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Revolutionizing Narrow-Scope Potato Breeding: Using Dry Matter and PVY as Selection Criteria for High Quality Cultivars

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ABSTRACT

Potato is one of the most important plants in terms of yield potential, adaptability and nutritional content. Although potato breeding programs are integrated with many new technologies, they are intensively carried out by phenotypic observation and selection in field conditions. In the research, high dry matter content and PVY resistance were determined as the basic selection criteria in the development of new cultivars. The research was carried out between 2017-2022 using 30.000 F_1 potato seeds as genetic material and by establishing comparative trials in different locations with commercial control cultivars. Selection and breeding studies were carried out considering PVY resistance according to the molecular marker test. As a result of the research, commercial candidate advanced lines suitable for PVY resistance, table, chip and French fry potato industries were developed by conducting phenotypic and genotypic selection and selection studies according to high dry matter content. Based on the findings of the present study, the lines 82-88-04, 82-45-24, 82-105-50, 82-78-16, 82-56-01, and 82-93-03, distinguished by their high yield potential and resistance to Potato virus Y (PVY), were identified as possessing significant potential for official registration and subsequent commercialization as candidate cultivars.

1. INTRODUCTION

Potato is one of the most difficult plants to breed with its tetraploid and vegetative structure. It is necessary to cross between different breeding materials and cultivars when developing new cultivars in potato. Within the framework of the narrow-scope potato breeding approach, it is necessary to work on a small number of suitable materials in order to develop new cultivars with the desired characteristics. In order to develop French fry potato cultivars, hybridization between cultivars with high dry matter content; to develop crisp processing and starch cultivars, hybridization between chip cultivars and breeding lines will increase the chance of success. In potato breeding programs, it would be useful to conduct a hybridization program between two materials to obtain at least 1000 seeds for breeding purposes. The breeding population can vary between 10,000 and 50,000 true potato seeds depending on the conditions. Since potato have tetraploid and heterozygous genetic structures, developing new cultivars as a result of breeding studies takes a long time and requires intensive effort (Gao et al., 2024; Aydin et al., 2025). As a result of studies conducted in the field of molecular genetics in the last 15 years; significant progress has been made in the analysis of quantitative traits such as tuber yield and starch content for viruses such as PVY, PVX and many nematodes, and the breeding period has been shortened (Ozkaynak, et. al., 2018; Slater et al., 2014; Slater et al., 2020).

In industrial potato production, basic selection criteria such as tuber shape and size, eye depth, specific gravity, high dry matter content, polyphenol, antioxidant content, yellow or white flesh colour, bitterness/sweetness of the tuber, starch content, reducing sugar content and proteins, high tuber yield (>30 t/ha), storage disease tolerance and generally long dormancy period have been determined (Caliskan et al., 2021; Islam et al., 2022; Park et al., 2024; Sapakhova et. al., 2024). In general, French fry potato cultivars are long and oval-long tuber cultivars, while crisp processing cultivars have round tubers (Gegov et al., 2007, Kirkman, 2007). The dry matter content, specific gravity and low sugar content in the tuber are three important components that determine the internal quality of the final product in industrial production (Park et al., 2024). In French fry potato cultivars, dry matter should not be lower than 19.5-20% (Kirkman, 2007), while the lowest limit should be around 20% in crisp processing cultivars.

In order to develop industrial quality tubers in potato, the development of superior lines/cultivars with standard dry matter content is a very important issue (Naeem & Çalışkan, 2020; Park et al., 2024). Dry matter content is affected by many factors such as solar radiation, temperature, humidity, soil structure and other soil characteristics, production and research location and climate changes during the growing season, N, P and K content in fertilizer, harvest time, haulm killing period during the growth period (Gegov et al., 2007; Haverkort, 2007; Islam et al., 2022; Mehta et al., 2011; Naeem & Çalışkan, 2020).

