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# Tuber yield and processing traits of potato advanced selections

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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**Abstract: World potato production continuously requires new cultivars to satisfy farmers' and consumers' demand. Tuber yield and quality are some of the main potato breeding targets. In this study, 27 advanced potato clones from 7 hybrid families were evaluated for yield, tuber specific gravity and chipping ability. Variability in tuber yield was found between families as well as between clones. Forty-eight percent of clones showed higher productivity compared to the best control (Agria, 1.1 Kg). Families displayed significant differences also in terms of tubers specific gravity, with about 70% of clones with a score higher than 1.080, which was considered the minimum acceptable value for processing. Chipping ability was evaluated at harvesting time and after cold storage with and without reconditioning. The majority of studied clones showed a good chipping ability score (<4.5) at harvest; five samples chipped well after cold storage with reconditioning, while good chippers were not identified after cold storage without reconditioning. The use of an arbitrary index calculated for each clone is proposed to assist the selection of materials with a good trait combination.**

## 1. Introduction

Potato, *Solanum tuberosum*, is the most cultivated not cereal crop in the world, ranking fourth after rice, wheat and corn (FAO Statistics, 2012). It represents an important component of human diet, because tubers are able to supply several nutrients, such as essential amino acids, vitamins (as vitamin C) and minerals. It can be consumed either as fresh product or as processed ready-to-eat food (i.e. chips and French fries) (Carputo *et al.,* 2005). Overall, the number of potato varieties cultivated for processing purposes is increasing and more than 50% of potato yield is driven to food industries. In order to follow the food market trends, new varieties with a specific combination of processing-related traits are continuously requested. A traditional potato breeding program begins with sexual hybridization of tetraploid varieties or *élite* clones, in order to generate biparental families. Progenies are then evaluated for quality traits and the most promising clones are then selected for further evaluations (MacKay, 2005; Rak and Palta, 2015; Melito *et al.*, 2017). Because of the autotetraploid nature of *S. tuberosum* and its heterozigosity level, the F1 presents trait segregation; as a consequence, vegetative propagation and field selection are needed for several years to identify superior clones (Haynes *et al.*, 2012). Tuber traits considered by breeders in developing new varieties are different. Among them, tuber yield and tuber quality characteristics, including both external (skin color, tuber size and shape, eye depth) and internal (dry matter content, chip ability) traits (Carputo and Frusciante, 2011) are deeply evaluated. External traits play an important role in potato fresh market, because they influence consumers' choice. On the counterpart, internal traits mainly affect tuber processing. One of the principal goals of potato breeding programs is the selection of varieties with a good chipping ability following cold storage. Indeed, following harvest, potato are normally stored at low temperatures (<8°C) to keep an interrupted supply used by the processing industries, to prevent sprouting, to reduce bacteria soft rot attack and to contain the loss of dry matter (Malone *et al.*, 2006; Zhao *et al.*, 2013). Unfortunately, in response to cold storage most potato varieties convert tuber starch to reducing sugars (glucose and fructose). This reaction is known as "cold-induced sweetening" and is recognized as a serious problem for potato processing industry (Dale and Bradshaw, 2003). The accumulated reducing sugars undergo the non enzymatic Maillard reaction with free amino acids when potatoes are fried in hot oil, resulting in dark unacceptable chips. Furthermore, Mottram *et al.* (2002) and Stadler *et al.* (2002) reported high level of acrylamide because of the Maillard reaction, which is potentially damaging for human health. Equally important for the potato processing industry is the availability of varieties with high tuber specific gravity. Tubers with specific gravity higher than 1.080 are generally considered suitable for processing.

The main aim of this study was to test the performance of 27 potato advanced clones belonging to 7 families with different genetic background. Tuber yield, specific gravity, chipping ability and earliness were determined to select the most promising clones. Finally, an evaluation index useful for selection of genotypes with a good combination of traits was calculated.

