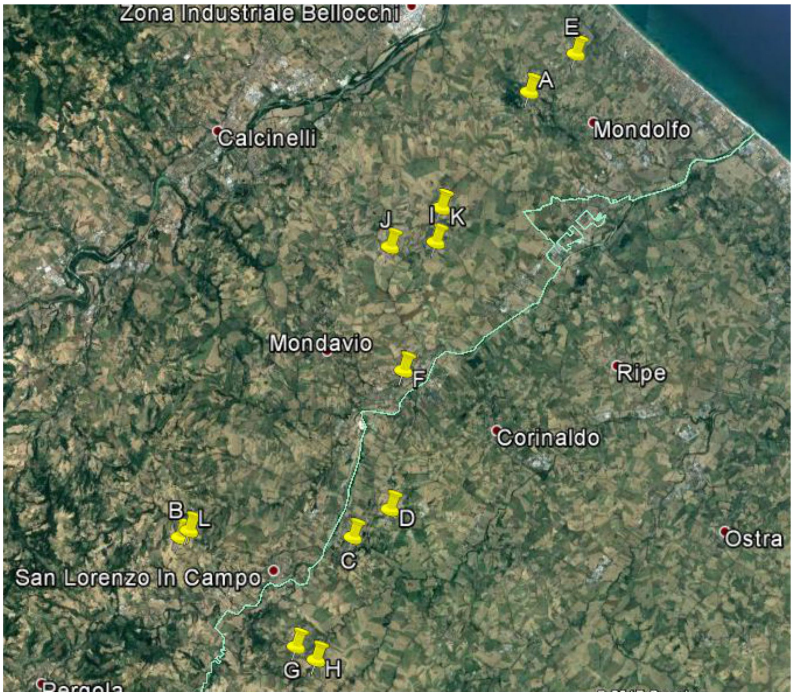

Figure 1. Geographical framework of the farms object of study (Google Earth, 2017 revised).

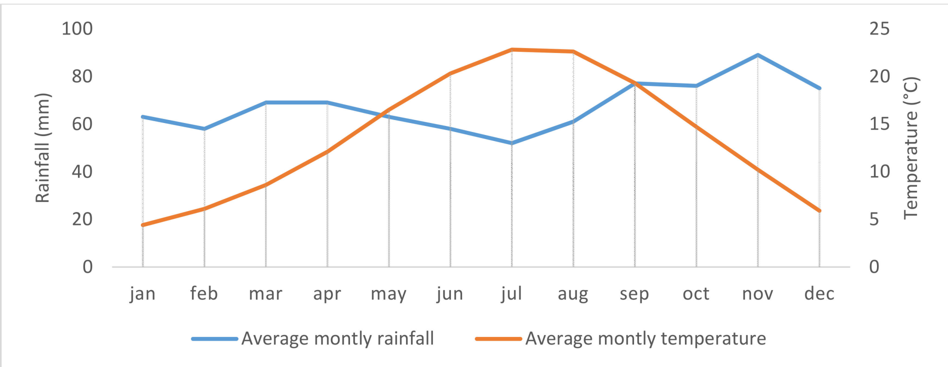

Figure 2. Low Cesano valley's annual thermo-pluviometric trend for the reference period (MeteoAM.it).

2.2. Farms Description

The first action regarded the construction of the preliminary information framework. Table 1 reports the information collected regarding different environmental and management aspects for the selected farms. The study was conducted in the cropping season of 2016 on 12 different fields. To each field has been assigned a progressive alphabetic code from A to L. Each field belongs to a different company except for G and H which are two portions of the same company with almost identical characteristics as shown in Table 1.

Table 1. Main technical and geographical characteristics of the companies.