In recent years, the use of molecular methods in genetic and breeding studies has provided significant developments (Slater et al., 2014; 2020). Despite advanced developments, the effectiveness of molecular approaches in complex traits such as yield and quality with low heritability, heterozygous populations and quantitative genetic analyses still remains low. Therefore, phenotypic selection is still used on a large scale in potato breeding programs. Potato Virus Y is still the most important virus in potato (Abd El-Aziz, 2020; Scholthof et al. 2011). PVY causes 10-100% yield losses worldwide and causes single and multiple infections together with PVX and PVA (Kreuze et al., 2020; Naveed et al., 2017; Ozturk & Yildirim 2020). Although there are different methods to control the virus, the most effective practical method is to develop new resistant cultivars (Kahveci et al., 2022; Kang et al. 2005; Özkaynak 2020,). Independent genes (Ryadg, Rysto, and Rychc) are used for resistance to infections caused by all known strains of PVY virus. Ryadg, Rysto, and Rychc resistance genes were determined using molecular markers with specific primers that are in close linkage with these genes (Elison et al., 2020). These molecular markers are widely used for screening PVY resistance in potato breeding programs (Hadzalo et al., 2024; Heldak et al. 2007; Herrera et al. 2018; Ottoman et al. 2009; Slater et al. 2020; Whitworth et al. 2009).

Herrera et al., (2018) evaluated that M45/M5 was 0.05 cM from M6 and 0.2 cM from RYSC3 from a large mapping population of 6521 individuals. Therefore, Slater et al., (2020) indicated that, M45 and RYSC3 were good and suitable markers for marker-assisted selection. In this study, M45 marker was used, which was determined to be in agreement with biological tests for Ryadg (Herrera et al. 2018; Kahveci et al., 2022). This study was conducted to show that narrow-scope breeding study can be used for specific purposes (PVY resistance and high dry matter content) in potato.

2. MATERIALS AND METHODS

Genetic materials

Selection and breeding program was carried out in 30 hybrid combinations created using 17 commercial cultivars and 7 advanced breeding lines with different dry matter content and PVY resistance (Table 1 scheme). The list of parents with their special characteristics is given in Table 2. 30.000 true potato seeds were planted in pots during the seedling selection stage in the greenhouse. In field selections, 25.000 single tubers were planted in 2018. In the first field generation, 1.238 breeding lines were selected. In 2019, 1.238 breeding lines were planted in two rows (3-5 plants in each row). In 2020, 246 advanced and superior breeding lines were selected as a result of the evaluations made from the breeder's perspective by considering the plant (plant development, stem number, leaf characteristics, flowering), agronomic (plant and tuber earliness) and tuber characteristics (tuber shape, plant tuber yield, tuber size, etc.).

Table 1. Description of breeding program used in this project

Breeding Stage	No. of years			
Crossing*	1 year	30.000 potato seed spring and 25.000 one tuber autumn season (P1-P20 populations 500 seed, P21-P30 populations 1500 seed)		2017
Primary individual selection of seedling	2 years	25.000 single hills in field		2018
Secondary individual clonal selection (4-10 tubers)	3 years	% 5 hard selection 1238 breeding line planted	1238 PVY molecular marker test	2019
Secondary individual clonal selection (2-6 kg total tuber)	4 years	246 superior breeding line (good tuber shape, yield, skin and flesh colour, earliness etc.)	246 superior breeding line dry matter and PVX test	2020
Preliminary performance yield test (60-80 tubers)	5 years	18 candidate cultivar selected (minituber production with tissue culture and large-scale yield test in two location)	18 candidate cultivar	2021
Commercial Candidate Lines	6 years	9 cultivar		2022

*: 30 Cross population

In 2019, 1238 lines were tested with Ryadg marker by taking samples from fresh leaves of the plant. In 2020, it was done for the second time and PVY marker results were confirmed. In general, in addition to PVY resistant lines, lines with good tuber features but not PVY resistance were also selected. In 2021, 18 lines were planted in two locations with 30-40 tubers in two rows. Important commercial cultivars were used as control cultivars in each growing season. VR-808 for crisp processing, Madeleine main crop season and Orchestra early crop season for table potato, and Agria and Lady Olympia were included in the trials as control cultivars in French fry. Field breeding and selection studies were carried out in the high location of Antalya in the Western Mediterranean Region of Turkey, Antalya / Korkuteli (30° E, 37° N, 1100 m above sea level). Planting in Antalya (Korkuteli) took place between 25 April and 15 May, while harvesting was completed between 20 September and 10 October. In 2022, 9 commercial candidate potato lines were tested with commercial cultivars in 2 locations (main crop season; Antalya / Korkuteli (30° E, 37° N, 1100 m above sea level) and (early crop season) Adana / Incirlik 33° E, 37° N, 23 m above sea level). In 2022, planting took place on 15 May in Antalya (Korkuteli), and harvesting was carried out on 5 October. In Adana, planting took place on 6 January, and harvesting was carried out on 7 June. The experiments were laid out in a Randomized Completely Block Design with four replications. 54 tubers of each commercial candidate lines/commercial cultivars were planted in two rows in each replication. Tuber yield

was subjected to analysis of variance and differences were compared with LSD tests using MSTAT-C statistic program (Freed et al., 1989).