## 2. Materials and Methods

*Genetic material and experimental design*

The material used in this study derived from a conventional program of clonal selection started in 2009 in a single hill plot. From 2010 to 2013 selected clones were cultivated in larger unreplicated plots with spaced plants. Clones with undesired characteristics (i.e. long stolons, deep tuber eyes and tuber defects) were discarded and the number of seed tubers was increased. Three commercial varieties (Spunta, Adora and Agria,) were used as control. The field trials were conducted at Marigliano (district of Naples) (Lat. 40.927759°, Long. 14.451370°).

*Tuber production and quality evaluation*

Control varieties and experimental clones were planted in a randomized complete block design with 3 replications. For each clone, 10 tubers were planted in a single row with spacing of 30 cm between plants and 70 cm between rows. Plants were grown following the standard cultural practices of the geographic area. Tubers were planted in March and harvested in July, when plants start senescing (roughly 120 days after plantation). Total yield (TY) was evaluated at harvest. Chips were produced by frying 10 longitudinally cut tuber slices from the center of each tuber and–2 tubers for each clone were used. The chips color was evaluated in 3 consequent times: at harvest, at three months of cold storage (7°C) and at 2 weeks of reconditioning (20 - 24°C) after cold storage. To optimize the chipping test, slices were washed in water before frying in soybean oil. Tubers were considered completely fried when oil end to bubble. A colorimetric scale, from 1 (very light) to 10 (very dark) was used to determinate chipping ability. Based on Carputo *et al*. (2002), clones with a score ≤ 4.5 were considered suitable for chipping. The specific gravity of tubers (TSG) of each clone was estimated on 1 Kg of tuber sample, evaluating the ratio weight in air/weight in water (Woolfe, 1987). Foliage earliness was evaluated at 90 days after planting. An earliness score (from 1= very late to 5= very early) was associated to each clone comparing foliage senescence to the control variety Spunta (earliness score= 3).

*Evaluation Index*

To assist the selection of clones, an evaluation index (EI) was elaborated, associating an arbitrary score to each trait based on the value obtained: TY

(Kg/plant): 1= <0.5; 2= 0.51-1 ; 3= 1.1-1.5; 4= 1.51-2 ; 5= >2.1. TSG: 1= ≤1.080 (not suitable for processing); 2= 1.081-1.085; 3= 1.086-1.090; 4= >1.091.
Chipping color: 1= >4.5 at each test after cold storage; 2= <4.5 at least in one test after cold storage; 3= <4.5 at both tests after cold storage.
Average earliness score: 1= ≤1.0; 2= 1.1-2.0; 3= 2.1-3.0; 4=> 3.1.

The EI was calculated summing the scores for each trait: the higher index values, the more desirable genotypes. The EI was calculated only for clones for which all the evaluation data were available.

*Statistical analysis*

One-way ANOVA was run using JMP 7 software (SAS Institute, Cary, NC, USA). When a significant F was found (P<0.05), data were compared using Tukey's post hoc multiple comparison test. Each trait was used to compare the mean values among clones and varieties and to varieties individually.

## 3. Results and Discussion

The development of new potato varieties addressing production efficiency and sustainability requires a well-planned breeding program. The accumulation of multiple traits in a single variety is one of the main goal of potato breeding programs. Among the available different strategies, those based on sexual hybridization between tetraploid varieties or clones, followed by selection, still represent a successfully and widely used option. In this research, 27 advanced clones were selected and evaluated for yield and processing traits. They belong to seven families obtained from crosses involving ten cultivated varieties (Spunta, Victoria, Jenny, Blondy, Agria, Bolesta, Sandy, Majestic, Alcmaria, Primura,) and one breeding clone (MC 329). As reported in Table 1, clones under evaluation showed differences in terms of flesh color and tuber shape, whereas skin color, eye

Table 1 - Tuber characteristics of the potato clones under selection. For each clone, pedigree, tuber skin color (TSC), tuber flesh color (TFC), tuber shape (TS), eye and stolon characteristics are reported.