Company Code	A	B	C	D	E	F	G	H	I	J	K	L
Cultivar	1	2	3	3	2	4	5	5	6	6	6	7
Surface (ha)	0.5	1.4	0.7	0.7	1.3	1.5	1.0	1.0	1.5	1.0	1.9	0.5
Ratio	2/2	8/4	8/4	8/4	8/4	8/4	8/4	8/4	8/4	8/4	8/4	3/1
Phytosanitary state	3	2	4	3	2	2	3	4	3	4	3	4
Drying	T	C	C	TG	T	T	TG	T	C	T	C	T
m a.s.l	152	346	218	179	77	223	236	193	216	185	98	315
Exposure	NW	ENE	NNW	ESE	NNE	N	ENE	NW	SE	ESE	NW	SSE
Soil texture	Loam	Loam	Clay	Clay	Loam	Sandy	Sandy	Sandy	Loam	Loam	Loam	Loam
Yield (kg/ha)	248	62	122	28	177	440	639	639	213	661	141	449

T: code for tunnel with plastic darkening and waterproof cover; TG: code for big tunnel; C: code for system with agricultural shed. Code for exposure: N: north; S: south; W: west; E: east.

The ratio indicates the ratio between pollen and seed-bearing lines. It indicates the number of rows of seed and pollen-bearing lines. The different ratio depends on physical and physiological characteristics of pollen and the same relationship tends to maximize the seed's pollination. The phytosanitary state is reported in a progressive sequence of numbers from 1 to 4 where 1 means the worst state and 4 means absence of disease. Table 2 is reports a synthetic description of cultivar for the different codes assigned.

Table 2. Cultivar main characteristics.

Cultivar	Colour	Shape	Type	Country of Selection	Downey Mildew Sensitivity
1	Golden	Round	Hybrid	Italy	sensitive
2	Yellow	Round	Hybrid	Holland	low sensitive
3	Red	Round	Hybrid	Holland	low sensitive
4	Red	Round	Hybrid	Holland	low sensitive
5	Yellow	Round	Hybrid	Holland	low sensitive
6	Yellow	Round	Hybrid	Holland	sensitive
7	White	Flattened	Hybrid	Italy	sensitive

2.3. Threshing Apparatus and Seed Sampling

The threshing machine used in this study has been made by a farmer involved in the production of onion seed and subsequently used by the seed company to which he is linked. The process is divided into two elaborations. The first one performs the threshing through the combined action of a cylindrical sifter and a rotating axis with paddles (450–500 rpm). The second elaboration consists of a physical and pneumatic separation, operated by sieves. Specifically, there are two sets of sieves with an air counter flow. The machine was patented in 1985 by Bianchi [21]. The patent ID is IT1187095 (B) and international classification code A01D HARVESTING; MOWING (parts, details or accessories of agricultural machines or implements in general A01B51/00-A01B75/00). The registration code is IT19850012017 19850603.

For each batch, the sampling has been performed in different ways for mechanically and manually threshed seeds. The primary seed sample from mechanical threshing has been taken following the ISTA standards and using a multilevel sampler. The standard establishes the withdrawal of at least five samples for seed lot of more than 500 kg. In the specific case study, the product lot coincides with the entire production of each individual company, thus the sampling has been conducted collecting the appropriate number of samples from each container.

The manually threshed seed sampling has been conducted by collecting some flower heads, about the same quantity sampled for the seeds mechanically threshed, from the drying frames according to a X-scheme.

Sampling was repeated on each chassis, taking five subsamples each. Sub-samples were then inserted inside a large container and on this the final sample has been withdrawn. Consecutively, each single capsule of each flower head was opened to free the seeds avoiding any kind of rubbing that could damage them or compromise their germination.

2.4. Germination Tests

Germination tests were carried out in the laboratory of the Agricultural Cooperative Cesenate (CAC) specialized in the seed sector and accredited to the International Seed Testing Association (ISTA). The method is established by the international Rules for Seed Testing that provides for:

- Random sampling of four sub-samples of 100 seeds each (replicates).
- Positioning of the seeds, of each replica, equidistant between them in separate trays and on sheets of paper soaked with 11 mL of distilled water (Figure 3).
- Vernalization in a refrigerator at 3 °C for 4 days (Prechill phase) (Figure 3).
- Germination in the climatic chamber at 20 °C for 6 days.