Cultural practices and measured traits

Tubers belonging to breeding lines were planted in 30 x 75 row and inter-row distances. In different experimental fields, 70 kg nitrogen, 50 kg phosphorus, 100 kg potassium and 40 kg calcium nitrate were applied per hectare. Weeds were controlled manually and with herbicide application at appropriate stages before and after emergence. Disease, pest and irrigation were done in accordance with general practical experience. Control of diseases such as PVX, PVY, *P. infestans* and *Alternaria spp*. and sprinkler irrigation application were carried out according to practice. Maturity, yield, tuber shape, tuber flesh and skin colour etc. traits were carried out as phenotypic observation according to breeder selection. Dry matter content (%) was measured by Zeal potato hydrometer and starch content (%) was determined with a polarimetric procedure (Haase, 2003).

DNA isolation and molecular marker testing

In this study, M45 marker was used, which was determined to be in agreement with biological tests for Ryadg (Herrera et al., 2018; Kahveci et al., 2022). In the study, DNA isolation and marker testing for PVY M45 marker were performed according to the method of Kahveci et. al., (2022). Plant genomic DNA was isolated from young leaves of potato lines using a Wizard Magnetic Kit (Promega, Madison, WI, USA) according to the manufacturer's instructions. Molecular markers for the *Ryadg* gene and their primer sequences are listed in Table 2.

Table 2. Primer sequences of markers for the *Ryadg* genes in potato

Gene	Marker Name	Primer	Primer Sequences (5'-3')	Reference
Ryadg	M45	M45F1 M45R1	TGGAGTATTTGGATCTAAGGG AACACATAAGGAGCGAT	Herrera et al. (2018); Kahveci et. al., (2022)

All primers were purchased from İontek (İstanbul, Turkey). PCR amplification was performed in a total volume of 25 µL containing 2.5 µL 10X PCR buffer, 0.2 mM dNTP, 0.4 mM of each primer, 2 mM $MgCI_2$, 20 ng of template DNA, and 1 unit taq DNA polymerase (Vivantis, Selangor DE, Malaysia). PCR amplification was carried out using a thermocycler (PTC-200, MJ Research, USA). The cycling conditions were as follows: 94°C for 3 minutes, 35 cycles of denaturation at 94°C for 30 s; annealing at 52°C for 30; and elongation at 72°C for 1 minute, with 72°C for 7 minutes as a final extension. The PCR products were separated on a 2% agarose gel containing TAE buffer at 110 V for 2 hours and visualized under UV light after staining with ethidium bromide (Kahveci et. al., 2022).

3. RESULTS AND DISCUSSION

Agronomic, plant and tuber characteristics

Developing a new potato cultivar, selection, measurement and evaluation are made according to more than 50 characteristic features, unlike many plants. Breeders make crosses between parents according to phenotypic characteristics (Bradshaw & Mackay 1994; Bradshaw, 2007). Elite cultivars are obtained as a result of crosses a large number of superior parents. The development of new cultivars can be successful as a result of a large number of year x environment interactions (Jansky, 2009; Slater et al., 2014; Aydin et al., 2025).

In research, a narrow-scope breeding strategy was implemented to reach the target quickly. 17 special commercial cultivars and 7 advanced lines with superior traits were used to develop a large number of superior lines with high general combination ability. Leonata, Acoustic, Florice, Banba, Victoria and Constance cultivars and 22-68-04, NL-CP-19 and PP-17-3 lines were used as parents in terms of good plant, agronomic, tuber and quality traits, although they were not resistant to PVY according to Ryadg marker (Table 3). The Asya, Boysan, Maraton, Soylu cultivars and the 13-73-26, 22-68-04, 22-99-33 advanced lines were tested with the PVY '0' isolate using a bioassay test, and their resistance was subsequently confirmed using a marker test with the Ryadg marker (Ozkaynak unpublished data). In 2019, a total of 246 advanced lines were selected from 30 hybrid populations, ranging from 4 to 21 depending on the populations. Important plant, agronomic, tuber and quality traits of some of the advanced lines are given in Table 4. The maximum number of lines in the study was 10 and above; P30 (Starch x Crisp processing), P28 (French fry x Crisp processing), P27 French fry, Fresh market x Crisp processing), P24 (Crisp processing x Crisp processing), P13 (Fresh market x Fresh market), P11 (Fresh market x Fresh market) and P25 (Fresh market x French fry) were selected in populations (Table 5). In 2020, tubers (2-6 kg) from 246

lines were planted in two rows in the field. Phenotypic selection was made according to leaf type, stem thickness, tuber shape, tuber quality, tuber homogeneity, tuber size and standard structure, earliness in plant and tuber (early, mid-early, late and very late), tuber skin and flesh colour and yield characteristics (Table 5).