| Families | Pedigree | TSC | TFC | TS | Eyes | Stolons |
|---|---|---|---|---|---|---|
| 'Spunta' x 'Victoria' | S04-2-10 | Yellow | Yellow | Oblong | Superficial | Short |
| | S04-2-17 | Yellow | Yellow | Round | Superficial | Short |
| | S04-2-18 | Yellow | Yellow | Long | Superficial | Short |
| | S04-2-28 | Yellow | Yellow | Oblong | Superficial | Short |
| | S04-2-34 | Yellow | Yellow | Oblong | Superficial | Short |
| | S04-2-40 | Yellow | Yellow | Oblong | Superficial | Short |
| | S04-2-53 | Yellow | Yellow | Long | Superficial | Short |
| | S04-2-55 | Yellow | Yellow | Long | Superficial | Short |
| | S05-7-15 | Yellow | Light yellow | Oblong | Superficial | Short |
| | S05-7-4 | Yellow | Yellow | Long | Superficial | Short |
| 'Jenny' x 'MC 329' | S04-7-2 | Yellow | White | Round | Superficial | Short |
| | S04-7-6 | Yellow | White | Round | Superficial | Short |
| | S04-7-27 | Yellow | White | Round | Superficial | Short |
| 'Blondy' x 'Victoria' | S05-1-2 | Yellow | Yellow | Long | Superficial | Short |
| | S05-1-25 | Yellow | White | Long | Superficial | Short |
| 'Bolesta' x 'MC 329' | S05-2-10 | Yellow | White | Round | Superficial | Short |
| | S05-2-11 | Yellow | Light yellow | Round | Superficial | Short |
| | S05-2-15 | Yellow | Yellow | Round | Hallowed | Short |
| | S05-2-18 | Yellow | Yellow | Round | Superficial | Short |
| | S05-2-23 | Yellow | Yellow | Round | Superficial | Short |
| | S05-2-3 | Yellow | Yellow | Round | Superficial | Short |
| | S05-2-4 | Yellow | Yellow | Oblong | Superficial | Short |
| | S05-8-5 | Yellow | Yellow | Round | Superficial | Short |
| 'Agria' x 'Sandy' | S04-5-32 | Yellow | Yellow | Round | Superficial | Short |
| 'Majestic' x 'Alcmaria' | S04-6-2 | Yellow | White | Oblong | Superficial | Short |
| 'Primura' x 'Alcmaria' | S05-4-2 | Yellow | Yellow | Oblong | Superficial | Short |
| *Solanum tuberosum* | Adora | Light yellow | Yellow | Round | Superficial | Short |
| | Agria | Yellow | Yellow | Oblong | Superficial | Short |
| | Spunta | Light yellow | Yellow | Oblong | Superficial | Short |

depth and stolon length were uniform. This is the result of the previous selection pressure aimed at discarding clones with undesired characteristics (e.g. deep eyes). Tuber yield, specific gravity, and chipping ability of material under evaluation are reported in Table 2. Data are summarized on a family basis. Overall, significant differences in TY were found among families. The average TY was 1.2 Kg/plant, ranging from 0.43 to 3.00 Kg, detected in a clone from 'Spunta' x 'Victoria' and 'Majestic' x 'Alcmaria', respectively. By contrast, the comparison between the mean TY of clones and that of control varieties revealed not significant difference (Table 3). However, analysis of ranges within each family revealed the presence of clones with good yield performances. In this research, 12 very promising clones for tuber yield were identified, belonging to 'Spunta' x 'Victoria' (5), 'Majestic' x 'Alcmaria' (1), 'Jenny' x 'MC 329' (1), 'Blondy' x 'Victoria' (1), 'Bolestra' x 'MC 329' (4) (not shown). This may outline the occurrence of allelic combinations providing satisfactory diversity, a prerequisite for heterosis in yield (Mendoza and Haynes, 1974).

Potato quality evaluation does not include only tuber yield, but also several qualitative and quantitative traits. Among them, tuber dry matter and chipping ability are fundamental for processing. In particular, the chipping ability is a quality parameter highly important for food industries because it influences not only yield of the processed product, but also oil absorption rate in fried products (Asmamaw *et al.*, 2010). On the other hand, tuber specific gravity (TSG) is commonly accepted as measure of the dry matter content and it provides the suitability of potato varieties for processing (Kabira and Berga, 2003). Based on this finding, Fitzpatrick *et al*., (1964) identified three classes of TSG: low (less than 1.077), intermediate (between 1.077 and 1.086), and high (more than 1.086). Furthermore, Kabira and Berga (2003) reported that tuber should have a specific gravity higher