At the end of the sixth day in the germination chamber, the trays were picked up and the first count was performed. Then the method considers re-inserting the containers under the same conditions and a subsequent count on the 12th day. At the end of the second count, some samples had further germinating potential for which the test was extended according to the standard.

Figure 3. Plastic trays with molded germination paper and seeds ready for the prechill at 3 °C for 4 days in refrigerator.

2.5. Quality Parameters

Quality parameters obtained after germination tests are reported below.

1. Germination energy (*G.E.*): Corresponds to the ratio between the total number of seeds of the sample and the sum of the products between seeds germinated at time *t* and the same time (formula (1)).

$$\overline{\boldsymbol{G.E.}}\ \% = \frac{\Sigma(n_1 \cdot t_1) + (n_2 \cdot t_2) + (n_i \cdot t_i)}{\mathrm{N}} \times 100 \quad (1)$$

as established by ISTA standards the germination energy has been calculated considering the number of germinated seeds at the first counting (t_1 = 1). The previous formula can be simplified as follows (2).

$$\overline{\boldsymbol{G.E.}}\ \% = \frac{n_1 \times t_1}{\mathrm{N}} \times 100 \quad (2)$$

2. Germinability (*G*): defined as the percentage of seeds germinated in the period prescribed by the standard method (3).

$$\overline{\mathbf{G}}\ \% = \frac{n_1 + n_2 + n_i}{\mathrm{N}} \times 100 \quad (3)$$

3. Rotten germs (*R.g.*): is the percentage of seeds that in the maximum period prescribed by the ISTA methods have developed shoots, but they are rotted due to pathogenic attacks (4).

$$\overline{\boldsymbol{R}}\boldsymbol{.g.}\ \% = \frac{n_{R.g.}}{\mathrm{N}} \times 100 \quad (4)$$

4. Rotten seeds (*R.s.*): is the percentage of seeds that, at the end of the test, have been marked by marshal or softening (5).

$$\overline{\boldsymbol{R}}\boldsymbol{.s.}\ \% = \frac{n_{R.s.}}{\mathrm{N}} \times 100 \quad (5)$$

5. Abnormal seeds (*A.s.*): is the percentage of seeds that, at the end of the test, have been marked by obvious changes to root, apex and cotyledons (6).

$$\overline{A}.s.\ \% = \frac{n_{A.s.}}{\mathrm{N}} \times 100 \quad (6)$$

The data were processed to obtain a significance assessment of the possible difference between the germinating characteristics of the seeds mechanically threshed and the maximum germination potential. Whereas the comparison is focused only on the evaluation of the mechanical threshing, the statistical analysis carried out regards the t-student tests of median comparison. Other variables have not been taken into account with only two exceptions which will be better described below.

The equation used for calculating the experimental t value is reported below (7).

$$t = \frac{\overline{X}_i - \overline{X}_j}{\sqrt{\frac{s_i^2 \times (n_i - 1) + s_j^2 \times (n_j - 1)}{n_i + n_j - 2} \times \left(\frac{1}{n_i} + \frac{1}{n_j}\right)}} \quad (7)$$

where X_i and X_j are the sample mean values for sample *i* and *j* for all the quality parameters tested. n_i and n_j are the sample size *i* and *j*.

s^2 is the variance (Average squared deviation) of the sample defined by the formula (8).