Table 3. Resistance to PVY and association of *Ryadg* marker and dry matter content of 24 materials used as parents in crossing.

	Cultivar	**DM (%)**	**PVY**			**Adv. Line and Cultivar**	**DM (%)**	**PVY**	
1	Fontane	23	R	French Fry	13	Soylu	19	R	Fresh market
2	Leonata	22	S	French Fry	14	13-73-26	20.8	R	Fresh market and French Fry
3	Madeleine	19.5	R	Fresh market	15	Maraton	19.1	R	Fresh market
4	Acoustic	18	S	Fresh market	16	13-62-32	21.2	R	French Fry
5	Florice	17. 6	S	Fresh market	17	22-68-04	22	S	Crisp processing
6	Saprodi	22	R	Starch	18	22-99-33	20	R	Fresh market and French Fry
7	Banba	20	S	Fresh market and French Fry	19	NL-CP-19	22	S	Crisp processing
8	Orchestra	18.5	R	Fresh market	20	CP-US-1	22	R	Crisp processing
9	Cronos	19.1	R	Fresh market	21	Asya	19	R	Fresh market
10	Touareg	21	R	Fresh market and French Fry	22	PP-17-3	22	S	French Fry
11	Victoria	21.4	S	Fresh market and French Fry	23	Cara	20	R	Fresh market
12	Constance	20	S	Fresh market	24	Boysan	19	R	Fresh market

DM: Dry matter content (%)

Table 4. Resistance to PVY and association of *Ryadg* marker and dry matter content of advanced breeding lines (best sample lines of 246 advanced lines)

No	Advanced Line	DM (%)	PVY	Parents	Important Plant, Tuber and Quality Traits	Candidate Cultivar
4	82-88-04	19	R	13-62-32 x Maraton	Long big tuber, early-medium early	Selected Fresh market
7	82-45-09	19	R	13-62-32 x Cara	Very high yield, good tuber shape	
11	82-45-24	20,5	R	13-62-32 x Cara	Red tubers, good tuber shape, high yield	Selected Fresh market
16	82-105-05	21	S	13-62-32 x PP-17-3	Oval-long tuber shape, yellow skin and flesh colour	Selected Fresh market, French Fry
18	82-105-50	22	R	13-62-32 x PP-17-3	Very high yield, standard, good tuber shape, yellow flesh colour	Selected French Fry
24	82-42-01	21	R	13-62-32 x Asya	High yield, oval tuber shape, medium-early	
28	82-43-08	21	S	13-62-32 x Cronos	High yield, good tuber shape, Fresh market	
33	82-21-18	21	R	13-62-32 x Fontane	High yield, long tubers, good tuber shape, French Fry	
35	82-21-21	21	R	13-62-32 x Fontane	Oval-round tuber shape, very high yield, Crisp processing	Selected Crisp processing
44	82-70-15	23	S	13-62-32 x CP-US-1	Very high yield, high dry matter, Crisp processing, good taste	
50	82-102-02	22	R	13-62-32 x Constance	Very high yield, good tuber shape, Crisp processing, good taste	
52	82-78-16	22	R	Florice x Orchestra	High yield, oval shape tubers, Crisp processing, good taste	Selected Crisp processing
55	82-78-21	21	R	Florice x Orchestra	Long tubers, white flesh colour, French Fry	
58	82-78-25	21	R	Florice x Orchestra	Oval-long tubers, high yield,	Selected French Fry and Crisp processing
64	82-92-A3	20,4	R	Soylu x Orchestra	Very high yield, oval, yellow tubers, Crisp processing, good taste	
67	82-27-06	21	R	Soylu x Cronos	High yield, medium-early, good tuber shape	Selected Fresh market and French Fry
68	82-27-18	21	R	Soylu x Cronos	Very high yield, red-oval tubers, white flesh colour, Crisp processing	
72	82-27-30	22	R	Soylu x Cronos	Oval-long tubers, good taste,	Selected Fresh market and French Fry
80	82-97-04	21	R	Soylu x CP-US-1	High yield, Long tubers, white French Fry	
84	82-56-01	21	R	Boysan x Madeleine	Very high yield, yellow tuber, medium-early, high quality	Selected Fresh market and French Fry
88	82-56-06	19	R	Boysan x Madeleine	High yield, good tuber shape, medium-early, high quality	Selected Fresh market
90	82-56-10	21	R	Boysan x Madeleine	Good tuber shape and quality tubers, oval tubers, medium-early	
95	82-16-10	21	R	13-73-26 x Madeleine	Oval and quality, medium-early, Fresh market	
100	82-37-05	21	R	Maraton x Madeleine	Strong plant, big and long tuber size, yellow flesh, good taste	Selected French fry
104	82-37-08	22	R	Maraton x Madeleine	Strong plant, big tuber size, high quality	
109	82-74-75	22	R	22-68-04 x Madeleine	High yield, good tuber shape, big tubers, French fry	