Table 2 - Tuber yield (Kg of tubers per plant) (TY), tuber specific gravity (TSG), chip category color and evaluation index (EI) of 27 potato advanced clones. Chip category color was evaluated at harvest and after 90 days of cold storage at 7°C, with and without reconditioning at room temperature for two weeks (respectively + Rec; - Rec) (see materials and methods). For each trait, the average family value (range) is reported

| Material | No. of clones | TY * | TSG * | Chip category colour * | | | EI * |
|---|---|---|---|---|---|---|---|
| | | | | Direct | Cold storage - Rec | Cold storage + Rec | |
| Families | | | | | | | |
| 'Spunta' x 'Victoria' | 10 | 1.09 (0.43-1.58) b | 1.081 (1.073-1.088) bc | 3.8 (2.0-7.0) | 8.5 (7.0-10.0) b | 6.1 (2.0-7.0) abc | 10.1 (6.0-14.0) c |
| 'Jenny' x 'MC 329' | 3 | 0.95 (0.48-1.51) b | 1.095 (1.086-1.104) a | 2.0 (2.0-2.0) | 10.0 (10.0-10.0 a | 4.3 (2.0-7.0) bc | 13.0 (11.0-15.0) ab |
| 'Blondy' x 'Victoria' | 2 | 1.20 (1.13-1.28) b | 1.087 (1.086-1.089) ab | 2.5 (2.0-3.0) | 8.5 (8.0-9.0) ab | 6.0 (5.0-7.0) abc | 11.5 (11.0-12.0) abc |
| 'Bolesta' x 'MC 329' | 9 | 1.20 (0.98-1.45) b | 1.086 (1.079-1.091) b | 4.0 (7.0-2.0) | 8.9 (7.0-10.0) ab | 6.7 (3.0-8.0) a | 10.6 (7.0-13.0) bc |
| 'Agria' x 'Sandy' | 1 | 0.76 b | 1.080 bc | 2 | 10.0 ab | 8.0 ab | 7.0 c |
| 'Majestic' x 'Alcmaria' | 1 | 3.00 a | 1.079 bc | 3 | 7.0 b | 3.0 c | 15.0 a |
| 'Primura' x 'Alcmaria' | 1 | 1.02 b | 1.070 c | 3 | 10.0 ab | 8.0 ab | 7.0 c |
| Varieties | | | | | | | |
| Adora | 1 | 0.80 b | 1.071 c | 2 | 9.0 ab | 5.0 abc | 8.0 c |
| Agria | 1 | 1.18 b | 1.075 bc | 5 | 10.0 ab | 5.0 abc | 11.0 abc |
| Spunta | 1 | 1.10 b | 1.078 bc | 4 | 8.0 ab | 7.0 abc | 10.0 abc |
| F-ratio | | 13.52 | 8.92 | NS | 3.03 | 3.56 | 5.42 |
| P-value | | <0.0001 | <0.0001 | | 0.0036 | 0.0009 | <0.0001 |

* Means comparison using Tukey's test. Levels not connected by the same letter are significantly different (P<0.05).
NS indicates not statistically significant data.

Table 3 - Means, ranges and comparisons between clones and control varieties (Spunta, Adora, Agria) obtained evaluating tuber yield (TY), tuber specific gravity (TSG), chipping ability (direct, after cold storage, ± Reconditioning, Rec) and the evaluation index (EI)

| Family | TY (Kg) (z) | TSG (z) | Chip category color (z) | | | EI (z) |
|---|---|---|---|---|---|---|
| | | | Direct | Cold storage - Rec | Cold storage + Rec | |
| Selections | 1.16 (0.43-3.00) | 1.083 (1.070-1.104) | 3.4 (2.0-7.0) | 8.8 (7.0-10.0) | 6.1 (2.0-8.0) | 10.5 (6.0-15.0) |
| Cultivars | 1.03 (0.80-1.18) | 1.075 (1.071-1.078) | 3.3 (2.0-4.0) | 8.3 (8.0-9.0) | 6.3 (5.0-7.0) | 9.7 (8.0-11.0) |
| Comparisons | | | | | | |
| Selection *vs* cultivar | NS | 11 ** | NS | NS | NS | NS |
| Selection *vs* Adora | NS | 13 ** | NS | NS | NS | NS |
| Selection *vs* Agria | NS | 7 ** | NS | NS | NS | NS |
| Selection *vs* Spunta | NS | 4 ** | NS | NS | NS | NS |