$$s^2 = \frac{\sum_{i=1}^{n} \left(x_i - \overline{X}\right)^2}{n-1} \quad (8)$$

As reported above, only two variables in precise contexts have been considered for a comparison using the same *t*-student test. The first one regards companies G and H. Indeed, these are two distinct but very similar fields of the same company as mentioned earlier. The only difference lies in the different drying system used. Big tunnel (TG) is used for field G and small tunnel (T) for field H. In this case, the comparison is performed using only the results coming from the seeds manually threshed to remove the influence of mechanical threshing. The second exception regards the comparison between two different companies. This last comparison is between companies E and F which differ only for cultivar and soil texture. The varietal difference plays a reduced role given the similarities between the two while the soil is expected to have a more pronounced influence on plant growth [22] and germination characteristics of the seed. The significance level (α) has been set at 0.05, 0.01 and 0.001. The type of test chosen is one tailed, because the values for reference tests were expected to be higher than the one for mechanically threshed seeds.

3. Results

Table 3 reports the comparison between the two different threshing methods (mechanical and manual).

Table 3. Results of median comparison test between seeds mechanically threshed and manually threshed.

Threshing Method		*G.E.*	*G.*	*R.g.*	*R.s.*	*A.s.*
Mechanical	average	80.2	83.2	3.9	7.5	5.4
	Std dev	10.9	8.8	2.8	3.4	4.4
Standard (manual)	average	90.0	91.7	1.7	4.9	1.3
	Std dev	3.9	3.5	1.2	3.0	0.6
	t-calc.	2.935	3.116	2.474	1.972	3.217
	Significance level	**	**	*	*	**

* α = 0.05, ** α = 0.01.

The average values for the tests related to the samples of seeds mechanically threshed show lower value with respect to the same for the control. Differences are also observed in the greater variability of the results for the mechanical threshing treatment. If we observe the standard deviation values we see that these show a greater dispersion for mechanical threshing than control.

Table 4 reports the results of means comparison. For each field, from A to L, the average and standard deviation values for seeds mechanically threshed and manually threshed have been indicated. They have been marked with 1 and 2 respectively as superscript, and in the last row of each field the results for statistical test of comparison have been indicated. The significance analysis shows different levels of significance for different parameters and fields. Fields A, B, E and F do not show any difference between the control and seeds mechanically threshed. Field C shows a weak significance for *G.* and *G.E.*, field D shows a medium significance for G., *A.s.* and *R.s.* and a weak significance for all the other parameters. Field G shows a strong significance for *G.* and *G.E.*, field H shows a weak significance only for *G.E.* and *A.s.*, field I shows a strong significance for *G.* and *G.E.* and a medium and weak significance for *A.s.* and *R.g.* respectively. Field J shows a weak significance for *R.g.* and a strong one for all the other parameters. Field K shows a strong significance for *G.E.* and *A.s.* and a medium one for *G.* and a weak significance for *R.s.*, field L shows a weak significance only for *R.g.* and *R.s.*

Table 4. Statistical analysis of means comparison for each field.