Table 4. (continued)

115	82-93-03	21	R	22-99-33 x Banba	Long-oval, good tuber shape, high yield, medium-early	Selected French fry
122	82-104-24	21	R	22-99-33 x 22-68-04	Red, big size tubers, high yield good quality Fresh market	
127	82-32-308	18	R	Asya x 22-68-04	Very high yield, oval, good shape tubers, Fresh market, salad type	
135	82-42-21	20	R	Asya x Cara	High yield, medium-early, long-red tubers	Selected French fry
142	82-23-11	20	R	Cara x Fontane	Good tuber shape, standard-yellow tubers, high yield	
148	82-04-05	20	S	CP-US-1 x Fontane	Early, oval-high quality tubers, yellow Crisp processing and French fry	
153	82-19-25	23	R	NL-CP-19 x Fontane	High yield, oval, medium-early Crisp processing	
157	82-19-40	21	R	NL-CP-19 x Fontane	Long-oval tubers, medium early	Selected French fry
163	82-109-10	23	R	CP-US-1 x NL-CP-19	Oval, yellow flesh colour tuber, very high yield Crisp processing and French fry	
164	82-109-11	23	R	CP-US-1 x NL-CP-19	Oval, high yield, Crisp processing	
168	82-109-15	23	R	CP-US-1 x NL-CP-19	Very high yield, good taste, Crisp processing and French fry, Purple skin and flesh	Purple skin and flesh
175	82-41-02	21	R	Acoustic x Leonata	High yield, medium-early, yellow flesh colour Crisp processing	
177	82-41-05	22	R	Acoustic x Leonata	Long tuber shape, white flesh, quality tubers, Crisp processing and French fry	
184	82-48-03	22	R	Maraton x Leonata	Very high yield, oval tuber shape, yellow flesh, Crisp processing	
190	82-91-02	24	R	Touareg x CP-US-1	Good quality, oval, dark yellow flesh, good taste Crisp processing and French fry	
195	82-91-08	20,8	S	Touareg x CP-US-1	Oval-long tubers, high yield French fry,	
199	82-91-80	23	S	Touareg x CP-US-1	Very high yield, good tuber shape, yellow tuber, good taste, Crisp processing	
203	82-128-13	22	R	Leonata x CP-US-1	Oval tuber, white flesh, high yield, good taste Crisp processing	
204	82-128-14	23	R	Leonata x CP-US-1	Very high yield, yellow flesh, high quality	Selected Crisp processing
210	82-128-19	22	R	Leonata x CP-US-1	High yield, oval, white flesh, Crips processing	
214	82-128-24	19	R	Leonata x CP-US-1	Oval tuber, good tuber shape and quality, Crisp processing	
217	82-128-27	21	R	Leonata x CP-US-1	Long tuber, medium-early, French fry	
221	82-128-83	21	R	Leonata x CP-US-1	Oval tuber, high yield, medium-early, Crisp processing	
225	82-67-07	23	R	Maraton x CP-US-1	Oval tuber, high yield, white flesh, Crisp processing	
227	82-110-10	21	R	Saprodi x Victoria	Strong plant, oval tuber, high quality tubers, Crisp processing and French fry	Selected Crisp processing
228	82-110-11	21	R	Saprodi x Victoria	Oval tuber, very high yield, white flesh,	
235	82-110-18	23	R	Saprodi x Victoria	Medium-late, oval-long tubers	