(z) Number of clones with a significantly better score compared to the control.
NS, *, ** indicates that means are not different or statistically different at P<0.05 and P<0.01, respectively (LSD 0.05).

than 1.080 to ensure good processing ability. In this research, TSG significantly varied among families studied (Table 2). On average, the specific gravity was 1.083, higher than the three control varieties used (1.075). It ranged from 1.070 ('Primura' x 'Alcmaria') to 1.104 (a clone from 'Jenny' x 'MC 329'). Nineteen clones (70%) showed a specific gravity higher than 1.080; and 4 clones, belonging to 'Bolesta' x 'MC 329' (2) and 'Jenny' x 'MC 329' (2), revealed a TSG higher than 1.090 (Table 2). The mean specific gravity of the studied potato clones was significantly higher than that of the controls, with 11 clones showing a higher specific gravity than the mean of the controls (Table 3). The chipping ability of the selected clones was evaluated at three times (at harvest and 90 days of cold storage at 7°C, with and without reconditioning at room temperature), based on the requirement of the potato processing market. Indeed, cold storage allows potato industries to process tubers when fresh product is not available, preventing sprouting and diseases (Malone *et al.*, 2006). Meanwhile, cold storage induces degradation of starch, conversion of sucrose in glucose and fructose causing an accumulation of reducing sugars. This process is extremely disadvantageous for the potato processing industry because it induces browning of chips (Dale and Bradshaw, 2003). During frying, high temperatures on reducing sugars activate the Maillard reaction on chips, which became dark colored and bitter, and so not marketable (Kumar *et al*., 2004). Variability in chipping ability was found among families, with significant differences after cold storage with or without reconditioning (Table 2). By contrast, no significant contrast between the mean chipping value of clones and that of control varieties fried at harvest and after cold storage was found (Table 3). However, the analysis of the chipping score ranges of clones indicated that at harvest and after cold storage with reconditioning, 11 and 5 clones respectively, presented a chipping score lower than 4.5 (not shown). Therefore, they were all good chippers. By contrast, good chippers were not identified after chips were fried directly out of cold storage. These data were expected considering that during cold storage two principal phenomena occur. The first is called "reversion" and is caused by reducing sugar accumulation: potatoes that generally show a good chipping ability after harvest, give dark, not acceptable chips (Oltmans and Novy, 2002). The second event occurs when stored potatoes are subjected to a warm (room temperature) period. It is called "reconditioning" and it induces a decrease of reducing sugars in the tuber. This phenomenon happens because during the warming period about 80% of reducing sugars (glucose and fructose) are converted back to starch (Oltmans and Novy, 2002). Consequently, tuber cold storage may produce lighter colored chips compared to the chips produced without a warming period.

In order to support the selection of clones with interesting trait combination, an arbitrary evaluation index (EI) was estimated (Melito *et al.*, 2017) (Table 2). The average family EI was 10.90, ranging from 7 in 'Spunta' x 'Victoria' (1) and 'Primura' x 'Alcmaria' (1) to 16 in 'Majestic' x 'Alcmaria' (1). The best control variety was Agria, with an EI of 11. In general, high variability and significant differences in EI were observed among the seven families studied (Table 2). Analysis of ranges revealed that in almost all families clones with EI higher than that of control varieties were present. The development of a score to evaluate the performance of breeding materials can be used to summarize the analysis of multiple traits, providing a synthetic parameter to support and simplify the practical selection of potato: high EI could indicate interesting genotypes that can be further analyzed deeper for additional traits, while low EI could be discarded as inferior genotypes. Additional experiments will be carried out to evaluate the most promising genotypes for new traits, with the purpose to either produce new variety/s useful in Mediterranean environmental conditions or select parental lines for further breeding.

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