Field		***G.E.***	***G.***	***R.g.***	***R.s.***	***A.s.***	**Field**		***G.E.***	***G.***	***R.g.***	***R.s.***	***A.s.***
A [1]	average	92.8	93.5	1.8	3.0	1.5	**B** [1]	average	82.5	85.3	2.3	9.5	3.0
	Std dev	2.9	2.5	1.0	1.2	1.7		Std dev	4.4	3.1	1.7	2.4	1.8
A [2]	average	93.8	95.8	0.5	2.0	1.5	**B** [2]	average	86.5	88.3	1.0	9.0	1.8
	Std dev	1.5	1.9	1.0	0.8	1.7		Std dev	5.2	4.2	1.4	2.4	1.5
p		ns	ns	ns	ns	ns	**p**		ns	ns	ns	ns	ns
C [1]	average	86.8	87.3	3.5	6.3	3.0	**D** [1]	average	79.0	83.0	6.0	9.0	2.0
	Std dev	3.3	2.6	1.3	2.4	2.2		Std dev	3.6	4.8	2.6	2.2	0.8
C [2]	average	92.3	92.3	2.3	3.3	1.3	**D** [2]	average	89.8	95.0	1.8	3.0	0.3
	Std dev	2.8	2.8	1.0	2.1	1.5		Std dev	6.7	2.9	1.0	1.8	0.5
p		*	*	ns	ns	ns	**p**		*	**	*	**	**
E [1]	average	85.0	86.0	1.5	10.8	1.8	**F** [1]	average	94.3	95.0	2.0	2.3	0.8
	Std dev	1.6	2.0	1.0	1.7	1.3		Std dev	2.5	2.6	1.4	0.5	1.5
E [2]	average	84.3	87.3	0.8	8.8	1.5	**F** [2]	average	93.0	94.0	2.3	2.0	0.3
	Std dev	5.9	5.0	1.0	3.4	1.3		Std dev	1.4	1.2	1.0	1.4	0.5
p		ns	ns	ns	ns	ns	**p**		ns	ns	ns	ns	ns
G [1]	average	54.5	64.8	10.0	13.8	10.3	**H** [1]	average	83.5	89.0	2.0	3.8	5.3
	Std dev	6.8	4.8	3.6	4.3	5.3		Std dev	0.6	2.4	0.8	1.3	2.2
G [2]	average	92.5	94.3	2.0	2.8	1.0	**H** [2]	average	87.8	91.3	1.8	1.5	5.5
	Std dev	2.5	3.1	1.2	2.6	0.8		Std dev	3.0	2.8	1.0	0.6	3.4
p		***	***	**	**	**	**p**		*	ns	ns	ns	*
I [1]	average	68.8	73.8	8.3	9.3	8.3	**J** [1]	average	71.0	73.0	3.8	8.5	14.8
	Std dev	2.9	3.9	1.9	4.7	3.5		Std dev	5.8	6.5	2.5	1.3	4.3
I [2]	average	85.0	87.8	4.3	7.3	0.8	**J** [2]	average	96.5	97.3	0.0	1.5	1.3
	Std dev	2.8	1.7	2.4	3.9	1.0		Std dev	3.0	2.4	1.0	0.0	1.7
p		***	***	*	ns	**	**p**		***	***	*	***	***
K [1]	average	78.0	80.5	4.0	5.5	9.8	**L** [1]	average	84.3	86.0	1.8	8.0	4.3
	Std dev	1.8	1.7	2.9	2.6	3.0		Std dev	5.0	4.1	0.5	2.9	1.5
K [2]	average	86.5	88.0	1.3	9.5	1.3	**L** [2]	average	89.5	90.3	3.3	4.0	2.5
	Std dev	2.6	2.9	1.3	2.4	1.0		Std dev	2.1	2.6	1.3	1.4	1.7
p		***	**	ns	*	***	**p**		ns	ns	*	*	ns

[1] mechanically threshed seeds; [2] manually threshed seeds. * $\alpha = 0.05$, ** $\alpha = 0.01$, *** $\alpha = 0.001$, ns = no significance.

Table 5 reports the results for the comparison between field G and H belonging to the same company and differing only for the type of drying system adopted (big tunnel for G and standard tunnel for H). Drying, for both systems, is due to the greenhouse effect of the cover and the air circulation from the tunnel heads. Tunnels are agricultural greenhouses of different size. The standard tunnel has a height of 2.9 m at ridge and 4.2 m large, big tunnels 4.6 m at ridge and 10 m large. Results show that there is no significant difference between the two drying systems except the weak significance found for germination energy in favor of G (big tunnel).

Table 5. Statistical comparison between field G and H.

		G.E.	*G.*	*R.g.*	*R.s.*	*A.s.*
TG (big tunnel)	average	92.5	94.3	2.00	2.75	1.0
	Std dev	2.5	3.1	1.2	2.6	0.8
T (standard tunnel)	average	87.8	91.3	1.5	5.5	1.8
	Std dev	3.0	2.8	0.6	3.4	1.0
t-calc.		2.43	1.45	1.19	0.77	1.28
		*	ns	ns	ns	ns

* $\alpha = 0.05$, ns = no significance.