Dry matter content

In potato, some phenotype-related features such as tuber yield, tuber size, tuber number, specific gravity and industrial processing quality are significantly affected by the plant's development and growth environment (Caliskan et al., 2021). Dry matter and starch content are two important quality criteria in potato. It has been reported that the dry matter content of commercial potato cultivars varies between 18-26% (Islam et al., 2022; Park et al., 2024; Sapakhova et. al., 2024 Storey, 2007). High level of genetic heterogeneity allowed the development of cultivars with multiple usage areas such as table, purple tuber skin and flesh colour, French fry, crisp processing and starch production. In the study, 18 advanced lines with superior characteristics were developed in 30 populations. The majority of the selected lines were suitable for French fry, crisp processing potato (Table 6). As a result of the trials conducted in two locations; 82-88-04, 82-45-24, 82-56-06, 82-105-50 and 82-93-03 (French fry), 82-78-16 (Crisp processing), 82-27-06, and 82-56-01 (Fresh market and French fry), 82-109-15 (Purple skin and flesh colour) lines were selected as commercial candidate cultivars (Table 6). In the study conducted in potato; it was stated that the most effective selection method determined for obtaining superior and advanced phenotypes is the screening of advanced populations and the definition of the characteristic features of superior parents (Slater et al., 2014).

Table 5. Number of selected advanced lines in 16 potato families

Family	Parents	Number of selected advanced line	Family	Parents	Number of selected advanced line
P1	13-62-32 x Maraton	4	P16	22-68-04 x Madeleine	5
P2	13-62-32 x Cara	7	P17	22-99-33 x Banba	6
P3	13-62-32 x PP-17-3	8	P18	22-99-33 x 22-68-04	7
P4	13-62-32 x Asya	5	P19	Asya x 22-68-04	6
P5	13-62-32 x Cronos	5	P20	Asya x Cara	7
P6	13-62-32 x Fontane	9	P21	Cara x Fontane	6
P7	13-62-32 x CP-US-1	6	P22	CP-US-1 x Fontane	7
P8	13-62-32 x Constance	6	P23	NL-CP-19 x Fontane	9
P9	Florice x Orchestra	9	P24	CP-US-1 x NL-CP-19	12
P10	Soylu x Orchestra	5	P25	Acoustic x Leonata	10
P11	Soylu x Cronos	10	P26	Maraton x Leonata	6
P12	Soylu x CP-US-1	6	P27	Touareg x CP-US-1	14
P13	Boysan x Madeleine	12	P28	Leonata x CP-US-1	20
P14	13-73-26 x Madeleine	6	P29	Maraton X CP-US-1	5
P15	Maraton x Madeleine	7	P30	Saprodi X Victoria	21
				Total	246

In the study conducted on potato lines, it was measured that the dry matter content could be even be between 15-17% (Özkaynak, unpublished data). The highest dry matter ratio in commercial candidate cultivars was obtained in the 82-78-16, 82-105-50 lines and the 82-109-15 line with 22%, 22% and 23%, respectively. It has been reported that dry matter content is closely related to the transport efficiency of tuber assimilation products and is largely controlled by genetic structure (Parlar et al., 2001, Tekalign & Hammes, 2005). Dry matter content is affected by many factors such as ecological conditions, vegetation period duration, plant and soil nutrient characteristics, soil moisture and temperature, solar radiation time and duration, and cultural practices, as well as genetic characteristics (Col-Keskin & Ada, 2022; Park et al., 2024; Sapakhova et. al., 2024; Slater et al. 2014; Storey 2007; Wayumba et al., 2019). The accumulation of dry matter begins with the start of vegetative growth of the plant and continues until harvest. The root and stolon system in potato continues to work as long as there is moisture in the soil. Even before the plant dies, it tries to grow the potato tuber by exerting all its strength. After the green part is chemically dried, the amount of dry matter in the tuber decreases suddenly. As time goes by, new entrepreneurs are investing in the potato industry, while existing producers are expanding their operational capacity. Starch is the main component of the tuber dry matter content (Storey, 2007). The distribution in terms of starch content varied between 12.7 % and 16.9%. Of the candidate cultivars, the cultivars 82-105-50, 82-78-16, 82-27-06, 82-56-01, 82-93-03 and 82-109-15 were given higher starch content than other candidates.

Ryadg marker for PVY

Molecular markers linked to resistance genes can be successfully made regardless of the growth stage and conditions, and without the need for special conditions for biological evaluation (Bradshaw, 2022; Fullodolsa et al., 2015; Mori et al., 2011). The use of molecular markers reduces costs and increases the efficiency and precision of selection (Fullodolsa et al., 2015; Gao et al., 2024; Herrera et al., 2018). However, when the number of alleles

segregating in any cross reaches twelve or more, the frequency of the desired allele combinations can become a limiting factor in the breeding program (Bradshaw, 2017, 2021). The frequency of 12 simplex alleles (e.g. 1 for each chromosome) that are not linked to each other is 1 to 4096, while the frequency of 24 alleles is 1 to 16.777.216. Thus, increasing the allele frequency by recurrent selection in a short cycle time of one year in creating multiplex parents, can be part of the general breeding strategy. This means that using marker assisted selection in seedling generation is more practical and more cost-effective in terms of performance compared to the second field generation (Bradshaw, 2022; Slater et al., 2013).

Table 6. PVY resistance, dry matter content and starch content of selected advanced breeding lines

Family	No	Parents	Line Name	PVY[a]	DM (%)	Starch (%)	Use
P1	**YT-1***	**13-62-32 x Maraton**	**82-88-04**	**R**	**19**	**12.7**	**Selected Fresh market**
P2	**YT-2***	**13-62-32 x Cara**	**82-45-24**	**R**	**20.5**	**14.3**	**Selected Fresh market**
P3	YT-3	13-62-32 x PP-17-3	82-105-05	S	21	14.4	Selected Fresh market and French Fry
P3	**YT-4-**	**13-62-32 x PP-17-3**	**82-105-50**	**R**	**22**	**15.8**	**Selected French Fry**
P6	YT-5	13-62-32 x Fontane	82-21-21	R	21	14.5	Selected Crisp processing
P9	**YT-6***	**Florice x Orchestra**	**82-78-16**	**R**	**22**	**15.8**	**Selected Crisp processing**
P9	YT-7	Florice x Orchestra	82-78-25	R	21	14.3	Selected French Fry and Crisp processing
P11	**YT-8***	**Soylu x Cronos**	**82-27-06**	**R**	**21**	**14.5**	**Selected French Fry**
P11	YT-9	Soylu x Cronos	82-27-30	R	22	15.7	Selected Fresh market and French Fry
P13	**YT-10***	**Boysan x Madeleine**	**82-56-01**	**R**	**21**	**14.6**	**Selected Fresh market and French Fry**
P13	**YT-11***	**Boysan x Madeleine**	**82-56-06**	**R**	**19**	**12.8**	**Selected Fresh market**
P15	YT-12	Maraton x Madeleine	82-37-05	R	21	14.4	Selected French fry
P17	**YT-13***	**22-99-33 x Banba**	**82-93-03**	**R**	**21**	**14.6**	**Selected Fresh market and French Fry**
P20	YT-14	Asya x Cara	82-42-21	R	20	13.7	Selected French fry
P23	YT-15	NL-CP-19 x Fontane	82-19-40	R	21	14.2	Selected French fry
P24	**YT-16***	**CP-US-1 x NL-CP-19**	**82-109-15**	**R**	**23**	**16.9**	**Purple Skin and Flesh**
P28	YT-17	Leonata x CP-US-1	82-128-14	R	23	16.8	Selected Crisp processing
P30	YT-18	Saprodi x Victoria	82-110-10	R	21	14.4	Selected Crisp processing

DM (%): Dry matter content (%), PVY[a:] *Ryadg* marker, *: These lines selected as a commercial candidate.

Table 7. Tuber yield results of candidate lines with comparing commercial varieties with two location in 2022