Table 6 reports the results for the last comparison between field E and F. This comparison has been selected to highlight a known phenomenon to field operators but is not supported by any findings in scientific literature. In cultivation practices, sandy soils are preferable, while loam or even clay ones are considered less suitable. It should be highlighted that this comparison is based on data of only one year and it could be useful to repeat the study in different years to also evaluate the influence of climatic conditions.

Table 6. Statistical comparison between field E and F.

		G.E.	*G.*	*R.g.*	*R.s.*	*A.s.*
Loam	average	84.25	87.25	0.75	8.75	1.50
	Std dev	5.91	4.99	0.96	3.40	1.29
Sandy	average	93.00	94.00	2.25	2.00	0.25
	Std dev	1.41	1.15	0.96	1.41	0.50
t-calc.		2.88	2.63	1.81	2.22	3.66
		*	*	*	**	ns

* $\alpha = 0.05$, ** $\alpha = 0.01$, ns = no significance.

4. Discussion

The mean comparison between the two threshing methods shows that the mechanical threshing has the capacity of reducing the working load of this phase keeping the seed quality parameters above the threshold established by FAO or the Italian government. Nevertheless, with respect to the control, the mechanical threshing reduces significantly the positive quality parameters and increases the negative ones. With respect to the control, the action of threshing machine elements causes a reduction of 9.8% for *G.E.* and 8.5% for germination. On the other hand, *R.g.*, *R.s.* and *A.s.* increase to 2.2, 2.6 and 4.1 percentage points respectively.

Looking at the results for single field, some fields do not show any significant difference, others show a strong difference. This proves that it is not the mechanical threshing itself that causes the seed quality reduction but most probably the specific use for each farm and, specially, the working conditions. Regarding the results related to the comparison between big tunnel and standard tunnel for the drying of flower heads, the almost total absence of significant difference would lead one to consider the small one the best solution in relation to the smaller size and the reduced installation cost. This comparison has been made only on one condition; it should be considered as representative of the specific situation. The last result (comparison between field E and F), shows how the cultivation on sandy soil could be considered the best solution (with respect to other soils) to improve the quality of seeds. In fact, the germination tests for the seeds produced on sandy soil gives better values for *G.E.*, *G.*, *R.s.*, and *R.g.* In this last case, the results should be considered as indicative since a representative analysis should be repeated for at least three years. The only possible comparison with other studies comes from Theertha D.P., 2013. In his thesis, Dr Theertha found germination values above 89.3% for all the machine settings, but the machine itself has been developed in recent years and is based on a completely different threshing system. In detail, the extraction system in based on a rubber wrapped drum and a stationary perforated surface.

5. Conclusions

It can be stated that in comparison to the pre-existing condition, the introduction of a machine dedicated to the specific purpose can easily reduce the working time by guaranteeing a good quality of the seeds. In the present study, the germinability ranged from 64.8% to 95.8% for mechanical threshing. The comparison with the manual threshing highlights a general better performance for the manual threshing as expected. The germination value for mechanically threshed seeds is barely above the minimum allowed for marketing value. In general terms, mechanical threshing causes a reduction of about 10% for germination energy and 8.5% points for germination. On the other hand, *R.g.*, *R.s.* and *A.s.* are slightly increased.

The system replacement, for the companies involved, is mainly due to the need of drastic reduction of working time, leaving the seed quality unchanged. For the specific case study, seed quality is less dependent on threshing and more dependent on environmental conditions. The specific behavior of the machine with respect to other more recent ones returns incomparable results because the umbel extraction capacity is completely different. The machine developed by Theertha has a maximum extraction capacity of 30.9 kg/h, this makes it unsuitable for the use on large plots with a production that can exceed 600 kg/ha. Considering the better performances of other technological solutions, it would also be advisable to evaluate a modernization.

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