Cultivar/Candidate Line	Tuber Yield (ton ha^{-1})					
	Antalya (Korkuteli)	Adana (İncirlik)	Mean	Vs	Use	Main/Early Crop Season Production
Madeleine	**52.5 a**	**38.4 b**	**45.5 ab**	3	Fresh market	Main
82-88-04	54.7 a	38.5 b	46.6 a	2	Fresh market	Main
82-56-06	44.7 c	34.3 bc	39.5 b	8	Fresh market	Main
Orchestra	**37.5 e**	**53.2 a**	**45.4 ab**	4	Fresh market	Early
82-45-24	40.6 d	54.4 a	47.5 a	1	Fresh market	Early
Lady Olympia	**40.4 d**	**35.6 bc**	**38 bc**	9	French Fry	Main
82-105-50	50.4 b	40.2 b	45.3 ab	5	French Fry	Main
82-27-06	41.4 cd	30.2 cd	35.8 c	10	French Fry	Main
Agria	**39.2 de**	**32.1 c**	**35.7 c**	11	Fresh and French Fry	Main
82-56-01	43.6 cd	39.2 b	41.4 b	6	Fresh and French Fry	Main and Early
82-93-03	45.8 c	34.4 bc	40.1 b	7	Fresh and French Fry	Main and Early
82-109-15	33.6 e	30.8 cd	32.2 d	13	Purple Skin and Flesh	Fresh and French Fry
VR-808	**34.6 e**	**30.2 cd**	**32.4 d**	12	Crisp processing	Main
82-78-16	42.6 cd	33.4 c	38 bc	9	Crisp processing	Main
General Mean	42.97	37.49	40.23			
Comm. Varieties Mean	40.84	37.90	39.37			
% CV	13.21	14.12	13.09			
F	18.24**	25.53**	21.74**			
LSD	4.34	5.11	3.38			

*: Within columns, means followed by the same letter are not significantly different by ANOVA protected LSD test ($p<0.01$).

Tuber Yield

Tuber yield is the most important character besides the plant, tuber, agronomic and quality characteristics of potato. Tuber yields were given in Table 7 on a two-location basis. In the two-location evaluation conducted within the study, the genotypes 82-88-04 and 82-45-24 were classified as fresh potato candidates, 82-105-50 as a finger type, 82-56-01 and 82-93-03 as both fresh and French fry tyopes, and 82-78-16 as a chip-processing type. All of these canditates exhibited superior yield performance compared to the control cultivars within their respective usage categories (Table 7). Many traits contributing to the phenotype of a potato plant can be highly influenced by the growing season and location, like tuber yield, tuber number, tuber size, specific gravity and processing quality (Jansky, 2009; Slater et al., 2014).

In the study, parents, breeding lines and advanced lines were screened with M45 marker. In 2019, 1238 potato lines were tested with Ryadg, M45 marker. 928 potato lines were found to be resistant according to marker test (unpublished data). 82-88-04, 82-45-24, -82-105-50, 82-78-16, 82-27-06, 82-56-01, 82-56-06 and 82-93-03 commercial candidate cultivars gave the expected DNA band. These candidates were evaluated as high PVY tolerant cultivars according to the marker test.

The M45 marker was developed and validated by Herrera et al. (2018) and provides information about the presence/absence of the Ryadg gene. In this study, parents and selected lines were tested with the M45 marker. Slater et al., (2020) tested 13 Austrian germplasm with this marker in their study and found 12 of them resistant. 1 of the 12 resistant materials was observed as sensitive in the phenotypic screening. Kahveci et al., (2022) found complete agreement between the M45 marker and pathological test results. The results we obtained in this study are consistent with previous studies (Herrera et al., 2028, Kahveci et al., 2022; Slater et al., 2020).

The advanced lines selected for PVY resistance also have great potential for gene integration. It has been reported that sometimes in studies, incorrect results can be obtained in pathological tests due to insufficient inoculation or infection in screening for disease resistance (Kahveci et al., 2022; Slater et al., 2020). Significant advances in disease resistance such as PVY virus resistance in potato cultivars indicate that effective gains can be achieved in reaching the breeding target quickly. It has been shown that the use of MAS can be used successfully and effectively in breeding programs to create an effective target due to its cost-effectiveness. As a result of the research, nine PVY resistant superior lines (high agronomic, plant, and tuber characteristics) were selected for commercial registration.

In the study, the 25.000 specific hybrid lines were propagated and selected 2017 to 2022 with PVY resistance, an acceptable tuber shape, tuber size, eye depth, tuber yield and dry matter content continued in the cultivar development process for subsequent years for the evaluation of agronomic, plant, quality and other disease resistance traits and/or used as parental lines in our selection program. As a result of the research, nine PVY resistant superior lines (high agronomic, plant, and tuber characteristics) were selected from the specific narrow-scope breeding program for commercial registration.

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Compliance with ethical standards and conflict of interest

The author state in the article that no unethical studies were conducted on humans or animals.

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author's Contributions

The author declares that he has contributed to the article.

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